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Tactile discrimination activates the visual cortex of the recently blind naive to Braille: a functional magnetic resonance imaging study in humans

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Abstract

The occipital cortex of blind subjects is known to be activated during tactile discrimination tasks such as Braille reading. To investigate whether this is due to long-term learning of Braille or to sensory deafferentation, we used fMRI to study tactile discrimination tasks in subjects who had recently lost their sight and never learned Braille. The occipital cortex of the blind subjects without Braille training was activated during the tactile discrimination task, whereas that of control sighted subjects was not. This finding suggests that the activation of the visual cortex of the blind during performance of a tactile discrimination task may be due to sensory deafferentation, wherein a competitive imbalance favors the tactile over the visual modality.

Keywords: Functional magnetic resonance imaging; Visual cortex; Tactile discrimination; Blind; Blood flow; Braille reading

Braille is the most successful system for the transmission of written information to the blind. In this method, visual perception of printed characters is replaced by tactile interpretation of raised dots. Braille is a complex mental process involving finger movement control, dot perception, pattern recognition, and lexical and semantic processing. Braille reading is known to activate the visual cortex of the blind [2,3,12–14], indicating remarkable cortical plasticity. However, such findings typically come from experiments employing early blind subjects who have undergone Braille training from a young age. As a result, it is not clear whether visual cortex activation is related to long-term Braille training or to visual deafferentation. A previous study has shown that non-Braille haptic processes activate the visual cortex of the blind who read Braille proficiently, which is consistent with the latter hypothesis [13]. To address this question directly, we examined visual cortex activation during performance of a passive tactile discrimination task in late-onset blind subjects who were naive to Braille reading, and in sighted controls.

For the fMRI study, we recruited two late blind subjects suffering from retinitis pigmentosa. The first was a 36-year-old man who, 2 years prior, had been sufficiently sighted to conduct a clerkship; however, over the following 2 years, his visual angle decreased to five degrees. At the time of the fMRI study, his visual resolution was limited to the detection of hand movements. The second subject was a 40-year-old woman who, 9 years prior to the study, had a visual angle of five degrees; by the year preceding the study, she had lost all vision with the exception of subtle light perception. Neither subject had learned Braille prior to the fMRI scanning. As controls, we recruited 19 sighted volunteers, eight women and 11 men (24.9 ± 3.6 years, mean ± SD). All subjects were right-handed by the Edinburgh handedness inventory [10]. None of the volunteers had a history of neurological or psychiatric illness, or suffered from any neurological deficits, with the exception of the two cases of blindness. The protocol was approved by the ethics committee of Fukui Medical University, and all subjects provided written informed consent for the study. For the blind participants, all the documents were read aloud

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by the experimenter with the presence of the sighted witness unrelated to the experiment.

We employed the same task and scanning protocol as previously described by Sadato et al. [14]. In brief, the Braille tactile discrimination task session consisted of six task and six rest periods in alternation, each 30 s in duration. Stimuli were presented passively on a plastic rail imprinted with different pairs of two-dot standard Braille characters (5 mm center-to-center distance). The rail was contained inside a skid (1 m in length) affixed to the left side of the subject's body, and was moved manually by an examiner located outside the MRI gantry. The subject placed his right arm across his chest and rested his fingers at a fixed position on the skid, with the pad of his right index finger on the rail. The subject's finger was initially placed between two consecutive pairs of Braille characters. During the task, the examiner moved the rail to present the pair of Braille characters to the subject's finger pad. The rail was moved three times in 3 s: 30 mm in the head-to-foot direction for 1 s, 30 mm in the foot-to-head direction for the next second, and 30 mm again in the head-to-foot direction for 1 s. Three seconds after the rail stopped moving, the examiner touched the subject's left toe, cuing him to respond. Using his left hand, which was placed on a box connected to a microcomputer, the subject pushed a button using his index finger if the pair-wise characters were the same, or a different button using his middle finger if the characters were different. This was followed by a 30 s rest period during which no tactile stimulus was presented; instead, every 6 s the subject was cued (again by a touch to his left toe) to push buttons alternately with his left index and middle fingers. A total of 30 pairs of Braille characters were presented, half different and half identical. The blind subjects kept their eyes closed through all sessions. Task conditions were the same for sighted subjects, except that the response cue was given visually. This was to control the eye movement of the sighted subjects, because saccadic eye movement is known to suppress the activity of the striate cortex even in darkness [14].

A time-course series of 126 volumes was acquired using T2*-weighted, gradient echo, echo planar imaging (EPI) sequences with a 3.0 Tesla MR imager (VP, General Electric, Milwaukee, WI). Each volume consisted of 36 slices, with a slice thickness of 3.5 mm and a 0.5 mm gap, to

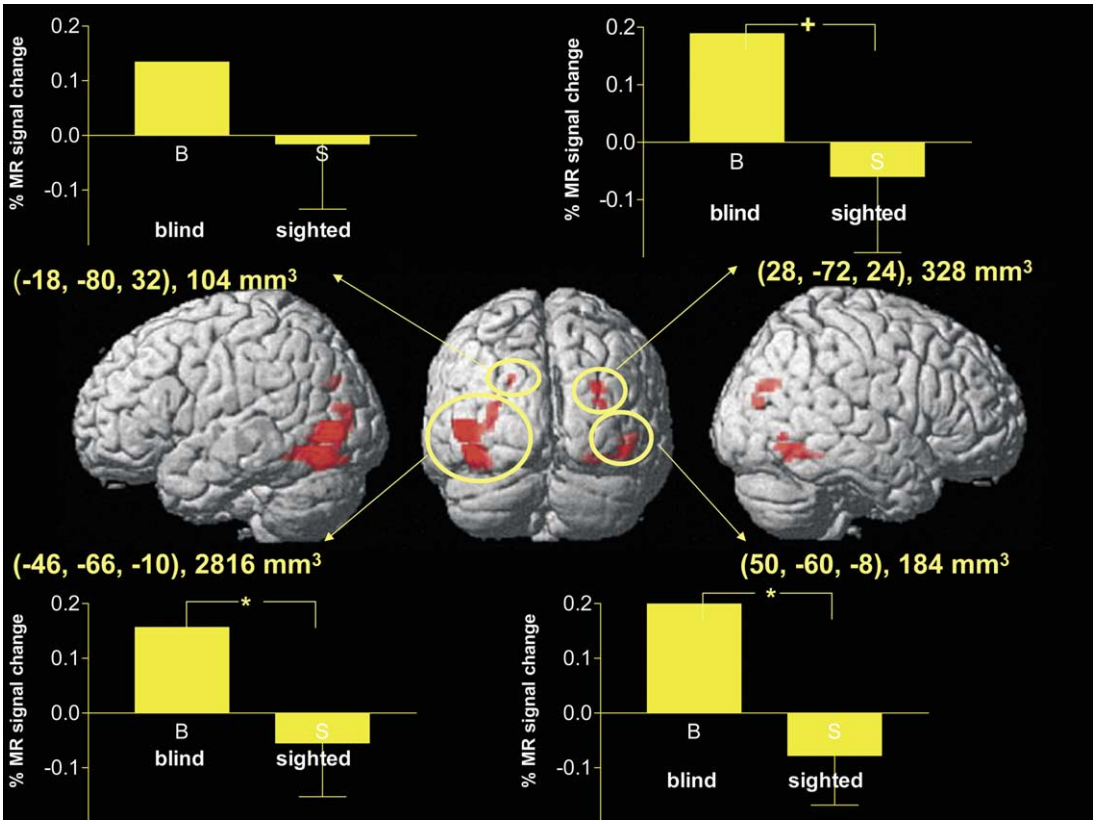

Fig. 1. Regional activation during tactile discrimination task performance by late blind subjects who had never learned Braille. (Middle row) Statistical parametric maps of significant activation ($P < 0.05$ with correction for multiple comparisons in each subject) common to both subjects during the tactile discrimination task as compared with the rest period. Functional activation is superimposed on surface-rendered, high-resolution MRI scans of unrelated individuals viewed from the left (middle left), from the back (middle center), and from the right (middle right) of the head. Averaged task-related percent signal change of the cluster in the left (upper left) and right (upper right) superior occipital gyrus, and in the left (bottom left) and right fusiform gyrus (bottom right) of blind ($N = 2$) and sighted ($N = 19$) subjects. The local maximum (in Talairach's coordinates) and size (mm^3) of each cluster are also indicated. A two-sample t-test revealed a significant group difference in the bilateral fusiform gyrus ($^*P < 0.01$), and the right superior occipital gyrus ($^+P = 0.018$), whereas the left superior occipital gyrus did not reach the predefined threshold ($P = 0.099$).

include the entire cerebral and cerebellar cortex. The time interval between two successive acquisitions of the same image was 3000 ms, and the echo time was 30 ms. The field of view (FOV) was 22 cm.

Data were analyzed using statistical parametric mapping (SPM99, Wellcome Department of Cognitive Neurology, London, UK) implemented in Matlab (Mathworks, Sherborn, MA) [5–7]. Statistical analysis was tailored to each blind subject to focus on appropriate regions of interest in the occipital cortex. The threshold of individual analyses was set at $P < 0.05$ with a correction for multiple comparisons for the occipital cortex [8]. Common activation of the blind subjects during the discrimination conditions was depicted by the intersection of the areas significantly activated in each subject. The percentage signal change within these clusters in the blind subjects was compared with that of sighted controls.

Blind subjects responded correctly at a rate of 53.3%, whereas normal sighted subjects did so at 67.4 ± 7.6%. In the late blind subjects, tactile discrimination activated bilateral fusiform gyrus (Brodmann area 37) with local maxima at (−46, −66, −10) and (50, −60, −8) in Talairach's coordinates [15], and the superior occipital gyrus (Brodmann area 19) with local maxima at (−18, −80, 32) and (28, −72, 24). These areas did not show any significant activation in the sighted group (Fig. 1). Group difference assessed by the two-sample *t*-test at the second level analysis with random effect model revealed a significantly more prominent activation in the blind than the sighted in the bilateral fusiform gyrus ($P < 0.01$), and right superior occipital gyrus ($P = 0.018$), whereas the left superior occipital gyrus did not reach the predefine threshold ($P = 0.099$).

Blind subjects, both early and late onset, usually acquire Braille reading because it is an important skill for their daily life. Hence it is a rare chance to include the blind subjects who are naive to Braille in fMRI studies. Although confirmation of the reproducibility is difficult because of the limited number of subjects, individual analysis confirmed that the occipital activation of each blind subject was statistically significant. Furthermore, group comparison at the second level analysis with random effect model revealed significant group difference. Hence the present study can be regarded as a preliminary case report which revealed that the tactile-visual cross-modal plasticity seen in the late blind is not learning-dependent.

We show that a tactile discrimination task activated the association visual cortex of recently blind subjects who had never learned Braille, but not that of sighted controls. Both blind subjects had lost pattern vision but not light perception; this suggests that loss of higher, but not total, visual processing is sufficient for this activation [14].

Several prior studies have shown that tactile object recognition tasks activate the bimodal visual cortex of the blind [1,4]. In the sighted, such tasks typically activate the ventral visual cortex, a region that overlaps with the area responsible for visual object recognition [1]. This finding suggests the existence of nodes responsible for directing interactions among modality-specific sensory pathways. However, the present tactile discrimination task did not activate the visual cortex of the sighted [14]. Therefore, cross-modal activation appears to be task-dependent, and may depend on task characteristics. For example, the bimodal activation of the occipital cortex reported by Amedi et al. [1] and Deibert et al. [4] may reflect stored object-related visual information that can be accessed via cues from the somatosensory modality [1].

Taken together, these data suggest that visual and tactile processing are competitively balanced in the occipital cortex [11]. During the execution of tasks with a significant tactile element, deafferented areas of the visual cortex are recruited in the blind, but not in the sighted. Our results suggest that this recruitment is not a learning-related phenomenon, but rather due to sensory influences.

Our results do not reveal a significant difference in task performance between blind and sighted subjects. Studies have recently shown that long-term visual deafferentation can improve tactile acuity independent of prior Braille learning [9], possibly due to plasticity in the occipital cortex. Our study indicates that there is no such tactile advantage in the recently blind, yet their occipital cortices already are showing activity in response to tactile stimuli. Additional studies will be required to further delineate the functional relevance of the association visual cortex in the blind. In particular, the comparison of subjects at various stages of blindness onset could yield information regarding the time course of the plasticity of these cortical areas.

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