Brief Report

The effect of visual and auditory enhancement on excitability of the primary motor cortex during motor imagery: a pilot study

(Revised version)

Kohei Ikeda [a], Toshio Higashi [b], Kenichi Sugawara [b], Kounosuke Tomori [b], Hiroshi Kinoshita [c], Tatsuya Kasai [d]

a. Yokohama Miyazaki Hospital of Neurosurgery, 218-9 Kariba-cho, Hodogayaku, Yokohama, Kanagawa, Japan

b. School of Rehabilitation, Faculty of Health and Social Work, Kanagawa University of Human Services, 1-10-1 Heisei-cho, Yokosuka, Kanagawa, Japan

c. Graduate School of Medicine, Osaka University, 1-17 Machikaneyama-cho Toyonaka City, Osaka

d. Department of Rehabilitation of Locomotor System Dysfunction, Graduate School of Health Sciences, Hiroshima University, 1-2-3 Kasumi, Minamiku, Hiroshima, Japan

Tel.: +81 46 828 2728

Fax: +81 46 828 2729

Correspondence to: Toshio Higashi, Associate Professor & Ph.D.

E-mail: higashi-t@kuhs.ac.jp

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Abstract

The effect of visual (VIS) and auditory (AUD) enhancement of finger movement on corticospinal excitability during motor imagery (MI) was investigated using transcranial magnetic stimulation (TMS) technique. Motor evoked potentials (MEPs) were elicited from the abductor digit minimi muscle during MI with information of AUD, VIS, AUD and VIS (AUD+VIS), and no information (NI). Ten healthy subjects were instructed to imagine repetitive abduction and adduction of the fifth finger. After each condition, the extent of vividness of MI was rated using a visual analogue scale (VAS). The results showed that mean VAS score and MEP amplitude for the AUD+VIS condition were higher than those of other conditions, indicating enhanced excitability of the primary motor cortex with a clearer image of motor action during MI.

Introduction

Motor imagery (MI) is a familiar aspect of our daily cognitive experience. Correspondence in functional neural substrates involved in MI and real movements has been demonstrated by studies using functional brain imaging technique (de Lange et al., 2008; Guillot et al., 2009). Psychophysical experiments have shown that MI can be used to study motor rules for speed-accuracy trade-off (Radulescu et al., 2010) and biomechanical constraints of real movement (Dietrich, 2008). MI thus allows us to investigate planning and preparation for motor actions, while avoiding interactions between sensory feedback and motor functions related to motor execution. In recent studies, attempts have been made to use MI for post stroke rehabilitation (Sharma et al., 2006; Zimmermann-Schlatter et al., 2008; Page et al., 2009).

MI represents the result of conscious access to the content of an intentional movement. Although conscious and unconscious MI, that is, vivid or non-vivid MI, may share common neural mechanisms, their effectiveness may differ. This may be the reason why there is a large inter-individual difference in the effectiveness of MI. Kasai and his colleagues have repeatedly shown that kinesthetic sensation stemming from imagined movement plays an important role in mental simulation of movement during MI (Kasai et al. 1997; Yahagi and Kasai 1998). The present study attempted to extend our findings by investigating the relationship between corticospinal excitability and vividness of MI. Motor evoked potentials (MEPs) in the abductor digit minimi (ADM) muscle produced by transcranial magnetic stimulation (TMS) were compared under four different sensory input conditions while healthy subjects imagined repetitive abduction and adduction movement of the fifth finger.

Methods

Ten right-handed volunteers (20-36 years old), who were free from any known neuromuscular disorders, participated in the present study.

The subjects were seated in a chair with both arms on a table. The hand was kept open and relaxed with the palm facing downward. The PC monitor was placed in front of the subjects (80 cm viewing distance). MEPs were evoked under five conditions, which were (1) no information (NI), (2) auditory (AUD), (3) visual (VIS), (4) auditory with visual (AUD+VIS), and (5) relaxed (control) condition. In the NI condition, the subjects were instructed to close their eyes and to imagine repetitive fifth finger abduction and adduction at 0.5 Hz. In the AUD condition, the subjects were instructed to close their eyes and to imagine repetitive fifth finger abduction and adduction using an auditory cue of 0.5 Hz beeps coming from a metronome. In the NI and AUD conditions, TMS was delivered at approximately 4.8 s when the third abduction was performed during MI. In the VIS condition, the subjects imagined the same finger movement while observing the video-clip of the task performed by a third person. In the AUD+VIS condition, the subjects imagined the finger movement while observing the video-clip with the beep sounds. In the VIS and AUD+VIS conditions, TMS was delivered at a pre-determined delay in the video-clip, which corresponded to the fifth finger being abducted at approximately 60 degrees from the initial (closed) position. In the control condition, the subjects were instructed to relax completely and to think about nothing. Seven trials for each condition (35 total trials) for each subject were performed while the order of the conditions was randomized for each subject. At the end of each condition, in order to rate the vividness of subjects' motor imagery, the subjects were asked to complete a self-evaluation using a visual analogue scale (VAS). That is, the subjects marked a location on a 100 mm horizontal line, the two ends of which were labeled '0=None at all' and '100=Very vivid image', according to the vividness of the imagery they experienced(Trebblay et al., 2008; Lotze and Halsband, 2006). The surface EMG was recorded from right ADM muscle. TMS was given to the motor hot spot, using a figure-of-eight-shaped coil. The test stimulus was adjusted to evoke a control response with peak-to-peak MEP amplitude of approximately 0.5-1 mV in the ADM muscle (1.1-1.3 times of rMT).

Changes in peak-to-peak amplitude of MEP obtained from all conditions were expressed as a percentage of the control MEP size (amplitude). In order to test the condition difference in MEPs and VAS scores, one-way repeated measure analysis of variance (ANOVA) was performed. If a significant interaction was obtained, post hoc analysis was carried out using Tukey HSD. The level of statistical significance was set at $P<0.05$.

The study was approved by the ethical committee of Kanagawa University of Human Services.

Results

Figure 1 shows typical specimen recordings of MEPs from three trials superimposed for each condition from a single subject. MEP amplitude was clearly smallest for the control condition. Note that the amplitude was largest for the AUD+VIS condition.

Figure 2-A shows the group means of MEPs for the NI, AUD, VIS, and AUD+VIS conditions. ANOVA revealed a significant condition effect (F=5.630, $P < 0.05$). A post-hoc Tukey HSD revealed that the mean for the AUD+VIS condition was significantly larger than in the NI and AUD conditions ($P < 0.05$). The mean value for the VIS condition was also significantly larger than in the NI condition ($P<0.05$). We also examined if the mean values of pre-stimulus EMG activity for all conditions were different. ANOVA revealed no difference among the means.

Figure 2-B shows the mean values of VAS scores (N=10) for the NI, AUD, VIS, and AUD+VIS conditions. ANOVA revealed a significant condition effect (F=4.225, $P < 0.05$). A Tukey test further revealed that the mean for the AUD+VIS was significantly larger than that for the NI condition.

Discussion

Our hypothesis was that a larger amount of sensory information on the target motor action would provide a higher level vividness image of motor action than no or a smaller amount of information during MI, and the level of corticospinal excitability would be enhanced if MI was better executed.

In line with our hypothesis, the VAS score was higher for the AUD+VIS condition than the other conditions, and the NI was lowest. In addition, the MEP amplitude of the ADM muscle was largest for the AUD+VIS condition than the others, and the NI condition had the lowest MEP amplitude. These findings clearly indicated that, depending on the kind and amount of sensory information given, MEP amplitudes and thus corticospinal excitability during MI would increase at different levels. Furthermore, involvement of the corticospinal pathway was shown by several TMS studies in which the motor evoked potential was significantly higher during observation or imagery of a motor task than rest condition (Fadiga et al., 1999, Roosink et al., 2010, Tremblay et al., 2008). Several magnetic response imaging experiments have further demonstrated primary motor cortex activation during MI (Porro et al., 1996; Lacourse et al,. 2005; Rodriguez et al., 2004) or movement observation (Buccino et al., 2006). Taken together, it is possible to state that the primary motor cortex, a motor execution center, also plays a functional role in movement observation as well as forming and executing motor imagery, which supports the notion proposed in previous studies (Decety, 1996; Jeannerod, 2001).

In summary, we have shown that combining visual and auditory information enhanced vividness of MI and facilitated corticospinal excitability. The present findings provide a new possibility for enhancing the mental aspects of neuro-rehabilitation and for advancing the development of an evidence-based motor learning program.

References

Buccino G, Soldkin A, Small SL (2006). Functions of the Mirror Neuron System: Implication for Neurorehabilitation. Cognitive and Behavioral Neurology 19: 55-63.

Decety J (1996). The neurophysiologocal basis of motor imagery. Behavioural Brain Research 77:45-52.

de Lange FP, Frolis P, Roelofs K, Toni I (2008). Motor imagery : A window into the mechanisms and alterations of the motor system. Cortex 44:494-506.

Dietrich A: Imaging the imagination: The trouble with motor imagery (2008). Methods 45: 319-324.

Fadiga L, Buccino G, Craighero L, Fogassi L, Gallese V, Pavesi G (1999). Corticospinal excitability is specifically modulated by motor imagery: a magnetic stimulation study. Neuropsychologia 37:147-158.

Guillot A, Collet C, Nguyen VA, Malouin F, Richards C, Doyon J (2009). Brain activity during visually versus kinesthetic imagery: An fMRI study. Human Brain Mapping 30:2157-2172.

Jeannerod M. Neural simulation of action : a unifying mechanism for motor cognition (2001). Neuroimage 14:S103-9.

Kasai T, Kawai S, Kawanishi M, Yahagi S (1997). Evidence for facilitation of motor evoked potentials (MEPs) induced by motor imagery. Brain Research 744:147-150.

Lacourse MG, Orr ELR, Cramer SC, Cohen MJ (2005). Brain activation during execution and motor imagery of novel and skilled sequential hand movement. NeuroImage 27:505-519.

Lotze M, Halsband U (2006). Motor imagery. J Physiol 99: 386-395.

Page S， Szaflarski J, Eliassen J, Pan H, Cramer S (2009). Cortical plasticity following motor skill learning during mental practice in stroke. Neurorehabilitation and Neural Repair 23(4): 382-388.

Porro CA, Francescato MP, Cettolo V, Diamond ME, Baraldi P, Zuiani Chiava, Bazzocchi M, Prampero PE (1996). Primary Motor and Sensory Cortex Activation during Motor Performance and motor imagery: A functional Magnetic Resonance Imaging Study. Journal of neuroscience

16(23), 7688-7698.

Radulescu P, Adam JJ, Fisher MH, Pratt J (2010). Fitts’s Law violation and motor imagery: area imaged movements truthful or lawful?. Exp Brain Res 201:607-611.

Rodriguez M, Muniz R, Gonzalez B, Sabate M (2004). Hand movement distribution in the motor cortex: The influence of a concurrent task and motor imagery. NeuroImage 22:1480-1491.

Roosink M, Zijdewind E (2010). Corticospinal excitability during observation and imagery of simple and complex hand tasks: Implications for motor rehabilitation. Behav Brain Res 213:35-41.

Sharma N, Pomeroy V, Baron J (2010): Motor Imagery: A Backdoor to the Motor System After Stroke? Stroke 37:1941-1952.

Tremblay F, Leonard G, Tremblay L (2008). Corticomotor facilitation associated with observation and imagery of hand actions is impaired in Parkinson’s disease. Experimental Brain Research 185: 249-257.

Yahagi S, Kasai T (1998). Facilitation of motor evoked potentials (MEPs) in first dorsal interosseous (FDI) muscle is dependent on different motor images. Electroencphalography and clinical Neurophysiology 109:409-417.

Zimmermann-Schlatter A， Schuster C, Puhan M, Siekierka E, Steurer J (2008). Efficacy of motor imagery in post-stroke rehabilitation: a systematic review. Journal of NeuroEngineering and Rehabilitation 5：1-10.

Figure Legends

Fig. 1 Typical MEP responses in the ADM muscle of a single subject for each condition.

Fig. 2 The means and standard deviations of MEP amplitude and VAS score for all subjects for each of the imagery conditions. The asterisks indicate levels of significance. *P<0.05

Figure

Fig.1

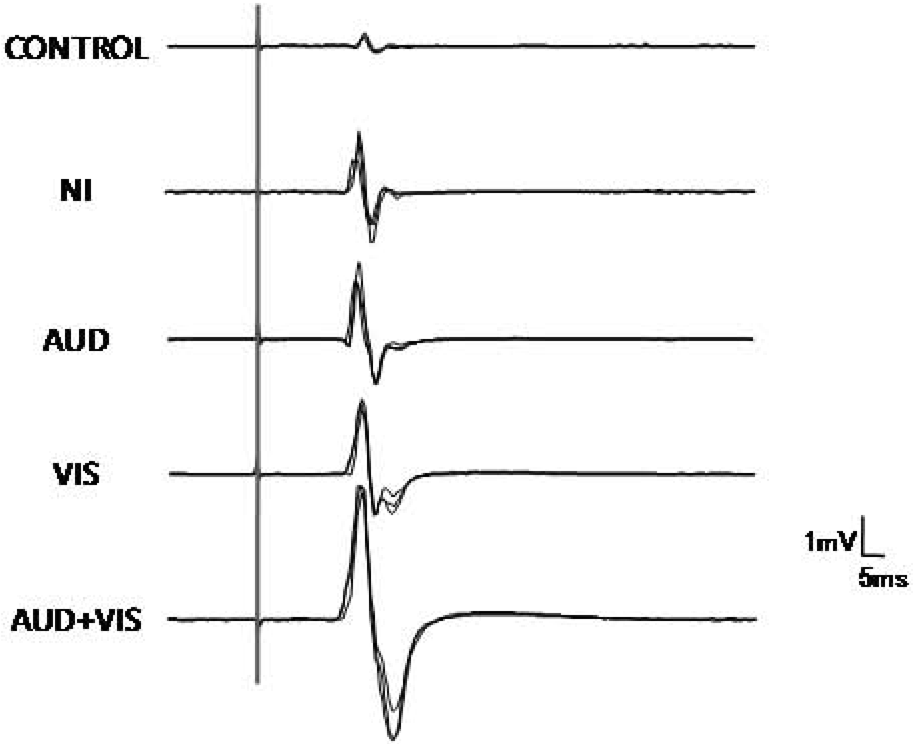
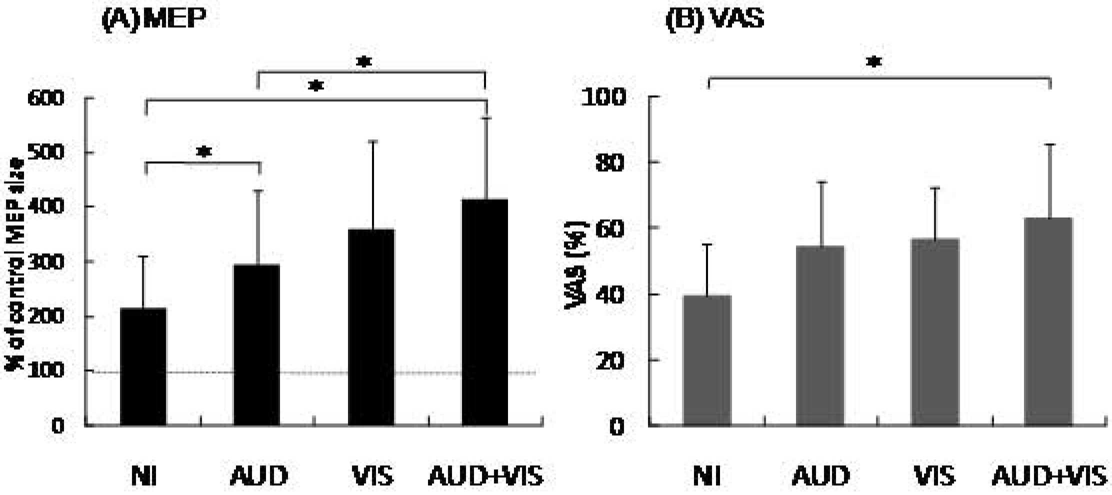


Fig.2


(A) MEP
% of control MEP size
600
500
400
300
200
100
0
*
*
*
NI
AUD
VIS
AUD+VIS
(B) VAS
VAS (%)
100
80
60
40
20
0
*
NI
AUD
VIS
AUD+VIS