Cortical and Subcortical Organization Participating in Tactual Pattern Perception in Man: A PET study

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IV. 11. Cortical and Subcortical Organization Participating in Tactual Pattern Perception in Man: A PET Study

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Introduction

Positron emission tomography (PET) allows measurements of regional cerebral blood flow (rCBF) changes during various tasks. This approach has been successfully used to identify anatomical structures that subserve a particular higher psychological function. As to the somatosensory system, an attempt has been made to examine the activations of the primary somatosensory and motor cortex during voluntary movements, especially stereognostic discrimination in man[1,2]. More recently, however, co-activation patterns with other cortical[3,4] and subcortical structures[5] have been studied. The aim of the present study was to map the anatomical structures which changed their rCBF during tactual pattern perception of two-dimensional figures, using a rest-activation paradigm. We also evaluated effects of stimulus presentation modes on their co-activation patterns of rCBF changes. No available PET data has been obtained about tactual pattern perception.

Methods

SUBJECTS

Four right-handed healthy men, ranging in age from 22 to 28 years, participated in this experiment. All subjects were volunteers from the department of Psychology, Tohoku University. Written and informed consents were obtained from each subject before the experiment. All had gone through extensive medical examinations and none had any symptoms of neurological or other disorders.

MEASUREMENTS OF rCBF

The oxygen-15 labeled CO_2 gas steady-state inhalation technique was used to rCBF changes. The positron camera was PT931 (Computer Technology & Imaging Knoxville, Tennessee), with a measured spatial resolution of 7 mm in a plane and a slice thickness of 7 mm. Count images were used to estimate relative rCBF without arterial sampling. We obtained 2 emission scans of 1.5 min during each tactual mode, and reconstructed a total of

14 PET images of the brain. Emission scans were corrected for individual attenuation characteristics by using transmission scan on the same planes. Furthermore, MRI scanning was performed for each subject with magnetic field of 0.15 telsa and could be used as anatomical templates.

STIMULI AND MODES OF TOUCH

The tactual stimuli were twelve raised-line drawings of familiar objects, produced by the stereo copying system. All drawings were formed by a single continuous line on cards, which defined the outline of the object easily identifiable by sight. An average outline length of 12 drawings was 72.9 cm. The width of the raised lines was 1.5 mm.

The subject explored the drawings with his right index finger in either of 2 modes 2, 3). In the active mode, the drawings was stationary, and the subject was free to tactually explore one of 12 drawings with any force or velocity. In the tactile mode, the exploring finger remained stationary and the raised drawing was moved, along its outline, beneath his finger tip by the experimenter. Exploration began at the upper part of the raised drawing and proceeded in a clock-wise direction. The same drawing was explored with repetition until the subject made the verbal identification of the drawing.

PROCEDURES

The experiment was conducted at the Cyclotron Radioisotope Center, Tohoku University. The subject lay in the scanning bed on his back, with his head position being carefully set by using light projectors. He had small tubes fixed in his mouth for the inhalation of $^{15}O\text{-}CO_2$ gas. The right forearm was suspended in a freely moving sling. Thus, exploratory movements in the active mode involved rotations of the elbow and shoulder joints.

Table 1 shows a time schedule used in this experiment. First, a reference of rCBF was determined at a control 1 state. The subject was lying comfortably, with his eyes being closed. He was told not to move and to think of nothing at this state. Then, the subject began to perform each task three or six min prior to rCBF measurements during the tasks in order to facilitate neuronal activities associated with a demand of each task. Prior to the experiment, the subject was instructed to concentrate his fingertip to be stimulated during execution of the task. The presentation order of 12 raised drawings was randomized, and the order of the active and tactile modes was as counterbalanced as possible over 4 subjects.

Results

Serial rCBF images over 4 subjects were accumulated and mean rCBF change images were calculated by pixel-by-pixel (256x256) subtraction of each tactual mode minus control 1. Figure 1 shows the descriptive t-images of mean rCBF changes. Statistically significant increases in rCBF during each mode compared to the control condition (t-test, $p<005$) are represented in the red zone. As seen in Figure. 1, it is clear that activated areas extended over multiple regions of the whole brain beyond the somatosensory and motor cortex. There also appeared hemispheric asymmetries in the activation patterns: the somatosensory association areas were activated contralaterally to the stimulated hand, whereas there were the bilateral and ipsilateral increases in rCBF in other regions.

The active mode increased rCBF in the contralateral somatosensory cortex, motor cortex, parietal association cortex, cingulate gyrus, ipsilateral midfrontal cortex, midtemporal and inferior temporal cortex, bilateral basal ganglia, and thalamus nuclei. During the tactile mode, rCBF increases were found in the contralateral somatosensory cortex, motor cortex, parietal association cortex, cingulate gyrus, ipsilateral midfrontal and inferior frontal cortex, bilateral basal ganglia, and thalamus nuclei. It appeared that the similar areas were activated during the both modes. However, if the brain organized its activities in a modular way, activities in the somatosensory association areas were strongly co-activated with those in the right temporal cortex in the active mode, and with those in the right frontal cortex in the tactile mode.

Discussion

The main finding in this study was that the tactile mode increased rCBF in about the same regions as the active mode. This finding was parallel to that reported by Roland et al., who demonstrated that tactile learning and tactile recognition of complicated geometrical objects increased rCBF in the same anatomical structures in the cerebral cortex, thalamus, and basal ganglia[5)]. The activated areas in this study agreed well with those earlier reported during stereognostic discrimination of three-dimensional objects, except the temporal cortex[1,2,4,6)]. The fact that about the same areas could be activated during the both modes suggests that the co-activation patterns of the whole brain are dependent on what is required in the tasks, i.e. identification of tactually perceived figures in this study, rather than on what degree sensory inputs are involved in the tasks. However, a degree of activation or strength of the co-activations seems different between the two modes.

In the psychological experiments, the tactile mode allowed poorest performance at identifying the figures of all the four modes[7,8)]. In addition to the active and tactile modes, the passive, where the exploring hand was guided along the raised lines by the experimenter, and proprioceptive modes, where the exploring hand was guided passively along the outline of a figure with no raised lines, were involved in their experiments. With regard to the source of information available to the subject, they indicated that tactile inputs in the absence of proprioceptive ones in the tactile mode were not sufficient to give optimal performance. Therefore, they suggested that proprioceptive information concomitant with movement played a critical role in the tactual pattern recognition. If it is appropriate to apply these findings in this study, a degree of activation during the tactile mode should be smaller than that during the active mode within the peri-rolandic cerebral cortex contralateral to the stimulated hand. As seen in Figure 1 however, the apparent degree of activation during the active mode was rather less within those areas, despite that a larger amount of information was available to the subject in the active than in the tactile mode. Ginsberg et al.[3] have compared cerebral glucose metabolic rate during active manipulation of mah-jongg tiles with that during passive vibratory stimulation within the somatosensory cortex and found that the mere passive reception of stimuli influenced cortical metabolism less vigorously. They indicated that somatosensory tasks involving active participation and conscious effort could elevate glucose metabolism in the somatosensory cortex. The discrepancy between poorer performance and the larger amount of activation may be explained by conscious effort: that is, the subject may concentrate more attention on his fingertip in the tactile mode because of the limited amount of information.

During the active mode, there were increases in rCBF in the midtemporal and inferior temporal cortex (area TE). It has recently been suggested that a ventral pathway of projections from the striate cortex to the inferior temporal cortex was crucial for the visual identification of objects[9]. Probably, the visual properties of the particular object is coded within area TE, and this area serves as the store for the later recognition. Sampled somatosensory information about the figures might be converted into a visual image, and then, stored visual information might be retrieved from TE for matching, which resulted in the increases in rCBF within these areas during the active mode. On the other hand, greater conscious effort caused rCBF increases within the somatosensory association cortex during the tactile mode, while, because of the limited amount of incoming information, visual images might not be reconstructed in this mode; so that this leads poorer performance than the active mode.

It has been found that the anterior superior prefrontal cortex was strongly activated during tasks in which subjects were required to direct their attention toward a specific sensory modality. Based on these findings, Roland[6] postulated a mechanism of differential turning: there existed two different neural mechanisms during execution of the goal-directed tasks. One participated in the modality-specific information processing such as feature extraction of incoming sensory inputs, perception, and cognition, and the other was selective attention-dependent mechanism independently on stimulus rates and intensities. However, different patterns of co-activation observed in this study support the idea that there exist some separate networks of attention that perform different but interrelated functions[10], rather than the idea that a single neural mechanism acts to control attention. Furthermore, the frontal cortex in the right hemisphere showed localized increases in rCBF during the active and tactile modes, which may indicate that these areas participate in the maintenance of an alert state[10].

In the present study, we could not superimpose PET images on MRI images on the same slice level, so that the anatomical structures participating in tactual pattern perception could not be identified in detail. Further analysis will be necessary in this point.

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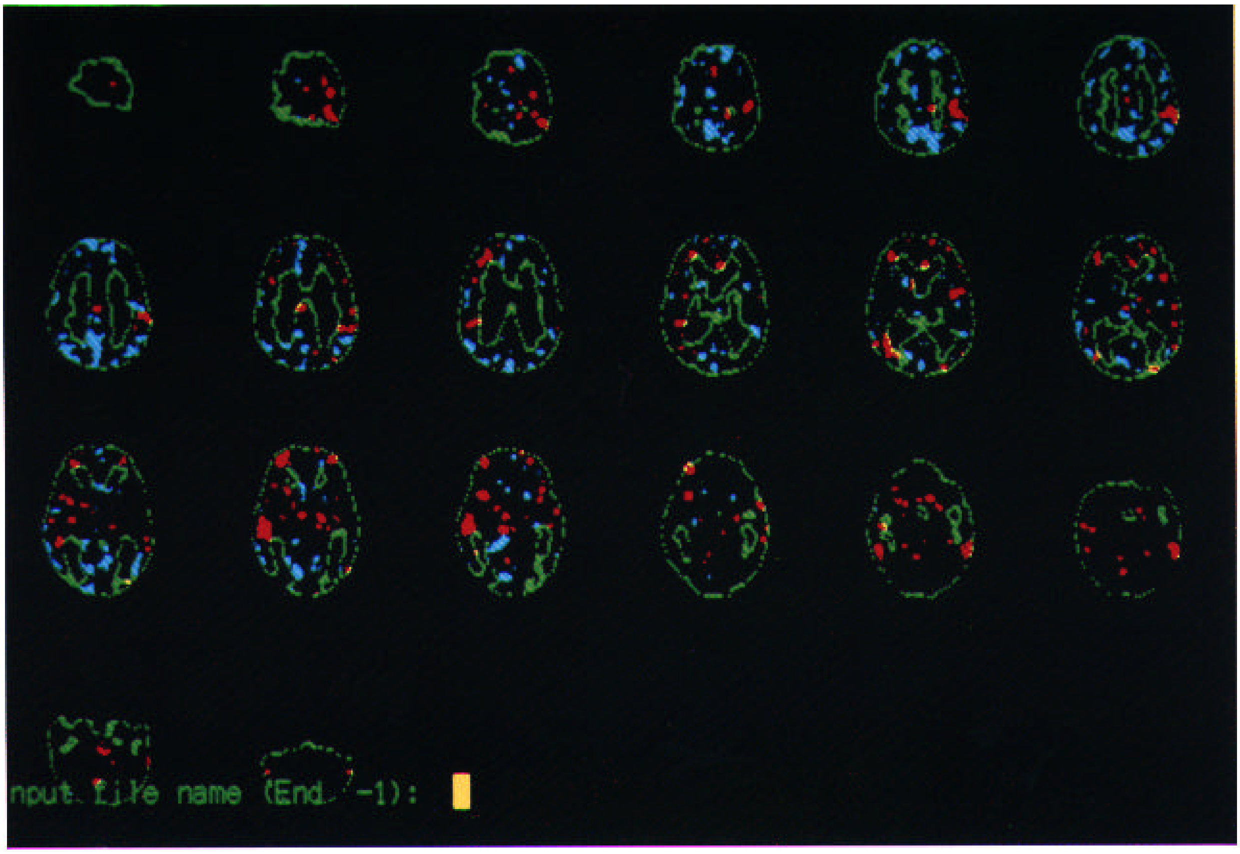
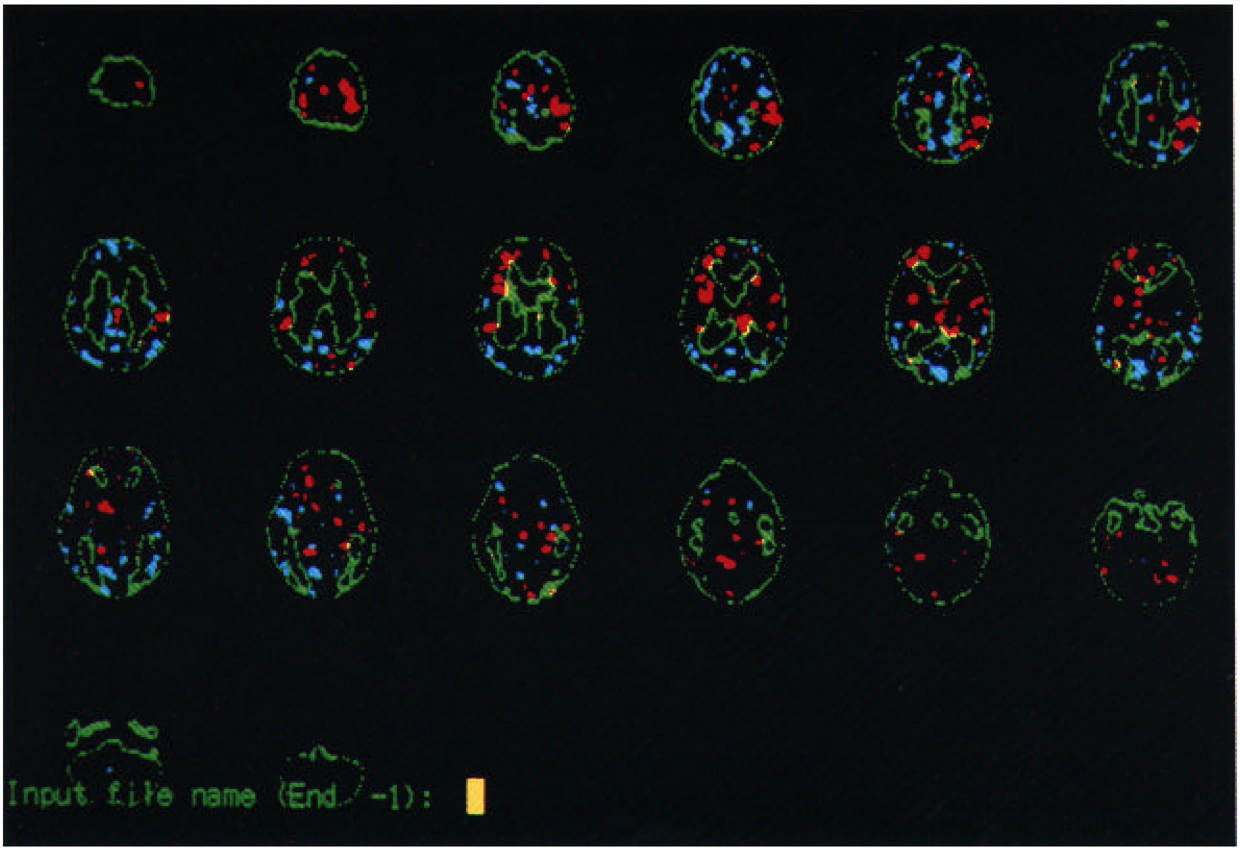
Table 1. The time schedule in the experiment.

Time (min)	*Task*	*PET scanning*
20	*rest*	*transmission scanning*
3	*control 1*	*emission scanning 1*
5	*rest*	
6 or 9	*active mode*	*emission scanning 2*
5	*rest*	
6 or 9	*tactile mode*	*emission scanning 3*
5	*rest*	
3	*control 2*	

Note: The presentation order of the active and tactile modes was counterbalanced as possible over 4 subjects.



(A)



(B)

Fig. 1. Changes in rCBF, induced by the active (upper picture) and tactile (lower picture) modes. Each section of the brain is viewed from below (shown with the right side of the brain to the left). The slices of the brain proceed from the top of the brain to the bottom. During each mode, a marked increase in rCBF compared to the rest condition (t-test; .5% in significance level) is represented in the red zone, and a significant decrease in the blue.