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Action observation facilitates motor cortical activity in patients with stroke and hemiplegia

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ABSTRACT

Motor imagery (MI) is a mental practice that reproduces the visual- and/or kinesthetic-modality brain activations accompanying movement. It is a useful rehabilitation technique as the affected motor cortex can be stimulated in patients with stroke and hemiplegia. However, most patients with stroke have difficulty with MI owing to advanced age and/or higher-cognitive dysfunction, thus impairing their ability to internally simulate the action. We therefore investigated whether action observation (AO), an alternative form of motor stimulation that works via the mirror-neuron system, could facilitate motor cortical activity in such patients. Combined AO and physical training of the observed actions has been reported to have a positive impact on motor deficits after stroke. Eleven patients with stroke and hemiplegia affecting the hand performed MI and AO with verbal and video instructions under 19 channels of electroencephalogram (EEG) recording. The event-related desynchronization (ERD) was measured as an electroencephalographic marker of motor cortical activity. The ERD power in the AO condition ($30.0 \pm 5.0\%$) was significantly higher than that in the MI condition ($12.2 \pm 3.9\%$). These results suggest that AO could be a good option for patients with stroke who have difficulty using MI to effectively stimulate and reestablish cortical-peripheral motor pathways.

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1. Introduction

Upper-limb motor impairment after stroke is reported to often result in poor functional recovery compared with lower-limb motor impairment (Duncan et al., 1992) and remains a serious dysfunction (Van der Lee et al., 2001). Providing efficient and effective training for restoring upper-limb function is therefore considered important for rehabilitating stroke survivors to the point of regaining the activities of daily life and social participation (Wade et al., 1983).

Motor imagery (MI) is one of the potential techniques for enhancing motor recovery in patients with stroke when used concurrently with physical practice (Zimmermann-Schlatter et al., 2008; Eaves et al., 2016). MI is currently defined as a dynamic neuronal state wherein one internally rehearses the movement in working memory regardless of the existence of actual movement output (Decety and Grezes, 1999). Since the brain regions involved in movement execution and MI mostly overlap (Solodkin et al.,

2004), mental training through MI may help patients retrain and reconstruct the formerly lost motor pathways.

Event-related desynchronization (ERD) is an event-related decrease in the mu-band (8–13 Hz) oscillatory activity recorded over the brain. When recorded over the sensorimotor cortex, it finds use as a measure of the excitation representing a central motor command, in MI as well as in movement execution (Pfurtscheller and Neuper, 1997). The mu rhythm is thought to represent the spontaneous firing (or idling state) of the thalamocortical motor circuit. ERD may result from the arrival of a depolarizing input from the thalamus that suppresses neuron activity in cortical layer IV (Lopes da Silva, 1991; Pfurtscheller et al., 1997). In healthy participants, the strength of an MI-induced ERD correlates well with corticospinal excitability (Takemi et al., 2013) and, in patients with stroke, with functional impairment (Kaiser et al., 2012).

Despite its demonstrated usefulness in sports science, combining MI with conventional therapy for stroke rehabilitation remains to be validated. Evidence of usefulness in this application remains modest due to the inconsistent outcomes of past studies (Zimmermann-Schlatter et al., 2008). Significantly, many patients with stroke have difficulty in generating MI in clinical settings in

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Table 1
Patient profiles.

Case	Age	Sex	Type of stroke	Damaged lesion	Hemiplegic side	Time since Stroke, Days	fin/ BRS	SIAS	Higher brain function disorder	Frequency range for ERD detection	MMSE
1	67	F	I	R IC	L	541	V	2	NS	7–11	28
2	43	F	I	R F, P, T, BG, CR, Ins	L	162	III	1	USN Frontal lobe dysfunction,	9–13	29
3	73	M	I	R IC	L	1260	IV	2	NS	6–10	–
4	76	F	H	R Th	L	33	III	1	USN, Frontal lobe dysfunction	8–12	25
5	75	M	I	R F,IC	L	54	IV	2	USN, Frontal lobe dysfunction	6–10	21
6	47	M	H	R PU	L	320	III	1	USN, Frontal lobe dysfunction	6–10	27
7	55	F	I	R F, P, BG, CR, Ins	L	537	III	1	NS	8–12	–
8	75	M	I	L P	R	22	V	2	NS	8–12	21
9	72	M	I	L GP	R	18	V	2	NS	8–12	27
10	59	M	I	L BG,CR	R	69	V	2	Aphasia, Apraxia, Frontal lobe dysfunction	6–9	24
11	37	F	H	L PU	R	1919	III	1	Aphasia	8–12	–

Abbreviations: M, Male; F, Female; I, Infarction; H, Hemorrhagic; PU, Putamen; BG, Basal ganglia; CR, Corona radiata; GP, Globus pallidus; P, Parietal lobe; Th, Thalamus; F, Frontal lobe; Ins, Insula; IC, Internal capsule; T, Temporal lobe; BRS, Brunnstrom stage; SIAS, Stroke Impairment Assessment Set; ERD, Event-Related Desynchronization; USN, Unilateral spatial neglect; MMSE, Mini-Mental State Examination; NS, No obvious symptom; R, Right; L, Left. MMSE was not performed on participants 3, 7, and 11 as the clinicians confirmed their cognitive ability as normal.

response to conventional verbal instructions. Moreover, [Gregg et al. \(2010\)](#) reported an interindividual difference in ability to generate MI, and [De Beni et al. \(2007\)](#) reported that the age of the participant affects their ability to generate MI. These findings raise the possibility that patients with stroke have difficulty in performing MI due to advanced age and/or an impaired ability to internally simulate an action without execution. The dependence of MI on the diverse abilities of patients may be limiting the use of MI-based mental practice for neurorehabilitation ([Teo and Chew, 2014](#)). A more reliable method for stimulating the affected motor cortex may be required to reach the next level of therapeutic outcomes.

Action observation (AO) is another promising methodology for promoting motor cortical activation even in the stroke brain. Acting via the brain's mirror neuron system (MNS), AO can subconsciously and directly activate the same group of motor neurons as those responsible for producing the observed action in the observer ([Rizzolatti et al., 2001, 2014](#)). Indeed, AO facilitates corticomotor excitability, improves motor function ([Nojima et al., 2015](#)), and appears to be a reliable technique for improving upper limb function after stroke ([Buccino, 2014; Kim, 2015](#)). These findings suggest that the involvement of the MNS plays a key role in inducing robust motor cortical activity and facilitating functional recovery of the stroke brain. However, most studies investigating the effect of AO in patients with stroke rely on a corticomuscular functional examination, such as motor evoked potential, and little attention has been paid to the effect of AO on ERD ([Kim et al., 2011, 2014; Frenkel-Toledo et al., 2014, 2016; Behmer and Fournier, 2016](#)). Previous studies in patients with stroke show that the AO-induced ERD is reduced in the affected hemisphere relative to the unaffected hemisphere ([Frenkel-Toledo et al., 2014](#)) and the extent of this impairment of the ERD correlates with the severity of ideomotor apraxia ([Frenkel-Toledo et al., 2016](#)). However, the contribution of the MNS to inducing ERD has not been clearly demonstrated due to the lack of any direct comparison between AO and MI in the same patients. Using sequential trunk exercises, [Kim et al. \(2014\)](#) reported AO to be superior to MI because it evoked stronger ERD in patients with stroke. However, all patients were in a chronic stage in that study and those with apraxia or cognitive impairment had been excluded. Since rehabilitation is maximally beneficial during the acute and recovery stages of stroke rather than the chronic stage, and since a non-negligible ratio of patients with stroke present with accompanying cognitive dysfunction, the beneficial effect of AO should be investigated in such patient populations.

The purpose of this study is, therefore, to examine the difference in ERD between MI and AO in a patient population ranging from acute to chronic stage and including those who suffer from cognitive dysfunction. We test the hypothesis that AO induces a larger ERD than does MI. If AO can help patients with stroke to produce robust ERDs despite having difficulty with MI, they might benefit from the ability of AO to activate the affected motor cortex and thus facilitate recovery.

2. Methods

2.1. Participants

Eleven patients with stroke participated in this study. All participants gave their written informed consent. The study was approved by the local ethics committee of Murata Hospital. Patients who had a bilateral lesion, mental disorder, or other neurologic disorder were excluded. The average time interval between stroke onset and the experiment was 466 days (range, 18–1,919 days). The age of the participants ranged from 37 to 76 years (mean \pm standard deviation: 64.1 ± 7.8 years). The detailed patient profile is summarized in [Table 1](#). On the day of the experiment, we evaluated the degree of paralysis by Brunnstrom recovery stage of the hand. We evaluated the degree of sensory disturbance based on the superficial touch and position senses of the upper extremity using the stroke impairment assessment set. Frontal lobe dysfunction of the cognitive and executive functions, including inhibitory control, problem solving, planning, and attentional switching was assessed by the trail making test, the frontal assessment battery, and the behavioral assessment of the dysexecutive syndrome. The scores of the participants who diagnosed with frontal lobe dysfunction are summarized in [Table 2](#).

2.2. Experimental procedures

All participants performed the experimental task under two conditions, using MI and using AO ([Fig. 1](#)). Both conditions consisted of 50 trials, each trial consisting of a "Rest" and a "Task" period, shown alternately on a 20.1-in. LCD monitor placed 50 cm from the participant. To maximize MNS activity, participants were instructed to gaze at the center of the screen, avoid eye movement throughout the experiment ([Maranesi et al., 2013](#)), and minimize body motion. The experimenter carefully observed the

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