Clinical Neurophysiology 123 (2012) 2429–2436

Contents lists available at SciVerse ScienceDirect

Clinical Neurophysiology

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

Effect of afferent input on motor cortex excitability during stroke recovery

Kristina Laaksonen [a,b,c,*], Erika Kirveskari [a,d], Jyrki P. Mäkelä [e], Markku Kaste [b,c], Satu Mustanoja [b,c], Lauri Nummenmaa [a,f,g], Turgut Tatlisumak [b,c], Nina Forss [a,b,c]

[a] Brain Research Unit, O.V. Lounasmaa Laboratory, School of Science, Aalto University, FI-00076 Aalto, Espoo, Finland
[b] Department of Neurological Sciences, University of Helsinki, FI-00014 HY, Helsinki, Finland
[c] Department of Neurology, HUSLAB, Helsinki University Central Hospital, FI-00029 HUS, Helsinki, Finland
[d] Department of Clinical Neurophysiology, HUSLAB, Helsinki University Central Hospital, FI-00029 HUS, Helsinki, Finland
[e] BioMag Laboratory, HUSLAB, Helsinki University Central Hospital, FI-00029 HUS, Helsinki, Finland
[f] Department of Biomedical Engineering and Computational Science, School of Science, Aalto University, FI-00076 Aalto, Espoo, Finland
[g] Turku PET Centre, FI-20521 Turku, Finland

ARTICLE INFO

Article history:
Accepted 23 May 2012
Available online 19 June 2012

Keywords:
Afferent input
Hand dexterity
Magnetoencephalography (MEG)
Stroke
Motor cortex excitability
Sensorimotor integration
Beta rhythm

HIGHLIGHTS

- Motor cortex excitability, modulated by afferent input, is increased in the affected hemisphere in the acute phase after stroke and decreases subsequently during recovery.
- Motor cortex excitability correlates with strength of secondary somatosensory cortex (SII) activation, suggesting that modulatory afferent input may reach the motor cortex via SII.
- Afferent input modulated motor cortex excitability is associated with hand function, underlining the importance of parallel recovery of the sensory and motor systems for normal hand dexterity.

ABSTRACT

Objective: Afferent input is proposed to mediate its effect on motor functions by modulating the excitability of the motor cortex. We aimed to clarify – in a longitudinal study – how afferent input affects motor cortex excitability after stroke and how it is associated with recovery of hand function.
Methods: The motor cortex excitability was studied by measuring the reactivity of the motor cortex beta rhythm to somatosensory stimulation. We recorded the amplitude of the suppression and subsequent rebound of the beta oscillations during tactile finger stimulation with MEG in 23 first-ever stroke patients within one week and at 1 and 3 months after stroke, with concomitant evaluation of hand function.
Results: The strength of the beta rhythm rebound, suggested to reflect decreased motor cortex excitability, was weak in the affected hemisphere after stroke and it was subsequently increased during recovery. The rebound strength correlated with hand function tests in all recordings.
Conclusion: Motor cortex excitability is modulated by afferent input after stroke. The motor cortex excitability is increased in the AH acutely after stroke and decreases in parallel with recovery of hand function.
Significance: The results implicate the importance of parallel recovery of both sensory and motor systems in functional recovery after stroke.

1. Introduction

Motor impairment is a common consequence of an ischemic stroke. Intracortical recordings in animals (Nudo and Milliken, 1996; Nudo et al., 1996) and functional imaging studies in humans have indicated that motor recovery is associated with reorganization of the motor (Calautti et al., 2001; Ward et al., 2003a,b) and somatosensory cortices (Roiha et al., 2011; Rossini et al., 1998, 2001). However, regaining of normal motor function demands not only recovery of the motor or somatosensory systems, but also a fluent integration of somatosensory afferent input with motor programs (Bornschlegl and Asanuma, 1987).

Afferent somatosensory input has been proposed to mediate its effect on motor functions by modulating the excitability of the motor cortex (Asanuma and Arissian, 1984; Favorov et al., 1988; Liepert et al., 2004; Ridding and Rothwell, 1999; Tokimura et al., 2000). Accordingly, afferent somatosensory input has been shown to modulate the motor cortex beta rhythm (~20-Hz), leading to an initial suppression followed by a transient rebound of the rhythm

* Corresponding author. Address: Brain Research Unit, O.V. Lounasmaa Laboratory, Aalto University, P.O. Box 15100, 00076 Aalto, Espoo, Finland. Tel.: +358 9 470 25619; fax: +358 9 470 22969.
E-mail address: roiha@neuro.hut.fi (K. Laaksonen).

1388-2457/$36.00
http://dx.doi.org/10.1016/j.clinph.2012.05.017

(Neuper and Pfurtscheller, 1996; Salmelin et al., 1995; Salmelin and Hari, 1994). The increase of the rebound strength has been suggested to reflect decreased motor cortex excitability (Hari et al., 1998; Salenius et al., 1997; Salmelin and Hari, 1994), and the beta rebound has been used in several prior studies to monitor the functional state of the motor cortex (Juottonen et al., 2002; Silen et al., 2000; Visani et al., 2006).

To investigate how afferent somatosensory input modulates motor cortex excitability after stroke and how it is associated with recovery of hand function, we recorded beta oscillations and somatosensory evoked responses during tactile finger stimulation with a whole-scalp magnetoencephalography (MEG) in 23 first-ever stroke patients within one week, and at 1 and 3 months from stroke onset and in 10 healthy control subjects, with concomitant clinical evaluation of hand function.

2. Materials and methods

2.1. Patients and control subjects

We studied 23 patients with first-ever ischemic stroke in the middle cerebral artery territory affecting upper extremity motor function, and 10 healthy control subjects (5 females; mean age 61 ± 2 years; all right-handed). The patients were recruited within 3 days from stroke onset from the Department of Neurology, Helsinki University Central Hospital (HUCH). Exclusion criteria were earlier neurological diseases, neurosurgical operations or head traumas, severe psychiatric disorder, unstable cardiovascular condition, and poor general condition. Three patients were excluded from the study after the first measurement as magnetic resonance imaging (MRI) revealed prior silent strokes, and one patient because of a reinfarction after the first measurement. One patient's MEG data were excluded due to large artifacts preventing reliable analysis. Thus the follow-up data of 18 patients (9 females; age 44–84 years, mean 66 years ± 2 years; all right-handed) were used for further analyzes. One patient refused the third measurement because of claustrophobia, the rest participated successfully in all three measurements.

Local Ethics Committee approved the study protocol. All patients and control subjects gave written informed consent. Somatosensory evoked fields to tactile finger stimulation from the same patients have been reported in detail in our earlier studies (Forss et al., 2012; Roiha et al., 2011).

2.2. Clinical evaluation

The patients underwent clinical examination and MEG measurements within 1–7 (mean 3.5 ± 0.5) days (T_0) and after one (T_1) and three (T_2) months from stroke. Anatomical MRIs were performed with a 3 T scanner (Philips) at T_0 and T_1. Clinical examination included National Institutes of Health Stroke Scale (NIHSS), Barthel Index (BI), and modified Rankin Scale (mRS) scoring. Tactile sensitivity of the affected hand (light and sharp touch) was categorized into two groups: normal or decreased (as compared with the healthy hand). To evaluate the hand dexterity, a physio- or ergotherapist performed the Nine Hole Pegboard test (Peg). In Peg, the amount of time needed to remove and replace nine pegs one at a time into nine holes is measured. The maximum time was defined as 120 s; this score was given if the task could not be performed faster.

2.3. Magnetoencephalographic (MEG) recordings

Rhythmic brain activity during rest and during tactile stimulation of the index fingers was recorded with a 306-channel helmet-shaped neuromagnetometer (Elekta Neuromag®, Helsinki, Finland) at T_0, T_1, and T_2. The recordings were performed in the BioMag Laboratory, HUCH, in a magnetically shielded room, and during the measurement the patients were, according to their clinical condition and their own wish, either in sitting or supine position with the head supported against the helmet-shaped sensor array. Tactile stimuli were alternately delivered to both index fingers with an interstimulus interval of 3005 ms with balloon diaphragms driven by compressed air, and raw-data during averaging of about 60–80 responses for each hand were recorded. Although tactile sensitivity was impaired in some patients, each subject was able to detect the stimuli as light touch. The stimulus intensity was kept constant across the subjects and measurement times, to allow direct comparison of the results during recovery. Eye movements were simultaneously recorded with a vertical electro-oculogram, and coinciding responses were automatically rejected. All subjects wore earplugs to avoid perception of any possible stimulus-related noise. The subjects were instructed to relax, not to move their head or fingers, and not to pay attention to the stimuli. In the second session spontaneous brain activity during rest was recorded for 6 min. A nurse inside the magnetically shielded room observed the patients for any possible movements.

To determine the exact head position with respect to the sensor array, four indicator coils were placed on the scalp, and magnetic signals produced by currents led into the coils were detected in the beginning of each measurement. To align the MEG and the anatomical MRI coordinate systems, a three-dimensional digitizer was used to determine the coil positions with respect to anatomical landmarks. The signals were filtered through 0.03–308 Hz and digitized at 941 Hz.

2.4. Data analysis

The MEG data were first processed with the temporal signal space separation (tSSS) method implanted in Maxfilter™ software (Taulu and Simola, 2006) to suppress the signals of interfering sources.

After preprocessing of the data, spectra of spontaneous brain activity (during rest, eyes open) were calculated in the frequency-range of 0–60 Hz to define the peak amplitudes and frequencies of spontaneous brain activity over the rolandic region. For each patient, amplitudes of the strongest spectral peaks (~10 Hz, ~15 Hz (beta 1), ~20 Hz (beta 2)) were quantified from 2–3 MEG channels over the left and the right sensorimotor region. Time–frequency representations (TFR; Tallon-Baudry et al., 1997) in the frequency-range of 10–30 Hz were calculated to define the frequency range of the strongest modulation of spontaneous brain activity to tactile stimulation. The TFR were calculated over all channels in each patient and each control subject. The channel showing the largest signal changes was used to determine the frequency-range for further analysis for each individual.

For each patient and control subject, a frequency band of 10 Hz width with an individual range between 12 and 26 Hz was chosen according to the observed spectral peaks of the beta rhythm and the TFR analysis. Earlier studies have shown that the beta rhythm is modulated by i.e. peripheral tactile stimulation, which leads to an initial suppression followed by a transient rebound of the rhythm (Salenius et al., 1997; Salmelin and Hari, 1994). The temporal spectral evolution method (TSE; Salmelin and Hari, 1994) was applied to analyze the temporal aspects and reactivity of the chosen frequency range in more detail. The averaged somatosensory evoked fields (SEFs) were first subtracted from the individual MEG signals. Thereafter the MEG signals were filtered through the individually chosen frequency-range between 12 and 26 Hz, rectified, and averaged time-locked to the stimuli. The analysis period was 3.5 s with a pre-stimulus baseline of 300 ms. The level of the