HEMISPHERE ASYMMETRY DURING DIFFERENT LEVELS OF CO-ACTIVATION OF ANTAGONIST MUSCLES: A TRANSCRANIAL MAGNETIC STIMULATION STUDY

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Abstract

Contralateral and ipsilateral silent periods were recorded from first dorsal interosseous muscles of the dominant and the non-dominant hand in response to contralateral and ipsilateral transcranial magnetic stimulation (TMS) in twelve right-handed healthy volunteers during isometric index finger abduction and co-activation of antagonist muscles.

In the dominant hand, contralateral silent period recorded during co-activation of antagonist muscles was significantly shorter than contralateral silent period recorded during isometric index finger abduction. In the non-dominant hand, we did not find significant differences.

In the dominant hand, ipsilateral silent period recorded during co-activation of antagonist muscles was significantly shorter than ipsilateral silent period recorded during isometric index finger abduction. In the non-dominant hand, we did not find significant differences.

In conclusion, our main finding was the hemisphere asymmetry during co-activation of antagonist muscles. Both, contralateral and ipsilateral silent periods recorded from the dominant right hand were shorter in comparison to those recorded from the non-dominant hand. These findings illustrate the role of co-activation for the better and precise usage of the dominant hand.

Key words: transcranial magnetic stimulation (TMS), hemisphere asymmetry, contralateral silent period (contralateral SP), ipsilateral silent period (ipsilateral SP), dominant and non-dominant hand

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Introduction. The transcranial magnetic stimulation (TMS) is a useful method to study motor cortex excitability and inhibitory pathways and can also be used to probe the excitability and inhibition of the corticospinal tract. The most recent occurrence of hemispheric asymmetry and an example of behavioural lateralization in humans is the choice of a dominant hand. More than 90% of human population prefer to use the right hand [1]. Handedness may impact the size of motor cortical area responsible to the given muscle. However, it is still under investigation whether differences in primary motor cortex (M1) organization are associated with the handedness. In right-handers, the activated corticospinal representation during abduction of the index finger is much larger in the non-dominant left hand compared to the activated neural representation performing the same motor task with the dominant right hand [2]. In humans modulation of the excitation and inhibition of the motor cortex according to the motor task is observed [3]. Also, there is a suggestion that the non-dominant hand basically stabilizes and maintains the posture, creating conditions for the dominant hand which performs finer movements [4].

The silent period (SP) is a short interruption in electromyography (EMG) which is observed during the active muscle contraction after the motor evoked potential (MEP) induced by TMS. It is widely accepted that the initial part of SP has a spinal origin and the later part has a cortical one [5], but there is a hypothesis that the entire SP has a cortical origin and it is generated in the primary motor cortex [6]. It is known that SP is a sign of a cortical inhibition and it represents inhibitory interneuron effects on excited motor cortical areas. According to the hemisphere to which TMS is applied, the SP is contralateral and ipsilateral. The contralateral silent period (cSP) is observed when the EMG activity is recorded from muscles located on the opposite side of the stimulated hemisphere. The ipsilateral silent period (iSP) is observed when the EMG activity is recorded from muscles located on the side of the stimulated hemisphere. In healthy subjects, SP duration has a highly inter-individual variation, but measurements have a good intra-individual repeatability and the hemispheric symmetry is high [6]. The SP shows cortical inhibitory pathways, mainly reflected by functions of GABA_B-receptors, and it is suitable for diagnostics and studies of conditions including nerve-degenerative diseases (Alzheimer’s disease, Parkinson’s disease, Huntington’s disease, epilepsy, amyotrophic lateral sclerosis (ALS), etc.).

The modulations of excitability in the ipsilateral M1 induced during unilateral movement shows that M1 are activated and interact with each other in both hemispheres. This interaction is mediated by the transcallosal pathway [7]. TMS study during hand motor tasks found changes in excitability of contralateral M1 and ipsilateral M1, confirming the complex mechanism involved in their activation [8].

The aim of the present study was to investigate the hemisphere asymmetry of primary motor cortex in right-handed individuals during active motor tasks in
dominant and non-dominant hand. According to this purpose, we examined, the duration of cSP and iSP in dominant right hand and in non-dominant left hand during isometric index finger abduction and co-activation of antagonist muscles.

**Materials and methods.** Twelve healthy right-handed subjects in the age range of 24–56 years (36 ± 12; mean ± SD) gave informed consent for participation in this study. The hand dominance was determined by the Edinburgh Handedness Inventory [9]. The experimental procedure was approved by the local ethics committee.

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

TMS was provided by MagStim200 stimulator (MagStim Co., United Kingdom) with figure of eight coil (mean diameter 7 mm). TMS intensities were determined as a percentage of maximum stimulator output. Stimulation coil was adjusted over the optimal area of motor cortex to produce MEPs in the first dorsal interosseous muscle. In separate series, contralateral motor thresholds for the right and the left hand in relax (RMTs) were detected by applying a threshold hunting paradigm [10] and responses with an amplitude of 0.05 mV (peak-to-peak) or greater were defined as MEPs [11]. All individual RMTs were determined as a minimum TMS intensity which produced 3 MEPs out of 5 consecutive stimuli. In separate series contralateral and ipsilateral SPs recorded from the dominant right hand and contralateral and ipsilateral SPs recorded from the non-dominant left hand were investigated during the isometric index finger abduction and during the co-activation of antagonist muscles. Contralateral and ipsilateral stimulation intensities over the left hemisphere were 130% of individually measured RMT in response to contralateral TMS detected in the right muscle. Contralateral and ipsilateral stimulation intensities over the right hemisphere were 130% of individually measured RMT in response to contralateral TMS detected in the left muscle.

For the experimental procedure, participants were seated comfortably in a chair, with arms gently fixed in slight abduction from the trunk (20°) and flexion in the elbow (110°). During the experiments, the two hands of the subject were fixed in two symmetrical manipulanda. The hands and forearms were pronated and relaxed on horizontal supports. The index fingers were positioned in a non-movable manipulandum connected to force transducers sensitive in all directions. The other fingers were immobilized with Velcro straps.
All experiments started with determination of the individual maximum voluntary contraction (MVC) level separately for the right and the left first dorsal interosseous muscle without TMS. Each subject’s force was measured as a maximal index finger contraction in direction of abduction. In all experiments a line indicator was used which shows the force data on a computer monitor and provides constant visual feedback of the target MVC level. TMS was delivered during isometric index finger abduction and co-activation of antagonist muscles. Subjects were instructed to perform a steady isometric abduction to a constant force, equal to 20% of their MVC level, and during the co-activation task, they were asked to activate simultaneously antagonist muscles, matching the same EMG level by increasing the angle stiffness without producing the external force. We determined the contralateral RMT for the dominant right muscle and contralateral RMT for the non-dominant left muscle.

In the first part of the experiment TMS was applied to the dominant left hemisphere. The first motor task was voluntary isometric index finger abduction of dominant right hand followed by co-activation of antagonist muscles. The next two motor tasks were the same but the active hand was the left hand. In the second part of the experiment TMS was applied to the right non-dominant hemisphere and the corresponding motor tasks were used symmetrical to the first part.

At each arrangement (the side of stimulation, the side of voluntary activity and the motor task) 10 stimuli were applied with randomized intervals between them. Epochs of 2 s duration (400 ms prior to and 1600 ms after the stimulus) were stored on a disk for the offline analysis. The measured parameters were: duration of contralateral and ipsilateral SPs of the dominant right hand and contralateral and ipsilateral SPs of the non-dominant left hand. The statistical analyses were made by “STATISTICA” data analysis software system, version 10 (StatSoft, Inc., USA). We used Duncan test for Post Hoc analysis and nonparametric Wilcoxon Matched Pairs test.

**Results.** Duration of the contralateral SP recorded from the dominant right hand showed significant dependence on the type of muscle activity. In the dominant right hand, contralateral SP recorded during co-activation of antagonist muscles was significantly shorter \((p < 0.05)\) than the contralateral SP recorded during the isometric index finger abduction (Fig. 1). The duration of the contralateral SP recorded from the non-dominant left hand did not depend on the type of muscle activity. In the non-dominant left hand, the duration of the contralateral SP recorded during isometric index finger abduction was not significantly different from those measured during co-activation of antagonist muscles (Fig. 1).

Duration of ipsilateral SP recorded from the dominant right hand showed a significant dependence on the type of muscle activity. In the dominant right hand, ipsilateral SP recorded during co-activation of antagonist muscles was significantly shorter \((p < 0.05)\) compared to those recorded during isometric index finger abduction (Fig. 2). In the non-dominant left hand, the duration of ipsilateral SP
Fig. 1. Duration of contralateral silent periods [mean ± SE] during isometric index finger abduction and co-activation of antagonist muscles recorded from dominant and non-dominant hands (significant differences: *p < 0.05)

Fig. 2. Duration of ipsilateral silent periods [mean ± SE] during isometric index finger abduction and co-activation of antagonist muscles recorded from dominant and non-dominant hands (significant differences: *p < 0.05)

did not show a significant dependence on the type of muscle activity and were almost the same during different motor tasks (Fig. 2).

Discussion and conclusions. In the dominant right hand, we found a significantly shorter contralateral SP recorded during co-activation of antagonist muscles compared to contralateral SP recorded during isometric index fin-
ger abduction. This finding shows asymmetry between the hemispheres during co-activation of antagonist muscles, and demonstrates that the intracortical inhibition is more pronounced for the non-dominant left hand. Also, during co-activation of antagonist muscles, our results show significant shortening of the ipsilateral SP measured in the dominant right hand compared to those measured in the non-dominant left hand, indicating that the intrahemispheric inhibition during co-activation of antagonist muscles is more pronounced when stimulating the dominant hemisphere. In our previous studies of right-handed individuals, during co-activation of antagonist muscles and TMS of the dominant left hemisphere, bigger ipsilateral MEPs have been observed in comparison to those measured during isometric index finger abduction [12]. It can be suggested that during co-activation of antagonist muscles, the ipsilateral inhibitory and excitatory effects of the dominant hemisphere upon the non-dominant hand are more pronounced than those from the non-dominant hemisphere upon the dominant hand. Such a hemisphere asymmetry was not established at isometric index finger abduction.

Although the motor task was relatively simple (maintaining unilateral isometric contraction with or without co-activation of antagonist muscles), we found a well pronounced hemisphere asymmetry of the intracortical and intrahemispheric inhibitory processes during co-activation of antagonist muscles. Our result supports the hypothesis about the role of co-activation of antagonist muscles in motor training and finer movements of the dominant hand. It could be suggested that the asymmetric inhibitory control of the excitability of the cortical motor systems is related to the co-activation of the muscles with the established asymmetry of the surrounding inhibition [13]. The surrounding inhibition in the human motor system is an essential physiological mechanism which focuses the neuronal activity in the central nervous system for selective performance of the desired movement [14]. It can be assumed that co-activation of antagonist muscles is essential for the process of selective activation of the muscles in performing a precise movement. However, it is still unclear to what extent the corticospinal neurons are involved to ipsilateral movements [15], but it is known that plasticity of the movement cortical control is essential in rehabilitation after stroke [16] and some spinal cord injuries [17].

In conclusion, our main finding is the hemisphere asymmetry observed during co-activation of antagonist muscles. Both, contralateral and ipsilateral silent periods recorded from the dominant right hand were shorter in comparison to those recorded from the non-dominant hand. These findings support the hypothesis for the role of co-activation for the better and precise usage of the dominant hand.
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