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Enhancement of motor coordination by applying high frequency repetitive TMS on the sensory cortex

Eun-Hi Choi [a,1], Woo-Kyoung Yoo [b,c,*], Suk Hoon Ohn [b,2], SeungHo Ahn [b,3], Han Jun Kim [b,3], Kwang-Ik Jung [b,4]

[a] Department of Physical and Rehabilitation Medicine, Chuncheon Sacred Heart Hospital, 77 Sakju-ro, Chuncheon-si, Gangwon-do 220-704, Republic of Korea
[b] Department of Physical and Rehabilitation Medicine, Hallym University Sacred Heart Hospital, 896, Pyoungchon-dong, Dongan-ku, Anyang 431-070, Republic of Korea
[c] Hallym Institute for Translational Genomics & Bioinformatics, Hallym University College of Medicine, Republic of Korea

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The sensory function plays an important role for successful motor performance. We investigated the modulating effects of high frequency repetitive transcranial magnetic stimulation (rTMS) on sensory discrimination and motor coordination. Twenty healthy participants were assigned into two random groups; the real- and sham-rTMS group. Total of 900 rTMS pulses at a frequency of 10 Hz (stimulus intensity of 90% RMT) were given over deltoid representational areas of the somatosensory cortex. Sensory discrimination ability was evaluated using two-point discrimination test. Motor coordination was measured by the latency difference between the synchronized contraction of deltoid and abductor pollicis brevis muscles before and after rTMS. The sensory discrimination was significantly increased only in the deltoid area and the difference in the latency of synchronized contraction of two muscles was significantly shortened after real-rTMS compared sham condition, which had tendency of negative correlation following real-rTMS condition. The results of this study demonstrated rTMS-induced enhancement of sensorimotor integration, which may contribute to develop effective therapeutic strategies for rehabilitation of various sensorimotor disorders in the clinical setting.

1. Introduction

The sensory function plays an important role for successful motor performance in healthy individuals and also pathological conditions such as stroke with sensory deficits, which tends to have less motor recovery (Rose et al., 1994). Based on studies involving individuals with compromised sensory ability due to large fiber sensory neuropathy, sensory function has been shown to play an important role in the control of muscle interaction torques (Sainburg et al., 1995), monitoring motor output (Rothwell et al., 1982) and acquiring internal models of skilled movement (Ingram et al., 2000; Messier et al., 2003).

Plenty of researches regarding use-dependent plasticity of the sensory and motor cortex have been reported (Recanzone et al., 1992; Karni et al., 1995; Nudo and Milliken, 1996; Classen et al., 1998; Butefisch et al., 2000; Bütefisch et al., 2002). It has been suggested that synaptic efficacy can be modified in an activity-dependent manner, resulting long-term potentiation (LTP) at synapse level.

Repetitive transcranial magnetic stimulation (rTMS) is a non-invasive stimulation technic, which can be used for therapeutic applications by modulating the excitability at the cortical level. The underlying mechanism of rTMS is largely unknown, however, it has been suggested to be related with LTP-like process (Touge et al., 2001). As the training produced a status that is less amenable to subsequent LTP production, combining it with rTMS could have additive effect based on similar mechanism (Hodgson et al., 2005). In addition, previous evidences have been shown that rTMS on somatosensory cortex can modulate sensory function in frequency dependent manner. Low frequency rTMS has been shown to interfere with somatosensory processing (Knecht et al., 2003; Satow

* Corresponding author at: Department of Physical and Rehabilitation Medicine, Hallym University Sacred Heart Hospital, 896, Pyoungchon-dong, Dongan-ku, Anyang 431-070, Republic of Korea. Tel.: +82 31 380 1887; fax: +82 31 380 3864.
E-mail addresses: choi.eunhi@gmail.com (E.-H. Choi), wooky@hallym.ac.kr, mdwooky@gmail.com (W.-K. Yoo), ohnsh@hallym.ac.kr (S.H. Ohn), 0916hun@hanmail.net (S. Ahn), joooning@hallym.or.kr (H.J. Kim), jki@hallym.ac.kr (K.-I. Jung).
[1] Tel.: +82 33 240 5299; fax: +82 31 380 3864.
[2] Tel.: +82 31 380 1887; fax: +82 31 380 3864.
[3] Tel.: +82 31 380 3865; fax: +82 31 380 3864.
[4] Tel.: +82 31 380 3862; fax: +82 31 380 3864.

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et al., 2003), whereas high frequency rTMS enhanced discrimination ability (Ragert, 2003; Tegenthoff et al., 2005).

Taken together with use dependent plasticity in sensory and motor function with plasticity of the sensory function observed by somatosensory cortex stimulation, facilitation of sensory cortex by high frequency rTMS would enhance motor performance, which hasn't been investigated yet enough, although, its clinical importance of sensorimotor integration in the rehabilitation field.

The aim of this study was to investigate the effect of 10 Hz rTMS on sensorimotor integration whether high frequency rTMS on deltoid representation of the somatosensory cortex would shorten the latency of synchronized contraction of deltoid and abductor pollicis (APB) muscle or not. The underlying hypothesis in this study is that 10 Hz rTMS on the somatosensory cortex of deltoid muscle would increase the sensory discrimination function on the representational area of deltoid muscle. In addition, increase of the sensory discrimination function might have influence on the synchronized contraction of deltoid and APB muscles. Finally, it would show correlation between changes of sensory discrimination and changes of synchronized contraction time.

2. Materials and methods

2.1. Subjects

Twenty healthy right-handed subjects (eight man and twelve women, mean age: 26.5 ± 4.6 years) participated in this study. We received the approval of the local ethics committee for the experimental procedures, and all the participants provided a written informed consent.

The subjects were assigned into two random groups: a real-rTMS stimulation group ($n = 12$) and a sham stimulation group ($n = 8$). The groups did not differ in their mean age (24.5 ± 3.6 vs. 28.9 ± 5.2, respectively) and mean educational levels (13.9 ± 0.6 vs. 15.0 ± 0.6, respectively).

2.2. Experimental procedures

2.2.1. Sensory discrimination measurement

Two-point discrimination was measured by employing a conventional paired needle device on the skin over the deltoid and the APB muscle bellies. Three consecutive trials were conducted to obtain the consistent values for each assessment session that was performed before and after the intervention.

2.2.2. Motor performance measurement

The subjects were comfortably seated in an armchair with both hands pronated on a pillow. Motor task consisted of a synchronized movement of APB and deltoid muscle, which paradigm was used by Tegenthoff et al. (2004). The participants were instructed to make a brisk, short contraction of both muscles as synchronously as possible. Over 1 h, three co-contractions per minute had to be performed with a guidance of beep tone. This is a motor learning paradigm consisted of synchronized contraction of proximal and distal muscle, that is not used in usual activity of daily living. As proximal muscles are adapted for postural functional roles rather than high contraction speeds, contraction of deltoid muscle is slower than APB muscle (Fig. 2), which was shortened as the training session of synchronized contraction underwent. To minimize the training effect of this motor performance task, the experiment was preceded after we trained the subjects until they felt comfortable to perform the desired patterned movement. The dynamic EMG system (DELSYS®, Bagnoli-8 EMG System, Boston, MD, USA) was used for the measurements of the latency difference between the onsets of both muscle contractions (sampling rate; 1000 Hz). EMG data were collected via surface electrodes that were placed over these muscles in a belly-tendon montage. We measured the latency differences between deltoid and APB muscles, which was defined as *synchronization time* (Fig. 2) before and after intervention (rTMS or sham). Three blocks of motor performance were done before and after intervention (rTMS or sham), one block consisted of a period of 10 min and inter block interval was set as 1 min for the purpose of prevention of the muscle fatigue (Fig. 1).

2.2.3. rTMS procedure

With a subject comfortably seated and relaxed in a chair, a NeuroScreen Plus® EMG system (Erich Jaeger, Germany) was used to record and monitor the activity of the right APB muscle. The optimal scalp location ("the hot spot") was determined using a transcranial magnetic stimulation (TMS) system (Magstim Rapid2® stimulator: Magstim Ltd, UK) equipped with a 70-mm figure-of-eight coil that evoked motor potentials (MEPs) of maximum peak-to-peak amplitude in the deltoid muscle. Specifically, the figure of eight coil was positioned tangentially to the scalp at an angle of 45° from the mid-sagittal line such that the electromagnetic current flow perpendicular to the central sulcus. The coil was systematically moved in 1 cm steps at constant supra-threshold stimulus intensity to detect the hot spot. Once the hot spot had been identified, a single pulse TMS was delivered to the location starting at a supra-threshold intensity and then gradually reducing it by decrements of 2% of the stimulator output. Muscle relaxation recorded in the EMG was carefully monitored prior to stimulation to prevent any motion artifacts. The resting motor threshold (RMT) was defined as the lowest stimulus intensity necessary for inducing MEPs of $\leqslant$50 μV peak-to-peak amplitude in 5 of 10 consecutive trials (Rossini et al., 1994). For the stimulation of the somatosensory cortex of the deltoid muscle representation, we marked the point, which was located 1.5 cm posterior to the 'hot spot' of the deltoid muscle.

In rTMS session, a total of 900 stimuli (50 trains × 18 trials with an inter-train interval of 10 s) were applied at a frequency of 10 Hz. The stimulus intensity was set at 90% of the RMT. Sham group received stimulation by tilting the stimulator coil 45° so that subjects feel the pressure on the scalp along with a same auditory input, but this was done without actual electrical stimulation to the cortex (Fig. 2).

2.3. Data analysis

The effect of rTMS was evaluated by analysis of variance (ANOVA) for repeated measures with the condition (sham vs. rTMS) as the between-subject factor, and time was used as the within-subject factor (pre-session 1, pre-session 2, pre-session 3, post-session 1 (0–10 min), post-session 2 (10–20 min) and post-session 3 (20–30 min)). Post-hoc testing was done between the sum of the three pre-session and each post-session for evaluating the p value. Pearson's correlation coefficient r was calculated in order to detect a possible relationship between the sensory discrimination and the synchronization time.

3. Results

3.1. Sensory discrimination

The two-points discrimination measured on the skin over deltoid area, changed from 43.2 ± 17.6 mm to 33.3 ± 7.9 mm after rTMS on somatosensory cortex of deltoid muscle representation. A paired t test revealed a significant difference [$p = 0.0152$]. Two-points discrimination measured over APB muscle changed also from 8.1 ± 3.1 mm to 7.1 ± 2.9 mm without any statistical