INT. J. BIOAUTOMATION, 2020, 24(4), 393-402 doi: 10.7546/ijba.2020.24.4.000755

Recruitment Curves during Different Types of Muscle Activity in Non-dominant Hand: A Transcranial Magnetic Stimulation Study

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Received: February 24, 2020 **Accepted: November 20, 2020**

Published: December 31, 2020

Abstract: *Motor evoked potentials (MEPs) were recorded from first dorsal interosseous muscle of non-dominant hand in response to contralateral transcranial magnetic stimulation (TMS) in seven right-handed healthy volunteers during relaxed muscles (without electromyorgaphic activity and zero force production), isometric index finger abduction (20% of individual measured maximum voluntary contraction in direction of abduction) and co-activation of antagonist muscles (simultaneously activated antagonist muscles, matching level equal to 20% of individual measured maximum voluntary contraction in direction of abduction by increasing the angle stiffness without producing of external force). The excitability of motor cortex was assessed by the amplitudes of MEPs recorded in response to increasing stimulation intensity: 100%, 110%, 120%, 130%, 140% of individually measured motor threshold at relax. The aim of the present study was using the method of transcranial magnetic stimulation to investigate the effect of different types of muscle activity in non-dominant hand. The secondary purpose was to compare new collected data with our previous data about dominant hand. At non-dominant hand we found significant changes between relax condition and each of the two active motor tasks almost at all five investigated TMS intensities. Also, we found that MEP amplitudes during abduction were significantly bigger than MEP amplitudes during co-activation of antagonist muscles, both in non-dominant hand and in dominant hand. We observed changes between MEP amplitudes of non-dominant and dominant hand during the performance of the same motor task.*

Keywords: *Transcranial magnetic stimulation, Motor evoked potential, Recruitment curves.*

Introduction

Transcranial magnetic stimulation (TMS) is a useful method to study motor cortex excitability and also can be used to investigate the excitability of the corticospinal tract by measuring motor evoked potentials (MEPs) in selected muscles [2]. MEPs are the responses which have been observed and recorded at electromyograms (EMG) after transcranial stimulation. MEP allows direct, objective, non-invasive assessment of the motor system, and gives information about excitability and inhibition of the motor cortex, because it integrates both central and peripheral neuronal pathways. One of the most important parameters measured routinely in TMS studies is motor threshold at relax (RMT). RMT has been defined as a minimum TMS intensity which produced 3 MEPs out of 5 consecutive stimuli with a given amplitude. It is used to standardize stimulus intensities between individuals and to minimalize individual changes at cortical excitability. The choice of a dominant hand is the most recent occurrence of hemispheric asymmetry in humans and an example of behavioral lateralization. More than 90% of human population prefers to use right hand [7]. It is thought that differences in cognitive ability, personality, motivation, perception and language are connected to handedness [3, 12, 18, 27, 29]. Handedness may also impact the size of motor cortical area responsible to the given muscle. Some studies with functional magnetic resonance imaging (fMRI) and magnetoencephalography demonstrated larger functional activation and an increase in the size of the hand area in dominant primary motor cortex (M1) no matter which hand is dominant [8, 38]. However, it is still under investigation whether differences in M1 organization are associated with the handedness. Probably, the location and the size of non-dominant cortical muscle representation differ between right-handers and left-handers [28].

There is a suggestion that during performing a motor task, the non-dominant hand basically has a stabilizing function and is associated with maintaining the posture thus creating conditions where the dominant hand is able to perform finer and more precise movements [13]. In humans is observed modulation of the excitability of cortical neuronal mechanisms according to the motor task [10]. TMS is routinely used to evaluate the excitability of motor cortex during various motor tasks in association with the first dorsal interosseous muscle. This muscle is the only agonist who realizes the abduction of the index finger. This functional specification making it convenient to examine and preferred for comparing motor tasks requiring co-activation of different antagonist muscles [5, 10, 14, 20]. Co-activation of antagonist muscles increases the stiffness of the joints, providing mechanical stability during maintaining the posture [26] and during the movement of the limb [6, 39]. MEPs measured during different types of activity are one of the most discussed parameters in TMS studies. Different types of activity usually are being examined in separate studies but it is known that while submaximal isometric contraction is maintained, the activity of antagonist muscles increases in parallel with the activity of agonist muscle [9, 16, 21, 32], but the activity of the antagonists is suppressed during movements [40]. It is observed that in right-handers, the activated corticospinal representation during abduction of the index finger is much larger in the non-dominant hand compared to the activated neural representation performing the same motor task with the dominant hand [34].

The aim of the present study was to investigate the effect of different types of muscle activity (relax, isometric index finger abduction and co-activation of antagonists) during TMS of the hemisphere contralateral to the non-dominant hand. The recruitment curves (separate line for each of the three motor tasks) have been made by connecting the MEP amplitudes in response to five different TMS intensities (100%, 110%, 120%, 130%, 140% RMT). The secondary purpose was to compare the new collected data with our previous data about recruitment curves of dominant hand [25].

Materials and methods

Seven healthy right-handed subjects (age range 21-29 years) gave informed consent for participation in this study. Hand dominance was determined by the Edinburg Handedness Inventory [30]. The experimental procedure was approved by the local ethics committee. TMS was provided by MagStim200 stimulator (MagStim Co., United Kingdom) connected to a BiStim module with figure of eight coil (mean diameter 7 cm). All TMS intensities were determined as a percentage of maximum stimulator output. Stimulation coil was adjusted over the optimal area of right motor cortex to produce MEPs in the left first dorsal interosseous muscle. RMT was detected by applying a threshold hunting paradigm [1], according to which the investigation starts with higher TMS intensities and goes to lower intensities. All individual RMT were determined as a minimum TMS intensity which produced 3 MEPs out of 5 consecutive stimuli. Responses with an amplitude of 0.05 mV (peak-to-peak) or greater were defined as MEPs [33]. The participants performed different types of muscle activity during TMS with intensity 100%, 110%, 120%, 130% and 140% of individual RMT. The recruitment curves which have been made by connecting of the points of MEP amplitudes at the fifth TMS intensities were investigated during relaxed muscles, isometric index finger abduction and co-activation of antagonist muscles.

Surface EMG were recorded from the left first dorsal interosseous muscle by a pair of surface Ag/AgCl disc electrodes (8 mm diameter). The active pole of the electrode was fixed on the muscle belly and the reference pole – on distal tendon at the index finger base. The EMG activity and the force signal were continuously monitored to control the correct implementation of motor task. After amplification and filtering (band pass 10 Hz – 1 kHz), EMG signals were digitized (sampling rate 2 kHz) and stored on a disk for offline analysis. To reduce unwanted outdoor signals, we used land electrode.

For the experimental procedure, participants were seated comfortable in a chair, with left arm gently fixed in slight abduction from the trunk (20°) and flexion in the elbow (110°). The hand and forearm were pronated and relaxed on horizontal support. The left index finger was positioned in a non-movable manipulandum connected to a force transducer (sensitive in all directions). The other fingers were immobilized with Velcro straps.

All experiments started with determination of individual maximum voluntary contraction (MVC) level without TMS. Each subject's force was measured as a maximal index finger contraction in direction of abduction. At all experiments it was used line indicator which shows the force data to a computer monitor and provides constant visual feedback of the target MVC level. Then we determined individual RMT. After these procedures, TMS was delivered during three motor tasks: 1) relaxed muscles – without EMG activity and zero force production; 2) isometric index finger abduction – 20% of individual measured MVC level in direction of abduction; 3) co-activation of antagonist muscles – simultaneously activated antagonist muscles, matching level equal to 20% MVC in direction of abduction by increasing the angle stiffness and without producing of external force. TMS intensities during each motor task were 100%, 110%, 120%, 130% and 140% of individual RMT. For each subject were made 5 samples for each TMS intensity at each motor task.

Epochs of 2 s duration (400 ms prior and 1600 ms after the stimulus) were stored on a disk for offline analysis. The measured parameter was peak-to-peak amplitude of MEPs (Fig. 1). All statistical analyses were made by STATISTICA v. 10 data analysis software system (StatSoft, Inc., USA). The effect of the different types of muscle activity in recruitment curves during TMS was evaluated by two-way repeated measures ANOVA (general linear model, GLM) with factors "TMS intensity" (100%, 110%, 120%, 130%, 140% RMT) and "motor task" (relaxed muscles, index finger abduction, co-activation of antagonist muscles). For Post Hoc analysis we used Duncan test. Because of the abnormal distribution, we used nonparametric Wilcoxon Matched Pairs test for dependent samples.

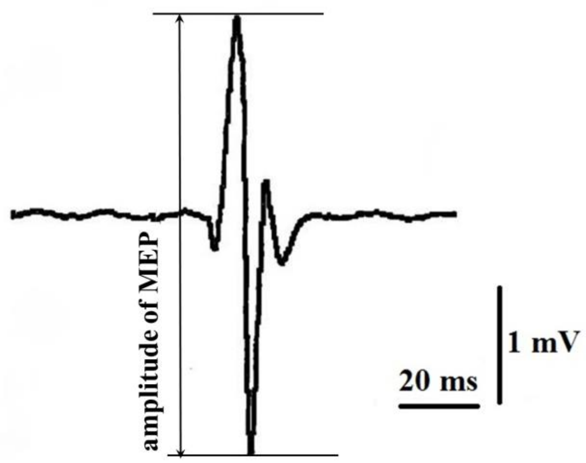

Fig. 1 The measured parameter: peak-to-peak amplitude of MEP

Results

All measured MEP amplitudes (mean ± SE) are given in Table 1. Amplitudes of MEPs during relaxed muscles were smallest at all investigated TMS intensities. MEP amplitudes measured during isometric index abduction were bigger than those measured during co-activation of antagonist muscles – see Table 1.

Table 1. MEP amplitudes (mean ± SE) measured during relaxed muscles, isometric index finger abduction and co-activation of antagonist muscles

TMS intensity, [% RMT]	Relaxed muscles, [mV]	Isometric index finger abduction, [mV]	Co-activation of antagonist muscles, [mV]
100	0.32 ± 0.05	1.48 ± 0.22	0.95 ± 0.12
110	0.59 ± 0.12	2.18 ± 0.28	0.91 ± 0.13
120	1.11 ± 0.15	2.89 ± 0.38	1.35 ± 0.06
130	1.53 ± 0.17	3.26 ± 0.33	2.37 ± 0.41
140	2.09 ± 0.22	3.81 ± 0.40	3.00 ± 0.29

Two-way repeated measures ANOVA showed significant effect of both factors "TMS intensity" and "motor task" for recruitment curves ($p < 0.001$) of non-dominant hand. Duncan Post Hoc test also showed significant differences ($p < 0.001$) between motor tasks. Wilcoxon Matched Pairs test demonstrated significance between relax condition and each of the two active motor tasks almost at all investigated TMS intensities (Fig. 2A and 2B). The only exception without significant difference was between relax and co-activation at TMS intensity 120% RMT (Fig. 2B). We found that MEP amplitudes during abduction were significantly bigger than MEP amplitudes during co-activation at TMS intensities 100% RMT ($p < 0.001$), 110% RMT ($p < 0.001$), 120% RMT ($p < 0.001$) and 130% RMT ($p < 0.001$) (Fig. 2C).

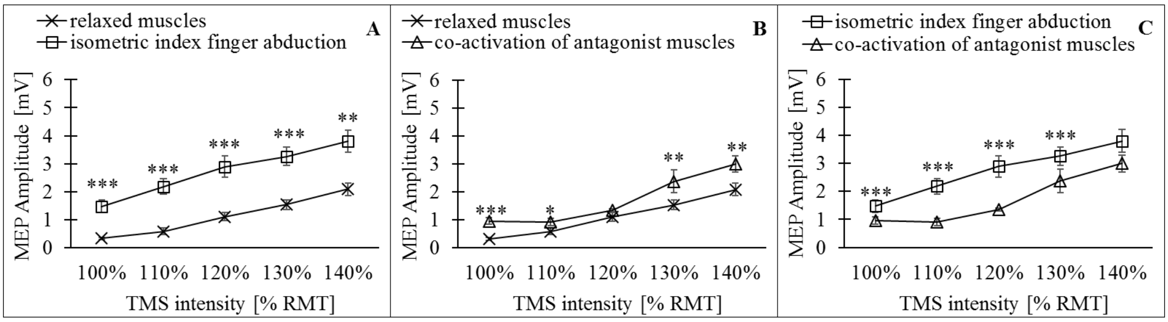

Fig. 2 Recruitment curves of non-dominant hand:
A) MEP amplitudes during relaxed muscles and isometric index finger abduction;
B) MEP amplitudes during relaxed muscles and co-activation of antagonists;
C) MEP amplitudes during isometric index finger abduction and co-activation of antagonist muscles. Asterisks show significant differences (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$), and missing * means that there is no significant difference.

Comparison of recruitment curves of non-dominant hand and recruitment curves of dominant hand (data from our previous study [25]) during contralateral TMS is given in Fig. 3. During relaxed muscles, MEP amplitudes have no significant differences (Fig. 3A). During isometric index finger abduction, there are significant differences at TMS intensities 100% RMT ($p < 0.01$), 110% RMT ($p < 0.001$), 120% RMT ($p < 0.01$) and 130% RMT ($p < 0.01$) (Fig. 2B). During co-activation of antagonist muscles, there are significant differences at TMS intensities 110% RMT ($p < 0.001$), 120% RMT ($p < 0.001$) and 130% RMT ($p < 0.01$) (Fig. 2C).

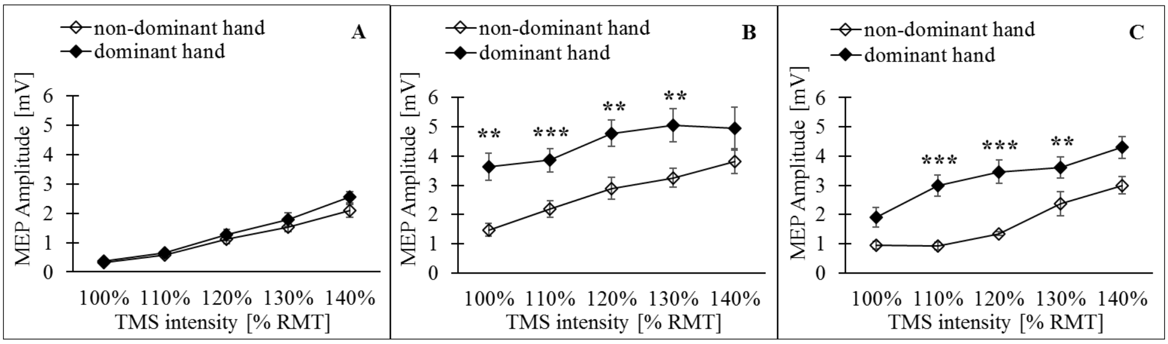

Fig. 3 Recruitment curves of non-dominant and dominant hand during contralateral TMS:
A) MEP amplitudes during relaxed muscles;
B) MEP amplitudes during isometric index finger abduction;
C) MEP amplitudes during co-activation of antagonist muscles.
Asterisks show significant differences (** $p < 0.01$, *** $p < 0.001$), and missing * means that there is no significant difference.

Discussion

The most interesting finding in our research is that in the entire range of used TMS intensities, the recruitment curve in co-activation of antagonist muscles was almost always significantly lower than the recruitment curve in isometric index finger abduction in the non-dominant hand. This finding repeated our previous data about recruitment curves of dominant hand [25]. These observations could be an evidence that there is a lower level of excitability during co-activation of antagonist muscles than in reciprocal activity of the agonist muscle [17, 19, 31], and that in cortical excitability are involved different populations of nerve cells during different types of muscle activity [11, 15, 22].

Also, we found significant differences between recruitment curves of non-dominant and dominant hand during the both active motor tasks. We observed that recruitment curves in isometric index finger abduction and co-activation of antagonist muscles recorded from the dominant hand are significantly higher than the recruitment curves of non-dominant hand. This may be an opposite observation of some authors [34] who found that MEPs during isometric index finger abduction are much larger in the non-dominant hand compared to those in the dominant hand. These differences may be due to the fact that they used circular coil and we used figure of eight coil which is much focal. Some TMS studies showed no differences across hemispheres in MEP amplitudes, latency and motor thresholds [23, 35, 36] but our results show that MEP amplitudes in dominant hand are significantly bigger. There are observations that RMT is lower for preferred hand no matter which hand is dominant [4, 24, 37] but we did not observe such differences. All of our participants were right-handers and had almost the same RMT for non-dominant and dominant hand. Probably the reason for this result are higher individual differences in the usage of the non-dominant hand. Also, the main differences observed between non-dominant and dominant hand may relate to the extent to which individuals use one or the other hand in their daily activities. However, right- and left-handers did not differ in the extent of overlap between muscle representations [28]. This may support our data about recruitment curves of non-dominant and dominant hand in relaxed muscles which showed no differences.

Our observations about recruitment curves during different types of muscle activity in non-dominant hand may support the idea for different central control of co-activation of antagonist muscles and isometric muscle activity.

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