

Cortical Activation Pattern according to Discrimination of One-Point and Two-Point Tactile Sensory Inputs: an fMRI Study

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Abstract. [Purpose] The aim of this study was to investigate which of cortical areas are precisely involved in performing the two-point discrimination task (TPD), using functional magnetic resonance image (fMRI). [Subjects and Methods] Nine healthy right-handed subjects were recruited. During fMRI scanning, tactile sensory stimulation of one- or two-points was conducted on the dominant thumb with a two-point discriminator. At that time, The subject pressed a corresponding button when perceived one point or two points, corresponding to the two types of delivered tactile stimulation. [Results] In group analysis, the averaged cortical maps showed that the left and right primary sensory cortices and inferior parietal cortices were activated. In the bilateral primary sensory cortex, the peak intensities were 7.34 and 5.14, in the left and right hemispheres, respectively. In addition, the left and right inferior parietal cortices were activated, and the peak intensities were 4.30 and 6.18, respectively. [Conclusion] Our results revealed that the performance of a TPD task is likely to require the higher order sensory discriminative modality which is processed by the cortical cognitive function. In addition, the neural processing of TPD was specifically associated with bilateral activity in the inferior parietal cortex.

Key words: Sensory stimulation, Two-point discrimination, Cortical activation

(This article was submitted Aug. 26, 2011, and was accepted Sep. 16, 2011)

INTRODUCTION

The somatosensory system is involved in many aspects of human movement and the processed information allows us to control our movement, protect against injuries, and perceive the external environment^{1,2)}. Deficits of sensory processing can induce physical dysfunction by abnormal movement. Therefore, the assessment and treatment of the sensory system in clinical practice is becoming increasingly important in the preservation and restoration of motor performance. In general, the assessment of sensory deficits are classified into three categories: exteroceptive, proprioceptive, and cortical sensory³⁾. Sensory modalities of the cortical level involve tactile localization, two-point discrimination, stereognosis, barognosis, and graphesthesia.

Two-point discrimination (TPD) is defined as the ability to perceive the nearest distance between two stimuli placed, as distinct points on the skin⁴⁻⁶⁾. TPD has been frequently used to evaluate somatosensory conditions and to prove the effects of the treatment for its dysfunction. Normal values are different, depending on body location, ranging from 2–5 mm on the fingertips to 400–600 mm on the back⁷⁻¹⁰⁾. Both the peripheral and central nervous systems are involved in the neural processing of TPD. In particular, the central nervous system has a critical role in accomplishing the

higher function of somatosensory perception. According to the study of Tamura et al., TPD is the cognitive process for evaluation of the absolute distance between the stimuli^{11,12)}. Therefore, at the cortical level, TPD is necessarily to be modulated by both cognitive and psychological factors. However, there are only a few neuroimaging studies which have investigated the cortical activation pattern induced during discrimination of two-point stimuli. Therefore, in this study, we investigated the cortical activation areas involved in TPD processing, using functional MRI (fMRI).

SUBJECTS AND METHODS

Nine healthy subjects without neurological or psychiatric history (5 men, mean age: 23.36 ± 1.78 years) were recruited for this experiment. All participants were right-handed as verified by the modified Edinburgh Handedness Inventory¹³⁾. The participants understood the purpose of this study, and gave their prior written, informed consent prior to enrollment.

Subjects were placed in the supine position with their eyes closed. To prevent motion artifacts during fMRI scanning, movements of the head, trunk, and arms were prohibited. During fMRI scanning, tactile sensory stimulation of either one- or two-points was delivered to the right

thumb with a two-point discriminator (Baseline, USA), and a distance between points of 3 mm. During each session with the two types of tactile stimulation, the subjects were instructed to press the corresponding button when they perceived one point (the first button) or two points (second button). Each of stimulations was presented for 3 seconds, 10 times per cycle. In the control session, the subjects alternately pressed the two buttons their own. The fMRI protocol had four repetitive stimulation phases, and each stimulation phase consisted of two alternating cycles including stimulation (tactile stimulation for 30 seconds) and control (no stimulation for 30 seconds). Consequently, fMRI scanning of four repetitive stimulation phases was performed in 240 seconds for each participant (i.e. four stimulation phases of 60 seconds each). Finally, to test regionally-specific condition effects for pure tactile stimulation through elimination of the motor effect, we subtracted the control cycles from the stimulation phases.

Echo Planar Imaging (EPI) blood oxygenation level-dependent (BOLD) fMRI measurements were performed on a 1.5T MR scanner (Gyrosan Intera System, Phillips, Germany) with a standard head coil. For anatomic base images, 20 axial, 5-mm thick, T1-weighted, spin echo images were obtained with a matrix size of 256×205 and a field of view (FOV) of 210 mm, parallel to the bicommissural line of the anterior/posterior commissure. EPI-BOLD images were acquired over 20 identical axial sections, producing a total of 240 images for each subject, including 10 dummy images. Imaging parameters consisted of TR/TE = 3.0 sec/50 ms, FOV = 210 mm, matrix size = 64×64 , and slice thickness = 5 mm. fMRI data analysis was performed using the SPM8 software (Wellcome Department of Cognitive Neurology, UK) in the MATLAB environment (The Mathworks, USA). The functional data of each participant were motion-corrected. All images were realigned and normalized. Images were smoothed with an 8-mm isotropic Gaussian kernel. Statistical parametric maps were obtained, and voxels were considered significant at an uncorrected $p < 0.001$. Activations were based on regions of five voxels. For group analysis of the normal group, images associated with the amplitude of the hemodynamic response were used for one-sample t-test random effects analysis, and translated to the standard stereotaxic space of Talairach coordinates for the creation of statistical parametric maps documenting the group average. The differences in brain activation between the two tasks were compared by a random effect group analysis (uncorrected $p < 0.001$). Regions of interest (ROIs) were drawn around the primary motor cortex, primary sensory cortex, inferior frontal cortex, and parietal cortex. The primary motor cortex and primary sensory cortex included the precentral and postcentral gyrus centered on the precentral knob. We conducted voxel counts and measured peak intensity to estimate the amount of cortical activation in response to the two types of sensory stimulation, because these have been proven reliable indicators of cortical activation and changes in the cerebral blood flow^{14,15}.

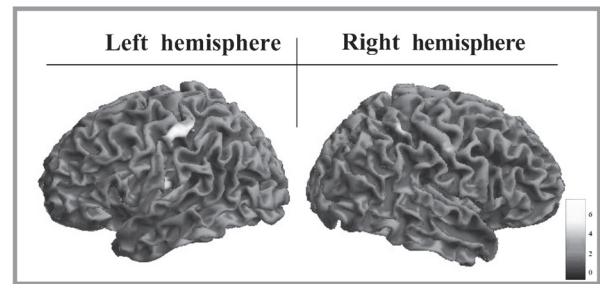


Fig. 1. Averaged cortical map produced by fMRI analysis of discrimination of the two types of tactile stimulation (i.e. one-point or two-point). All brain scan images show a series of slices with a 3-mm gap. The color bar in the right corner indicates the p-value of each pixel showing significant activation.

RESULTS

Fig. 1 shows the averaged maps produced in the group analysis of functional echo planar imaging in each of the regional activation clusters, induced by tactile stimulation of TPD. The averaged map revealed that both the left and right primary sensory cortices were activated, and the peak intensities were 7.34 ($x, y, z = -55, -22, 58$) and 5.14 ($x, y, z = 56, -22, 44$), respectively. In addition, the inferior parietal cortex was activated bilaterally, and the peak intensities were 4.30 ($x, y, z = -56, -40, 55$) and 6.18 ($x, y, z = 64, -44, 44$), respectively.

DISCUSSION

In the current study, we investigated the cortical areas activated in discriminating between one and two-points tactile stimulation of the right thumb. fMRI was adapted to identify the blood flow changes and cortical activation sites during performance of various sensorimotor tasks, due to its good spatial resolution in the cortex^{16,17}. As results, Blood-oxygen-level-dependent (BOLD) signal activities were observed bilaterally in the primary sensorimotor cortex (SM1) and the inferior parietal cortex (IPC). It is well known that these cortical areas are related to sensorimotor function and its associated cognitive function (Ref). Therefore, the performance of a TPD task is likely to require a higher function of somatosensory perception and cognitive processing at the cortical level.

Our findings were compatible with previous TPD studies investigating central mechanisms of sensory discriminative modalities^{4,11,12,18,19}. According to the event-related potentials study by Tamura et al.¹², the negative potential of approximately 140 ms after stimulation (N140) and the late positive component (LPC) were significantly enhanced during performance of a TPD task. They suggested that the increase in these components was caused by conscious somatosensory discrimination and attention directed to the stimulation. In addition, the fMRI study by Akatsuka et al.⁴ showed that the IPC and supramarginal gyrus were activated during on whether stimulation was delivered to

one as point or two point. They suggested that the IPC is involved in both discrimination and recognition of somatosensory tactile stimulation. Many prior studies have shown that the IPC and the supramarginal gyrus played an important roles in several discrimination modalities related to shape, object, and spatial components^{19–22}). Therefore, our findings confirmed that TPD is a higher order sensory discriminative modality which is processed by the cortical cognitive function, and its neural process is significantly associated with the IPC.

Understanding of sensory dysfunction and its recovery mechanism is one of the most important issues in the field of physical therapy. In particular, TPD processed at the cortical level is a mandatory for manipulating and identifying objects through sensory perception of the hand. Such hand functions play an important role in performing the activities of daily life. In addition, TPD has been clinically used for measurement/prognosis of sensory and motor function in patients with damage to the nervous system, together with functional sensibility, by and it shows good inter-rater and test-retest reliability⁹). The neural mechanism for TPD processed at subcortical structures is well known up to now. However, there are only a few studies which have investigated which the cortical areas are involved in TPD processing. Therefore, we consider that identification of the neuronal mechanism in the cerebral cortices will be useful for physical therapists attempting to predict sensory symptoms through brain lesion location and the establishment of treatment plans. The limitations of this study were the small sample size and the lack of comparison with other somatosensory stimuli. Further study will be required to ascertain in more detail the neural mechanisms of TPD considering these elements.

ACKNOWLEDGEMENT

This work was supported by research grants from the Catholic University of Daegu in 2010.

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