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● RESEARCH ARTICLE

Effects of visual information regarding tactile stimulation on the somatosensory cortical activation: a functional MRI study

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Abstract

Many studies have investigated the evidence for tactile and visual interactive responses to activation of various brain regions. However, few studies have reported on the effects of visuo-tactile multisensory integration on the amount of brain activation on the somatosensory cortical regions. The aim of this study was to examine whether coincidental information obtained by tactile stimulation can affect the somatosensory cortical activation using functional MRI. Ten right-handed healthy subjects were recruited for this study. Two tasks (tactile stimulation and visuotactile stimulation) were performed using a block paradigm during fMRI scanning. In the tactile stimulation task, in subjects with eyes closed, tactile stimulation was applied on the dorsum of the right hand, corresponding to the proximal to distal directions, using a rubber brush. In the visuotactile stimulation task, tactile stimulation was applied to observe the attached mirror in the MRI chamber reflecting their hands being touched with the brush. In the result of SPM group analysis, we found brain activation on the somatosensory cortical area. Tactile stimulation task induced brain activations in the left primary sensory-motor cortex (SM1) and secondary somatosensory cortex (S2). In the visuo-tactile stimulation task, brain activations were observed in the both SM1, both S2, and right posterior parietal cortex. In all tasks, the peak activation was detected in the contralateral SM1. We examined the effects of visuo-tactile multisensory integration on the SM1 and found that visual information during tactile stimulation could enhance activations on SM1 compared to the tactile unisensory stimulation.

Key Words: *nerve regeneration; functional MRI; somatosensory cortex; somatosensory cortical activation; visuotactile stimulation; neural regeneration*

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Introduction

The human brain acquires a number of sensory inputs from the body periphery and external environment, which are synthetically integrated within the brain. Then, this information influences accurate motor performance during movement (Borich et al., 2015). Previous studies have reported that sensory dysfunction due to injury of the somatosensory cortex causes motor dysfunction such as clumsy fine motor skills and impairment of motor learning (Bogousslavsky and Caplan, 2001; Sommerfeld and von Arbin, 2004; Sullivan and Hedman, 2008). Therefore, in terms of motor function, recovery of the somatosensory cortex from brain damage is essential for recovery of motor function.

Many recent studies have reported that multisensory integration such as visuo-tactile, audio-tactile, and audio-visual integration leads to enhanced behavioral response, resulting in improvement of discrimination threshold and reduced reaction time (McGurk and MacDonald, 1976; Frens et al., 1995; Kennett et al., 2001; Johnson et al., 2006; Schaefer et al., 2006; Haggard et al., 2007; Hotting and Roder, 2009; Pasalar et al., 2010; Mahoney et al., 2014; Sekiyama et al., 2014). Among these multisensory integrations, visuo-tactile multisensory integration is known to be an important technique for use in the field of behavioral neuroscience and rehabilitation (Banati et al., 2000; Haggard et al., 2007; Kim and James, 2010; Gentile et al., 2011; Mahoney et al., 2014). Therefore, many studies have investigated the evidence for tactile and visual interactive responses to activation of various brain regions (Banati et al., 2000; Nakashita et al., 2008; Gentile et al., 2011; Martinez-Jauand et al., 2012; Schaefer et al., 2012). However, few studies have reported on the effects of visuo-tactile multisensory integration on the amount of brain activation on the somatosensory cortical regions (Kim and James, 2010; Gentile et al., 2011).

The aim of the current study was to determine whether coincidental visual information obtained by tactile stimulation can affect the somatosensory cortical activation using functional MRI (fMRI).

Participants and Methods

Participants

Ten right-handed healthy subjects (five males; mean age

25.20 ± 2.49 years, range 22–29 years) with no history of neurological, physical, or psychiatric illness were recruited for this study *via* bulletin board notices. All subjects understood the purpose of the study and provided written, informed consent prior to participation. The study protocol was conducted in accordance with the ethical principles stated in the *Declaration of Helsinki* and approved by the Institutional Review Board of Daegu Oriental Hospital of Daegu Haany University (DHUMC-D-14001).

Functional MRI

All subjects were examined in a supine position and firmly secured with an immobilizing frame. Two tasks (tactile stimulation and visuo-tactile stimulation) were performed using a block paradigm (20-second rest, 20-second stimulation). In the tactile stimulation task, in subjects with eyes closed, tactile stimulation was applied on the dorsum of the right hand, corresponding to the proximal to distal direction, using a rubber brush at a frequency of 1 Hz under metronome guidance. Rest block was not applied tactile stimulation. In the visuo-tactile stimulation task, tactile stimulation was applied in the same manner. In addition, subjects were instructed to watch the attached mirror in the MRI chamber reflecting their own hand being touched by the brush. Rest block was seeing the untouched hand. All stimulations were performed by the same experimenter. Each task was repeated three times and the sequences of tasks were assigned randomly.

A 1.5-T Philips Gyroscan Intera scanner (Hoffma n-La-Roche, Best, the Netherlands) and a standard head coil were used in performance of blood oxygenation level dependent (BOLD) fMRI. BOLD-weighted Echo Planar Imaging (EPI) parameters were as follows: repetition time /echo time = 2 seconds/60 ms, field of view = 210 mm, flip angle = 90°, matrix size = 64 × 64, and slice thickness = 5 mm. In addition, T1-weighted anatomical reference images were obtained using the following parameters: 20 axial, 5 mm-thick, spin echo images were acquired with a matrix size of 128 × 128, and a field of view of 210 mm. A total of 2,400 images were acquired parallel to the bicommissure line of the anterior commissure-posterior commissure.

fMRI data analysis was performed using statistical parametric mapping software (SPM 8, Wellcome Department of Cognitive Neurology, London, UK) implemented in the MATLAB environment (The Mathworks, USA). All images were realigned, co-registered, and normalized. The data were then smoothed spatially with a Gaussian kernel at a full width at half maximum (FWHM) of 8 mm to improve signal to noise ratio. First level analysis for each subject was conducted to investigate individual brain activation maps. A second level analysis was performed using a random effect model with one-sample *t*-tests for group analysis. Then, images were registered to the standard stereotaxic space of Talairach coordinates for creation of statistical parametric maps documenting the group average. Activations were based on clusters larger than five voxels. Quantitative comparisons between stimulations were made by comparison of changes in BOLD signals. Also, differences in brain activation during each condition in subjects were compared using paired *t*-test within the SPM. An uncorrected threshold of $P < 0.001$ was considered statistically significant.

To analyze volume data mapped to the cortical surface, we projected fMRI group analysis results onto the left and right hemispheres of the Human Colin surface-based atlas mapped to the PALS-B12 surface ("Population-Average Landmark- and Surface-Based" atlas) using version 5.61 of the computerized anatomical reconstruction and editing toolkit (CARET: Washington University, St. Louis, MO, USA) software (Nakahara et al., 2001; Van Essen et al., 2001; Van Essen, 2002, 2005). Data values in voxels that intersected the cortical surface were directly mapped to the vertices of each participant-specific fiducial cortical surface using the intersections of enclosing voxels and nodes. Nodes representing an individual hemisphere were deformed to the standard PALS-B12 atlas sphere with 73,730 nodes using selective landmarks and spherical alignment (Van Essen, 2005). Regions of interest were drawn around the primary sensory-motor cortex (SM1: Brodmann area (BA) 1, 2, 3, 4), posterior parietal cortex (PPC: BA 5, 7), and secondary somatosensory cortex (S2: BA 43), which are known for their contribution to somatosensory processing (Forss et al., 1999; Cramer st al., 2000; Jang et al., 2010). Voxel counts were used as a measure of amounts of cortical activation in response to each tactile stimulation in each region of interest.

Results

Comparison of brain activations between stimulation and rest conditions

In the result of one sample *t*-test for group analysis, the cortical activated clusters were found on the various areas related to somatosensory function. In the tactile stimulation task, brain activations were observed on the left postcentral gyrus and thalamus and right insular, fusiform gyrus, caudate, limbic lobe, and cerebellum ($P < 0.001$, uncorrected). The peak activation of whole brain areas was detected in the left SM1 ($x = -38$, $y = -24$, $z = 54$; Brodmann area 3). In the visuo-tactile stimulation task, brain activations were observed on left precentral gyrus, occipital gyrus, and medial frontal gyrus, right precuneus, fingulate, superior and inferior temporal gyrus, caudate, meddle and inferior frontal gyrus, and cerebellem, and both postcentral gyrus and insula ($P < 0.001$, uncorrected). The peak activation of whole brain was also seen in the left SM1 ($x = P38$, $y = P24$, $z = 58$; Brodmann area 4) (**Figure 1** and **Table 1**).

We identified the voxel count for the amount of brain activation on the somatosensory cortical regions. Visuo-tactile stimulation task was performed to induce cortical activation on the left SM1 (voxel count: 2434) and S2 (voxel count: 12). On the other hand, visuo-tactile stimulation task had brain activations on the left SM1 (voxel count: 4203), right SM1 (voxel count: 154), left S2 (voxel count: 86), right S2 (voxel count: 178), and right PPC (voxel count: 337) (**Table 2**).

Table 1 Significant brain activation area during tactile and visuo-tactile stimulations relative to rest in right-handed healthy participants

Brain region		Brodmann area	Peak MNI coordinates (mm)			Peak *t* value
			x	*y*	*z*	
Tactile stimulation task: Stimulation > rest						
Left	Postcentral gyrus	3	–38	–24	54	13.19
	Thalamus		–12	–22	4	10.02
Right	Cerebellum		30	–52	–26	9.55
	Insula	13	36	–8	24	6.87
	Fusiform gyrus	37	36	–50	–10	6.01
	Caudate nucleus		6	10	10	5.70
	Limbic lobe	24	22	–14	40	4.79
Visuo-tactile stimulation task : Stimulation > rest						
Left	Precentral gyrus	4	–38	–24	58	14.05
	Postcentral gyrus	3	–35	–32	52	12.40
	Insula	13	–38	–16	16	7.66
	Occipital gyrus	19	–50	–76	–12	6.41
	Medial frontal gyrus	6	–4	–22	50	6.12
Right	Precuneus	7	32	–46	52	11.82
	Inferior parietal lobule	40	38	–50	58	5.71
	Superior temporal gyrus	38	46	10	–6	9.91
	Inferior temporal gyrus	19	54	–74	–2	7.30
	Caudate nucleus		18	–18	20	7.46
	Middle frontal gyrus	9	58	10	36	6.52
	Inferior frontal gyrus	44	60	16	20	5.19
	Insula	13	46	–4	10	6.47
	Cerebellum		16	–50	–26	4.71

Brain regions with uncorreted $P < 0.001$ were listed.

Table 2 Voxel counts of activation related to somatosensory cortical regions during tactile and visuo-tactile stimulations in right-handed healthy participants

Brain region	Brodmann area	Tactile stimulation		Visuo-tactile stimulation	
		Left hemisphere	Right hemisphere	Left hemisphere	Right hemisphere
SM1	1, 2, 3, 4	2,434	0	4,203	154
S2	43	12	0	86	178
PPC	5, 7	0	0	0	337
	Total	2,446	0	4,289	669

SM1: Primary somatosensory cortex; S2: secondary somatosensory cortex; PPC: posterior parietal cortex.

Comparison of brain activations between visuo-tactile and tactile stimulation tasks

Visuo-tactile stimulation task induced significant higher activation in both SM1 and PPC, left meddle frontal gyrus and fusiform, right inferior frontal gyrus, inferior temporal gyrus, and anterior cingulate than tactile stimulation task ($P < 0.001$, uncorrected) (**Table 3**).

Discussion

In the current study, we investigated whether observation of being touched the body during tactile stimulation can affect the brain activation on the somatosensory cortical regions. As a result, we found that visuo-tactile stimulation induced extended somatosensory cortical activations in both hemispheres of the SM1, S2, and the right hemisphere of the PPC compared with those of only tactile stimulation. In addition, higher peak activated response to SM1 was detected in visuo-tactile stimulation compared with that of only tactile stimulation. Our results appeared to indicate that integration of visual information during tactile stimulation would facilitate activation in the cortical area related to the somatosensory response.

Visuo-tactile multisensory integration is known to be involved in various brain regions, particularly the PPC, premotor regions, and putamen. In addition, many studies have reported the effects of concurrent visual stimulation and that tactile stimulation improved both motor function and brain activations using various techniques including TMS, fMRI (Banati et al., 2000; Haggard et al., 2007; Kim and James, 2010; Gentile et al., 2011; Mahoney et al., 2014). In a behavior study, Haggard et al. (2007) reported that discrimination performance was improved when providing visuo-tactile stimulation compared to that of tactile stimulation in 10 healthy subjects. Mahoney et al. (2014) reported that the

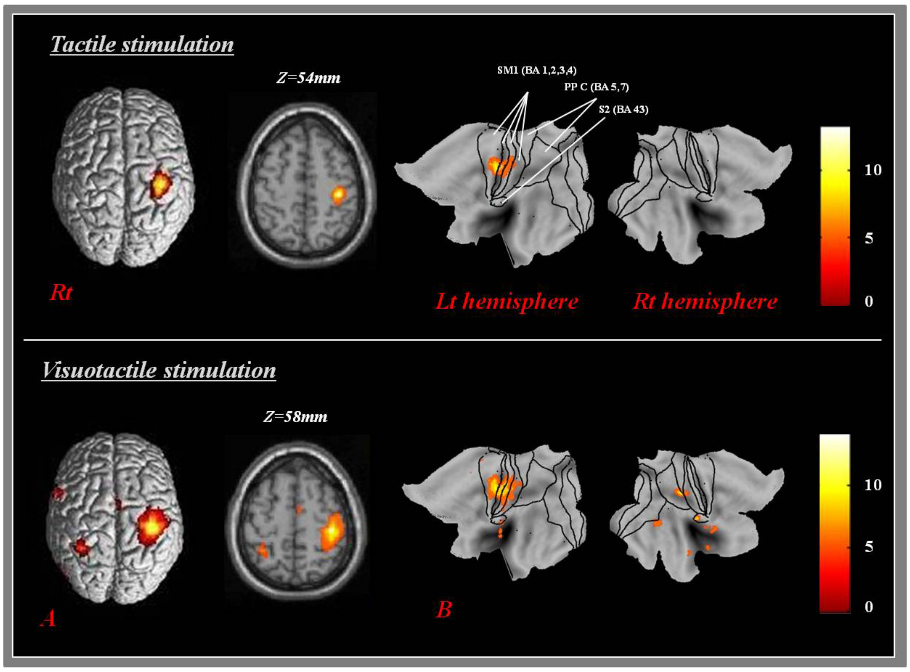

Figure 1 3D rendering of SPM (A) and projecting PALS-B12 atlas (B) for cortical activation in a right-handed healthy participant.
The cortical activated clusters (orange) were found on the regions of interest related to somatosensory function. In the tactile stimulation task, cortical activations are observed in the left primary somatosensory cortex (SM1) and secondary somatosensory cortex (S2). In contrast, regarding the visuo-tactile stimulation task, cortical activations are observed in the both hemispheres of the SM1, S2, and the right posterior parietal cortex (PPC). Statistical map was significant at $P < 0.001$ uncorrected, five voxels extent threshold. Lt: Left; Rt: right.

Table 3 Significant brain activation area between visuo-tactile and tactile stimulation tasks in right-handed healthy participants

Brain region		Brodmann area	Peak MNI coordinates (mm)			Peak *t* value
			x	*y*	*z*	
Visuo-tactile stimulation task–rest > tactile stimulation task–rest						
Left	Postcentral gyrus	7	–38	–30	46	5.98
	Superior parietal lobule	5	–26	–66	55	4.82
	Precentral gyrus	4	–26	–24	60	5.70
	Middle frontal gyrus	9	–26	18	26	6.42
	Fusiform gyrus	37	–42	–60	–8	6.01
Right	Postcentral gyrus	43	66	–8	20	4.59
	Precentral gyrus	6	60	2	32	6.20
	Inferior frontal gyrus	42	56	30	12	6.78
	Inferior temporal gyrus	19	54	–74	–2	5.54
	Anterior cingulate		6	30	2	5.11

Brain regions with uncorreted $P < 0.001$ were listed.

visuo-tactile stimulation reduced reaction time than simple visual or tactile stimulation in 147 healthy older subjects. In a neuroimaging study, using positron emission tomography, Banati et al. (2000) observed higher cerebral blood flow in the inferior parietal lobules, including S2, after visuo-tactile stimulation than visual stimulation in eight healthy subjects. Subsequently, Kim and James (2010) reported that visual in combination with haptic stimulation induced higher activations on the contralateral occipital, fusiform gyrus, and intraparietal sulcus than simple visual or haptic stimulation in seven healthy subjects using fMRI. Gentilte et al. (2011) compared brain activation regions between simple visual or tactile stimulation and visuo-tactile stimulation in 24 healthy subjects and found that visuo-tactile stimulation induced greater BOLD activation in various brain regions including the contralateral ventral and dorsal premotor cortex, anterior part of the intraparietal sulcus, and inferior parietal cortex than simple visual or tactile stimulation.

Our results are comparable with those of previous studies. Previous studies (Banati et al., 2000; Kim and James, 2010; Gentile et al., 2011) focused on the distribution of brain activation regions rather than the SM1, which is an important region for sensori-motor function. Although our results showed that visuo-tactile stimulation led to greater activation in SM1 than tactile stimulation in healthy subjects, we believe that visuo-tactile stimulation could contribute to recovery of injured sensorimotor cortical area in patients who need sensorimotor rehabilitation. In addition, our results could provide evidence for research in the field of neural regeneration and therapies.

In conclusion, we investigated the effects of visuo-tactile multisensory stimulation on the SM1 and found that visual information during tactile stimulation could enhance activations on the SM1 compared to the tactile unisensory stimulation. However, this study recruited only healthy subjects, which is a major limitation. Future studies addressing clinical significance in relation to brain activation or recovery of sensorimotor function following injury of sensorimotor cortical area should be encouraged.

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Declaration of participant consent: *The authors certify that they have obtained all appropriate participant consent forms. In the form the participants have given their consent for their images and other clinical information to be reported in the journal. The participants understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.*

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