RESEARCH ARTICLE

Brain activation induced by different strengths of hand grasp: a functional magnetic resonance imaging study

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Abstract

Mirror neuron system can be activated by observation and execution of an action. It has an important function of action understanding. We investigated brain activations in humans by observing the strength of a hand grasp using functional magnetic resonance imaging. Twenty right-handed healthy individuals, consisting of 10 males and 10 females, aged 22.40 ± 2.04 years, were recruited into this study from September to November 2017 via posters. Light hand grasp task video showed a hand lightly grasping and releasing a ball repeatedly. Powerful hand grasp task video showed a hand tightly grasping and releasing a ball repeatedly. Functional magnetic resonance imaging block design paradigm comprised five stimulation blocks alternating with five baseline blocks. Stimulation blocks were presented with two stimulus tasks, consisting of a light grasp and a powerful grasp. Region of interest was defined around the inferior parietal lobule, inferior frontal gyrus, and superior temporal sulcus which have been called mirror neuron system. The inferior parietal lobule, fusiform, postcentral, occipital, temporal, and frontal gyri were activated during light and powerful grasp tasks. The BOLD signal response of a powerful grasp was stronger than that of a light grasp. These results suggest that brain activation of the inferior parietal lobule, which is the core brain region of the mirror neuron system, was stronger in the powerful grasp task than in the light grasp task. We believe that our results might be helpful for instructing rehabilitation of brain injury. This study was approved by the Institutional Review Board of Daegu Oriental Hospital of Daegu Haany University on September 8, 2017 (approval No. DHUMC-D-17020-PRO-01).

Key Words: *brain activation; fMRI; human brain; inferior parietal lobule; light grasp; mirror neuron system; powerful grasp*

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Introduction

In the 1990s, the discovery of mirror neuron (MN) in the ventral premotor cortex (area F5) of the macaque monkey brain was a momentous one for neuroscience (Gallese et al., 1996; Rizzolatti et al., 1996). Consequently, several researchers attempted to find corresponding brain regions and investigated the function of MN in the human brain (Rizzolatti et al., 1996, 2001; Rizzolatti and Arbib, 1998; Decety and Grezes, 1999; Iacoboni et al., 1999, 2005; Iacoboni and Dapretto, 2006; Caspers et al., 2010). Various human brain regions are related to the MN such as the premotor cortex, supplementary motor area, primary somatosensory cortex, inferior parietal lobule (IPL), inferior frontal gyrus (IFG), and superior temporal sulcus (STS) (Rizzolatti et al., 1996, 2001; Rizzolatti and Arbib, 1998; Decety and Grezes, 1999; Iacoboni et al., 1999, 2005; Iacoboni and Dapretto, 2006; Caspers et al., 2010). Since various brain regions are involved in the MN, it was named the mirror neuron system (MNS) (Rizzolatti and Arbib, 1998; Rizzolatti et al., 2001; Iacoboni and Dapretto, 2006). In particular, STS, IFG, and IPL were known to be the core regions of the MNS in the human brain (Rizzolatti and Arbib, 1998; Decety and Grezes, 1999; Rizzolatti et al., 2001; Iacoboni and Dapretto, 2006). Several researchers reported that the MNS was activated by observation and execution of an action. It is essential for understanding the intentions of other (Caspers et al., 2010; Acharya and Shukla, 2012; Garcia Carrasco and Aboitiz Cantalapiedra, 2016). The MNS is also involved in empathy, language, and imitation behaviors (Garcia Carrasco and Aboitiz Cantalapiedra, 2016; Bonavita, 2017). Dysfunction of the MNS is related with apraxia, autism, and schizophrenia (Arbib and Mundhenk, 2005; Goldenberg and Karnath, 2006; Iacoboni and Dapretto, 2006).

Earlier studies on the MN used electrophysiological methods such as electroencephalography and transcranial magnetic stimulation in monkeys and human brains (Fadiga et al., 1995; Hari et al., 1998; Cochin et al., 1999; Strafella and Paus, 2000). Although these methods can be used to investigate the specific brain regions related with the MNS, it is difficult to investigate whole brain regions at once. However, after development of fMRI, it is possible to investigate whole brain regions with various effectors such as the hands, feet, body, and mouth (Salles et al., 2015). Many studies have found that several brain regions (IFG, STS, intraparietal sulcus, occipital sulcus, and IPL) were involved in observation of hand actions (Buccino et al., 2001, 2004; Grezes and Decety, 2001; Hamilton and Grafton, 2006; Chong et al., 2008a; Caspers et al., 2010). However, little is known about MNS based on the strength used for observation of hand actions.

Based on previous studies on MNS, we hypothesized that MNS might help detect different strengths of hand grasps and powerful grasp provides stronger brain activation in the MSN than light grasp. Therefore, the purpose of this study was to investigate brain activation during observation of different strengths of hand grasp on functional magnetic resonance imaging (fMRI).

Participants and Methods

Participants

This study was a prospective single-arm trial. Twenty right-handed healthy subjects, consisting of 10 males and 10 females, aged 22.40 ± 2.04 years, had no history of physical, neurological, or psychiatric illness diagnosed by local community hospital and were included in this study. This study was approved by the Institutional Review Board of Daegu Oriental Hospital of Daegu Haany University on September 8, 2017 (approval No. DHUMC-D-17020-PRO-01) and was carried out according to the *Declaration of Helsinki*. All subjects provided written informed consent prior to participation.

fMRI

Experimental design

All subjects were examined in the supine, and subjects' heads were restrained with foam padding, soft pillows, and a Velcro band across their foreheads. An MRI-compatible VisualSystem (NordicNeuroLab, Bergen, Norway) and video goggles fixed in place with a head coil were used for presenting visual stimuli. All subjects were instructed to view two different stimuli tasks on the screen using a block paradigm and to maintain their attention during fMRI scanning. fMRI block design paradigm consisted of five stimulation blocks alternating with five baseline blocks. Stimulation blocks were presented with two stimuli tasks, consisting of light and powerful hand grasps. For the light hand grasp task, the video showed a hand lightly grasping and releasing a ball repeatedly. The powerful hand grasp task video showed a hand tightly grasping and releasing a ball repeatedly. Baseline blocks showed a fixed cross located in the center of a blank screen. Block duration was 20 seconds and duration of one cycle was 3 minutes and 20 seconds. Sequence of the different stimulus tasks was assigned randomly. The experimental design is shown in **Figure 1**.

fMRI parameters

Magnetom Skyra 3T MRI system (Siemens, Erlangen, Germany) was used to perform blood oxygenation level-dependent (BOLD) fMRI. BOLD-weighted Echo Planar Imaging (EPI) parameters were as follows: repetition time (TR) = 2000 ms, echo time (TE) = 30 ms, slice thickness = 4 mm, field of view (FOV) = 210 mm, matrix size = 64 × 64, and flip angle = 90°. T1-weighted anatomical reference image parameters were as follows: 28 axial, 4-mm thick slices, an FOV of 210 mm, and spin echo images were obtained with a matrix size of 128 × 128. Total images were acquired parallel to the bicommissural line of the anterior commissure-posterior commissure.

fMRI data analysis

fMRI data were analyzed using statistical parametric mapping software (SPM 8: Wellcome Department of Cognitive Neurology, London, UK). Functional images were realigned for motion corrections. The realigned images were normalized to Montreal Neurological Institute (MNI) space. Then, the data were smoothed spatially with a Gaussian kernel at full width at half maximum (FWHM) of 8 mm to improve the signal-to-noise ratio. The first level of analysis for each subject's contrast images was conducted to investigate the individual brain activation maps. The second level of analysis was performed using a random effect model with one-sample *t*-tests to examine the activation pattern of each stimulus condition. Statistics threshold was set at a family-wise error (FWE) corrected with voxel-wise $P < 0.05$ with 10 consecutive voxels forming a valid cluster.

Results

In observation for light grasp, significant brain activations were shown in the left hemisphere: IPL, cuneus, inferior occipital, inferior temporal, postcentral, and middle, superior, and medial frontal gyrus and in the right hemisphere: middle occipital, middle temporal, fusiform, and lingual gyrus (FWE $P < 0.05$). In observation for powerful grasp, significant brain activations were shown in the left hemisphere: IPL, inferior and middle occipital, middle frontal, and postcentral gyrus and in the right hemisphere: superior parietal lobule, middle occipital, middle temporal, fusiform, and postcentral gyrus (FWE $P < 0.05$) (**Table 1** and **Figure 2**).

Both hand grasps induced the activation of IPL, which is the core of MNS. The BOLD signal response produced by powerful grasp ($x = -34$, $y = -30$, $z = 42$, peak t-value = 8.25) was stronger than that produced by light grasp ($x = -50$, $y = -50$, $z = 50$, peak t-value = 7.28). **Table 1** presents the results of brain activation corresponding to different strengths of hand grasp.

Discussion

In the present study, we investigated the brain activations during different strengths of hand grasps in healthy subjects. Results showed that IPL, fusiform, postcentral, occipital, temporal, and frontal gyrus were activated in both hand grasps. Brain activation of the IPL, during the powerful grasp was greater than that during the light grasp. The IPL, as the lower part of the postcentral gyrus, was reported to be involved in the interpretation of sensory information and important for visuomotor function (Caspers et al., 2013). The IPL receives the information from the STS and then conveys it to the ven-

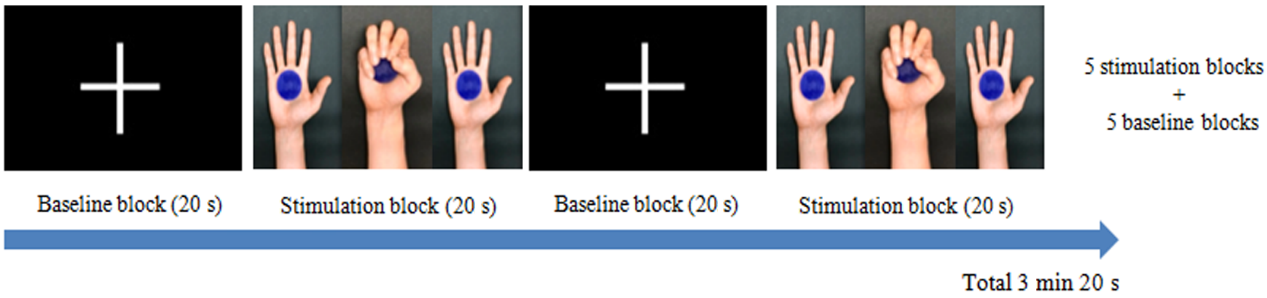

Figure 1 Functional MRI experimental design consisted of five stimulation blocks alternating with five baseline blocks.
Stimulation block video shows a hand lightly or powerfully grasping and releasing the ball repeatedly.

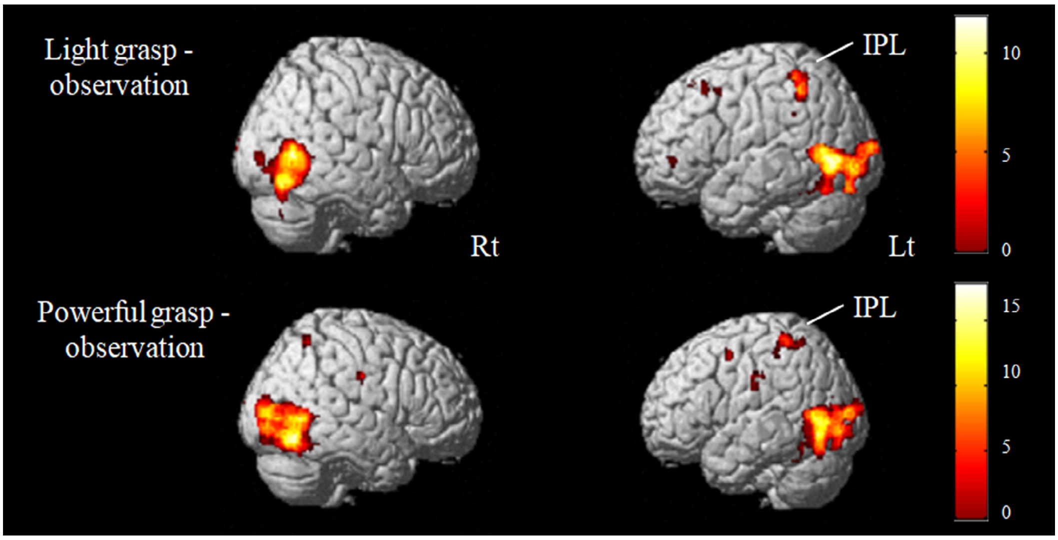

Figure 2 Brain activation for light grasp (above) and powerful grasp (below) observations.
Regarding the IPL which is the core of the MNS, BOLD signal response produced by observation of powerful grasp (peak t-value = 8.25) was greater than that produced by light grasp (peak t-value = 7.28). Each right color bars (red to yellow) mean the intensity of brain activation. BOLD: Blood oxygenation level-dependent; IPL: inferior parietal lobule; MNS: mirror neuron system.

tral premotor cortex (Meltzoff and Prinz, 2002). Therefore, it is one of the most important regions of the MNS.

Several studies have investigated the MNS with various effectors such as the hands, feet, body, and mouth using fMRI and found that the IPL was involved (Buccino et al., 2001, 2004; Grezes and Decety, 2001; Grosbras and Paus, 2006; Hamilton and Grafton, 2006; Cheng et al., 2007; Chong et al., 2008a, b; Caspers et al., 2010). Grosbras and Paus (2006) found that several brain regions including the premotor, prefrontal cortex, anterior insula and supramarginal gyrus were considered as the MNS during the observation of hand actions with emotions in 20 healthy participants. In 2007, Cheng et al. demonstrated that observation of hand actions (grasping food and other objects) produced brain activations in the IPL, STS, IFG, and post- and pre-central gyrus in 20 healthy subjects. In 2008, Chong et al. reported that the IPL responded regardless of observation or execution of hand actions in healthy subjects. They suggested that among the MNS, the IPL plays a key role in understanding the intention of others (Chong et al., 2008b). These studies indicate that activation of the IPL was associated with the MNS by observation of hand actions. Our study also showed activation of the IPL by observation of both powerful and light hand grasps, and observation of powerful grasp showed greater activation in the IPL than observation of light grasp.

Several studies have reported that observation of motor action has treatment value for the rehabilitation and improvement of the motor functions in patients with brain injury (Liu et al., 2004; Franceschini et al., 2010; Ertelt et al., 2012; Franceschini et al., 2012; Cowles et al., 2013; Garrison et al., 2013; Timmermans et al., 2013; Harmsen et al., 2015; Salles et al., 2015; Garcia Carrasco and Aboitiz Cantalapiedra, 2016). In 2004, Liu et al. demonstrated that observation of motor actions improved relearning and motor performance related to daily living tasks in 46 acute stroke patients. In 2012, Ertelt et al. suggested that observation of hand and arm actions would be beneficial for instructing treatment for early stage stroke. Subsequently, Timmermans et al. (2013) reported that the arm-hand function and performance of daily activities were enhanced by training the observation

Table 1 Results of brain activations during the observation of different strengths of hand grasp

Brain region	Peak MNI coordinates (mm)			Peak *t*-value	Brodmann area
	x	*y*	*z*		
Light grasp: observation > rest					
Inferior temporal gyrus (L)	–54	–70	2	11.85	37
Inferior occipital gyrus (L)	–32	–88	–6	11.07	18
Cuneus (L)	–20	–60	2	11.07	18
Middle temporal gyrus (R)	52	–100	12	10.32	37
Fusiform gyrus (R)	42	–66	–14	10.73	19
Middle occipital gyrus (R)	48	–72	–6	9.01	19
Lingual gyrus (R)	12	–88	–10	8.2	18
Postcentral gyrus (L)	–30	–44	58	8.07	5
Inferior parietal lobule (L)	–50	–50	50	7.28	40
Medial frontal gyrus (L)	–12	26	46	7.91	8
Superior frontal gyrus (L)	–28	22	50	7.25	8
Middle frontal gyrus (L)	–28	10	46	6.94	6
Powerful grasp: observation > rest					
Fusiform gyrus (R)	44	–66	–12	17.95	19
Middle temporal gyrus (R)	48	–60	2	15.81	37
Middle occipital gyrus (R)	26	–86	16	11.47	18
Middle occipital gyrus (L)	–54	–70	4	13.24	37
Inferior occipital gyrus (L)	–44	–70	–6	13.02	19
Postcentral gyrus (L)	–32	–44	62	9.21	5
Inferior parietal lobule (L)	–34	–30	42	8.25	40
Middle frontal gyrus (L)	–42	2	50	7.84	6
Postcentral gyrus (R)	56	–16	32	7.68	3
Superior parietal lobule (R)	28	–56	58	7.44	7

Inferior parietal lobule in bold is the core of NMS. Family-wise error correction *P*-value < 0.05. L: Left; MNI: Montreal Neurological Institute; R: right.

of daily motor performance in 32 subacute stroke patients. These studies showed that the MNS would be useful in planning a treatment strategy for patients with brain injury. Therefore, we believe that our results might be helpful for rehabilitation of patients with brain injury.

In conclusion, we investigated the brain activations during the observation of different strengths of hand grasps and found that brain activation of the IPL during the observation of a powerful grasp was greater than that of light grasp. There are some limitations to this study. First, because this study recruited only healthy subjects, we could not investigate the effects of observation of different strengths of hand action in patients with brain injury. Second, we did not identify difference in brain activation pattern between genders. However, to minimize deviation between genders, subjects at a male to female ratio of 1:1 (10 males and 10 females) were recruited in this study. Therefore, further studies should be conducted to investigate these issues.

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