Title of Thesis

Study on Human Neural Substrates of Visual and Tactile Attention by Functional Magnetic Resonance Imaging

March, 2014

Qiong Wu

The Graduate School of
Natural Science and Technology
(Doctor's Course)
OKAYAMA UNIVERSITY

Abstract

Attention is an ability that can help people choose useful information and ignore other information when people manage the information from the outside. For people, they can sort the information into visual, auditory, somatosensory, taste and olfaction. For visual, auditory and somatosensory information, they can sort them also into spatial, temporal and character information. For example, when the people are come to a crossroad and stop to check whether they are safe to though. When other cars near the crossroad were checked, people should estimate the car’s location, speed, and timing of come into the cross. In this case, the spatial and temporal information were used for the attention process.

The human brain is a highly efficient information processing system capable of processing a large amount of information rapidly and simultaneously. If be able to accurately elucidate the sophisticated mechanisms of the brain, so could construct humanlike, efficient, and flexible artificial systems. So the peoples also have the capacity to assess the most relevant ways to present information, and in the most appropriate manner.

The attention studies could be divided into several kinds. There are mainly two kinds, one is involuntary attention and the other is voluntary attention, which was used when people manipulate the information to satisfy their aim. The top-down attention experimental paradigm which was developed by M.I. Posner (Posner, 1980) has been widely used. Recent brain studies used a visual cue to investigate visual top-down attention by event-related potentials (ERPs) and functional magnetic resonance imaging (fMRI) revealed that a frontal-parietal network was associated with spatial attention, especially within right hemisphere; the same network was reportedly also in voluntary temporal attention. Furthermore, some studies on investigating the neural network involved in visual and tactile attention indicated that there is a similar neural activation between visual and tactile spatial attention cognition.

Behavioral experiment in which visual cue was used to direct the attention to locations of visual

and tactile target showed an improved reaction time of target occurrence (Backes et al., 2000). Similar studies on cross-modal with a visual cue to an tactile target revealed that symbolic spatial cuing caused the negative ERPs related to validly cued targets more than the ERPs related to invalidly cued targets over a broad time range (Eimer and van Velzen, 2005). The same result was also observed when using a tactile cue to a visual target. Similarly, an electrophysiology primate study on attention found that enhanced neuron activity (spikes/s) occurred when target appeared in the focused location (Breier et al., 2003). Furthermore, the fact that a visual cue would influence the tactile attention modulation in the right DLPFC (rDLPFC) within the right hemisphere (Macaluso et al., 2003) might be consistent with the theory of attentional set on the rule and task-relevant information (Coull et al., 2000) and with the theory of working memory that rDLPFC maintain spatial and non-spatial information online. The lack of fMRI data so far, however, tampered direct validation on the attention modulation within the rDLPFC especially whether it modulates the tactile attention mechanism both in spatial and temporal domain. These studies were note that the need for direct validation is additional and confirmatory recognizing the previous reports that the rDLPFC associates with top-down control and attention execution, and the working memory within the rDLPFC processed spatial and non-spatial information online (Craig and Evans, 1995) and manipulated the information to influence the incoming sensory or motor stimulation (Opitz et al., 2002).

The aim of the dissertation

The main aim of this dissertation research was to investigate the neural network for spatial and temporal attention for selective visual and tactile information process in the brain cortex. Also of interest was the identification of neural substrates related to divide visual tactile attention. To achieve these aims, four related experiments were conducted.

The contents of the dissertation

The dissertation contains descriptions of the four experiments and a general discussion briefly introduced below.

Chapter 2 introduces the first experiment, in which functional magnetic resonance imaging (fMRI) was used to measure the brain activities of subjects as they pay attention to target location spatially. The targets used in this experiment are single tactile target. As the result, this study was found that the right brain hemisphere was mainly activated during the attention task. The frontal-parietal neural network exists for the tactile spatial attention.

Chapter 3 describes the second experiment. In this experiment, a top-down attention paradigm was been used in which a visual cue directs the attention of participants to tactile target stimulus in TT (tactile temporal) task and TN (tactile neural) attention task. In the task, the attention was manipulated to tactile temporal information (cue-target interval is short or long) by a visual cue, and the tactile target stimulus was told to be. Neutral task was gave no information about spatial location. Subjects were also scanned during a resting baseline condition in which subjects clicked the reaction key ten times. The reaction time for spatial location attention is faster than that without a tactile stimulus. Brain-imaging data showed that IPL (inferior parietal lobe) and ACC (anterior cingulate cortex) were activated in the visual spatial attention task and the activation was enhanced during the task with the tactile stimulus.

Chapter 4 describes the Third experiment. To investigate neural substrates of integration between tactile spatial attention and tactile temporal attention, and used the visually spatial and temporal cue, in which the visual and the tactile would present simultaneous. From the fMRI imaging results, bilateral frontal-parietal neural network was be found in the TS (spatial task) and TT (temporal task), but TN (neutral task) activated somatosensory areas only which was consistent with the TT and TS.

Chapter 5 describes the fourth experiment. In this experiment, this study was focus on the neural substrates of divided attention process, used a top-down attention paradigm in which a visual cue directs the attention of participants to both visual and tactile target stimulus in a spatial (attention was directed to unilateral target distinctly) in visual spatial attention task and tactile-visual spatial attention task. And the attention was manipulated to visual spatial orienting by a visual cue, tactile target stimulus was told to be ignored. Subjects were also scanned during a resting baseline condition in which subjects clicked the reaction key ten times. Brain-imaging data showed that IPL (inferior parietal lobe) and MFG (middle frontal gyrus) were activated in the visual spatial attention task and the activation was enhanced during the task with the tactile stimulus.

Chapter 6 gives a general discussion and conclusions based on the findings of the four experiments.

Finally, the appendices present topics related to the experiments, describing the principles of fMRI and a tool for fMRI experiment data processing: Statistical Parametric Mapping (SPM).

Contents

Chapter 1 Introduction

Summary

This chapter introduces previous studies on attention processing in the brain, especially studies focusing on visual and tactile attention processing in the Frontal Parietal Network. The aim and contents of the dissertation are also briefly described.

1.1 Attention manipulation in brain

Attention is an ability that can help people choose useful information and ignore other information when people manage the information from the outside. For people, they can sort the information into visual, auditory, somatosensory, taste and olfaction. For visual, auditory and somatosensory information, can sort them also into spatial, temporal and character information. For example, when the people come to a crossroad and stop to check whether it is safe to though. When other cars near the crossroad were checked, people should estimate the car’s location, speed, and timing of come into the cross. In this case, the spatial and temporal information were used for the attention process.

The human brain is a highly efficient information processing system capable of processing a large amount of information rapidly and simultaneously. If be able to accurately elucidate the sophisticated mechanisms of the brain, we could construct humanlike, efficient, and flexible artificial systems. We would also have the capacity to assess the most relevant ways to present information, and in the most appropriate manner.

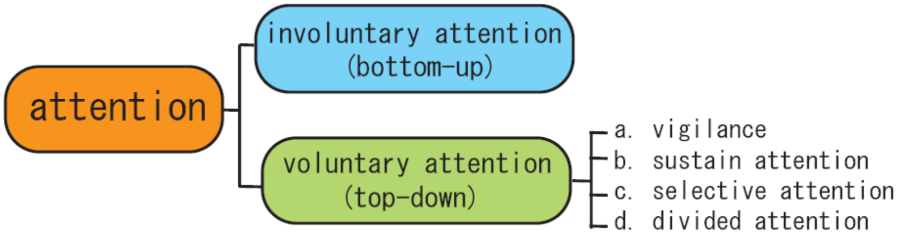

Figure 1.1 Category of attention study

The attention studies could be divided into several kinds that shown in figure 1.1, there are mainly two kinds, one is involuntary attention and the other is voluntary attention, which was used when people manipulate the information to satisfy their aim. According the study of visual voluntary attention, a brain model of the attention for visual information process was completed as shown in figure 1.2.

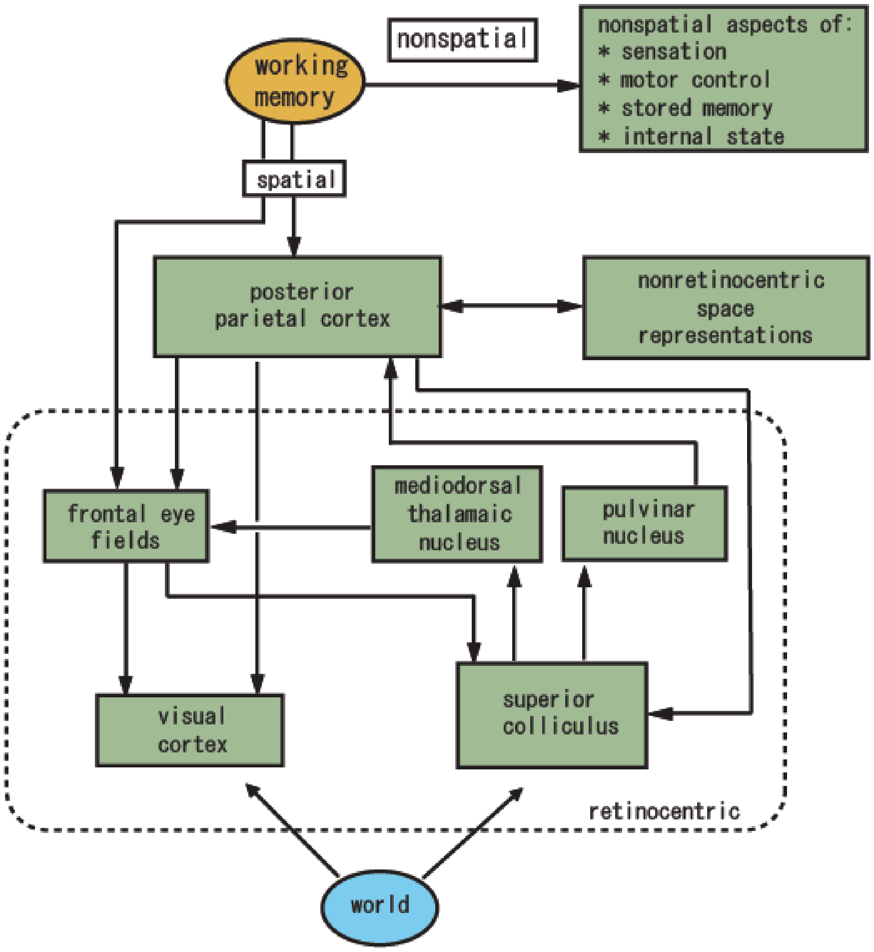

Figure 1.2 Neural network model of visual attention

The top-down attention experimental paradigm which was developed by M.I. Posner (Posner, 1980) has been widely used. Recent brain studies used a visual cue to investigate visual top-down attention by event-related potentials (ERPs) and functional magnetic resonance imaging (fMRI) revealed that a frontal-parietal network was associated with spatial attention, especially within right hemisphere (Coull and Nobre, 1998), the same network was reportedly also in voluntary temporal attention (Coull and Nobre, 1998). Furthermore, some studies (Recanzone et al., 1992) on investigating the neural network involved in visual and tactile attention indicated that there is a similar neural activation between visual and tactile spatial attention cognition.

Behavioral experiment in which visual cue was used to direct the attention to locations of visual and tactile target showed an improved reaction time of target occurrence (Sathian and Burton, 1991). Similar studies on cross-modal with a visual cue to an tactile target revealed that symbolic spatial cuing caused the negative ERPs related to validly cued targets more than the ERPs related to invalidly cued targets over a broad time range (Eimer and van Velzen, 2005). The same result was also observed when using a tactile cue to a visual target. Similarly, an electrophysiology primate study on attention found that enhanced neuron activity (spikes/s) occurred when target appeared in the focused location(Sathian and Burton, 1991). Furthermore, the fact that a visual cue would influence the tactile attention modulation in the right DLPFC (rDLPFC) within the right hemisphere (Frohlich, 1994) might be consistent with the theory of attentional set on the rule and task-relevant information (Coull et al., 2000) and with the theory of working memory that rDLPFC maintain spatial and non-spatial information online (Li et al., 2012). The lack of fMRI data so far, however, tampered direct validation on the attention modulation within the rDLPFC especially whether it modulates the tactile attention mechanism both in spatial and temporal domain. This study note that the need for direct validation is additional and confirmatory recognizing the previous reports that the rDLPFC associates with top-down control and attention execution, and the working memory within the rDLPFC processed spatial and non-spatial information online (Vossel et al., 2006) and manipulated the information to influence the incoming sensory or motor stimulation (van Ede et al., 2011).

1.2 The aim of the dissertation

The main aim of this dissertation research was to investigate the neural network for spatial and temporal attention for selective visual and tactile information process in the brain cortex. Also of interest was the identification of neural substrates related to divide visual tactile attention. To achieve these aims, four related experiments were conducted.

1.3 The contents of the dissertation

The dissertation contains descriptions of the four experiments and a general discussion briefly introduced below.

Chapter 2 introduces the first experiment, in which functional magnetic resonance imaging (fMRI) was used to measure the brain activities of subjects as they pay attention to target location spatially. The targets used in this experiment are single tactile target. These result found that the right brain hemisphere was mainly activated during the attention task. The frontal-parietal neural network exists for the tactile spatial attention.

Chapter 3 describes the second experiment, and used a top-down attention paradigm in which a visual cue directs the attention of participants to tactile target stimulus in TT (tactile temporal) task and TN (tactile neural) attention task. In the task, the attention was manipulated to tactile temporal information (cue-target interval is short or long) by a visual cue, and the tactile target stimulus was told to be. Neutral task was gave no information about spatial location. Subjects were also scanned during a resting baseline condition in which subjects clicked the reaction key ten times. The reaction time for spatial location attention is faster than that without a tactile stimulus. Brain-imaging data showed that IPL (inferior parietal lobe) and ACC (anterior cingulate cortex) were activated in the visual spatial attention task and the activation was enhanced during the task with the tactile stimulus.

Chapter 4 describes the Third experiment. To investigate neural substrates of integration between tactile spatial attention and tactile temporal attention, and used the visually spatial and temporal cue, in which the visual and the tactile would present simultaneous. From the fMRI imaging results, the bilateral frontal-parietal neural network was been found in TS (spatial task) and TT (temporal task) activated, but the somatosensory areas was been activated only in which consistent with the TT and TS.

Chapter 5 describes the fourth experiment. This experiment focus on the neural substrates of divided attention process. Used a top-down attention paradigm in which a visual cue directs the attention of participants to both visual and tactile target stimulus in a spatial (attention was directed to unilateral target distinctly) in visual spatial attention task and tactile-visual spatial attention task. And the attention was manipulated to visual spatial orienting by a visual cue, tactile target stimulus was told to be ignored. Subjects were also scanned during a resting baseline condition in which subjects clicked the reaction key ten times. Brain-imaging data showed that IPL (inferior parietal lobe) and MFG (middle frontal gyrus) were activated in the visual spatial attention task and the activation was enhanced during the task with the tactile stimulus.

Chapter 6 gives a general discussion and conclusions based on the findings of the four experiments.

Finally, the appendices present topics related to the experiments, describing the principles of fMRI and a tool for fMRI experiment data processing: Statistical Parametric Mapping (SPM).

Chapter 2 fMRI studies on tactile spatial attention

Summary

Visual cue-oriented, tactile top-down attention (vTA) has been behaviorally well investigated. However, vTA-related brain activation remains unclear, and whether SI (primary somatosensory cortex) or SII (secondary somatosensory cortex) is modulated by the top-down process of tactile cognition remains particularly controversial. Used the Posner paradigm in which a visual spatial cue directed attention to a tactile target (TS: tactile spatial attention task). The TS is compared with a visual non-spatially cued, tactile attention task (TN: tactile neutral attention task). The behavioral results showed no significant differences between the TS and TN tasks. However, authors were considered the possibility that the visual spatial hint affected the tactile spatial attention neural network. Brain-imaging data showed that the IPL (inferior parietal lobe) was more activated in the TS task than in the TN task. Furthermore, they present evidence to support SII modulation by top-down processing during the TS task.

Keywords – selective attention, frontal-parietal neural network, right Dorsal Prefrontal Cortex

2.1 Introduction

M.I. Posner developed the most widely used experimental paradigm for studying the orientation of visual spatial attention (Posner, 1980). A cue can provide either a directional or a non-directional hint to the position of an upcoming target stimulus, thereby affecting the response to this target stimulus. This voluntary, visual spatial attention is usually referred to as visual, top-down spatial attention. Functional magnetic resonance imaging (fMRI) studies have revealed the importance of the fronto-parietal network (FPN), which includes the bilateral frontal eye field (FEF) and intraparietal lobe (IPL) in top-down spatial attention processing(Coull and Nobre, 1998, Corbetta and Shulman, 2002). Furthermore, right hemisphere dominance has been reported during top-down, visual spatial attention tasks involving the inferior parietal lobe/temporal parietal junction (IPL/TPJ), the dorsolateral prefrontal cortex (DLPFC) and the ventrolateral prefrontal cortex (VLPFC) (Desimone and Duncan, 1995, Esterman et al., 2008, Doricchi et al., 2010, Li et al., 2012, Tang et al., 2013).

Recently, studies on tactile, top-down attention have provided several interesting findings with behavioral and imaging data. Previous studies of crossmodality (Spence et al., 2000, Spence and McGlone, 2001) showed that individuals obtain faster reaction times to a tactile target when provided with a visual or auditory spatial cue compared to a task with a non-spatial cue. The facilitation of crossmodality was confirmed. To reveal the pattern of brain activation, Macaluso et al. used two positron-emission tomography (PET) experiments to explore the neural basis of selective spatial attention in vision and touch and tested for modality-specific versus multi-modal activations in the attended side (Macaluso et al., 2000). First, they found no significant activations for attending left minus right, and they observed activation within the left intraparietal sulcus (Macaluso and Driver, 2001). In their second study, only tactile stimuli were used. The uni-modal activation was confirmed for tactile spatial attention in the left, superior, post-central gyrus and left intraparietal sulcus. These results reveal mechanisms of sustained spatial attention operating at both modality-specific and multi-modal levels (Bauer et al., 2006, Poliakoff et al., 2007). In another tactile attention study, Macaluso et al. used event-related fMRI to study the neural correlates of endogenous spatial attention for vision and touch. The authors examined activity associated with attention-directing cues (central auditory pure tones) and symbolically instructed subjects to attend to one hemi-field or the other prior to the upcoming stimuli for a visual or tactile task. The imaging results confirmed the activation of the FPN for both the visual target and the tactile target (Macaluso et al., 2000, Macaluso et al., 2003).

In contrast, other studies have provided evidence linking somatosensory areas with tactile top-down attention. Some studies suggest that both SI and SII are modulated by tactile spatial attention processing (Schubert et al., 2008, Van Hulle et al., 2013). For example, Schubert et al. (Schubert et al., 2008) employed simultaneous electroencephalography (EEG)-fMRI in right-handed subjects during bilateral index finger Braille stimulation to investigate the relationship between attentional effects on somatosensory evoked potential (SEP) components and the blood oxygenation level-dependent (BOLD) signal. They found that attentional modulations of the fast electrophysiological signals and the slow hemodynamic response are linearly related in the SI as well as the SII. However, another study reached a different conclusion that no attention effect was observed for the SI whereas attention enhanced SII activity bilaterally in the spatial and intensity discrimination task (Hoechstetter et al., 2000). Until now, these two contrary conclusions that whether tactile attentional effects are present in SI and SII or only in SII have not been resolved.

In order to clear whether tactile attentional effects are present in SI and SII or only in SII, this study used the visual spatial cue (left or right arrow)-tactile target paradigm to study tactile attention. To evaluate these processes behaviorally, and conducted psychological experiments in which measured the reaction times (RTs) for each task. To reveal the neuronal networks related to these attention systems, authors measured hemodynamic changes using fMRI, and authors hope to effectively demonstrate the correlation between somatosensory cortex and attention.

2.2 Methods

2.2.1 Participants

Twenty (10 females; mean age 24.5 years; range 21-32 years) volunteers with normal or corrected-to-normal vision from China Medical University participated in the experiment. All subjects reported that they were right-handed. None of the subjects had a history of neurological or psychiatric dysfunction. None of the subjects had participated in a neuropsychological experiment. Written informed consent was obtained from each subject following a detailed explanation of the study. The protocol was approved by the ethics committee of the Shengjing Hospital of China Medical University. fMRI data from four subjects were excluded because the head displacements were too large.

2.2.2 Experimental stimulus

As shown in figure 2.1, two types of cue stimuli were presented. The visual cues were displayed on a computer monitor. Specifically, a rhombus located outside a circle was displayed in the center of the paper screen (as part of the paper screen background). Visual cues (spatial stimulus) consisted highlighting the left half or the right half of the central rhombus and appearing as an arrow (pointing left or right). The spatial cues were used to direct the subject’s attention to one of two possible target locations (left or right) during the spatial tasks. The second visual cue stimulus, the neutral cue, highlighted both geometric shapes (the rhombus and circle), which served as a non-informative indication of an upcoming stimulus. The neutral cue that provided neither spatial nor temporal information was used during neutral tasks to prepare subjects for target detection.

For the tactile target stimulus, an ultrasonic motor (UN30ME-600; Canon Precision; Japan) was been used. The ultrasonic motor rotated a small brush with a rotation speed of 1.33 Hz, and the rotating brush produced friction on the subject’s hand. The brush was made from flexible material to prevent pain and itching. The tactile stimulus was presented in the palm of the subject's left hand, as shown in figure 2.1. Through preliminary experiments, authors confirmed that the subjects were able to specifically identify the position of the stimulus. (In simple tactile stimulation experiments, the subjects determined left and right with almost 100% accuracy.)

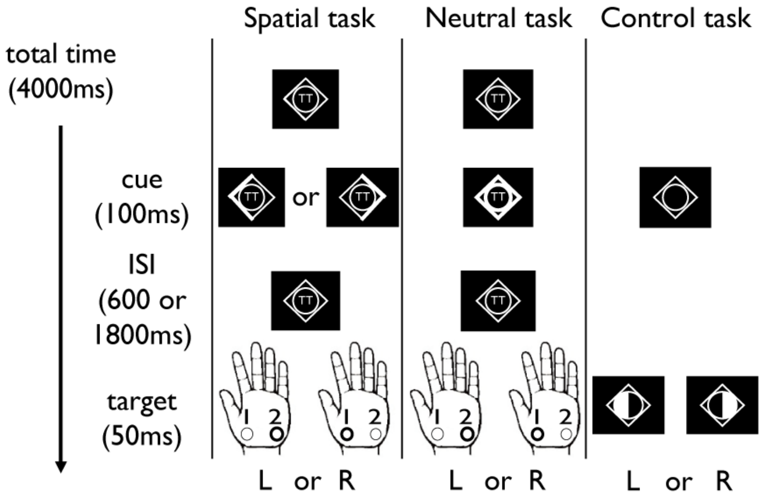

Figure 2.1 Experiment paradigm and stimuli. In this example, the visual cue was highlighted for 100 ms. after the cue–target interval (600 or 1,800 ms, randomly), the tactile target was presented for 50 ms. Central cues were used in the experimental task. The spatial cue was used in the spatial attention tasks. The right or left half of the cube was highlighted (stimulus) to provide information concerning the target location (i.e., the coarse circle is the location where the tactile target appeared; No. 1 is the right side, and No. 2 is the left side). The neutral cue was used in the control tasks and provided the spatial information. C. Either the left half or the right half of the inner circle turned white during the control task, and subjects were told to press the reaction key when the inner circle turned to white. RT was not required.

2.2.3 Experimental design

During the experimental tasks, the subjects were asked to fix their eyes on a central cue and to look for the spatial cue indicating one of two spatial directions. Specifically, during the spatial attention (TS) task, the subjects were instructed to pay attention to a right or left tactile target based on the spatial cue and respond to the target as quickly as possible after the cue appeared. A process of neutral attention (i.e., no induced spatial attention) was also carried out to determine non-specific, attention-related activity, and this process was used to cancel out basic visual and tactile cognition-mediated activity. During the neutral attention (TN) task, the cue was uninformative, and the subjects were told to respond to a target as quickly as possible when a target appeared. During the experiment, the subjects had to judge the target location (right or left) and press the reaction key correctly, even during the neutral task. The reaction time was defined as correct when the key was pressed 100–1000 ms after the target presentation.

During the two attention tasks, visual cues were presented for 100 ms, and the interval length between the presentation of the cue and the tactile target event was either 600 or 1800 ms, which occurred with equal probability. The tactile target stimulus lasted for 50 ms. The subjects were instructed to press a response key corresponding to either a right (by pressing the ‘‘right’’ key using the middle finger of their right hand) or a left tactile stimulus (by pressing the ‘‘left’’ key using the forefinger of their right hand) during the two attention tasks. The duration from the moment the tactile target was presented to the moment a key was pressed is the reaction times. The reaction accuracy was also recorded. Subjects performed 30 trials under each of the two attention tasks. A control task was used as a baseline to cancel out activation caused by detection-related processes evoked by hits. During the control task, the left half or the right half of the circle was highlighted (with equal probability), and the subjects were asked to press the reaction key once. Control tasks were performed 30 times. All trials were 4,000 ms (attention tasks and the control task). The experimental details were explained to each participant, and a practice/training course was performed before MR scanning. Brain activation data were obtained from the subjects who completed the training task with greater than 90% accuracy. A block design was used for these experiments in which the three tasks were randomized in blocks of ten trials, which were carried out three times, for a total of thirty trials. The experiment lasted for a total of six minutes. Subjects were instructed to respond as quickly as possible to the target stimulus.

2.2.4 fMRI scanning

A Philips 3 Tesla Magnetism Vision whole-body MRI system was used to measure brain activation with a head coil. The imaging area consisted of 36 functional gradient-echo planar imaging (EPI) axial slices (voxel size 1.8×1.8×4 mm, TR=4,000 ms, TE=50 ms, FA=90°, 132×130 matrix) that were used to obtain T2*-weighted fMRI images in the axial plane. The EPI images encompassed the entire cortex. 124 functional volumes were obtained for each task.

2.2.5 Data analysis

2.2.5.1 Behavioral data analysis

Reaction times measured during the fMRI experiment were used as behavioral data after discarding the error trials from each subject. All subjects responded with greater than 90% accuracy. Then, paired t-tests was been used to compare the TS and TN tasks (SPSS 16.0).

2.2.5.2MRI data analysis

For the functional image analyses, we first used MRIcro (http://www.mccausl-andcenter.sc.edu/CRNL/) to convert the DICOM files to NIFTI files. The first four functional volumes were excluded from each run. Subsequently, the functional data were analyzed using statistical parametric mapping (SPM8; Wellcome Department of Cognitive Neurology, London, UK; http://www.fil.ion.ucl.ac.uk/spm) with MATLAB (The Math-Works Inc., Natick, MA). The functional images from each run were realigned, and the first scan was used as a reference(Li et al., 2012). Realigned images were spatially normalized using the standard EPI template with the Montreal Neurological Institute (MNI) reference brain coordinates. Finally, these spatially normalized, functional images were smoothed using an isotopic Gaussian kernel of 8 mm. Statistical analyses were performed in two stages of a mixed-effects model. During the first level of analysis, the BOLD response was modeled as the neural activity convolved with a canonical hemodynamic response function (HRF), which yielded regressions in a general linear model (GLM) for each task (spatial task vs. control task, and neutral task vs. control task). The contrast (con) images from the first-level of analysis from all 16 subjects were then used for the second-level group analysis. First, authors performed a conjunction analysis that tested for activation common to both TS and TN tasks (TS+TN). To identify the areas of whole-brain activation in the TS vs. TN tasks (TS-TN), a one-sample t-test analysis was analyzed for the con images.

Based on the results of TS+TN and TS-TN, the region of interest (ROI) with the leave-one-out cross-validation estimate by the MarsBar toolbox was been determined (http://marsbar.sourceforge.net). Four spheres was identified, and each with a radius of 4 mm, centered at the voxel of peak activation in the following areas: left secondary somatosensory cortex (L-SII), right secondary somatosensory cortex (L-SII), left inferior parietal lobule (IPL) and right middle temporal gyrus (MTG). The first three ROIs are for TS+TN, and the rest are for TS-TN. Finally, paired t-tests were performed to examine the statistical significance of each ROI (SPSS 16.0).

2.3 Results

2.3.1 Behavioral results

The behavioral data were derived from the performance during the fMRI experiment. The RTs for each task were computed from the data for the 16 subjects (the average of 16×27=432 trials). And the paired t-test was been used to compare the TS task with the TN task. The comparison of RTs across the two tasks is shown in table 2.1. The TS task performance was significantly faster (617.1 ms) than the TN task (630.2 ms). However, there is no a significant deviation between the two tasks.

Table 2.1 Reaction times (RTs; ms) and accuracy for validly cued targets in the TS task and for all targets in the TN task. SE: standard error

	TS(SE)	TN(SE)
RTs	617.1(39.6)	630.2(38.8)
Accuracy	96%(5.1)	95.7%(5.2)

2.3.2 fMRI results

2.3.2.1 Activations during the TS task and TN task

Activation during the TS and TN tasks is shown in figure 2.2 and is summarized in table 2.2. The activation map rendered in the figure was generated using an uncorrected threshold ($p<0.005$). And found significant bilateral activation in the FEF and SII areas in both the left and right hemispheres. There was an overlap in the anatomical areas highlighted in the left and right hemispheres. Some similar results were been found when comparing the TN and TS tasks: activation of left and right SII.

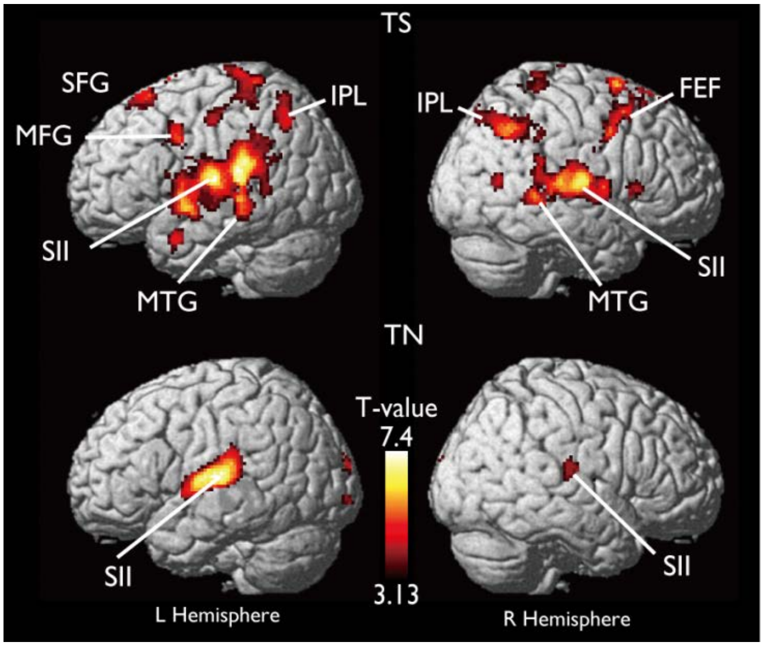

Figure 2.2 TS and TN: Activation during tactile attentional tasks. (Significance was uncorrected p<0.005.)

2.3.2.2 Common areas of activation by the TS and TN tasks

Figure 2.3 and table 2.2 show the areas of brain activation with the TS and TN tasks (uncorrected threshold p<0.005). Just SII were activated. For these regions, ROI analysis was be used and there are no difference between the TS and TN tasks.

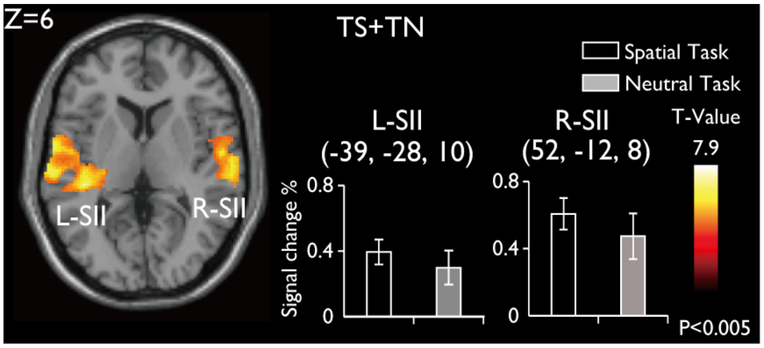

Figure 2.3 TS+TN: Areas activated during both the TS and TN tasks. (p<0.005, uncorrected)

2.3.2.3 Spatial versus neutral task

The contrast between the TS and TN tasks defines areas activated by spatially directional cues under an uncorrected threshold (p<0.005). This comparison showed a bilateral cluster of activation in the left IPL and a cluster in the right MTG with significant differences between the TS and TN tasks.

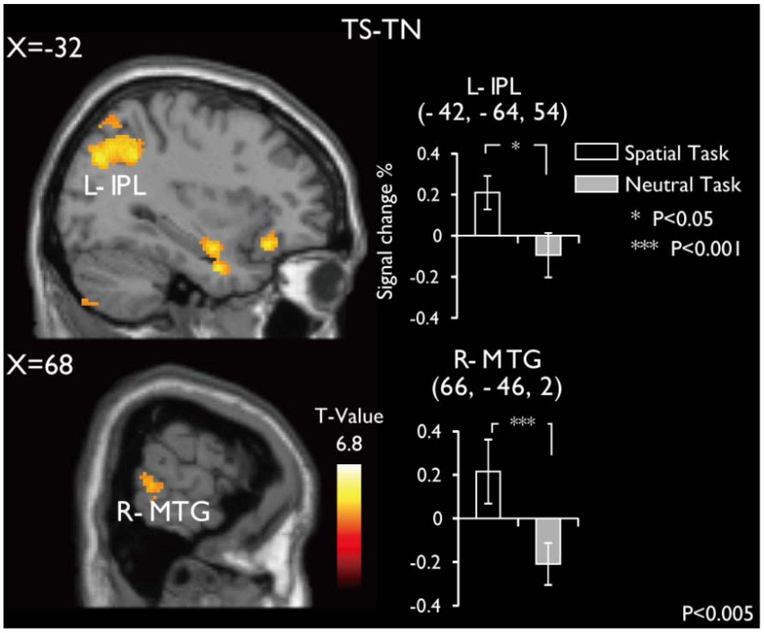

Figure 2.4 TS-TN: Areas activated during the TS versus TN tasks. (p<0.005, uncorrected)

Table 2.2 Activations related to attentional tasks. Significance was set at an uncorrected threshold of p<0.001 and cluster size = 50. The approximate anatomical regions and Brodmann areas are shown according to the Talairach atlas.

cluster size	*Z-value*	*anatomical region(BA)*	*x*	*y*	*z*
TS					
3859	4.73	L Precuneus(7)	-7	-58	36
1297	4.7	R SII	64	-18	15
1456	4.7	R Superior Frontal Gyrus(6)	12	4	66
324	3.81	L Postcentral Gyrus(3)	-13	-39	63
59	3.55	R Middle Temporal Gyrus(37)	54	-64	8
52	3.41	R Thalamus	29	-31	9
80	3.38	L Postcentral Gyrus(3)	-56	-14	45
213	3.22	L Superior Parietal Lobule(7)	-39	-58	50
174	3.16	L Middle Frontal Gyrus(6)	-45	4	39
87	3.13	R Postcentral Gyrus(5)	33	-41	64
54	3.02	R Inferior Frontal Gyrus(44)	45	15	10

TN					
1895	4.67	L Insula(13)	-45	-9	10
1895	4.29	L SII	-39	-26	10
637	3.74	R Insula(13)	35	-17	19
64	3.14	L Thalamus	-11	-26	18
75	2.99	R SII	54	-25	19
TS+TN					
3152	4.89	L SII	-39	-28	10
133	4.54	R Superior Frontal Gyrus(6)	12	4	66
982	4	R SII	52	-12	8
404	3.73	R Insula(13)	33	-15	23
500	3.6	L SI(3)	-18	-46	64
169	3.38	R Medial Frontal Gyrus(6)	7	3	53
57	2.97	L Precuneus(7)	-9	-56	40
TS-TN					
328	4.37	L Superior Frontal Gyrus(6)	-7	24	64
190	3.89	L Inferior Parietal Lobule(40)	-41	-60	46
482	3.89	R Inferior Parietal Lobule(40)	52	-55	38
487	3.67	L Temporo–parietal Junction (22)	-64	-40	13
99	3.64	L Middle Frontal Gyrus(9)	-41	4	32
107	3.21	R Middle Temporal Gyrus(22)	62	-48	3
99	3.2	R Middle Frontal Gyrus(6)	24	13	60
198	3.54	L Parahippocampal Gyrus	-30	-6	-13

2.4 Discussion

This study used the Posner task to investigate the relationship between somatosensory areas and top-down spatial attention. This results showed that, either in neutral cue task or spatial cue task, bilateral SII activated significantly while SI was absent, in consistency with the study of Hoechstetter et al. (Hoechstetter et al., 2000). These results suggest that SI play a role in somatosensory processing rather than in higher-order attention processing in visually cued tactile top-down spatial attention. Moreover, attention exerts a general control on neuronal activation in SII.

2.4.1 SII in tactile spatial attention modulation

The resting state has been used as a baseline in previous studies. This comparison is the most compatible with previous reports using visual fixation controls. In addition, the neutral condition itself engages and orients attention between two spatial locations and two temporal intervals. This study focused on activation without finger movement. Thus, the subjects were asked to click the reaction key ten times during each rest. The activation patterns observed during each task with activation observed during rest. As a result, except for the visual cortices, which showed enhanced activity in the hand area of SII contralateral to the focus of attention, significant activation occurred in somatosensory areas during the TS and TN task. This result is consistent with studies investigating cross-modal and non-selective attention, usually with only one stimulation site; these studies found the SII BOLD signal amplitude was amplified by attention more than SI. Thus, SII, which has long been assumed to be sensitive only to the physical attributes of somatosensory stimuli, such as frequency or intensity, also contributes to the highly cognitive process of spatial attention (Macaluso et al., 2000, Schubert et al., 2008, van Ede et al., 2011). This finding emphasizes the role of SII in the integration of somatosensory processes and cognitive functions.

2.4.2 Fronto-parietal areas of tactile spatial attention

Previous studies have suggested the involvement of the fronto-parietal cortex in spatial voluntary attention tasks (Soros et al., 2007, Burton et al., 2008, Miles et al., 2008). Thus, this study used the neutral task and the baseline to reveal activation resulting from spatial attention. The activation during TS-TN in the frontal (FEF) and parietal (IPL) cortices was similar to previous studies. However, in this study, FEF was only activated by the contrast of TS task. Within the fronto-parietal network, previous studies have found IPL participation during the spatial attention task in top-down and bottom-up uni-modal processes. This suggests that IPL and FEF are modulated by both the sensory distinctiveness of objects and top-down contextual information. These areas might be involved in generating the salience (activation) maps that are postulated in models of visual search, which combine bottom-up and top-down information to represent visual objects of interest. This study found that point to the importance of the IPL in spatial cognition. Other studies found that the IPS was one of the two most pronounced regions of activation when palpating objects, which may reflect a possible pathway from the post-central gyrus to the IPS. This pathway could play a role in tactile object processing and may be analogous to the ventral pathway, which is specialized for the recognition of visual objects (Corbetta and Shulman, 2002, Doricchi et al., 2010).

2.4.3 Crossmodality in tactile spatial attention

This study was also found that the right MTG was activated during the spatial attention tasks, which is consistent with a previous study (Macaluso and Driver, 2001, Li et al., 2012). The right MTG has been associated with selectivity of auditory stimuli involved in spatial or feature aspects. These previous authors found that the right MTG was significantly activated during spatial and neutral attention tasks. The M/STG is part of the activation pattern during somatosensory discrimination tasks with the recognition of shapes and textures, such as roughness (Macaluso and Driver, 2001). This study replaced the target modality but revealed the same activation pattern. Accordingly, these results propose that the MTG may be more closely associated with crossmodal attention than the basis of cognition.

2.5 Conclusion

This study was measured brain activation during voluntary tactile spatial attention with a 3 Tesla fMRI machine. These results revealed that the fronto-parietal network was functional during spatial attention and that brain activation was enhanced when using a visual spatial cue. Furthermore, this study suggests that secondary somatosensory areas contribute to top-down tactile spatial attention.

Chapter 3 fMRI studies on relationship between tactile spatial and temporal selective attention

Summary

Visual orienting attention is well researched by using a visual cue. The tactile spatial attention and the tactile-visual spatial attention have been compared by the brain-imaging data. But the tactile temporal orienting of attention is little be researched or not have any researched.

This study used a top-down attention paradigm in which a visual cue directs the attention of participants to tactile target stimulus in TT (tactile temporal) task and TN (tactile neural) attention task. In the task, the attention was manipulated to tactile temporal information (cue-target interval is short or long) by a visual cue, and the tactile target stimulus was told to be. Neutral task was gave no information about spatial location. Subjects were also scanned during a resting baseline condition in which subjects clicked the reaction key ten times. The reaction time for spatial location attention is faster than that without a tactile stimulus.

Behavioral results of reaction time not have any significant difference between tactile temporal task and tactile neutral task. This study thought that the visual information may be affecting the tactile temporal attention neural network.

Brain-imaging data showed that IPL (inferior parietal lobe) and ACC (anterior cingulate cortex) were activated in the visual spatial attention task and the activation was enhanced during the task with the tactile stimulus.

Key word: fMRI, tactile temporal attention, cue stimuli, attention, orienting

3.1 Introduction

Attention is the ability to attend to some things while ignoring others. It’s very important to cognitive neuroscience, in part because this cognitive ability supports our awareness and inferences our encode information in long-term memory (Posner, 1980). About attention that peoples do not have a better definition of attention than (James, 1976) had a century ago. “Everyone knows what attention is. It is the taking possessing of the mind in clear and vivid form of what seen several simultaneous objects of trains of thought.”

Peoples often divide attention into two broad categories, involuntary attention and voluntary attention (Esterman et al., 2008). Involuntary attention, a bottom-up, stimulus-driven, influence, is describes our attention which was captured by a sensory event. Voluntary attention, a top-down, goal-directed influence, is our planned to attend something. In this study was focus on the mechanisms of Voluntary attention. In human information-processing systems, voluntary attention plays an important role in selecting and integrating information. For example, the cocktail party effect is a typical selective attention. British psychologist examined the so-called cocktail party effect.

Until now visual spatial orienting attention is well researched by using a visual cue (Coull and Nobre, 1998), and visual temporal orienting is well researched too. But authors still poorly understand the common or different networks used by temporal tactile attention systems. Moreover, attention to distraction has not been researched sufficiently compared to that in terms of temporal times, and little research has compared the differences between tactile temporal with and without temporal distraction.

This study compared selection attention to integration attention for reveal the neuronal networks related to this attention system. This study developed a tactile temporal attention to compare a visual temporal cue and a visual neutral cue when tactile target was presented. To evaluate these processes behaviorally and conducted psychological experiments in which authors measured the reaction times (RTs) for each task. To reveal the neuronal networks related to these attention systems, we measured the hemodynamic changes using fMRI.

3.2 Materials

3.2.1 Subjects

The subjects were 16 healthy right-handed students from China Medical University, and age is 21–26 years. Male eight and female is eight. Informed consent was obtained from each participant following a detailed explanation of the study. Signed the fMRI experiment letter of consent and has accepted the health check-up. Before the experiment, all of the subjects had educated ethological experiment.

3.2.2 Experimental system

During fMRI scanning, visual information (background and cue stimuli) were generated on a personal computer and presented to the subjects via a projector-screen–mirror system. Tactile stimulus was generated in left band of subjects by two ultrasonic motors (made by canon).

3.2.3 Experimental stimuli

The tactile stimuli in the left hand of the subjects were prompted. An ultrasonic motor (Made in canon company) was be used, motor rotation frequency is 1.33Hz. So the subjects can clearly determine the direction of stimulus and the feeling of an appropriate stimulus, not feel pain.(location was showing in figure 3.1, black circle is the tactile stimuli was presented, that mean is the location is the right, because in the fMRI, if their palm in the diaphragmatic surface, subjects can feel the direction is antithesis.

Table 3.1 Experimental tasks

	Tactile
Temporal	TT
Neutral	TN

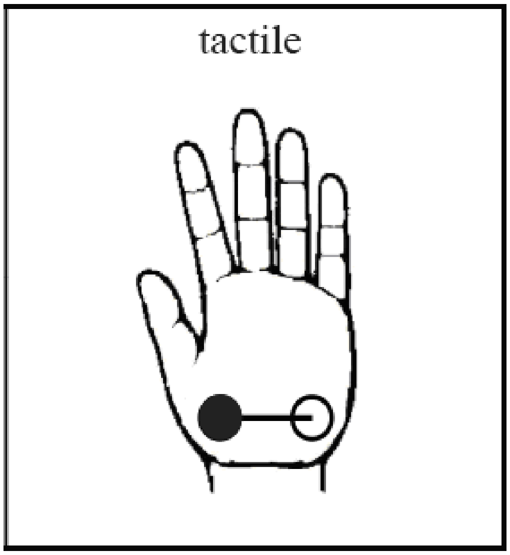

Figure 3.1 Target stimuli of the experimental

Cue stimuli were used to direct the subjects' attention to a particular onset time. The neutral cue provided neither temporal information; the temporal cue (bigger circle is long interval time, small circle is short interval time, bigger one and small one was appeared by random times) directed the subjects' attention to the interval is long or short; showing in the figure 3.2. The neutral cue not provided any information. This study recorded the RT, that is, the time from the presentation of a stimulus to response indicated by a reaction key. The subjects responded to a right stimulus using the middle finger and to a left stimulus with the forefinger of their right hand. The subjects performed 30 trials under each condition. There are two sessions, is only tactile stimuli. The visual information was presented using a projector as shown in the paper screen. Subject lied in MRI equipment viewed the visual information though the half mirror and the tactile stimuli though the ultrasonic motor. In order to remove the effect of right-hand pressing response button, the rest task also designed in this study (figure 3.3). In the rest task, there are no any cue factors, when the half (left or right) of the small circle was lie, this study designed a control task in which subjects had to click the response key consisted with spatial task simultaneously. The effects of clicking the response key were removed by subtracting the brain activations elicited by clicking the response key from the results of tactile attention task.

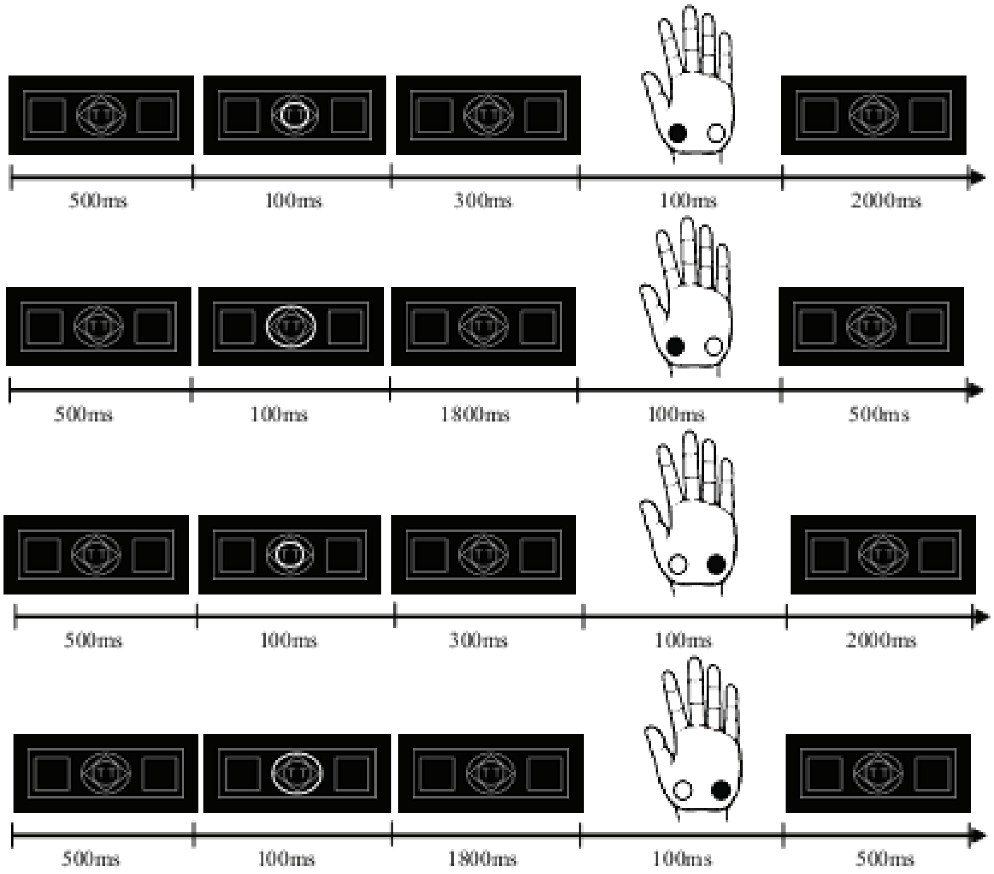

Figure 3.2 Example of trials in experimental.

The temporal cue was used in the TT tasks. As the stimulus, the bigger or smaller circle was lit to give the subjects information of the interval about the target was appeared. When the neutral cue was presented, hole of the cube and small circle was lit to not give the subjects any information on the target stimuli. After 500ms of the background, the visual cue was lit for 100 ms, and after the cue–target interval (300 or 1800 ms, random), the target was appeared for 50 ms. 'TT' means is Tactile Task. Hole of the experiment, the subjects were asked to focus the middle of the words "TT" in the small circle from the screen, other visual information was cannot watched.

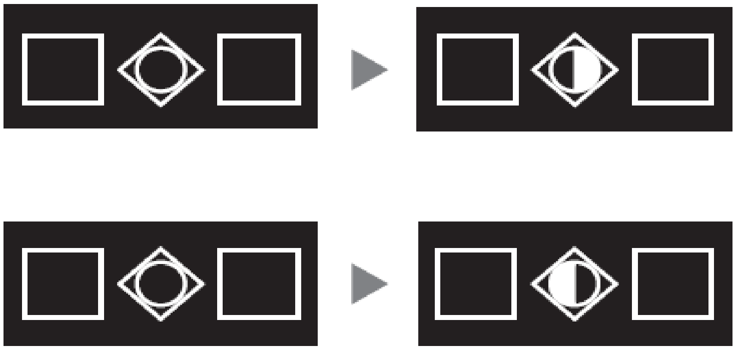

Figure 3.3 Rest task

3.3 Methods

3.3.1 fMRI scanning

A Philips 3.0 Tesla Magnetom Vision whole-body MRI system was be used to measure the brain activation with a head coil(From ShengJing hospital of China Medical University, No.36 Sanhao Street, Heping District Shenyang, Liaoning Zip code:100004). The imaging area consisted of 32 functional gradient-echo planar imaging (EPI) axial slices (voxel size 3×3×4 mm, TR=3000 ms, TE=50 ms, FA=90°, 128×128 matrix) that were used to obtain T2*-weighted fMRI images in the axial plane. The EPI imaged the entire cortex, 124 functional volumes were obtained for each task. Before the EPI scan, a T2-weighted volume was acquired for anatomical alignment (TR=3500 ms, TE=100 ms, FA=90°, 256×256 matrix, voxel size=0.75×0.75×4 mm). The T2 image acquisition used the same slices as the functional image acquisition.

3.3.2 Data analysis

Reaction times and accuracy were used as behavioral data. The RT (reaction time) data during the fMRI experiment were analyzed using repeated measures analysis of variance (ANOVA; SPSS 17.0j for Windows). For each task, 60 RTs (reaction time) were acquired from each subject. This study used the average of the RT data for the ANOVA, except for error trials (all subjects were reacted with accuracy above 90%). Two tasks were presented in this experiment, and compared the tactile temporal tasks and neutral task separately (TT and TN).

For the functional images, MRIcro was be used to change the DICOM files to MRIimg and MRIhdr files. In each task, the functional images of the first four volumes were not used for the data analysis. The DICOM files from the 5th through 124th scan were exported as MRIima and MRIhdr files. In addition, the DICOM files for the T2 images were exported as MRIimg and MRIhdr files.

The functional images were analyzed using statistical parametric mapping (SPM8, Wellcome Department of Cognitive Neurology, London, UK). The functional images from each task were realigned using the first scan as a reference. T2-weighted anatomical images were coregistered to the first scan in the functional images. Then, the coregistered T2-weighted anatomical images were normalized to standard T2 template images as defined by the Montreal Neurological Institute. Finally, these spatially normalized functional images were smoothed using an isotopic Gaussian kernel of 8 mm.

Statistical analyses sought to identify the brain areas shared by tactical temporal (TT, TN) attention, as well as the brain areas selectively engaged by each task. To eliminate the brain activation caused by finger motion, subjects need to click the reaction key ten times during every rest also.

3.4 Results

3.4.1 Behavioral result

Behavioral data were derived from the performance during the fMRI experiment. The reaction time for each task (shown in figure 3.4) was computed from the data for the 16 subjects (the average of 16×27=432 trials).

The paired *t*-test was be used for this study. The comparison of RTs across tactile tasks not shows any significant difference between TT and TN (figure 3.4). And in the accuracy, all of the subjects were able to have the corresponding response in the right direction; the accuracy was generally above 90 % (figure 3.5).

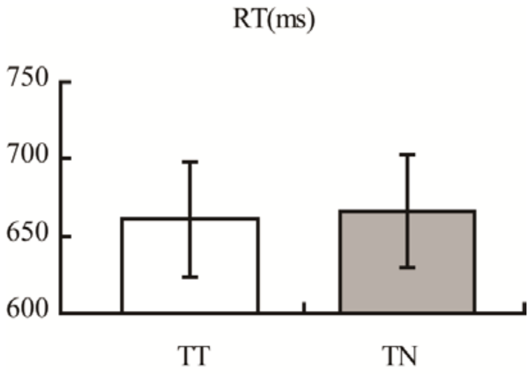

Figure 3.4 Result of the reaction time

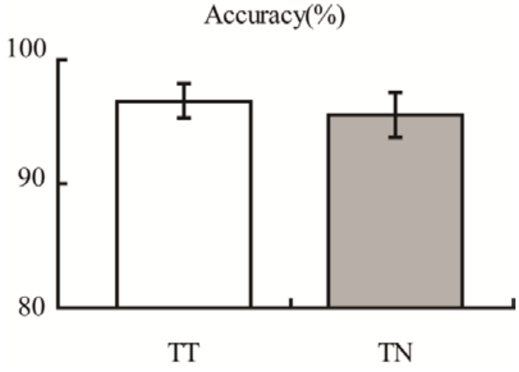

Figure 3.5 Result of the accuracy

3.4.2 fMRI results

Figure shows the main results that made by contrast TT task (figure 3.6) and TN task (figure 3.7), and both of the two tasks were be compared (TT-TN in figure 3.8). The rendered results were made under a threshold of $p < 0.001$(TT-TN used $p<0.05$) and a cluster size with 0. The table was showed that the activation area corresponding with all of fMRI results. This study focused on visual temporal cuing effect of tactile attention.

TT

In this result, significant activation occurred only in the bilateral parietal cortex. The right frontal eye field (FEF) and the left superior parietal lobe (SPL) had significant activation bilaterally when the tactile temporal attention was compared with baseline.

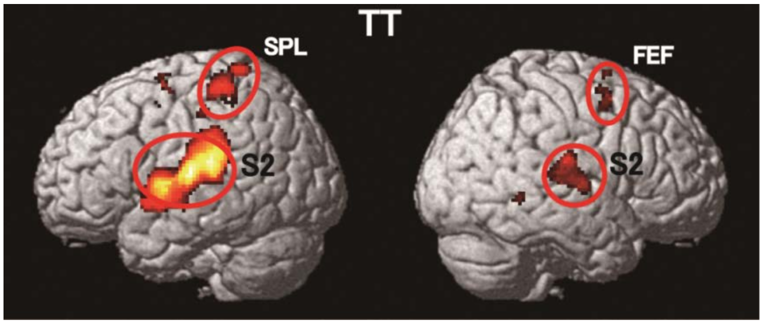

Figure 3.6 TT (Activations in tactile attention *p*<0.05, cluster size=0)

Table 3.2 Brain areas activated during TT Task

cluster	*Z-score*	*p-value*	*anatomical region(BA)*	*x*	*y*	*z*
8025	6.11	<0.001	(L)Transverse Temporal Gyrus(41)	-45	-21	11
3393	4.35	<0.001	(R)Insula(13)	48	-21	15
73	3.25	0.001	(R)Insula(13)	33	-40	17
41	3.1	0.001	(L)Cuneus(18)	-17	-102	7
143	2.94	0.001	(R)Precuneus(7)	13	-69	42
15	2.9	0.001	(R)Cuneus(18)	13	-100	5
17	2.88	0.001	(L)Uncus(34)	-20	3	-19
12	2.76	0.001	(R)Medial Frontal Gyrus(6)	13	-21	53
14	2.64	0.001	(R)Declive	33	-56	-8
21	2.58	0.001	(L)Middle Temporal Gyrus(37)	-43	-56	-5
17	2.57	0.001	(R)Inferior Parietal Lobule(40)	41	-50	50

All areas are significant at an uncorrected threshold of p<0.001. The approximate Brodmann areas are from MRIcro, and the x, y, and z coordinates are from SPM8. BA: brodmann area. SPL: superior parietal lobe; MFG: middle frontal gyrus; IFG: inferior frontal gyrus.

Figure 3.6 and the table 3.2 are the brain activations of TT task. From the figure and table, transverse temporal gyrus (BA41), medial frontal gyrus (BA6/37) and inferior parietal lobule (BA40) were activated this tasks as the same as the activations in parietal cortex which included IFG (BA9/44/45/47) and medial frontal gyrus (BA9/10/46). The activations in parietal cortex, superior parietal lobe (BA5/7) was associated with spatial attention task bilateral which play a role of spatial cognition. The activation of frontal eye field (BA5/7) was observed across this tasks that associate with a function of attention shift not only between visual information and tactile stimuli but also between intervals is long or short.

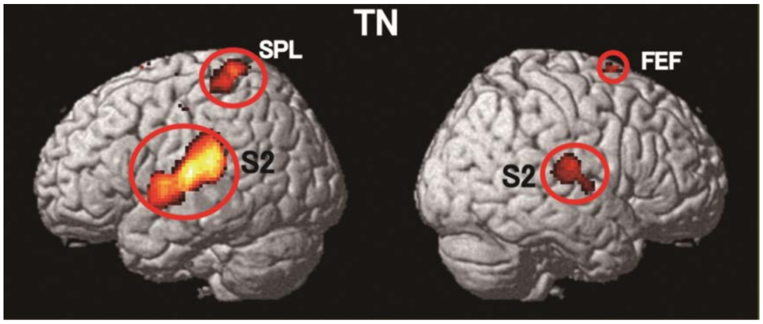

Figure 3.7 TN (Activations in tactile-visual attention p<0.001, cluster size=0)

Table 3.3 Brain areas activated during TN Task

cluster	*Z-score*	*p-value*	*anatomical region(BA)*	*x*	*y*	*z*
3948	6.69	<0.001	(L)Transverse Temporal Gyrus(41)	-45	-21	9
2048	5.22	<0.001	(R)Insula(40)	52	-21	15
90	4.23	<0.001	(R)Medial Frontal Gyrus(6)	15	3	63
1187	4.23	<0.001	(L)Superior Parietal Lobule(7)	-18	-46	61
117	3.82	<0.001	(L)Medial Frontal Gyrus(6)	-10	-21	53
377	3.65	<0.001	(L)Cingulate Gyrus(31)	-22	-48	25
149	3.62	<0.001	(R)Insula(13)	34	-40	19
114	3.38	<0.001	(R)Sub-Gyral(37)	52	-50	-5
228	3.32	<0.001	(L)Precentral Gyrus(6)	-32	-11	57
85	3.11	0.001	(R)Claustrum	31	3	10
45	2.98	0.001	(R)Parahippocampal Gyrus(28)	13	-21	-19
8	2.93	0.002	(L)Anterior Cingulate(25)	-1	10	-7
43	2.84	0.002	(R)Cingulate Gyrus(32)	17	10	32
23	2.8	0.003	(L)Parahippocampal Gyrus(19)	-29	-42	-6
54	2.73	0.003	(L)Cuneus(18)	-6	-100	5
26	2.59	0.005	(L)Lingual Gyrus(18)	-15	-91	-12
22	2.59	0.005	(L)Middle Frontal Gyrus(6)	-25	-5	40

All areas are significant at an uncorrected threshold of p<0.001. The approximate Brodmann areas are from MRIcro, and the x, y, and z coordinates are from SPM8. BA: brodmann area.

TN

As shown in figure 3.7, the brain activations of TN task, and Brain areas activated during TN Task is be showing in the table 3.3. From the figure and table, MFG (BA6), MTG (BA21) was activated in this task.

TT>TN

As shown in figure 3.8, the brain activations of TT-TN task, and Brain areas activated during this Task is be showing in the table 3.4. From the figure and table, just frontal eye field (FEF) and primary auditory cortex was activated in this task.

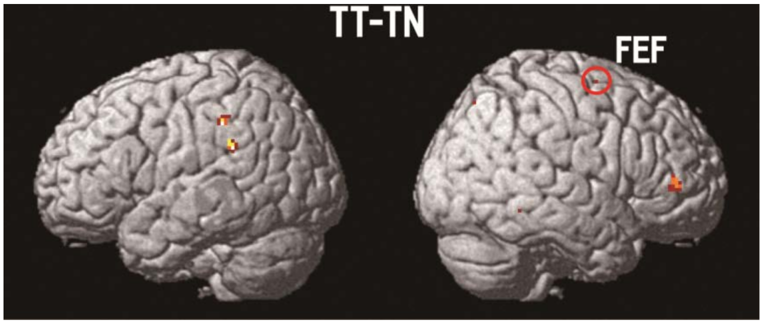

Figure 3.8 TT-TN (Activations in tactile-visual attention $p<0.05$, cluster size=0)

Table 3.4 Brain areas activated during TT-TN Task

cluster	Z-score	p-value	anatomical region(BA)	x	y	z
33	2.18	0.018	(R)Lentiform Nucleus	13	-7	-1
11	2.13	0.021	(R)Medial Frontal Gyrus(6)	17	-13	52
18	1.95	0.03	(R)Precuneus(7)	17	-71	40
19	1.93	0.031	(L)Superior Temporal Gyrus(13)	-54	-44	20
18	1.89	0.034	(L)Supramarginal Gyrus(40)	-40	-38	33
1	1.8	0.04	(L)Insula(13)	-32	20	4
1	1.74	0.045	(R)Fusiform Gyrus(37)	45	-48	-12
1	1.72	0.047	(L)Precuneus(7)	-11	-73	45

All areas are significant at an uncorrected threshold of p<0.05. The approximate Brodmann areas are from MRIcro, and the x, y, and z coordinates are from SPM8.

3.5 Discussion

3.5.1 Baseline: at rest or during the neutral task

The resting state as the baseline has been used in previous study (Spence et al., 2000), so that comparison is most compatible with previous reports using visual fixation controls (Macaluso and Driver, 2001). In addition, the neutral condition itself engages attention and orients it between two temporal intervals (Coull and Nobre, 1998). This study focused on activation without finger movement, so the subjects were asked to click the reaction key ten times during each rest. Authors compared the activation in each task with the rest. As a result, except for the visual cortices, significant activations occurred in somatosensory area and a small part of motor area in the TT and TN task (figure 3.6 and figure 3.7). Therefore, the control task was be used as the baseline to reveal the activation resulting from the interval is long or short. The activation in TT–TN in the frontal (BA4/8) and parietal (BA40) cortices was similar to that in previous studies.

3.5.2 Comparison of TT and TN

TT–TN cannot reveal bilateral activation in the parietal cortex (BA7/40) and the frontal cortex (BA6/8) (Coull and Nobre, 1998, Li et al., 2012). The right hemisphere bias for temporal orientation in TT task in this study is consistent with a previous report. Therefore, this study concludes that visual orienting attention uses a frontal–parietal neutral network for tactile temporal orienting attention without visual information (Corbetta and Shulman, 2002).

3.5.3 Similarity between TT and TN temporal attention

Previous study reported activation of frontal eye fields; superior parietal lobule; inferior parietal lobule and medial frontal gyrus in which the frontal cortex activated in temporal attention task (Tang et al., 2013). In this study, the activations in middle temporal gyrus, superior parietal lobule, frontal eye fields, were revealed both in TT and TN attention task. But in our study, No any areas were be found about the inferior parietal lobule in the TN task, just activated in the TT task. And in some studies, the contribution of temporo-parietal junction was also reported for tactile temporal attention (Macaluso et al., 2000). That in our study was not found any task. These results suppose that the frontal cortex and parietal lobe were associated with both TT and TN neural network.

Chapter 4 fMRI studies on relationship between the tactile spatial and temporal selective attention

Summary

This chapter focused on the relationship between the tactile spatial and temporal attention. Top-down attention to spatial and temporal cues has been thoroughly studied in the visual and auditory domains. However, the neural systems that are important for tactile top-down temporal attention (i.e., attention based on time interval cues) remain undefined. Thus, the differences in brain activity between directed attention to tactile spatial location and time intervals are unclear. Authors measured brain activity during a task in sixteen healthy volunteers with functional magnetic resonance imaging (fMRI). The task manipulated cued attention to spatial locations (S) and temporal intervals (T) in a factorial design. Symbolic central cues oriented the subjects toward S only (left or right), toward T only (600 ms or 1800 ms), or toward both S and T simultaneously (no information was provided regarding S or T). The behavioral data indicated that the benefits and costs of performance during temporal attention were similar to those established for tactile spatial attention. The brain-imaging data revealed a partial overlap between neural systems involved in the performance of spatial versus temporal orientation of tactile attention tasks.

Keywords – selective attention, tactile attention; space; time; orienting; temporal orienting

4.1 Introduction

M.I. Posner developed the paradigm for studying the orientation of visual spatial attention, which is widely used for experimentation (Posner, 1980). In this paradigm, a spatial cue (usually an arrow) is presented in the center of the visual field (pointing either left or right), which provides a spatial hint of the location of an upcoming target stimulus. Using this information, participants can predict the location of the upcoming target, and they voluntarily pay attention to that location. This voluntary visual spatial attention is usually referred to as visual top-down spatial attention.

The Posner task has now been extended to similar experiments for temporal (as opposed to spatial) attention (Coull and Nobre, 1998, Breier et al., 2003, Vossel et al., 2006). For example, two concentric circles (rather than an arrow) can be presented in the center of the field of vision, which is commonly used as a visual temporal cue for determining the neural correlates of visual top-down temporal attention. The circles provide a hint for the time interval duration (short or long) between the cue and target stimuli. Specifically, when the inner circle was presented, the target stimuli were presented after a short interval; when the outer circle was presented, the target stimuli was presented after a longer interval. According to the imaging results, the same frontoparietal network (FPN) involved in spatial attention is also involved in visual top-down temporal attention.

In another study (Li et al., 2012), the Posner task was expanded to auditory temporal spatial attention. Li and colleagues determined the neural correlates involved in auditory top-down temporal attention and compare them to with the neural correlates involved in auditory top-down spatial attention. These results demonstrated brain activity in the dorsal FPN, including the bilateral IPL and the bilateral FEF. Activity was also found in the PFC, including the right middle PFC (BA6), the bilateral DLPFC and the VLPFC. By contrast, the neural activity of tactile spatial temporal attention is also important, and there has been little or no research in this area. The relationship between the somatosensory cortex and tactile attention has been unclear until now.

The aim of this study was to reveal the brain regions involved in directing tactile attention toward a particular time point once the time interval and a spatial hint of the location has been estimated. Furthermore, this study investigated the anatomical overlap between the neural systems involved in tactile spatial and temporal attention, and developed a temporal analog of the spatial orientation of the attention task (Posner, 1980). In this task, the subjects were asked to respond as quickly as possible to visual targets appearing in peripheral locations. Immediately preceding the target was a visual cue that either correctly ("valid cue") or incorrectly ("invalid cue") predicted the location of the upcoming target. In the temporal attention task, we assessed whether stimuli that occurred at predictable cued intervals were detected more efficiently than those that did not occur at the predicted moment. Brain imaging fMRI visualized the neural systems involved in attention direction across time, which was compared directly with imaging obtained during spatial orienting.

4.2 Methods

4.2.1 Subjects

Twenty (10 females; mean age 24.5 years; range 21-32 years) volunteers with normal or corrected-to-normal vision from China Medical University participated in the experiment. All subjects reported that they were right-handed. None of the subjects had a history of neurological or psychiatric dysfunction or experience with neuropsychological experimentation. Written informed consent was obtained from each subject following a detailed explanation of the study. The protocol was approved by the ethics committee of the Shengjing Hospital of China Medical University. fMRI data from four subjects were abandoned because the head displacement was too large.

4.2.2 Stimuli

Visual and tactile stimuli were generated on a computer and presented to the participants via a custom-built, magnet-compatible visual-tactile system during MR scanning. To attenuate the acoustic noise that accompanies fMRI scanning, the participant wore shooting ear muffs. An ultrasonic motor (UN30ME-600; Canon Precision; Japan) was be used in this study, which drove a small brush with a rotation speed of 1.33 Hz. The motorized brush provided friction (tactile stimulus). The brush was made from non-rigid material to prevent pain or itching. The tactile stimulus was presented in the palm of the subject's left hand (figure 4.1). Through preliminary experiments, the subjects were able to very specifically identify the position of the stimulus. (In simple tactile stimulation experiments, the subjects determined left and right with almost 100% accuracy). Presentation 0.61 (http://www.neurobs.com/) was used to generate tactile and visual stimuli.

4.2.3 Procedure

The task manipulated subjects' expectations of where or when the target stimuli would appear within their left hand. A 2*2 factorial design was used, in which the experimental factors were spatial cueing (S) and temporal cueing (T). Across runs, there were three types of cues that predicted the following: target location only (S), target onset time only (T), and neutral cues that predicted neither target location nor onset time (N). As shown in figure 4.1, four separate tasks were used during these studies. Visual cues of spatial or temporal stimuli were used to direct the subject's attention to one of two possible target locations (left or right) during the spatial tasks or one of two time intervals (600 ms or 1800 ms) during the temporal tasks.

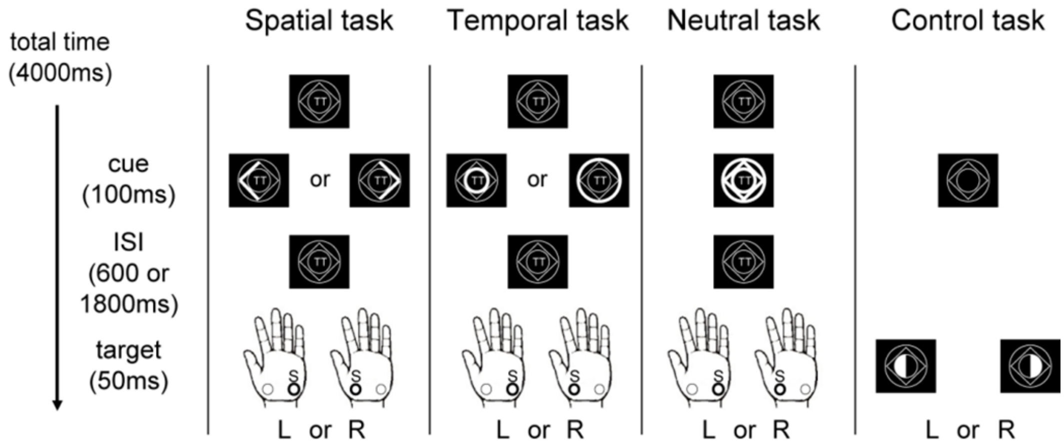

Figure 4.1 Experimental paradigm and stimuli. Central cues used during the experimental tasks. The spatial cue was used during the spatial attention tasks; the right or left half of the cube was lit to provide the

subjects with information concerning the target location (i.e., right or left). The temporal cue was used during the temporal attention tasks. When the target appeared within a short cue–target interval (600 ms), the inner circle was lit; when the target appeared after a long cue–target interval (1800 ms), the outer circle was lit. The neutral cue was used during the control tasks and provided neither spatial nor temporal information. A double ‘T’ in the center of the cue indicated a visual experiment. All three types of cues were presented for 100 ms, and the duration of target presentation was 50 ms. Either the left half or the right half of the inner circle turned white during the control task, and participants would press the reaction key. RT was not required.

The visual cues were displayed on a computer monitor. Specifically, a rhombus located between two concentric circles was displayed in the center of the monitor as part of the dimmed computer screen background. Visual cues were presented for 100 ms. Spatial attention task cues consisted of lighting the left half or the right half of the central rhombus and appearing as an arrow (pointing left or right). For the temporal attention tasks, the cue consisted of concentric, small and large circles, which lit up and were followed with either a long or short time-interval prior to the tactile event. For the neutral task, all three geometric shapes (the rhombus, inner circle, and outer circle) lit up as a non-informative indication of an upcoming stimulus. During all three attention tasks, the interval length between the presentation of the cue and the tactile target event was either 600 or 1,800 ms, which occurred with equal probability. The tactile target stimulus was friction provided by a small rotating brush that lasted for 50 ms following the interval after cue-stimulus presentation. The participants were instructed to press response keys corresponding to either a right (by pressing the ‘‘right’’ key using the middle finger of their right hand) or a left audio stimulus (by pressing the ‘‘left’’ key using the forefinger of their right hand) during all three attention tasks. Their reaction times were recorded (RTs) (the length of time from the onset of the audio target event to the time a key was pressed). The reaction accuracy was also recorded. The participants performed thirty trials under each of the three attention conditions. A control task served as a baseline to cancel out activation caused by detection-related processes evoked by key pressing. During the control task, the left half or the right half of the inner circle was lit (with equal probability), and the participants were asked to press the reaction key once. Control tasks were carried out 30 times in total. All trials (attention tasks and control tasks) were 4000 ms in duration. The experimental details were explained to each participant, and a practice/training course was performed before MR scanning. Authors obtained brain activation from participants who completed the training task with greater than 90% accuracy. A block design was used for these experiments, in which the three tasks were randomized into blocks of ten trials, which were carried out three times for a total of thirty trials. The experiment lasted a total of eight minutes. The participants were instructed to respond as quickly as possible to the target stimulus.

4.2.4 MRI Acquisition

A Philips 3 Tesla Magnetism Vision whole-body MRI system was used to measure brain activation with a head coil. The imaging area consisted of 36 functional gradient-echo planar imaging (EPI) axial slices (voxel size 1.8×1.8×4 mm, TR=4000 ms, TE=50 ms, FA=90°, 132×130 matrix) that were used to obtain T2*-weighted fMRI images in the axial plane. The EPI images encompassed the entire cortex. 124 functional volumes were obtained for each task.

4.2.5 Behavioral Data Analysis

The reaction times and accuracy recorded during the fMRI experiment were used as behavioral data after discarding the error trials from each subject. All subjects responded with greater than 90% accuracy. Then, the paired t-test was used to compare the TS, TT and TN tasks (SPSS 16.0).

4.2.6 fMRI data analysis

For the functional image analyses, MRIcro (http://www.mccausl- andcenter.sc.edu/CRNL/) was used to convert the DICOM files to NIFTI files firstly. The first four functional volumes were excluded from each run. Subsequently, the functional data were analyzed with statistical parametric mapping (SPM8; Wellcome Department of Cognitive Neurology, London, UK; http://www.fil.ion.ucl.ac.uk/spm) from MATLAB (The Math-Works Inc., Natick, MA). The functional images from each run were realigned, and the first scan was used as a reference (Li et al., 2012). Realigned images were spatially normalized using the standard EPI template from the

Montreal Neurological Institute (MNI) reference brain coordinates. Finally, these spatially normalized, functional images were smoothed with an isotopic Gaussian kernel of 8 mm. Statistical analyses were performed in two stages with a mixed-effects model. During the first level of analysis, the BOLD response was modeled as the neural activity corresponding to a canonical hemodynamic response function (HRF), which yielded a repressor in a general linear model (GLM) for each task (spatial task vs. control task, temporal task vs. control task and neutral task vs. control task). The contrast (con) images from the first level of analysis from all 16 subjects were subsequently used for the second level group analysis. First, a conjunction analysis was performed that means to test for common activation among TS, TT and TN tasks (TS+TT+TN). To identify the areas of whole-brain activation during the TS vs. TT tasks (TS-TT) and TT vs. TS tasks (TT-TS), a one-sample t-test analysis was performed for the con images.

4.3 Results

4.3.1 Behavioral results

The behavioral data were derived during the fMRI experiments. The RTs for each task were computed for all 16 subjects. RTs during the spatial task, temporal task and neutral task are summarized in table 4.1. The paired t-test was used to compare the TS task and TN task, the TT task and TN task, and the TS and TT task. However, there was no significant difference between the two tasks.

Table 4.1 Reaction times (ms) and accuracy (%) for the TS, TT and TN tasks. The standard errors are shown in parentheses.

	TS	TT	TN
RT	658.3(38.9)	661.2(37.0)	666.1(37.2)
Accuracy	95.6(1.5)	96.7(1.4)	95.6(1.8)

4.3.2 fMRI results

Next, the areas of activation were investigated which during tactile target detection with respect to the three attentional cues. And investigated how these cues modulate similarities and differences of brain activation.

Activation during the Three Attention Tasks

Brain activation during the spatial, temporal and neutral tasks is shown in figure 4.2 and is summarized in table 4.2. The rendered activation map in figure was generated with an uncorrected threshold of $p<0.005$. The right hemisphere SFG/MFG was activated during all 3 conditions, and other similarities were observed between the three tasks. These results noted that the bilateral SII was significantly activated during all tasks. However, besides bilateral SII, there was no activation in the parietal lobe SPL/IPL of the brain.

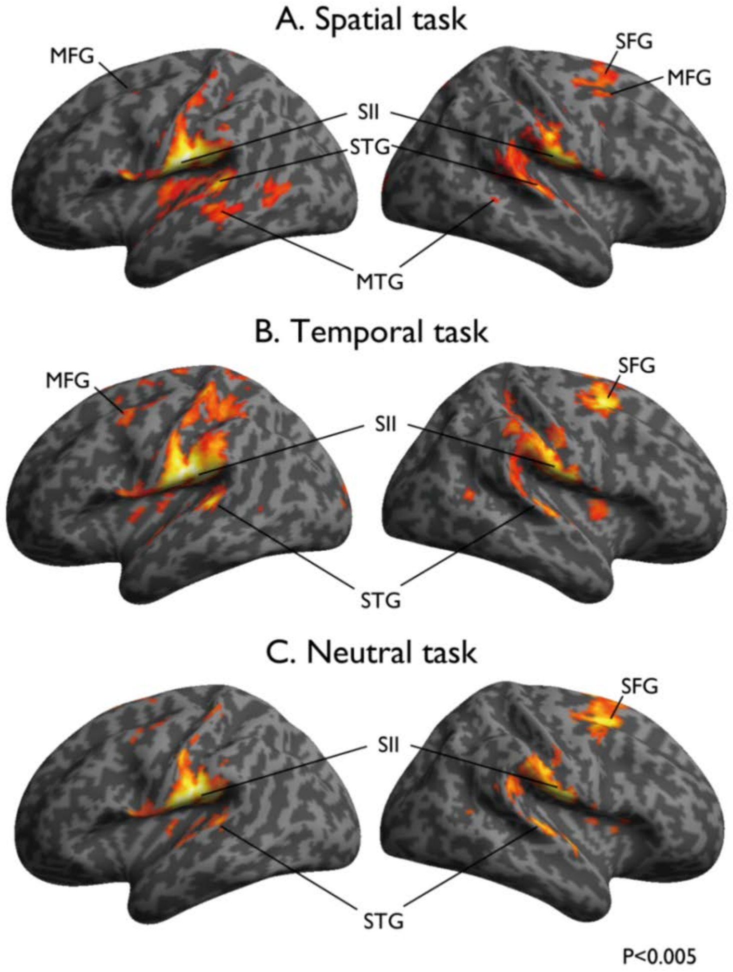

Figure 4.2 SPM results from the spatial task vs. control task (A), temporal task vs. control task (B), neutral task vs. control task (C). Significance was uncorrected, $p<0.005$.

Table 4.2 Activation related to attentional conditions. Significant activation was determined with an uncorrected threshold, p<0.005. The approximate anatomical regions and Brodmann areas are from the Talairach atlas, and the x, y, and z coordinates are from the SPM8. Abbreviations are as follows: MFG - Middle Frontal Lobe, SFG - Superior Frontal Gyrus, IFG - Inferior Frontal Gyrus, STG - Superior Temporal Gyrus, MTG - Middle Temporal Gyrus, R - right hemisphere, and L - left hemisphere

Lobe	*task*	*cluster*	*Z-score*	*anatomical region*	*x*	*y*	*z*	*BA*
Frontal	TS	703	4.81	R-SFG	18	4	70	*
		107	3.04	L-MFG	-4	8	52	40
		5	2.74	R-Precentral	44	0	34	6
		1	2.66	R-MFG	46	4	48	40
	TT	2052	5.59	R-MFG	28	2	50	6
		380	3.77	L-MFG	-34	4	50	43
		59	3.34	L-SFG	-10	-14	64	41
	TN	2094	5.55	R-SFG	18	4	70	6
		204	3.29	L-Precentral	-34	-6	58	41
		55	3.19	L-SFG	-14	0	68	39
Parietal	TS	4329	5.76	L-Postcentral	-54	-16	16	37
		2867	5.33	R-Postcentral	62	-16	14	7
		145	3.37	L-Supramarginal	-34	-42	38	7
		64	3.23	R-Precuneus	12	-66	58	6
		27	3.06	L-Precuneus	-10	-62	44	37
	TT	5473	5.45	L-Postcentral	-54	-18	18	6
		16	3	R-Precuneus	10	-61	49	6
		6	2.75	R-Postcentral	35	-24	38	7
	TN	94	3.2	L-Postcentral	-38	-32	62	6
		2	2.66	L-Precuneus	-12	-56	58	3
		1	2.59	L-SPL	-18	-46	68	6
Temporal	TS	239	3.24	L-MTG	-56	-68	6	6
		11	2.82	R-ITG	62	-60	-4	22
		2	2.73	R-STG	66	-50	14	22
		1	2.67	L-STG	-60	4	-10	6
	TT	2550	4.77	R-TTG	62	-14	12	*
		6	2.83	R-Caudate	40	-26	-8	*
		1	2.78	L-Sub-Gyral	-34	-48	12	2
		1	2.59	L-ITG	-44	-54	2	37
	TN	1907	5.03	R-TTG	62	-14	12	7
		35	3.37	R-MTG	42	-50	6	7

Common Significant Activation during the Three Attention Tasks

To determine the common areas of activation during the three tasks, the activated areas were compared which in conjunction with the spatial, temporal and neutral attention tasks. The results are shown in figure 4.3 and summarized in table 4.3. The bilateral SII, STG, and the right S/MFG were significantly activated. The other areas are summarized in table 4.3.

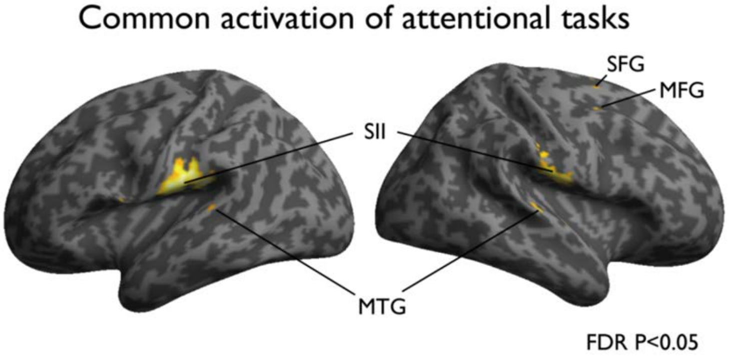

Figure 4.3 Common activations during attentional tasks. The activation maps show the common patterns of activation between the three conditions (spatial, temporal and neutral). Significance was FDR corrected, $p<0.05$.

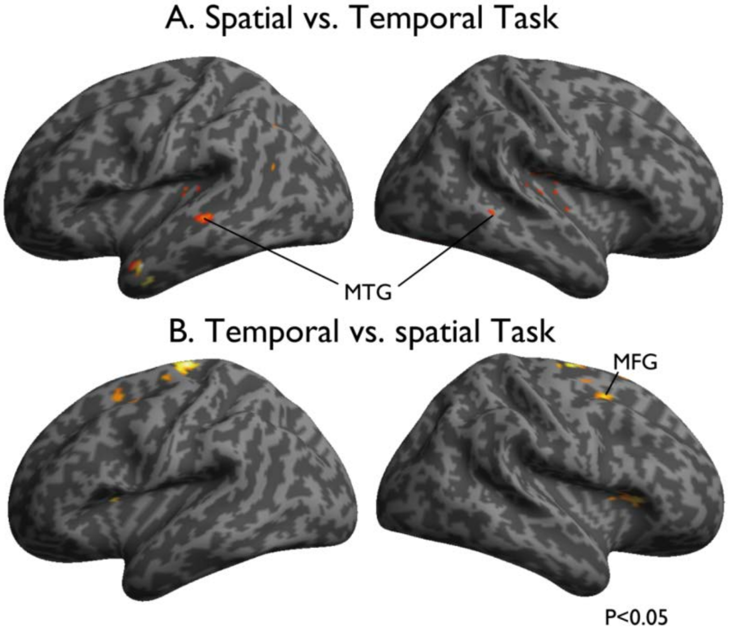

Figure 4.4 Activations difference between (A) spatial task and temporal task (B) temporal task and spatial task. Significant activation was an uncorrected threshold, $p<0.05$.

Table 4.3 Activation related to compared attentional conditions. Significant activation was determined with an uncorrected threshold, $p<0.05$ in compared conditions. However, the common pattern of activation between the three tasks was established with an FDR corrected threshold, $p<0.05$. The approximate anatomical regions and Brodmann areas are from the Talairach atlas, and the x, y, and z coordinates are from the SPM8. Abbreviations are as follows: MFG - Middle Frontal Lobe, SFG - Superior Frontal Gyrus, IFG - Inferior Frontal Gyrus, STG - Superior Temporal Gyrus, MTG - Middle Temporal Gyrus, R - right hemisphere, and L - left hemisphere.

lobe	*task*	*cluster*	*Z-score*	*anatomical region*	*x*	*y*	*z*	*BA*
Frontal	Common	48	4.81	R-SFG	18	4	70	6
		65	4.15	R-MFG	30	0	52	6
		5	3.58	L-Precentral	-60	-16	46	6
		1	3.45	R-Sub-Gyral	22	8	58	6
	TT-TS	225	2.93	L-Precentral	-12	-20	64	6
		81	2.5	R-MFG	20	-10	62	6
		8	1.89	R-SFG	14	14	58	6
Parietal	Common	824	5.06	L-Postcentral	-66	-20	16	43
		400	4.13	R-Postcentral	56	-20	22	40
	TS-TT	67	2.99	L-Precuneus	-10	-60	38	7
		24	2.19	L-Angular	-42	-62	44	39
		1	1.77	R-Precuneus	26	-78	54	7
		2	1.76	R-Postcentral	20	-36	78	3
	TT-TS	3	1.7	L-Precuneus	-8	-52	60	7
Temporal	Common	400	4.77	R-MTG	62	-14	12	41
	TS-TT	8	2.26	L-STG	-38	-60	20	22
		114	2.16	L-MTG	-50	-32	-6	21
		68	2.08	R-MTG	62	-40	4	22
		1	1.71	L-Sub-Gyral	-36	-6	-16	21
		2	1.69	R-STG	44	-36	10	41

Significant Activation Observed between Spatial Tasks and Temporal Tasks

To determine the differences between tasks, this study compared the activated areas during spatial and temporal tasks (spatial task – temporal task in brain regions where activation during spatial attention was significant, $p<0.05$ uncorrected; temporal task – spatial task, in brain regions where activation during spatial attention was significant, $p<0.05$ uncorrected.) The results are shown in figure 4.4 and summarized in table 4.3. In the spatial vs. temporal task, only the bilateral MTG were activated, whereas in the temporal vs. spatial task, only the right MFG was significantly activated.

4.4 Discussion

This study used a cue-target paradigm commonly employed in top-down attention studies, and authors discussed the reliability of whole brain activation associated with tactile tasks. This study examined the function of SII because there are few reports concerning the role of SII in modulating tactile temporal attention. Our findings clarify the role of SII in top-down spatial attention, as well as the involvement of a number of other previously reported brain regions (Sathian and Burton, 1991, Craig and Evans, 1995, Dalton et al., 2009, van Ede et al., 2011). Furthermore, authors found similar brain activation between spatial, temporal and neutral tasks, and also found differences between spatial and temporal task brain activation.

4.4.1 Common neural network for Spatial and Temporal Attention

Recent fMRI studies focused on the spatial orienting of visual attention (Frohlich, 1994, Coull and Nobre, 1998, Vossel et al., 2006) concluded that the amount of top-down information provided by predictive cues influences the neural correlates of reorienting the visuospatial attention by modulating activation of the right fronto-parietal attentional network. Subsequent studies have focused on the temporal orienting of visual attention (Coull et al., 2000, Vossel et al., 2006). These studies suggested that distinct brain areas are involved in redirecting attention based upon sensory events (bottom-up, exogenous shifts) and are based upon cognitive expectations (top-down, endogenous shifts). In our study, the bilateral STG was activated by spatial, temporal and neutral tasks compared to the control baseline, which suggests the existence of a ubiquitous system for allocating attentional resources, independent of stimulus dimension. However, when the neutral cue was used as a baseline for determining the overlap between the two attentional dimensions, very few brain areas were significantly different. This result indicates that the selective attention orientation in time or space utilizes the same brain areas (Coull and Nobre, 1998).

4.4.2 SII in Spatial and Temporal Attention

Functional neuroimaging studies have found SII activation in response to light touch, pain, visceral sensation, and tactile attention (Recanzone et al., 1992, Hsiao et al., 1993, Backes et al., 2000, Eimer and van Velzen, 2005, Eickhoff et al., 2006). This study focused on activation without finger movement. Thus, the subjects were asked to click the reaction key ten times during each control task. The activations were been compared which in each spatial, temporal and neutral task with the activation observed during the control task. As a result, except for the visual cortices, which showed enhanced activity in the hand area of SII contralateral to the focus of attention, significant activations occurred in the somatosensory cortex and a small portion of the motor area during all three tasks. A previous study (van Ede et al., 2011) recorded magneto encephalography while human participants performed a tactile discrimination task. They cued participants to the left or the right hand, after which a tactile stimulus was presented at one of several fixed temporal delays. Their results suggested that the anticipation of a tactile event involves a spatially and temporally specific modulation of ongoing sensorimotor alpha- and beta-band oscillations. The modulation of ongoing oscillations within the sensory cortex may therefore constitute a unifying mechanism underlying both spatial and temporal attention orientation. Thus, SII, which has long been assumed to be sensitive only to the physical attributes of somatosensory stimuli (such as frequency or intensity), also contributes to the processing of spatial attention in addition to temporal attention. This finding underlines the role of SII in the integration of somatosensory processes and cognitive functions (Eimer and van Velzen, 2005).

4.4.3 STG in the tactile crossmodal attention

This study also found that the bilateral STG was activated during all three tasks, which is consistent with some previous studies on tactile cross-modal attention (Macaluso et al., 2000, Macaluso et al., 2003). The bilateral STG has been associated with the selectivity of auditory stimuli involved in spatial or feature aspects (Eimer and van Velzen, 2005, Li et al., 2012).

Moreover, previous studies have also found that the bilateral STG was significantly activated during spatial and neutral attention tasks. The MTG/STG is part of the activation pattern during somatosensory discrimination tasks with the recognition of shapes and textures, such as roughness. In this study, authors replaced the target modality but revealed the same activation pattern. Accordingly, authors propose that the STG may be more closely associated with cross-modal attention than with the basis of cognition.

4.5 Conclusion

In conclusion, this study measured brain activation during voluntary tactile spatial and temporal attention. The results revealed that the same network (fronto-parietal network) was functional during spatial and temporal attention to touch. Furthermore, this study suggests that secondary somatosensory areas not only contribute to top-down tactile spatial attention but also contribute to top-down tactile temporal attention.

Chapter 5 Inhibition of Tactile Information on Visual Spatial Attention: An fMRI Study

Summary

Visual orienting attention is well researched by using a visual cue. But in the tactile orienting of the visual, Due to technical reasons, the explanations of the tactile information effect of visual attention is no clear, and just have few researches devote to this part. Visual cue in the top-down attention mechanism was investigated that it could effectively improve the target cognition reaction quality. Recent brain studies showed that the right dorsolateral prefrontal cortex (rDLPFC) played an important role to keep the task-relevant information and task rule during tasks.

This study used a top-down attention paradigm in which a visual cue directs the attention of participants to both visual and tactile target stimulus in a spatial (attention was directed to unilateral target distinctly) in visual spatial attention task and tactile-visual spatial attention task. And the attention was manipulated to visual spatial orienting by a visual cue, tactile target stimulus was told to be ignored. Subjects were also scanned during a resting baseline condition in which subjects clicked the reaction key ten times. The reaction time for spatial location attention is faster than that with the tactile stimulus.

Behavioral results of reaction time not have any significant difference between the two tasks. But the RTs of the VS task is faster than VtS task. So authors thought that the tactile information may affect the visual spatial attention neural network.Brain-imaging data showed that IPL (inferior parietal lobe) and MFG (middle frontal gyrus) were activated in the visual spatial attention task and the activation was enhanced during the task with the tactile stimulus.

Key word: fMRI, tactile-visual spatial attention, cue stimuli

5.1 Introduction

Attention is the ability to attend to some things while ignoring others (Posner, 1980). About attention that the peoples do not have a better definition of attention than William James had a century ago. “Everyone knows what attention is. It is the taking possessing of the mind in clear and vivid form of what seen several simultaneous objects of trains of thought (James, 1976).”

The peoples often divide attention into two broad categories, involuntary attention and voluntary attention. Involuntary attention, a bottom-up, stimulus-driven, influence, is describes our attention which was captured by a sensory event. Voluntary attention, a top-down, goal-directed influence, is our planned to attend something. This study was focus on the mechanisms of Voluntary attention. In human information-processing systems, voluntary attention plays an important role in selecting and integrating information. Selective attention suggested that individuals have a tendency to process information from only one part of the environment with the exclusion of other parts. For example, the cocktail party effect is a typical selective attention.

In the visual attention, Posner designed a cue-target task paradigm of the visual orienting of attention. The left and right arrow implies that the target direction will be proposed (Posner, 1980). Some studies of auditory attention, they extended posner task, the original visual target is extended to the auditory target and audio-visual target of the experiments, and successfully found the effects of auditory information in the visual spatial attention (Li et al., 2012). However, the tactile effects in the visual attention were still poorly understood. Moreover, attention to distraction has not been researched sufficiently to compare that visual attention with the visual-tactile target and only visual target.

This study analyzed visual spatial attention using both visual and tactile stimuli. To evaluate these processes behaviorally, authors conducted psychological experiments in which be measured the reaction times (RTs) for each task. To reveal the neuronal networks related to these attention systems, authors measured the hemodynamic changes using fMRI.

5.2 Materials

5.2.1 Subjects

The subjects were 16 healthy right-handed students from China Medical University, and age is 21–26 years. Male eight and female is eight. Informed consent was obtained from each participant following a detailed explanation of the study. Signed the fMRI experiment letter of consent and has accepted the health check-up.

5.2.2 Experimental system

During fMRI scanning, visual stimuli were generated on a personal computer and presented to the subjects via a projector-screen–mirror system. Subjects lying MRI put a coil in the head, at the same time fixed a mirror on the coil, subjects from the mirror can clear the observed visual information on the paper screen. Visual information from PC through to a diamagnetic projector, projected onto a paper screen. Tactile stimulation been fixed in the left hand of subjects, and in the right hand, have a response key, when the target was appeared in the left direction, then they push the left key or right, like the mouse.

5.2.3 Experimental stimuli

The visual stimulus consisted of a target (“X”, like the left of the figure 5.1) with a diameter of 1° that was shown for 50 ms, 7° to the right or left of the central point on a screen located 130 cm in front of the subjects. Visual experiments included space tasks (S), and control tasks. The tasks were designed in a factorial format, and are shown in table 5.1.

The tactile stimuli in the left hand of the subjects were prompted. An ultrasonic motor (Made in canon company) was be used in this study, motor rotation frequency is 1.33Hz. So the subjects can clearly determine the direction of stimulus and the feeling of an appropriate stimulus, not pain. (Showing in figure 5.1, the right of the picture)

Table 5.1 Experimental tasks

	Visual	Tactile-Visual (with visual distraction)
Spatial	TS	VtS

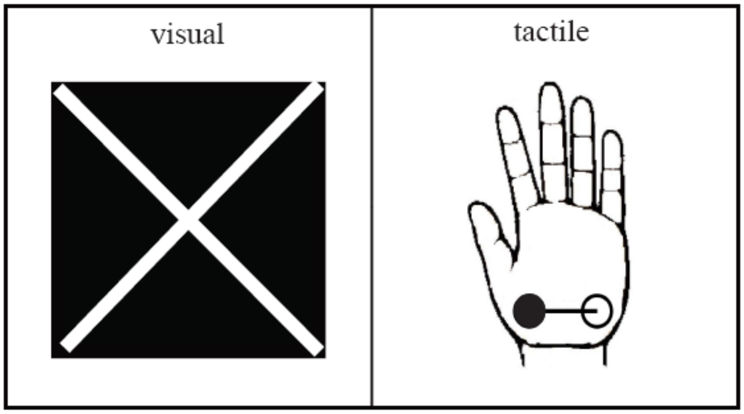

Figure 5.1 Target stimuli of the experimental

Cue stimuli were used to direct the subjects' attention to a particular target location or onset time. The spatial (space) cue (left or right arrow) directed the subjects' attention to the left or right; showing in the figure 5.2.

The RTs were recorded that is the time from the presentation of a stimulus to a response indicated by a reaction key. The subjects responded to a right stimulus using the middle finger of their right hand, and the left stimulus with the forefinger of their right hand. The subjects performed 30 trials under each condition. There are two sessions, one is only visual target stimuli and another is tactile and visual target stimuli. The visual information was presented using a projector as shown in the paper screen. The subject lied on MRI equipment viewed the visual stimuli though the half mirror and the tactile stimuli though the Ultrasonic Motor. In order to remove the references from the response the button used the right-hand.

The Rest Task was designed also (figure.5.3). In the rest task, there are no any spatial cue factors, when the half (left or right) of the small circle was lie, subjects had as faster and accurate as click the response key. The effects of clicking the response key were removed by subtracting the brain activations elicited by clicking the response key from the results of attention tasks.

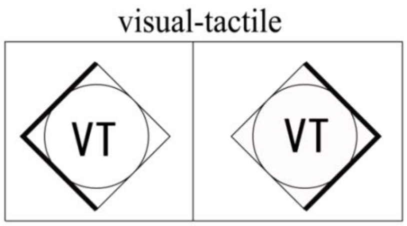

Figure 5.2 Cue stimuli of the experimental. Right or left half of the arrow was lit to give the subjects information on the target location (right or left). 'VT' means is Visual tactile task, hole of the experiment, the subjects were asked to monitor the Small circle the middle of the words "VT".

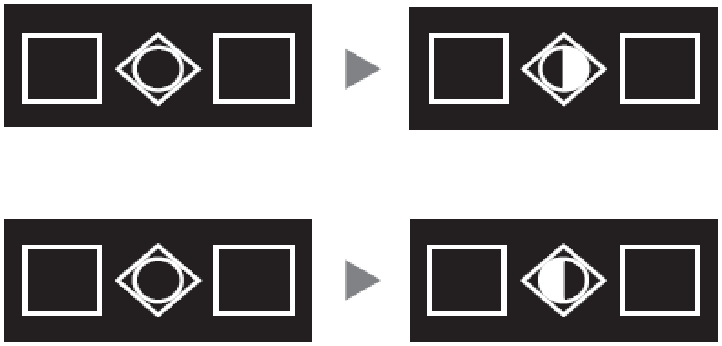

Figure 5.3 Rest task

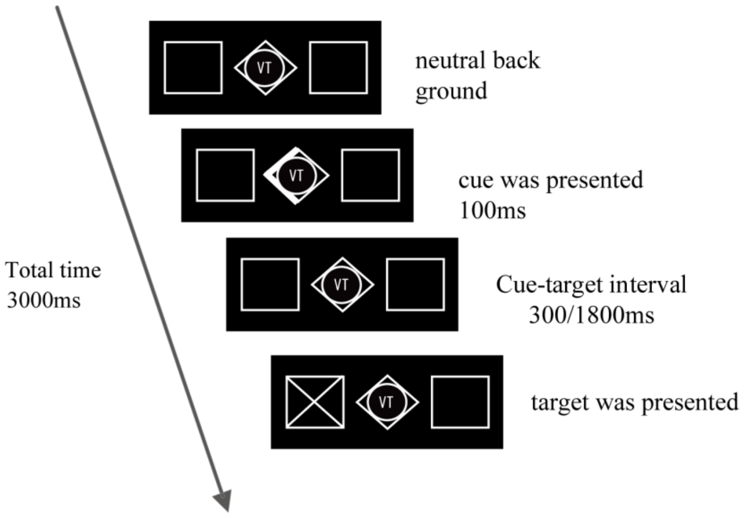

Figure 5.4 Example of one trial. In this example, the visual spatial cue indicates spatial information, but gives no information about the cue–target interval. The cue was lit for 100 ms, and after the cue–target

interval (300 or 1800 ms), the visual or visual-tactile target was illuminated for 50 ms.

5.3 Methods

5.3.1 fMRI scanning

A Philips 3 Tesla Magnetom Vision whole-body MRI system was used to measure the brain activation with a head coil(From ShengJing hospital of China Medical University, No.36 Sanhao Street, Heping District Shenyang, Liaoning Zip code:100004). The imaging area consisted of 32 functional gradient-echo planar imaging (EPI) axial slices (voxel size 3×3×3mm, TR=4000ms, TE=50ms, FA=90°, 128×128 matrix) that were used to obtain T1*-weighted fMRI images in the axial plane. The EPI imaged the entire cortex. obtained 124 functional volumes were obtained for each task. Before the EPI scan, a T1-weighted volume was acquired for anatomical alignment (TR=3000ms, TE=100ms, FA=90°, 256×256 matrix, voxel size=0.75×0.75×4mm). The T2 image acquisition used the same slices as the functional image acquisition.

5.3.2 Data analysis

Reaction times were used as behavioral data. The reaction time data during the fMRI experiment were analyzed using repeated measures analysis of variance (ANOVA; SPSS 16.0j for Windows). For each task, 60 RTs (reaction times) were acquired from each subject. Authors used the average of the RT data for the paired-samples t test, except for error trials. Therefore, there are sixteen RTs (reaction times) data for each task. Two tasks were presented in this experiment, and the visual spatial and visual-tactile spatial tasks were compared separately.

For the functional images, MRIcro was be used to change the DICOM files into MRIimg and MRIhdr files firstly. In each task, the functional images of the first four volumes were not used for the data analysis. The DICOM files from the 5th through 124th scan were exported as MRIima and MRIhdr files. In addition, the DICOM files for the T2 images were exported as MRIimg and MRIhdr files.

The functional images were analyzed using statistical parametric mapping (SPM8, Wellcome

Department of Cognitive Neurology, and London, UK). The functional images from each task were realigned using the first scan as a reference. T1-weighted anatomical images were coregistered to the first scan in the functional images. Then, the coregistered T1-weighted anatomical images were normalized to standard T1 template images as defined by the Montreal Neurological Institute. Finally, these spatially normalized functional images were smoothed using an isotopic Gaussian kernel of 8 mm.

Statistical analyses sought to identify the brain areas shared by visual spatial attention (VS) and visual-tactile spatial attention (TvS), as well as the brain areas selectively engaged by each task. To eliminate the brain activation caused by finger motion, the subjects need to click the reaction key ten times during every rest.

5.4 Results

5.4.1 Behavioral result

Behavioral data were derived from the performance during the fMRI experiment. The reaction time for each task (shown in figure 5.5) was computed from the data for the 16 subjects (the average of 16×27=432 trials).

The paired t-test was sued to analysis the behavioral results. The comparison of RTs across tactile tasks not showed any significant difference between VS task; VtS task and control task (figure 5.5). But in this result, RTs of VS task is the fastest (RT: 473.5 ms; TE: 107.6) than other two tasks. About the accuracy, all of the subjects were able to have the corresponding response in the right direction; the accuracy was generally above 90%, not show any picture about it.

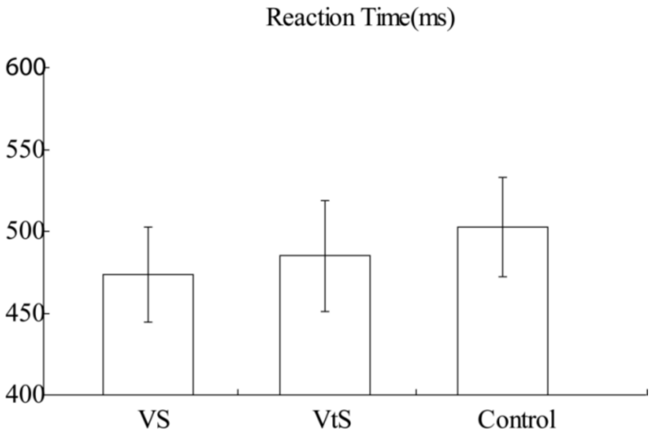

Figure 5.5 Result of the reaction time

5.4.2 fMRI results

The rendered results were made under a threshold of $p<0.05$ and a cluster size with 0. Tables show the activation area corresponding with the figure. This study focused on visual spatial attention, and visual spatial attention with tactile distraction.

VS

In the functional images about the VS task (figure 5.6), significant activation occurred in the left/right Frontal Lobe and the Parietal Lobe when the visual spatial attention was compared with baseline like previous studies (Coull and Nobre, 1998, Li et al., 2012, Tang et al., 2013). From the figure can clearly see that the activations of left hemisphere are stronger than the right hemisphere. Because there are a lot of areas are activated, so in this article, not one by one to the list produced, lists will in contrast with each other results be produce.

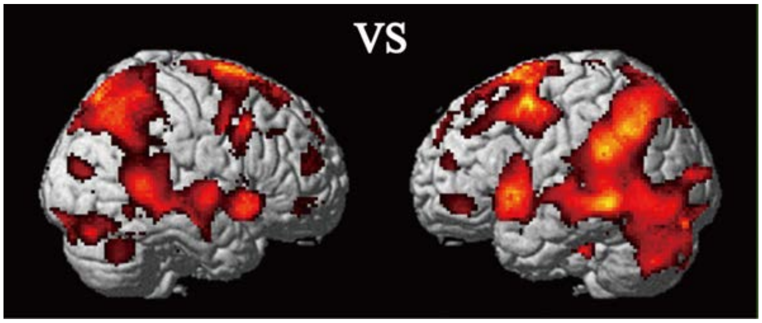

Figure 5.6 VS (Activations in visual spatial attention $p<0.05$, cluster size=0)

VtS

In the functional images about the VtS task (figure 5.7), as same as figure 5.6, significant activation occurred in the left/right Frontal Lobe and the Parietal Lobe when the visual spatial attention was compared with baseline like previous studies too (Tang et al., 2013). From the figure can clearly see that the activations of left hemisphere are stronger than the right hemisphere.

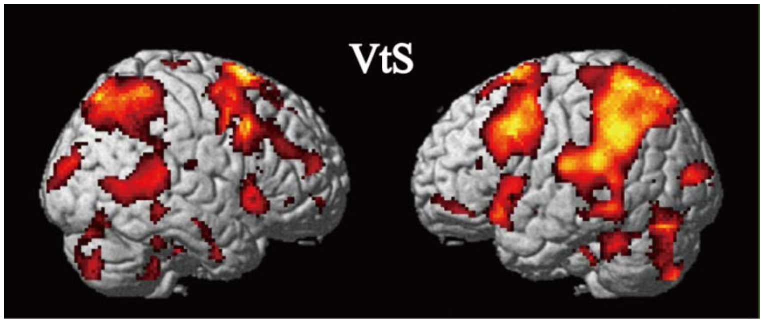

Figure 5.7 VtS (Activations in visual-tactile spatial attention p<0.05, cluster size=0)

VS >VtS

In this comparison, significant activation occurred in the bilateral parietal cortex. In a previous study, the Premotor cortex (Coull and Nobre, 1998) had significant activation bilaterally when the visual spatial task was compared with visual-tactile spatial task. And the left/right Frontal eye fields were found in this result. Left/right Superior temporal gyrus; Medial frontal gyrus were activated in this comparison, support of the previous works.

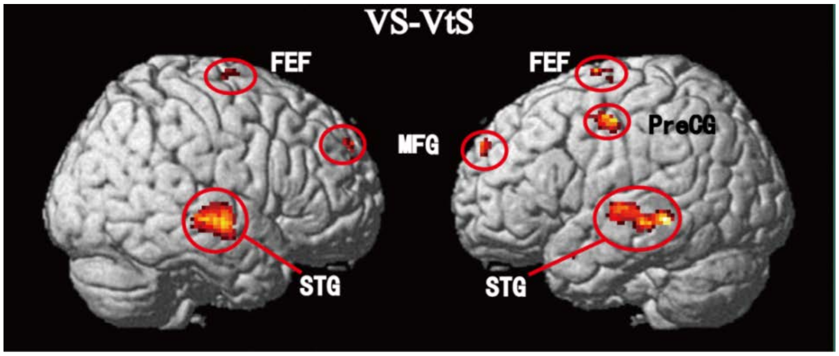

Figure 5.8 VS-VtS (Activations inVS versus VtS p<0.05, cluster size=200)

Table 5.2 Brain areas activated during VS-VtS Task

cluster	*Z-score*	*p-value*	*x*	*y*	*z*	*anatomical region(BA)*
719	3.53	<0.0001	0	30	14	L-Anterior Cingulate(24)
417	2.85	0.002	-50	-22	0	L-STG(21)
235	2.74	0.003	-38	-14	46	L-Precentral Gyrus(4)
812	2.69	0.004	-2	-6	26	L-Cingulate Gyrus(24)
337	2.46	0.007	-8	-16	66	L-SFG(6)
45	2.24	0.012	44	-70	40	R-Precuneus(19)
13	2.03	0.021	-16	24	50	L-SFG(6)
1	1.96	0.025	42	-40	-14	R-Fusiform Gyrus(37)
51	1.96	0.025	40	10	-10	R-Extra-Nuclear(13)
19	1.91	0.028	16	-94	-16	R-Lingual Gyrus(17)
5	1.81	0.035	-62	10	14	L-Precentral Gyrus(44)
11	1.77	0.038	-40	-84	-10	L-IOG(18)
2	1.7	0.044	4	4	48	R-MFG(6)

All areas are significant at an uncorrected threshold of p<0.05. K=200 voxels. The approximate Brodmann areas are from MRIcro, and the x, y, and z coordinates are from SPM8. BA: brodmann area. SPL: superior parietal lobe; MFG: middle frontal gyrus; IFG: inferior frontal gyrus.

As shown in figure 5.8, the brain activations of VS-VtS task, and Brain areas activated during this Task is be showing in the table 5.3. From the figure and table, Superior Frontal Gyrus (BA6), Middle Frontal Gyrus (BA6) and Inferior Parietal Lobule (BA40) were activated this tasks as the same as the activations in frontal cortex which included IFG (BA9/44/45/47) and MFG (BA9/10). The activations in parietal cortex, Superior Parietal Lobe (BA7) was associated with spatial attention task bilateral which play a role of spatial cognition. The activation of Precuneus (BA5/7) was observed across this tasks that associate with a function of attention shift not only between visual and tactile stimuli but also between spatial left and right.

VtS>VS

As shown in figure 5.9, the brain activations of VtS-VS task, and Brain areas activated during this task is be showing in the table 5.3. From the figure, Just Supplementary motor area and

Primary somatosensory cortex and inferior frontal gyrus were activated in the left hemisphere. No any areas in right hemisphere were activated.

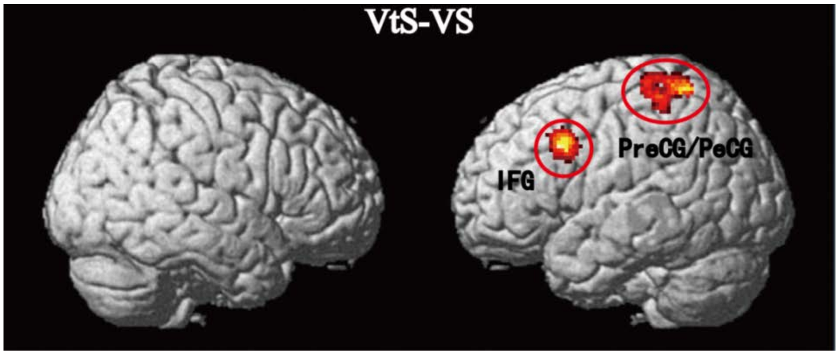

Figure 5.9 VtS-VS (Activations inVtS versus VS p<0.05, cluster size=250)

Table 5 3 Brain areas activated during VtS-VS Task

cluster	*Z-score*	*p-value*	*x*	*y*	*z*	*anatomical region(BA)*
152	2.54	0.005	22	-28	52	R-Postcentral Gyrus(3)
23	2.51	0.006	-30	32	14	L-MFG(10)
101	2.41	0.008	44	-2	-38	L-ITG(20)
17	2.39	0.008	-26	26	-16	L-MFG(11)
388	2.37	0.009	-42	12	32	L-MFG(9)
372	2.28	0.011	-32	-32	70	L-Postcentral Gyrus(3)
27	2.23	0.013	38	-22	-24	R-Parahippocampal G(36)
27	2.07	0.019	16	-102	2	R-Cuneus(18)
11	1.96	0.025	-52	-20	16	L-Insula(40)
19	1.94	0.026	34	22	16	R-Insula(13)
4	1.88	0.03	58	-20	16	R-Postcentral Gyrus(40)
11	1.81	0.035	28	-10	58	R-MFG(6)
3	1.77	0.039	32	2	58	R-MFG(6)

All areas are significant at an uncorrected threshold of p<0.05. K=250 voxels. The approximate Brodmann areas are from MRIcro, and the x, y, and z coordinates are from SPM8. BA: brodmann area. SPL: superior parietal lobe; MFG: middle frontal gyrus; IFG: inferior frontal gyrus; STG: superior temporal gyrus; MOG: middle occipital gyrus; ITG: inferior temporal gyrus.

5.5 Discussion

5.5.1 Inhibition of tactile information

From the result of VS-VtS, the Left/right superior temporal gyrus is the most strongly activated. In the previous study about the visual spatial attention (Coull and Nobre, 1998, Coull et al., 2000, Doricchi et al., 2010), they found that the STG promoted the selection of the spatial location of visual target. As same time, frontal eye fields have also successfully been activated, but in the result of Vts-VS not have any finding. This shows that tactile information in the VtS Task may not promoted the visual spatial orienting of attention, also did not created visual-tactile integration, inversely, may be have some inhibition of visual spatial attention. The same as the behavior results, because the tactile information was added, subjects' reaction times are slow to down (figure 5.5).

Moreover, the left and right MFG has also been activated also, some previous studies found that there have some inhibition of visual spatial orienting of attention from the MFG. So this study successfully discovered that in this study, the tactile information was inhibited the visual spatial attention.

5.5.2 VtS versus VS orienting of attention

From the VtS vs. VS task, only the somatosensory areas and motor areas; Inferior frontal gyrus in left hemisphere is activated. Previous finding suggest that the left IFG is the locus at which inhibitory activity from higher cortical areas interfaces with the action observation network, and that the susceptibility of the left IFG to attentional modulation reflects our ability to filter task-irrelevant actions during ongoing behavior (Desimone and Duncan, 1995). The left hemisphere bias for spatial orientation in VS task in this study is consistent with a previous report (Coull and Nobre, 1998, Li et al., 2012). Therefore, authors conclude that visual orienting attention uses a frontal–parietal neutral network for visual spatial orienting attention both with and without tactile distraction. But some tactile information may inhibitive the visual spatial orienting.

Chapter 6 General Discussion and Conclusion

Summary

This chapter discusses the main findings of the four experiments introduced in the previous four chapters. Regarding the neural network of attention, these studies defined a model of spatial and temporal attention.

Keywords – attention, selective attention, divided attention, visual and tactile integration, right Dorsal lateral prefrontal cortex

General Discussion

6.1 Visual and tactile selective attention with the stimuli modality integration

The first finding in this dissertation is the similarity and the difference between visual and tactile selective voluntary attention (using single visual target or tactile target). Previous study only indicated that during the voluntary visual spatial selective attention, the parietal-frontal neural network existed (Coull and Nobre, 1998). For extending, authors designed the tasks for comparison of voluntary visual and tactile selective attention. First, the comparison between voluntary visual spatial selective attention (VS) and voluntary tactile spatial selective attention (TS), authors found that there was a common neural network including the right parietal-frontal neural network for the two processes. The finding is partially different from the model showed in figure 1.1 in chapter 1 for voluntary tactile spatial attention process. The difference is the activation within the IPFC (inferior prefrontal cortex) which contributed with the top-down selective attention process and have not reported previously. Because these studies defined the neutral experimental task in which the IPFC din not activated, so authors considered that the IPFC is associated with the attention specifics, especially for spatial or temporal specifics. Furthermore, authors don’t think the activation of IPFC involves in working memory. TS the DLPFC (dorsal lateral prefrontal cortex) is defined as the area of working memory (Li et al., 2012).

Comparison between voluntary tactile temporal selective attention (TT) task and voluntary auditory temporal selective attention (AT) task, the difference is significant. The activation in TT task is only in the parietal (BA39/40) and the somatosensory cortex (BA2/3). The activation in AT task showed the same neural network with the model of visual voluntary attention. J.T.Coull etc. (Coull and Nobre, 1998). studied the voluntary visual temporal attention neural network and find the parietal-frontal network which is different from this dissertation. These studies considered that the baseline (rest task showed in figure 3.1 in chapter 3) in this voluntary visual attention study caused the trend. Activation in pre-motor cortex (BA4/6) was neutralized by contrasting the TT and rest task. As the result, activation of parietal and visual cortex is held. But the model shown in figure 2.1 in chapter 2 cannot apply to this TT task.

6.2 Difference of neural substrates between voluntary selective and voluntary divided attention

The second finding in this dissertation is the difference of neural substrates between selective and divided attention. The contrasts between voluntary selective attention and voluntary divided attention are shown in spatial attention and temporal attention. From the data of voluntary selective attention in chapter 4 and the data of voluntary divided attention in chapter 5, the main differences were summarized as below:

A. the activation of voluntary selective attention mainly used the right hemisphere which including parietal (BA7/40) and frontal cortex (BA4/6/9/10).

B. the activation of voluntary divided attention mainly used the bilateral that including parietal (BA7/40) and frontal cortex (BA4/6/9/10).

Reasons for the differences between voluntary selective attention and voluntary divided attention were considered as below:

A. during the voluntary selective attention task, the main experimental factor is “top-down attention” that controls the attention to target location or target presentation timing. Thus, the results for the voluntary visual and tactile selective attention mainly in the right hemisphere that consisted with the model summarized in previous study.

B. but during the voluntary divided attention task, there is one more factor that is “divided information process” except the “top-down attention”. Because participants should pay attention to both the visual and tactile target, the activations in the left hemisphere were considered be involved in the “divided information process” within the left prefrontal cortex.

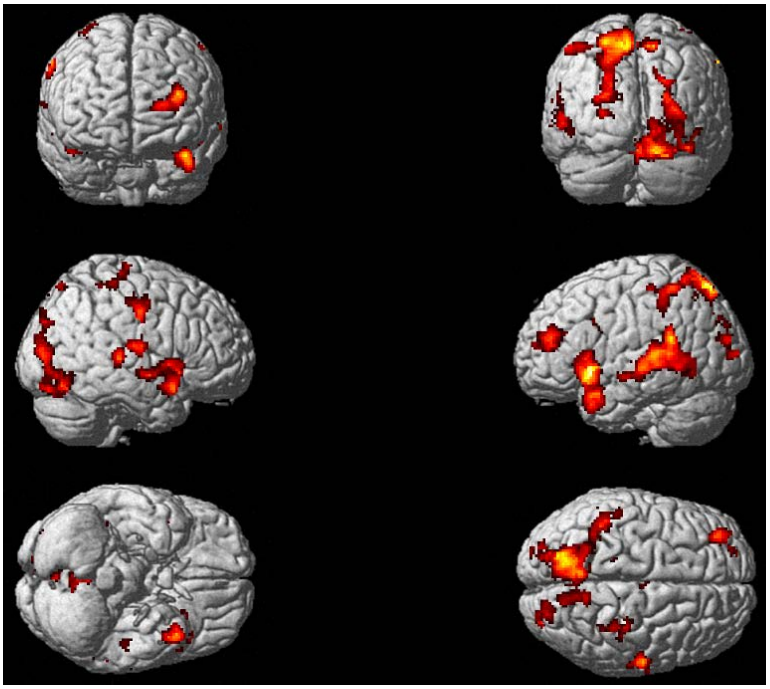

Figure 6.1 Activations of contrasting between divided and selective spatial attention task. All the activations were created under a threshold of p<0.05 corrected and a cluster level with 100 voxels

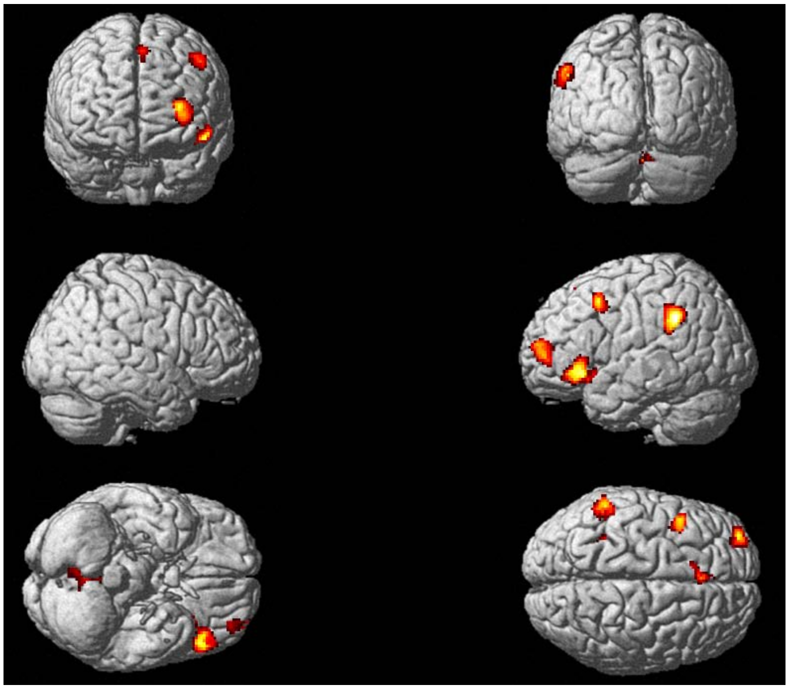

Figure 6.2 Activations of contrasting between divided and selective temporal attention task. All the activations were created under a threshold of p<0.05 corrected and a cluster level with 100 voxels

ROI (region of interesting) analysis was carried out based on the brain activations involved in divided spatial attention and divided temporal attention. The regional sphere that used in analysis is determined with 4 mm radii in all ROI analysis. The ROI results shown in figure 2.3 and 2.4 revealed that the left inferior frontal cortex and bilateral cerebellum significant activated during tactile spatial attention when compared to tactile neutral attention. The trend is also observed from the ROI analysis involved in divided temporal attention when compared to selective temporal attention. This finding is partially same with previous study (Macaluso et al., 2000, Macaluso and Driver, 2001, Macaluso et al., 2003) in which it revealed that cerebellum was involved in temporal attention. As the new finding, authors consider that the left inferior frontal cortex used in divided attention processing to integration the visual and tactile stimulus, and the cerebellum control the presentation of attention bilateral.

6.3 Difference of neural substrates between modality integration and selective attention

The third finding in this dissertation is the difference of neural substrates between modality integration and selective attention. This dissertation used the single visual target or single tactile target in the voluntary selective attention experiments, and used the visual-tactile target in the modality integration experiments. Although the participants were constructed to pay attention to only visual target or tactile target during the modality integration experiments, from the imaging results authors could easily find the differences between modality integration and voluntary selective attention. The differences indicated that although participants try to ignore the unattended modality, the brain would be affected. The study on modality integration reported that although people try to ignore the unattended modality, the integration would occur automatically. These studies considered that the mainly reason for the differences between of neural substrates between modality integration and selective attention (Wu et al., 2012b, a).

Furthermore, by contrasting the imaging results, it shows that during the tactile stimuli integration on the visual target (TS and VtS task) experiments, neural substrates significantly activated compared to voluntary selective tactile attention (TS and TT task) experiments. It indicated that there was facilitation between visual and tactile modality when participants attended the visual modality. But when participants attended to the tactile modality, it seems that the visual modality retrained the cognition of tactile target and the imaging results of the neural substrates showed that only the prefrontal cortex (BA9/10) activated except the middle temporal cortex (BA22) and somatosensory cortex (BA2/3).

6.4 Attention neural network in brain

From the discussion above, authors considered an attention model of neural substrates which is also the extended from the previous study in 2008 and 2013 for the visual and tacitle attention. In this attention model, it contains the condition as below:

a. voluntary visual spatial selective attention (VS)
b. voluntary visual temporal selective attention (VT)
c. voluntary tactile spatial selective attention (TS)
d. voluntary tactile temporal selective attention (TT)
e. tactile stimuli integration on selective visual spatial attention (VtS)
f. tactile stimuli integration on selective temporal attention (VtT)
g. visual stimuli integration on selective tactile spatial attention (TvS)
h. visual stimuli integration on selective tactile temporal attention (TvT)
i. voluntary visual-tactile spatial divided attention (VTS)
j. voluntary visual-tactile temporal divided attention (VTT)

The neural substrates model of attention is shown in figure 6.3

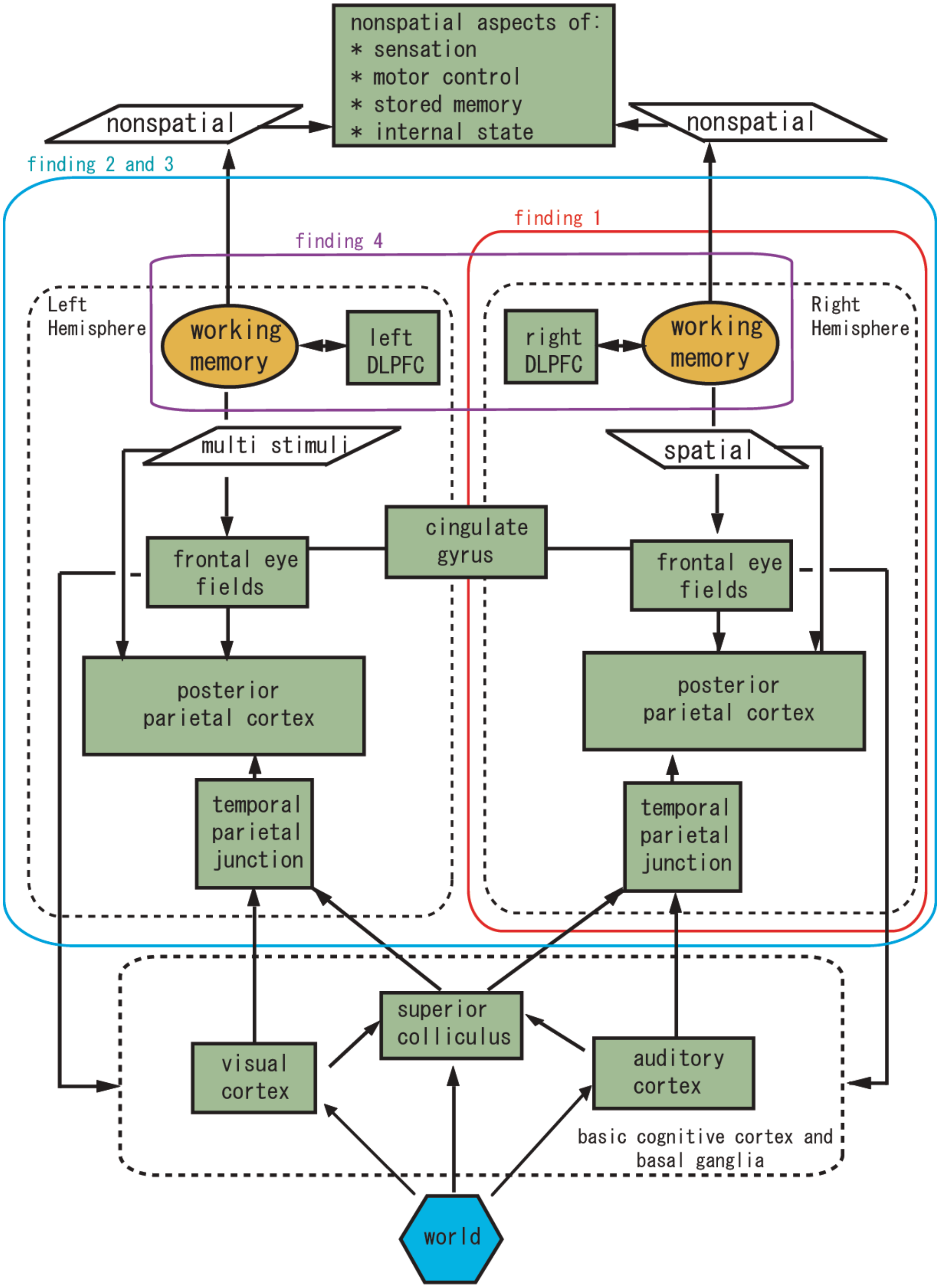

Figure 6.3 Neural substrates model of attention. The divided attention used the entire model and the selective attention with and without integration used the part which circled with red line.

General Conclusion

This research measured brain activity of volunteers by using functional magnetic resonance imaging (fMRI), Compared spatial attention and temporal attention through visual and tactile attention task. Parietal-frontal network activated with spatial attention and Left middle frontal gyrus (BA8/10) activated with temporal attention. Inferior frontal gyrus (BA47) and Left inferior parietal lobe (BA40) activated not only with spatial attention but also with temporal attention. And suggest that these areas may be important in the execution of controlled processing when attention is divided between two sources of information.

Appendix A—A simple introduction to functional magnetic resonance imaging

What is fMRI?

Functional magnetic resonance imaging (fMRI) is based on the principles of magnetic resonance, plus the fact that increases in neural activity are accompanied by changes in regional cerebral blood flow (rCBF) and blood oxygenation. This blood oxygenation level dependent (BOLD) effect is the basis for most of the fMRI studies to map patterns of activation in the working human brain. The scanners used in our experiment are shown in figure A.1.

Figure A. 1. The Philip fMRI scanner used in our experiment

BOLD signal and EPI

fMRI is a non-invasive method since it uses blood a since it uses blood as intrinsic contrast agent (BOLD-contrast) to assess neural activity in the brain. In detail, the iron in blood hemoglobin is nature’s own intrinsic contrast agent, because it can change the blood’s magnetic susceptibility. Oxygenated arterial blood contains oxygenated hemoglobin, which is diamagnetic and has about the same magnetic susceptibility as other brain tissue. Therefore it does not alter the regional magnetic field and does not affect tissue T2* much. Deoxygenation of hemoglobin produces deoxyhemoglobin, which is a paramagnetic compound and disturbs the local magnetic field, relative to the surrounding tissue water, leading to the large observed magnetic susceptibility effect. The difference in magnetic susceptibility creates a local magnetic field gradient, consequently inhomogeneities in the magnetic field. The local T2*, critical in fMRI contrast, is thus determined by the balance of deoxygenated to oxygenated hemoglobin in blood within a voxel.

In the normal awake brain about 40% of the oxygen delivered to the capillary bed in arterial blood is extracted and metabolized. Thus there is a large amount of deoxyhemoglobin in the venous vessels. When the brain is activated, as illustrated in figure A.2., the local blood flow increases substantially, but oxygen metabolism increases only a small amount. As a result, the venous blood is more oxygenated. The reduction in deoxyhemoglobin concentration leads to a longer T2* and thus a signal increase (a few percent). This signal increase depends on the magnetic field strength and is higher at higher field strength. Nevertheless, one can never see the activation in a reconstructed fMRI with the naked eye. Statistical analysis is necessary to reliably detect these activations.

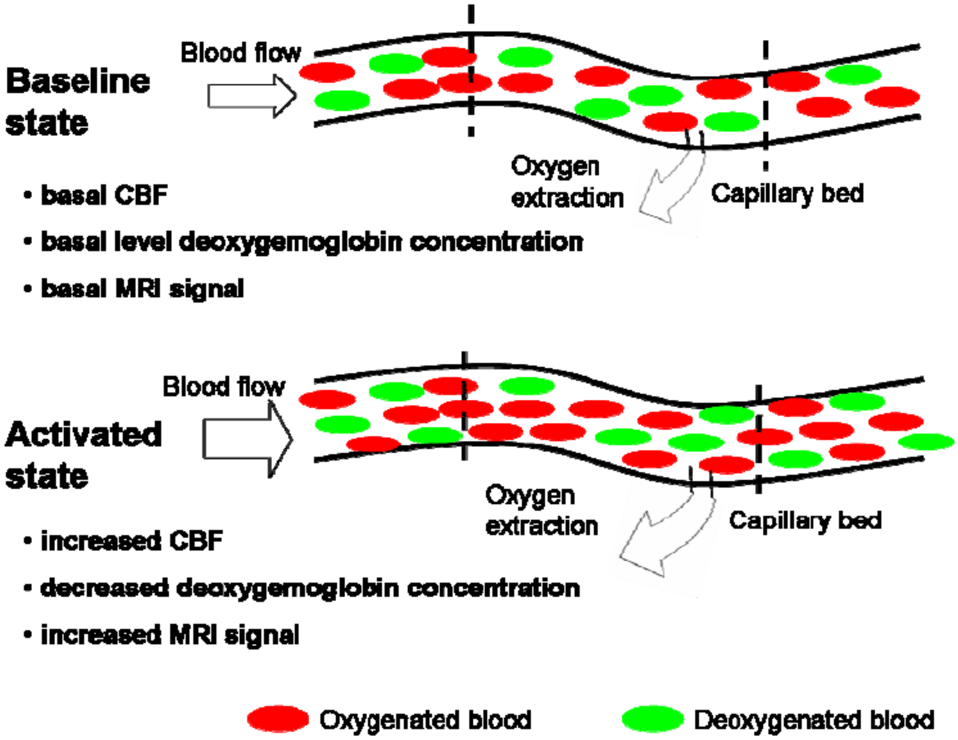

Figure A.2 Illustration of fMRI BOLD Neural activity increases the blood flow in the active region to provide the neurons with more oxygen and decreased deoxyhemoglobin concentrations. Reduced field inhomogeneities lead to a longer T2* and therefore to an increased MRI signal.

Since the discovery that brain activation can be detected and localized through the BOLD effect, a number of imaging approaches have been used to measure this activation. The prototype brain mapping experiment consists of alternating periods of a stimulus task and a control/rest task and this cycle is repeated several times. During these cycles of stimulus and control, echo planar images (EPI) are collected covering all or part of the brain. This is achieved by dividing the brain into several slices (usually 5-35) and imaging them consecutively with EPI. EPI is a very fast imaging method, requiring about 100 ms to acquire one slice, hence, about one to three seconds to cover the whole brain, and has a high signal to noise ratio (SNR). Series of images of the brain can be collected throughout stimulus/control cycles. The price paid for the speed is that the images have a lower spatial resolution than conventional MR images. But also the BOLD effect itself imposes an intrinsic resolution limit for the fMRI, since oxygenation changes can be detected several mm downstream in the venous system from the site of neuronal activity. The set of resulted images can be interpreted as a four dimensional data set, three spatial dimensions and time. The image examples are shown in figure A.3.

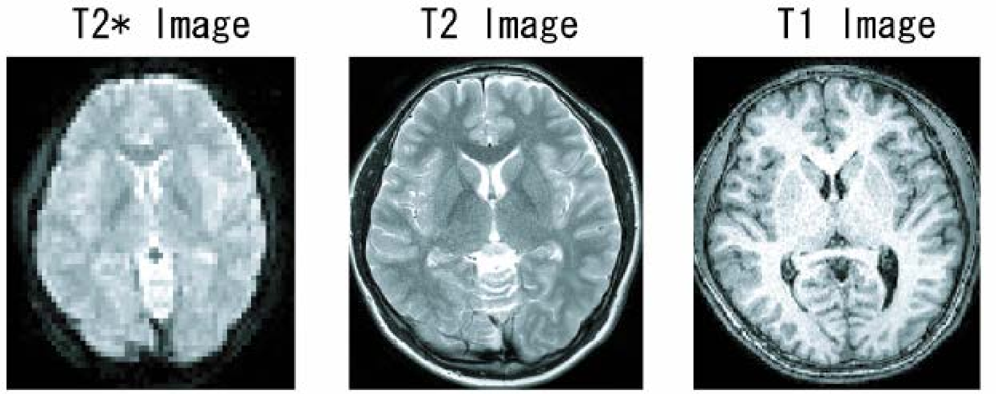

Figure A.3 Image examples of fMRI and MRI scanning

T2* image is the functional image with low resolution; T2 image and T1 image are structural images with higher resolution.

Important concepts of fMRI scanning

TR: repetition time, the time interval between successive excitation pulses usually expressed in seconds.

TE: echo time, the time interval between an excitation pulse and data acquisition (defines as the collection of data from the center of *k-space*), usually expressed in milliseconds.

Flip Angle: the change in the precession angle of the net magnetization following excitation.

Field of view: the extent of the imaging volume within a slice and is generally expressed in centimeters.

Matrix size: how many voxels in each direction. Matrix used in fMRI is generally powers of 2, such as 64, 128, or 256, to facilitate use of the FFT for image construction.

Slice thickness: provides the third dimension (through-plane) and is generally the same or larger than the in-plane voxel size (e.g., 5mm).

Safety considerations

Since the inception of clinical MRI testing in the early 1980s, more than 200 million MRI scans have been performed, with an additional 50000 scans performed every day. The vast majority of these scans are performed without incident, confirming the safety of MRI as an imaging technique.

Appendix B－fMRI data processing and analysis with statistical parametric mapping (SPM)

A simple introduction to statistical parametric mapping

Statistical parametric mapping refers to the construction and assessment of spatially extended statistical processes used to test hypotheses about neural imaging data from SPECT/PET and fMRI. These ideas have been instantiated in software that is called SPM, and is a suite of Matlab functions and subroutines (with some externally compiled C routines). It is freely available for research purposes at http://www.fil.ion.ucl.ac.uk/spm. SPM was written to organize and interpret functional neuroimaging data. Some of the main features of the software are: realignment of image sequences, automated non-linear spatial normalization, spatial smoothing, model building and statistical image assessment. The data analyzing processes are briefly shown in Figure B.1.

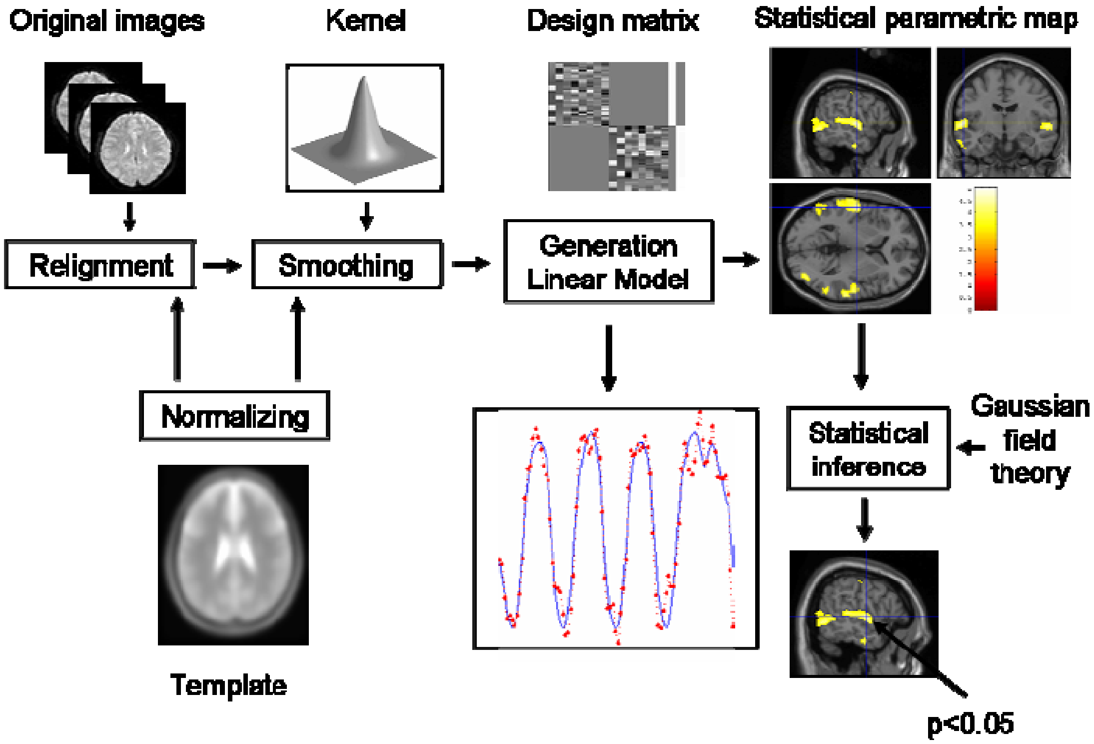

Figure B. 1. fMRI data analysis process using SPM

This preprocessing step realigns the images spatially. It is performed to remove movement artifact in fMRI time series. This routine realigns a time series of images acquired from the same subject using a least squares approach and a 6 parameter (rigid body) spatial transformation (3 translations and 3 rotations about orthogonal axes). The first image in the list, specified by the user is used as a reference to which all subsequent scans are realigned. The reference scan can be chosen and it is wise to choose a ‘representative scan’ in this role. Then the transformation is applied by resampling the data using sinc or trilinear interpolation. Realignment to one scan of a series of scans is from one subject, due to movement artifacts. An example of results of the realignment is shown in Figure B.2.

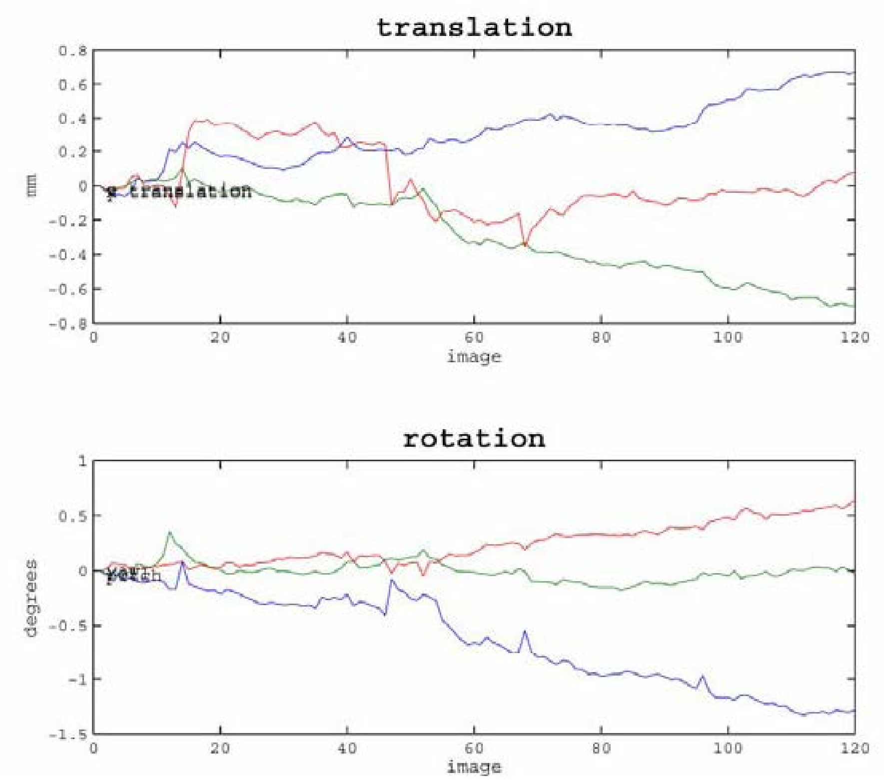

Figure B. 2. An example of realignment results

Normalization

MRI images are normalized into a standard space defined by some ideal model or template image(s). The template is a reference image according to the space of Talairach. SPM uses a 152 subject average 3D brain image from the fMRI mean images. The algorithms work by minimizing the sum of squares difference (least squares optimization) between the image which is to be normalized and a linear combination of the template image(s). There are two steps to do the work. The first step is to determine the optimum 12-parameter affine transformation. The second step is to estimate nonlinear deformations, which are defined by a linear combination of 3 dimensional discrete cosine transform (DCT) basis functions. The example of normalized image is shown in Figure B.3.

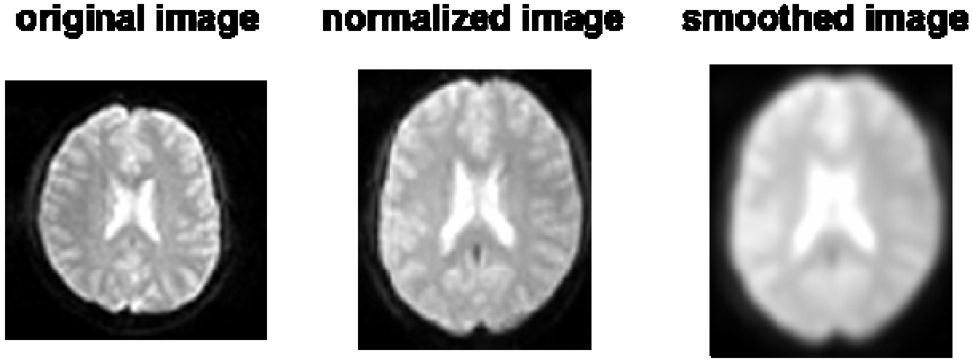

Figure B. 3. Examples of pre-processed images

Spatial smoothing

The motivations for smoothing the data are fourfold. (i) By the matched filter theorem, the optimum smoothing kernel corresponds to the size of the effect that one anticipates. The spatial scale of hemodynamic responses is, according to high-resolution optical imaging experiments, about 2 to 5mm. Despite the potentially high resolution afforded by fMRI an equivalent smoothing is suggested for most applications. (ii) By the central limit theorem, smoothing the data will render the errors more normal in their distribution and ensure the validity of inferences based on parametric tests. (iii) When making inferences about regional effects using Gaussian random field theory (see below) the assumption is that the error terms are a reasonable lattice representation of an underlying and smooth Gaussian field. This necessitates smoothness to be substantially greater than voxel size. If the voxels are large, then they can be reduced by sub-sampling the data and smoothing (with the original point spread function) with little loss of intrinsic resolution. (iv) In the context of inter-subject averaging it is often necessary to smooth more (*e.g.* 8 mm in fMRI or 16mm in PET) to project the data onto a spatial scale where homologies in functional anatomy are expressed among subjects. An example of smoothed image is shown in Figure B.3.

Theory of SPM

Functional mapping studies are usually analyzed with some form of statistical parametric mapping. Statistical parametric mapping entails the construction of spatially extended statistical processes to test hypotheses about regionally specific effects. Statistical parametric maps (SPMs) are image processes with voxel values that are, under the null hypothesis, distributed according to a known probability density function, usually the Student's T or F distributions. These are known colloquially as T- or F-maps. The success of statistical parametric mapping is due largely to the simplicity of the idea. Namely, one analyses each and every voxel using any standard (univariate) statistical test. The resulting statistical parameters are assembled into an image - the SPM. SPMs are interpreted as spatially extended statistical processes by referring to the probabilistic behavior of Gaussian fields. Gaussian random fields model both the univariate probabilistic characteristics of a SPM and any nonstationary spatial covariance structure. 'Unlikely' excursions of the SPM are interpreted as regionally specific effects, attributable to the sensorimotor or cognitive process that has been manipulated experimentally.

Over the years statistical parametric mapping has come to refer to the conjoint use of *the general linear model* (GLM) and *Gaussian random field* (GRF) theory to analyze and make classical inferences about spatially extended data through statistical parametric maps (SPMs). The GLM is used to estimate some parameters that could explain the spatially continuous data in exactly the same way as in conventional analysis of discrete data. GRF theory is used to resolve the multiple comparison problem that ensues when making inferences over a volume of the brain. GRF theory provides a method for correcting *p* values for the search volume of a SPM and plays the same role for *continuous* data (*i.e.* images) as the Bonferonni correction for the number of discontinuous or *discrete* statistical tests.

References

1. Backes W, Mess W, van Kranen-Mastenbroek V, Reulen J (2000) Somatosensory cortex responses to median nerve stimulation: fMRI effects of current amplitude and selective attention. Clinical neurophysiology 111:1738-1744.
2. Bauer M, Oostenveld R, Peeters M, Fries P (2006) Tactile spatial attention enhances gamma-band activity in somatosensory cortex and reduces low-frequency activity in parieto-occipital areas. J Neurosci 26:490-501.
3. Breier JI, Fletcher JM, Foorman BR, Klaas P, Gray LC (2003) Auditory temporal processing in children with specific reading disability with and without attention deficit/hyperactivity disorder. Journal of speech, language and hearing research 46:31.
4. Burton H, Sinclair RJ, McLaren DG (2008) Cortical network for vibrotactile attention: A fMRI study. Human brain mapping 29:207-221.
5. Corbetta M, Shulman GL (2002) Control of goal-directed and stimulus-driven attention in the brain. Nature reviews neuroscience 3:201-215.
6. Coull JT, Frith C, Büchel C, Nobre A (2000) Orienting attention in time: behavioural and neuroanatomical distinction between exogenous and endogenous shifts. Neuropsychologia 38:808-819.
7. Coull JT, Nobre AC (1998) Where and when to pay attention: the neural systems for directing attention to spatial locations and to time intervals as revealed by both PET and fMRI. The Journal of Neuroscience 18:7426-7435.
8. Craig JC, Evans PM (1995) Tactile selective attention and temporal masking. Perception & Psychophysics 57:511-518.
9. Dalton P, Lavie N, Spence C (2009) The role of working memory in tactile selective attention. The Quarterly Journal of Experimental Psychology 62:635-644.
10. Desimone R, Duncan J (1995) Neural mechanisms of selective visual attention. Annu Rev

Neurosci 18:193-222.

11. Doricchi F, Macci E, Silvetti M, Macaluso E (2010) Neural correlates of the spatial and expectancy components of endogenous and stimulus-driven orienting of attention in the Posner task. Cereb Cortex 20:1574-1585.
12. Eickhoff SB, Amunts K, Mohlberg H, Zilles K (2006) The human parietal operculum. II. Stereotaxic maps and correlation with functional imaging results. Cerebral cortex 16:268-279.
13. Eimer M, van Velzen J (2005) Spatial tuning of tactile attention modulates visual processing within hemifields: an ERP investigation of crossmodal attention. Experimental brain research 166:402-410.
14. Esterman M, Prinzmetal W, DeGutis J, Landau A, Hazeltine E, Verstynen T, Robertson L (2008) Voluntary and involuntary attention affect face discrimination differently. Neuropsychologia 46:1032-1040.
15. Frohlich Z (1994) Combined spatial and temporal imaging of brain activity during visual selective attention in humans. Nature 372:8.
16. Hoechstetter K, Rupp A, Meinck H-M, Weckesser D, Bornfleth H, Stippich C, Berg P, Scherg M (2000) Magnetic source imaging of tactile input shows task-independent attention effects in SII. Neuroreport 11:2461-2465.
17. Hsiao SS, O'shaughnessy D, Johnson KO (1993) Effects of selective attention on spatial form processing in monkey primary and secondary somatosensory cortex. Journal of neurophysiology 70:444-447.
18. James W (1976) Essays in radical empiricism: Harvard University Press.
19. Li C, Chen K, Han H, Chui D, Wu J (2012) An fMRI study of the neural systems involved in visually cued auditory top-down spatial and temporal attention. PloS one 7:e49948.
20. Macaluso E, Driver J (2001) Spatial attention and crossmodal interactions between vision and touch. Neuropsychologia 39:1304-1316.

21. Macaluso E, Eimer M, Frith C, Driver J (2003) Preparatory states in crossmodal spatial attention: spatial specificity and possible control mechanisms. Experimental brain research 149:62-74.
22. Macaluso E, Frith C, Driver J (2000) Selective spatial attention in vision and touch: unimodal and multimodal mechanisms revealed by PET. Journal of neurophysiology 83:3062-3075.
23. Miles E, Poliakoff E, Brown RJ (2008) Investigating the time course of tactile reflexive attention using a non-spatial discrimination task. Acta psychologica 128:210-215.
24. Opitz B, Rinne T, Mecklinger A, Von Cramon DY, Schröger E (2002) Differential contribution of frontal and temporal cortices to auditory change detection: fMRI and ERP results. Neuroimage 15:167-174.
25. Poliakoff E, Miles E, Li X, Blanchette I (2007) The effect of visual threat on spatial attention to touch. Cognition 102:405-414.
26. Posner MI (1980) Orienting of attention. Quarterly journal of experimental psychology 32:3-25.
27. Recanzone GH, Merzenich MM, Schreiner CE (1992) Changes in the distributed temporal response properties of SI cortical neurons reflect improvements in performance on a temporally based tactile discrimination task. Journal of neurophysiology 67:1071-1091.
28. Sathian K, Burton H (1991) The role of spatially selective attention in the tactile perception of texture. Perception & Psychophysics 50:237-248.
29. Schubert R, Ritter P, Wustenberg T, Preuschhof C, Curio G, Sommer W, Villringer A (2008) Spatial attention related SEP amplitude modulations covary with BOLD signal in S1--a simultaneous EEG--fMRI study. Cereb Cortex 18:2686-2700.
30. Soros P, Marmurek J, Tam F, Baker N, Staines WR, Graham SJ (2007) Functional MRI of working memory and selective attention in vibrotactile frequency discrimination. BMC Neurosci 8:48.

31. Spence C, McGlone FP (2001) Reflexive spatial orienting of tactile attention. Exp Brain Res 141:324-330.
32. Spence C, Pavani F, Driver J (2000) Crossmodal links between vision and touch in covert endogenous spatial attention. Journal of Experimental Psychology: Human Perception and Performance 26:1298.
33. Tang X, Li C, Li Q, Gao Y, Yang W, Yang J, Ishikawa S, Wu J (2013) Modulation of auditory stimulus processing by visual spatial or temporal cue: an event-related potentials study. Neurosci Lett 553:40-45.
34. van Ede F, de Lange F, Jensen O, Maris E (2011) Orienting attention to an upcoming tactile event involves a spatially and temporally specific modulation of sensorimotor alpha-and beta-band oscillations. The Journal of Neuroscience 31:2016-2024.
35. Van Hulle L, Van Damme S, Spence C, Crombez G, Gallace A (2013) Spatial attention modulates tactile change detection. Exp Brain Res 224:295-302.
36. Vossel S, Thiel CM, Fink GR (2006) Cue validity modulates the neural correlates of covert endogenous orienting of attention in parietal and frontal cortex. Neuroimage 32:1257-1264.
37. Wu Q, Li C, Guo Q, Wu J (2012a) Inhibition of tactile information on visual spatial attention: An fMRI study. In: Mechatronics and Automation (ICMA), 2012 International Conference on, pp 2134-2139: IEEE.
38. Wu Q, Li C, Guo Q, Wu J (2012b) Visual temporal cuing effect on the tactile attention: An fMRI study. In: Complex Medical Engineering (CME), 2012 ICME International Conference on, pp 739-743: IEEE.
39. Backes W, Mess W, van Kranen-Mastenbroek V, Reulen J (2000) Somatosensory cortex responses to median nerve stimulation: fMRI effects of current amplitude and selective attention. Clinical neurophysiology 111:1738-1744.
40. Bauer M, Oostenveld R, Peeters M, Fries P (2006) Tactile spatial attention enhances gamma-band activity in somatosensory cortex and reduces low-frequency activity in parieto-occipital

areas. J Neurosci 26:490-501.

41. Breier JI, Fletcher JM, Foorman BR, Klaas P, Gray LC (2003) Auditory temporal processing in children with specific reading disability with and without attention deficit/hyperactivity disorder. Journal of speech, language and hearing research 46:31.
42. Burton H, Sinclair RJ, McLaren DG (2008) Cortical network for vibrotactile attention: A fMRI study. Human brain mapping 29:207-221.
43. Corbetta M, Shulman GL (2002) Control of goal-directed and stimulus-driven attention in the brain. Nature reviews neuroscience 3:201-215.
44. Coull JT, Frith C, Büchel C, Nobre A (2000) Orienting attention in time: behavioural and neuroanatomical distinction between exogenous and endogenous shifts. Neuropsychologia 38:808-819.
45. Coull JT, Nobre AC (1998) Where and when to pay attention: the neural systems for directing attention to spatial locations and to time intervals as revealed by both PET and fMRI. The Journal of Neuroscience 18:7426-7435.
46. Craig JC, Evans PM (1995) Tactile selective attention and temporal masking. Perception & Psychophysics 57:511-518.
47. Dalton P, Lavie N, Spence C (2009) The role of working memory in tactile selective attention. The Quarterly Journal of Experimental Psychology 62:635-644.
48. Desimone R, Duncan J (1995) Neural mechanisms of selective visual attention. Annu Rev Neurosci 18:193-222.
49. Doricchi F, Macci E, Silvetti M, Macaluso E (2010) Neural correlates of the spatial and expectancy components of endogenous and stimulus-driven orienting of attention in the Posner task. Cereb Cortex 20:1574-1585.
50. Eickhoff SB, Amunts K, Mohlberg H, Zilles K (2006) The human parietal operculum. II. Stereotaxic maps and correlation with functional imaging results. Cerebral cortex 16:268-279.

51. Eimer M, van Velzen J (2005) Spatial tuning of tactile attention modulates visual processing within hemifields: an ERP investigation of crossmodal attention. Experimental brain research 166:402-410.
52. Esterman M, Prinzmetal W, DeGutis J, Landau A, Hazeltine E, Verstynen T, Robertson L (2008) Voluntary and involuntary attention affect face discrimination differently. Neuropsychologia 46:1032-1040.
53. Frohlich Z (1994) Combined spatial and temporal imaging of brain activity during visual selective attention in humans. Nature 372:8.
54. Hoechstetter K, Rupp A, Meinck H-M, Weckesser D, Bornfleth H, Stippich C, Berg P, Scherg M (2000) Magnetic source imaging of tactile input shows task-independent attention effects in SII. Neuroreport 11:2461-2465.
55. Hsiao SS, O'shaughnessy D, Johnson KO (1993) Effects of selective attention on spatial form processing in monkey primary and secondary somatosensory cortex. Journal of neurophysiology 70:444-447.
56. James W (1976) Essays in radical empiricism: Harvard University Press.
57. Li C, Chen K, Han H, Chui D, Wu J (2012) An fMRI study of the neural systems involved in visually cued auditory top-down spatial and temporal attention. PloS one 7:e49948.
58. Macaluso E, Driver J (2001) Spatial attention and crossmodal interactions between vision and touch. Neuropsychologia 39:1304-1316.
59. Macaluso E, Eimer M, Frith C, Driver J (2003) Preparatory states in crossmodal spatial attention: spatial specificity and possible control mechanisms. Experimental brain research 149:62-74.
60. Macaluso E, Frith C, Driver J (2000) Selective spatial attention in vision and touch: unimodal and multimodal mechanisms revealed by PET. Journal of neurophysiology 83:3062-3075.
61. Miles E, Poliakoff E, Brown RJ (2008) Investigating the time course of tactile reflexive

attention using a non-spatial discrimination task. Acta psychologica 128:210-215.

62. Opitz B, Rinne T, Mecklinger A, Von Cramon DY, Schröger E (2002) Differential contribution of frontal and temporal cortices to auditory change detection: fMRI and ERP results. Neuroimage 15:167-174.
63. Poliakoff E, Miles E, Li X, Blanchette I (2007) The effect of visual threat on spatial attention to touch. Cognition 102:405-414.
64. Posner MI (1980) Orienting of attention. Quarterly journal of experimental psychology 32:3-25.
65. Recanzone GH, Merzenich MM, Schreiner CE (1992) Changes in the distributed temporal response properties of SI cortical neurons reflect improvements in performance on a temporally based tactile discrimination task. Journal of neurophysiology 67:1071-1091.
66. Sathian K, Burton H (1991) The role of spatially selective attention in the tactile perception of texture. Perception & Psychophysics 50:237-248.
67. Schubert R, Ritter P, Wustenberg T, Preuschhof C, Curio G, Sommer W, Villringer A (2008) Spatial attention related SEP amplitude modulations covary with BOLD signal in S1--a simultaneous EEG--fMRI study. Cereb Cortex 18:2686-2700.
68. Soros P, Marmurek J, Tam F, Baker N, Staines WR, Graham SJ (2007) Functional MRI of working memory and selective attention in vibrotactile frequency discrimination. BMC Neurosci 8:48.
69. Spence C, McGlone FP (2001) Reflexive spatial orienting of tactile attention. Exp Brain Res 141:324-330.
70. Spence C, Pavani F, Driver J (2000) Crossmodal links between vision and touch in covert endogenous spatial attention. Journal of Experimental Psychology: Human Perception and Performance 26:1298.
71. Tang X, Li C, Li Q, Gao Y, Yang W, Yang J, Ishikawa S, Wu J (2013) Modulation of auditory stimulus processing by visual spatial or temporal cue: an event-related potentials

study. Neurosci Lett 553:40-45.

72. van Ede F, de Lange F, Jensen O, Maris E (2011) Orienting attention to an upcoming tactile event involves a spatially and temporally specific modulation of sensorimotor alpha-and beta-band oscillations. The Journal of Neuroscience 31:2016-2024.
73. Van Hulle L, Van Damme S, Spence C, Crombez G, Gallace A (2013) Spatial attention modulates tactile change detection. Exp Brain Res 224:295-302.
74. Vossel S, Thiel CM, Fink GR (2006) Cue validity modulates the neural correlates of covert endogenous orienting of attention in parietal and frontal cortex. Neuroimage 32:1257-1264.
75. Wu Q, Li C, Guo Q, Wu J (2012a) Inhibition of tactile information on visual spatial attention: An fMRI study. In: Mechatronics and Automation (ICMA), 2012 International Conference on, pp 2134-2139: IEEE.
76. Wu Q, Li C, Guo Q, Wu J (2012b) Visual temporal cuing effect on the tactile attention: An fMRI study. In: Complex Medical Engineering (CME), 2012 ICME International Conference on, pp 739-743: IEEE.

Publication

Journal publication:

1. SII and the Fronto-parietal Areas are Involved in Visually Cued Tactile Top down Spatial Attention: An fMRI Study, Qiong Wu, Chunlin Li, Yujie Li, Hongzan Sun, Qiyong Guo, Jinglong Wu NeuroReport, In press

lEEE publication:

1. Effect of visual spatial information on tactile spatial attention: An fMRI study, Qiong Wu, Chunlin Li, Qiyong Guo, Jinglong Wu, Proceeding of the 2011 IEEE/ICME International Conference on Complex Medical Engineering, pp.565-570 (2011. 5)
2. Visual temporal cuing effect on the tactile attention: An fMRI study, Qiong Wu, Chunlin Li, Qiyong Guo, Jinglong Wu, Proceeding of the 2012 IEEE/ICME International Conference on Complex Medical Engineering, pp.739-743 (2012. 7)
3. Inhibition of tactile information on visual spatial attention: An fMRI study, Qiong Wu, Chunlin Li, Qiyong Guo, Jinglong Wu, Proceeding of the 2012 IEEE/ICMA International Conference on Mechatronics and Automation, pp.2134-2139 (2012. 8)
4. Evaluation of human pointing movement characteristics for improvement of human computer interface, Qiong Wu, Jiajia Yang, Jinglong Wu, Proceeding of the 2010 IEEE/ICIA International Conference on Information and Automation, pp.2134-2139 (2010. 6)

Chapters in books:

1. Visual-Tactile Bottom-Up and Top-Down Attention, Qiong Wu, Chunlin Li, Satoshi Takahashi, Jinglong Wu, IGI Global, pp.183-191 (2012. 9)

Acknowledgements

A part of this work was supported by the Grant-in-Aid for Scientific Research (A) 25249026 and (B) 25303013, JSPS and VINNOVA under the Japan-Sweden Research Cooperative Program, (7401300030), Grant-in-Aid for Strategic Research Promotion by Okayama University.

I express my heartfelt thanks and gratitude to my mentor, Professor Jinglong Wu, who provided valuable instruction during my study and the writing of this dissertation. I have been greatly inspired by Professor Wu’s diligence, will power, courage, and kindness. His *Helix Theory of Study* led me to the study of cognitive neuroscience. Beyond the university, Professor Wu has also kindly helped me, a foreigner in Japan, with everyday life.

I additionally extend my great appreciation to Professor Yanase Shinichiro, Professor Tomita Eiji and Associate Professor Satoshi Takahashi, who provided valuable advice about writing the dissertation and oral presentations.

I also thank Doctor Chunlin Li in Capital Medical University, who gave me the basic education of research and kindly helped me during my everyday life in the undergraduate course.

I thank Professors Qiyong Guo and Hongzan Sun in Shengjing Hospital of China Medical University, who provided the fMRI experiment environment and helped with the data acquisition.

I also thank the Assistant Professor Jiajia Yang, students and staff in Wu lab. Without their cooperation, I cannot imagine how I could have finished my experiments. I sincerely thank all those who contributed to my experiment, my paper, and my dissertation.

Finally, I extend my deep appreciation and dedicate this dissertation to my family, especially to my parents and my wife, who have always supported and understood me.