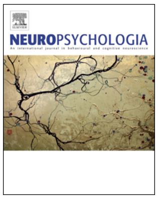
Neuropsychologia 85 (2016) 199–207

Contents lists available at ScienceDirect

Neuropsychologia

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



The influence of unilateral contraction of hand muscles on the contralateral corticomuscular coherence during bimanual motor tasks

Yang Zheng[a,b], Lin Gao[a,b,*], Gang Wang[a,b], Yingtuo Wang[a,b], Zi Yang[a], Xiuyue Wang[a], Tianqi Li[c], Chuan Dang[a], Ruohan Zhu[a], Jue Wang[a,b,*]

[a] The Key Laboratory of Biomedical Information Engineering of Ministry of Education, Institute of Biomedical Engineering, School of Life Science and Technology, Xi'an Jiaotong University, China
[b] National Engineering Research Center of Health Care and Medical Devices, Xi'an Jiaotong University Branch, China
[c] School of Mechanical Engineering, Xi'an Jiaotong University, China

ARTICLE INFO

Article history:
Received 15 September 2015
Received in revised form
20 February 2016
Accepted 23 March 2016
Available online 24 March 2016

Keywords:
Corticomuscular coherence
bimanual
oscillations
electroencephalography
electromyography

ABSTRACT

The mechanisms behind how muscle contractions in one hand influence corticomuscular coherence in the opposite hand are still undetermined. Twenty-two subjects were recruited to finish bimanual and unimanual motor tasks. In the unimanual tasks, subjects performed precision grip using their right hand with visual feedback of exerted forces. The bimanual tasks involved simultaneous finger abduction of their left hand with visual feedback and precision grip of their right hand. They were divided into four conditions according to the two contraction levels of the left-hand muscles and whether visual feedback existed for the right hand. Measures of coherence and power spectrum were calculated from EEG and EMG data and statistically analyzed to identify changes in corticomuscular coupling and oscillatory activity. Results showed that compared with the unimanual task, a significant increase in the mean corticomuscular coherence of the right hand was found when left-hand muscles contracted at 5% of the maximal isometric voluntary contraction (MVC). No significant changes were found when the contraction level was 50% of the MVC. Furthermore, both the increase of muscle contraction levels and the elimination of visual feedback for right hand can significantly decrease the corticomuscular coupling in right hand during bimanual tasks. In summary, the involvement of moderate left-hand muscle contractions resulted in an increase tendency of corticomuscular coherence in right hand while strong left-hand muscle contractions eliminated it. We speculated that the perturbation of activities in one corticospinal tract resulted from the movement of the opposite hand can enhance the corticomuscular coupling when attention distraction is limited.

1. Introduction

The synchronized discharge of corticospinal cells is believed to be reflected by the coherent activities of the beta band (15–30 Hz) between the motor cortex and the muscles (Baker et al., 1997; Conway et al., 1995). The information from the synaptic drive to spinal motoneurons during a voluntary contraction can be evaluated by estimating the coherence (Baker, 2007; Witham et al., 2010) which measures the strength of coupling between signals in the frequency domain (Rosenberg et al., 1989). Coherence analysis for monkeys (Baker et al., 1999, 1997; Murthy and Fetz, 1992, 1996; Witham et al., 2010) and humans (Halliday et al., 1998; Kilner et al., 2000; Kristeva et al., 2007; Riddle and Baker, 2006) in previous studies has demonstrated that synchronization between cortical and contralateral muscle activities is most pronounced in the beta-band range during steady muscle contractions. Coherence in the beta band is also assumed to be associated with strategies for controlling submaximal muscle forces (Conway et al., 1995; Halliday et al., 1998; Kilner et al., 2000).

The mechanisms underlying corticomuscular coupling are still being discussed, and detailed understanding of such mechanisms will greatly enhance their research potentials (Boonstra, 2013). Previous studies mainly focused on the features of corticomuscular coherence (CMC) retrieved from electroencephalography (EEG)/magnetoencephalography (MEG) and electromyography (EMG) analysis during unimanual motor tasks in healthy individuals. Several factors that influence the corticomuscular coherence have been identified, such as the strength level of contractions (Kilner et al., 2000; Omlor et al., 2011; Witte et al., 2007), attention

---

[*] Corresponding authors at: The Key Laboratory of Biomedical Information Engineering of Ministry of Education, Institute of Biomedical Engineering, School of Life Science and Technology, Xi'an Jiaotong University, No. 28, Xianning West Road, Xi'an, Shaanxi 710049, China.
E-mail addresses: gaolin2013@mail.xjtu.edu.cn (L. Gao), zytu25@126.com (J. Wang).

http://dx.doi.org/10.1016/j.neuropsychologia.2016.03.028
0028-3932/© 2016 Elsevier Ltd. All rights reserved.

(Johnson et al., 2011; Kristeva-Feige et al., 2002), age (Johnson and Shinohara, 2012), frequency of modulated forces (Naranjo et al., 2010) and motor learning (Mendez-Balbuena et al., 2012; Perez et al., 2006). Studies based on clinical populations have shown that weakened corticomuscular coherence may reflect an underlying mechanism that produces motor deficits of the post-stroke (Fang et al., 2009; Mima et al., 2001).

Bimanual motions are important for humans because many daily-life tasks require effectors of both hands to produce different and coordinated motor outputs that are usually bound together by an object-directed goal. Thus, studying the corticospinal outputs during bimanual tasks is of great significance. Previous studies that used transcranial magnetic stimulation have demonstrated that the corticospinal output measured in a voluntarily active arm may be changed by the voluntary contraction of an opposite arm muscle (Netz et al., 1995; Stinear and Byblow, 2004; Yedimenko and Perez, 2010). Gross et al. (2005) demonstrated that the corticomuscular coherence in one hand may be modulated by the direction of the opposite hand's movement. Some studies obtained seemingly contradictory results about how the contractions and contraction level of hand muscles can influence the corticomuscular coherence in the opposite hand with voluntary contractions (Johnson and Shinohara, 2012; Johnson et al., 2011; Perezet al., 2012). Johnson et al. (2011) concluded that the beta-band corticomuscular coherence in one hand decreased during the concurrent movement of the opposite hand due to the divided attention. On the contrary, Perez's study (Perez et al., 2012) showed that the beta-band corticomuscular coherence in one hand increases along with the contraction level of muscles from the opposite hand. She speculated that the complexity of controlling a fine motor task with one hand was increased by the diffuse mirrored activity induced by the strong muscle contraction from the opposite hand. Thus, the corticomuscular coupling needed for fine motor control was increased (Perez et al., 2012). The contradictory results were possibly caused by the different details of their experimental designs. However, the two inferred reasonable factors, namely, divided attention and diffuse mirrored activities, clearly have opposite effects. This difference reflects the complexity of the corticospinal output during bimanual tasks.

This study aimed to verify how the voluntary contraction of hand muscles can influence corticomuscular coherence in the opposite hand that is also performing a voluntary muscle contraction. Considering the results of previous studies (Johnson et al., 2011; Perez et al., 2012), we attempted to analyze the effects of simultaneous divided attention and other possible mechanisms during bimanual motor tasks, as well as identifying whether a dominant factor is present.

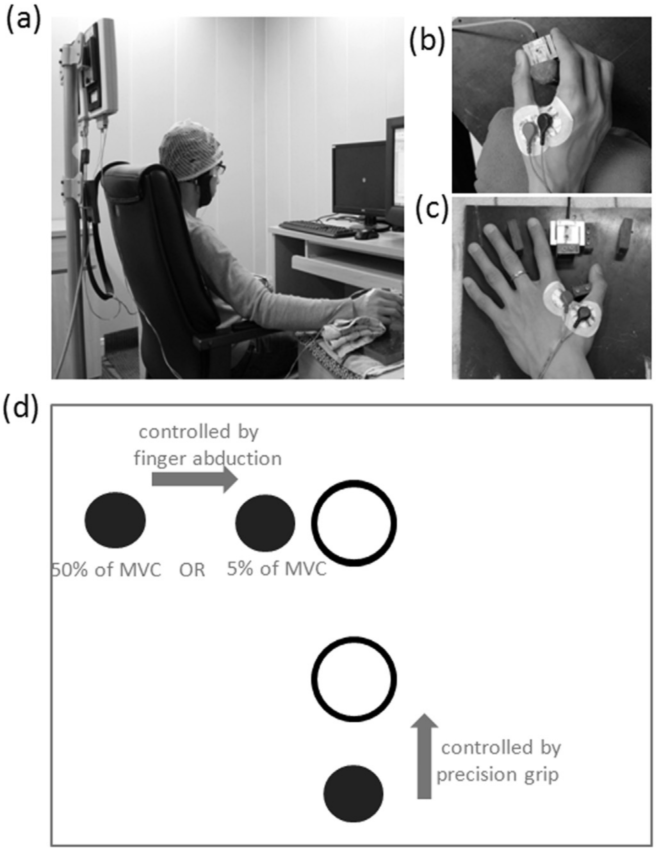


Fig. 1. Experimental paradigms and the visual feedback on screen. (a) The experiment was conducted in an electromagnetic shielding room. Subjects were seated on a chair with their forearms resting on tables, and their necks resting on a backrest to avoid fatigue and excessive muscle contractions. A screen was placed 100 cm in front of the subjects to provide them visual feedback of their exerted forces with hands. (b) In both unimanual and bimanual tasks, subjects were instructed to perform a precision grip using the thumb and index fingers of their right hands. (c) In bimanual tasks, subjects were instructed to simultaneously perform an abduction of index fingers of their left hands in addition to the right-hand motion. EMG signals were obtained from the first dorsal interosseous (FDI) muscles of both hands. (d) A trial was initiated when the lower vertically shifting circle and target ring showed on screen in unimanual tasks or both the lower circle and ring and the upper horizontally shifting circle and target ring showed on screen in bimanual tasks. The positions of target rings were fixed. Subjects were instructed to move the circles into the corresponding rings as soon as possible and maintain the contraction until the end of the trial when all feedback information disappeared. The horizontally shifting circle was controlled by the finger abduction of the left hand. The initial positions varied in different trials corresponding to target forces of 5% or 50% MVC. The vertically shifting circle was controlled by the precision grip of the right hand. The initial position was fixed corresponding to a target force of 2 N. In the steady-hold periods of task 'R-L5' and 'R-L50', the lower horizontally shifting circle and the target ring would disappear.

2. Materials and methods

2.1. Experimental paradigm

As the baseline condition, the unimanual task was designed as a precision grip, with the index finger and the thumb of right hand squeezing a strain gauge to exert a 2-N constant force [Fig. 1(b)]. During bimanual tasks, subjects were instructed to perform a finger abduction motion with the index finger of their left hand by squeezing another strain gauge [Fig. 1(c)] simultaneously with the precision grip motion described above. Visual feedback on the magnitude of exerted and target forces for both hands [Fig. 1(d)] was shown on a 19″ monitor placed approximately 100 cm in front of the subjects [Fig. 1(a)]. Two contraction levels for left-hand muscles were identified, i.e. 5% and 50% of the maximal isometric voluntary contraction (MVC), which was measured before the experiment for each subject. The 5% MVC level can be easily achieved by the left hand. Thus, this level was selected to involve left-hand motions without dividing the attention from the control of precision grip with right hand. By contrast, finger abduction at 50% MVC level was more complex and effortful. Thus, more attention had to be divided from the control of precision grip and directed toward the control of finger abduction with left hand. To further divide the attention for adjusting the muscle contractions of right hand, the visual feedback for right hand was eliminated in some bimanual conditions. Thus, four combined conditions were obtained for bimanual tasks based on the contraction level of left-hand muscles and whether visual feedback was retained for the right hand. The conditions were named 'RF-L5', 'R-L5', 'RF-L50' and 'R-L50', where 'RF' meant visual feedback for right hand was retained; 'R' meant visual feedback for right hand was eliminated. 'L5' meant the target force for left hand was 5% of MVC and 'L50' meant the target force was 50% of MVC. Meanwhile, the unimanual task was termed as 'RF-L0'.

In both unimanual and bimanual tasks, each trial lasted for 6 s. During the first 2 s, subjects needed to adjust the exerted force on the targets. Then, they were instructed to maintain the force until the end of a trial. For both unimanual and bimanual tasks, the first 2 s of a trial was the adjusting phase and the last 4 s was the steady-hold period. The elimination of visual feedback for right hand only occurred during the steady-hold period. Subjects needed to finish one block of unimanual tasks consisting of 60 trials and seven blocks of bimanual tasks consisting of 40 trials each. In each bimanual block, there were 10 trials for each of the 4 conditions that were distributed randomly. The time interval between two adjacent trials was approximately 2 s. To avoid muscle fatigue, several minutes of rest between two blocks were provided for the subjects. Subjects practiced before the experiments until target forces could be reached within the adjusting phase as required.