BRAIN MAPPING WITH ELECTRO-TACTILE STIMULATION OF THE FINGERS: AN FMRI STUDY

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ABSTRACT

The purpose of this study was to investigate differences in brain activation by electrotactile stimulation of two fingers of the right hand with different frequencies using fMRI. Non-painful electrotactile stimuli were delivered. Significant activation produced by the stimulation were found in the SI, SII, subcentral gyrus, precentral gyrus, and insula. In all participants statistically significant activation was observed in the contralateral SI area and bilateral SⅡ areas by the stimulation on the fingers but ipsilaterally dominant. The SI area representing the second finger generally located in the more lateral and inferior side than that of the third finger across all the subjects. But no difference in brain area was found for the stimulation of the fingers by different frequencies.

1. INTRODUCTION

In the late 1980s, functional imaging started to be used to study brain activity using electroencephalogram and Positron Emission Tomography (PET). Functional Magnetic Resonance Imaging (fMRI) determining the changes in the blood oxygenation level-dependent (BOLD) signal was introduced as a noninvasive method with an accurate spatial and relatively high temporal resolution (Ogawa et al., 1992).

FMRI made it possible to study the functional organization of human primary (SI) and secondary (SII) somatosensory cortex related with tactile stimulation. It is reported that the activation in the brain is somehow different depending on the characteristics of stimulus and its application site in the body.

The goal of this study includes the following: 1) To determine when electrotactile stimulation on the two nearby fingers is sufficient to differentiate in the SI area 2) To observe whether there is also any hemodynamic difference in the SI produced by stimulation with different frequencies 3) there is a correlation between the strength of tactile perception by different stimulus intensity and the level of brain activation measurable by means of fMRI.

2. METHOD

10 healthy right-handed female volunteers (aged 20-24 with mean of 23) with no history of neurological, psychiatric, or medical disorder participated in this study. The overall procedures were explained to all the participants, who released consent for the procedure. All examinations were performed under the regulations of our Institutional Review Committee.

Electrotactile stimuli were presented to the volar surface of the right index finger and/or ring finger through a low frequency stimulator (OTS H-306, Hanil Medical, Korea). All the tasks were conducted in a blocked design (15 s of stimulation ‘on’ followed by 15 s of rest ‘off’). The stimulation order of the five different frequencies (3, 10, 30, 100, and 300 Hz) was randomized across all the participants. Image scanning consisted of two sessions for two fingers, each consisting of five blocks. After scanning all participants were asked to evaluate their perceived intensity of the electrotactile stimulation applied to their fingers .

Scanning was conducted on a 3.0T whole-body ISOL Technology FORTE scanner (ISOL Technology, Korea). Single-shot echoplanar fMRI imges were acquired in 35 continuous slices. The parameters for fMRI were as follows: the repetition time/echo time [TR/TE] were 3000/35 ms, respectively, flip angle 60, field of view 240 mm, matrix 64 × 64, slice thickness 4 mm, and in-plane resolution 3.75mm. Five dummy scans were removed at the beginning of each run to decrease the effect of non-steady state longitudinal magnetization. T1-weighted anatomic images were obtained with a 3-D FLAIR sequence (TR/TE = 280/14 ms, flip angle = 60, FOV = 240 mm, matrix = 256* 256, slice thickness = 4 mm).

The fMRI data were analyzed with SPM99 (Wellcome Department of Cognitive Neurology, London, UK). All functional images were realigned, coregistered to the participant's anatomical images and then and normalized to the template image defined by the Montreal Neurologic Institute (MNI). The functional map was smoothened with a 7-mm isotropic Gaussian Kernel. Statistical analysis was done individually and then as a group using the general linear model and the theory of Gaussian random fields (Friston et al., 1995).

3. RESULT

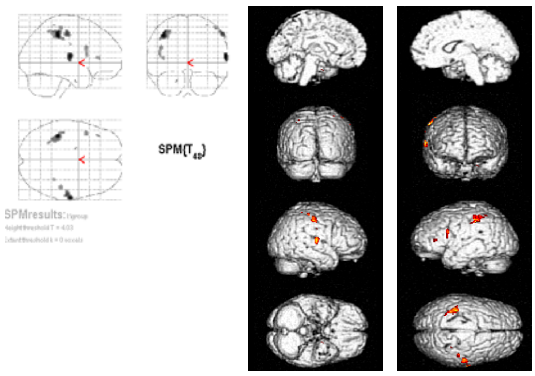
3.1 Brain activation by stimulation of fingers

Electrotactile stimulation of the fingers created changes in led to statistically significant signal intensity in the several cortical areas (Fig 3). The hand area of contralateral SI was activated among all the participants. In 4 of 10 subjects, the activation of bilateral SI area was observed. Bilateral activation of SII was also detected in all the participants. Group analysis across all the participants showed that brain significantly activated areas (uncorrected $p<0.01$) during the electrotactile stimulation of the fingers were as follows: the contralateral SI, bilateral SII, bilateral inferior frontal gyrus, bilateral middle frontal gyrus, right insula, and left inferior parietal lobule.

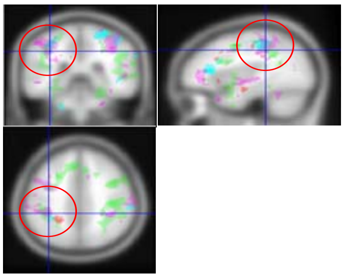
3.2 Brain activation with different frequencies

The primary focus of the study was on the detection of the activation in the primary somatosensory area in response to vibrotactile stimulation; for this reason, a region of interest (ROI) analysis was performed. For the analysis of SI, ROIs were defined from high-resolution anatomical scans for each subject. SI was defined by the central sulcus anteriorly, post-central sulcus posteriorly, knob or ‘hand region’ medially and most lateral edge of the post-central gyrus (Fig 4).

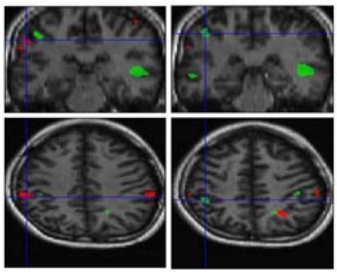
Although there observed differences in the locations of voxels which had the highest z scores due to stimulations with different frequencies, the clusters around those voxels were much overlapped. It, therefore, was hardly identifiable to localize those locations in the SI corresponding to different stimulus frequencies.



<Fig 3> Brain activation by group analysis



<Fig 4> Brain activations with different frequencies (Red: 3Hz, Yellow: 1Hz, Green: 30Hz, Blue: 100Hz, Purple: 300Hz)



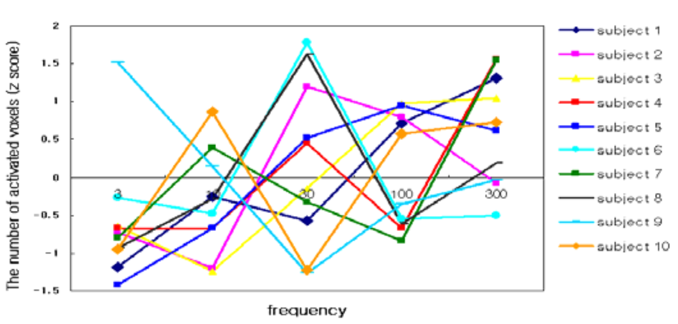
<Fig 5> Brain activations by stimulation of two different fingers (Red: second finger, Green: third finger)

3.3 Brain activation area by stimulation of two different fingers

In all subjects, we observed a difference concerning the brain representations of the two fingers. In 7 of 10, the second finger generally located at a more lateral and inferior position to the third finger. The activations due to simulation on the two different fingers in the area SI occurred in apparently different locations. In general, the second finger was located at a more lateral and inferior side than the third finger. Figure 5 shows a typical activation of an individual participant.

3.4. Voxel size by stimulation of different frequencies

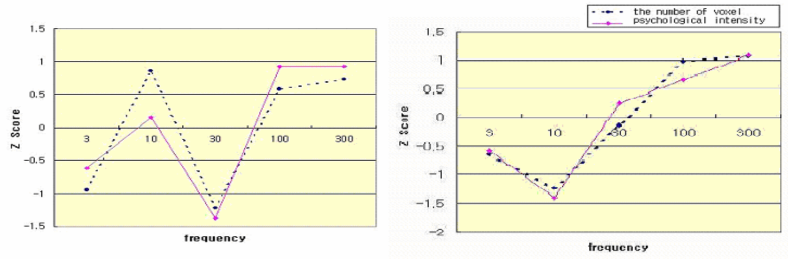
There was no consistent activation pattern in the SI among individuals due to the different stimulation-frequencies (Fig 6) and a significant individual difference was found across all the subjects.



<Fig 6> Activation pattern in the SI by different frequencies by individuals

3.5. The relationship between the perceived intensity and brain activation

Two typical patterns were observed on the relationship between the perceived psychological intensity and the amount of voxels in the primary sensory cortex during the stimulation (Fig 7). Interestingly enough, whatever the pattern it was when received the stimulus as more intense and it actually was increased activation in the SI area, which may indicates a very strong positive relationship between the two.



<Subject "A"> <Subject "B">

<Fig 7> Two typical patterns for the relationship between the perceived intensity and brain activation. (x axis represents stimulation frequencies, exponentially described)

4. DISCUSSION

The activation areas (the SI, SII, inferior frontal gyrus, middle frontal gyrus, insula, and inferior parietal lobule) in the brain were qualitatively as reported in other studies (Boakye et al., 2000; Francis et al., 2000; Kurth et al., 1988). In the SI in all cases, two or three distinct activation foci across the postcentral gyrus were seen. These distinct activation foci appear to reflect the activation of the different subareas of the SI in humans.

In the SI, a difference in the representations of the two fingers observed. The third finger generally located at a more medial and superior position than the second finger. In general, the second finger was located in the more lateral and inferior location than the third finger, reflecting the known somatotopic organization of the hand area of human SI that has been shown, in more or less detail, by different methods in the past.

However, there was no consistent pattern of activation in the SI among individuals by different stimulation-frequencies but a big individual difference was found across all the subjects. There must be largely overlapping representation sites by different stimulation frequencies, which challenges recent fMRI studies that reported distant representations of individual fingers even within the SI (Kurth et al. 1998; Francis et al., 2000).

The bilateral SII activations were observed in all the subjects in our study. The consistent activation of the contralateral SII region is in support of the recent fMRI studies performing different types of innocuous somatosensory stimulation (Disbrow et al., 2000; Ruben et al., 2001). Ipsilateral SII activation is due to neurons with bilateral receptive fields and is also reported in recent neuroimaging studies using, PET (Ledburg et al., 1995; Burton et al., 1993) and fMRI (Ruben et al., 2001; Disbrow et al., 2000; Francis et al., 2000). Activation of other cortical structures, occurring bilaterally sometimes due to neurons with bilateral receptive fields, are in line with the results from fMRI studies reporting activation of posterior parietal cortex (Francis et al. 2000; Polonara et al., 1999), Supplementary Motor Area(SMA) (Francis et al., 2000) and insula (Francis et al., 2000; Gelnar et al., 1998). This indicates that these areas are involved in the processing of somatosensory stimulation although their exact contribution is not defined. The insula is known to be involved in tactile object recognition (Reed et al., 2004).

Actually, the further analysis of the relationship between the perceived intensity of the stimulus and brain SI activation revealed that two typical patterns elicited during electrotactile stimulation and that most importantly the more intense the stimulus was, the more stronger activations in the SII occurred. It is possible to assume a plausible psycho-neural relationship. If we quantify or calibrate physical intensity of a stimulus more precisely, then we could open a new discipline of the psycho-neuro-physics.

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