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Activation of the primary visual cortex by Braille reading in blind subjects

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PRIMARY visual cortex receives visual input from the eyes through the lateral geniculate nuclei, but is not known to receive input from other sensory modalities[1]. Its level of activity, both at rest and during auditory or tactile tasks, is higher in blind subjects than in normal controls[2], suggesting that it can subserve non-visual functions; however, a direct effect of non-visual tasks on activation has not been demonstrated[2–4]. To determine whether the visual cortex receives input from the somatosensory system[5–8], we used positron emission tomography (PET) to measure activation during tactile discrimination tasks in normal subjects and in Braille readers blinded in early life. Blind subjects showed activation of primary and secondary visual cortical areas during tactile tasks, whereas normal controls showed deactivation. A simple tactile stimulus that did not require discrimination produced no activation of visual areas in either group. Thus, in blind subjects, cortical areas normally reserved for vision may be activated by other sensory modalities.

Eight proficient Braille readers were studied during Braille reading (Table 1). Eight-character, non-contracted Braille-letter strings were presented every 2.4 seconds. In the 'word' condition, 41 words and 3 non-words were presented. Subjects were asked to utter 'num' only when they encountered the non-words. In the 'non-word' condition, all were non-words except for three words. Subjects were told to respond only to the words. To compare the behaviour of the posterior brain regions of blind and normally sighted individuals, non-Braille tactile tasks were performed by six other blind and ten sighted subjects (Table 1). One non-discrimination task ('sweep') and three discrimination tasks ('angle', 'width' and 'character') were included. Stimulus patterns were presented every 5 seconds. In the 'sweep' task, subjects were to sweep their index finger over a rough surface homogeneously covered with Braille dots, without response. In the 'angle' task, two grooves with the same width (3.2 mm, separated by 6.4 mm) cut in a piece of paper homogeneously covered by Braille dots were presented in pairs. Subjects were to respond ('num') when the angles were the same. In the 'width' task, a response was expected when the two vertical grooves (either 3.2 mm or 4.6 mm in width) presented had the same width. In the 'character' task, three upper-case English letters embossed with Braille dots (12.7 mm in height and 10.2 mm in width) were presented together. Subjects were to respond if the three letters were identical. In each task, the pattern was identical in 3 of 30 presentations. No spatial or mental imagery was requested.

Braille reading by the blind activated the medial occipital lobe (Brodmann's area 17) extending to the extrastriate cortices bilaterally (Fig. 1*a*, Table 2). The three non-Braille discrimination tasks also activated the primary visual cortex in the blind subjects, (Fig. 1*b*), but with a smaller increase of regional cerebral blood flow (rCBF) than Braille reading (Table 2), whereas in sighted subjects these tasks elicited a decrease in rCBF (Fig. 1*c*). The non-discrimination task did not activate the primary visual cortex in either the blind or the sighted subjects (Table 2).

Whereas the non-discrimination task did not activate the primary visual cortex of the blind subjects, the tactile discrimination tasks did. Subjects made verbal responses in the discrimination tasks, but not in the non-discrimination task; however, as the number of responses was very low, it is unlikely that any activation was related to them. Although the tasks used do not allow us to interpret exactly what occurs in the visual cortex, it entails the use of the somatosensory information.

In contrast with the blind, the sighted subjects had a decrease in

rCBF in the primary visual cortex during the tactile discrimination tasks. This suppression could be a by-product of selective attention to the tactile modality. A decrease in rCBF in the auditory and somatosensory cortices during visual tasks has been reported, and it has been suggested that selective attention to one sensory modality is associated with decreased activity in areas dedicated to processing input from other sensory modalities[9]. Selective attention to vibrotactile stimulation of the fingers in normal subjects increased the CBF response in the primary sensorimotor cortex[10]. This evidence suggests that selective attention does not affect the primary visual cortex the same way in blind and sighted subjects.

Visual imagery[11] is an unlikely explanation of our findings because subjects blinded early in life have little or no 'visual' memory to aid their Braille reading, which was usually learned after the loss of sight. Spatial imagery based on haptic ('active touch') experience exists in congenitally blind people[12]. The congenitally blind subjects who performed Braille-reading tasks showed the same activation of the primary visual cortex as the other blind subjects.

The greater activation in the primary visual cortex during Braille reading than during non-Braille discrimination tasks could be a result of many factors, such as faster presentation of the stimuli, increased complexity of the task, or lexical processing.

TABLE 1 Subject data and task performance

	Blind		Sighted
	Braille ($N = 8$)	non-Braille ($N = 8$)	non-Braille ($N = 10$)
Age (years)	49.6 ± 7.1	42.2 ± 7.7	32.4 ± 8.1
Sex (men/women)	4/4	4/2	3/7
Handedness	right	7 right, 1 left	right
Age of onset of blindness	4.3 ± 5.5	1.5 ± 2.1	
Cause of blindness (congenital/acquired)	2/6	1/5	
Age of learning Braille	5.9 ± 1.1	5.3 ± 0.8	
Years of reading Braille	43.8 ± 6.6	36.8 ± 7.6	
Daily practice (h per day)	2.2 ± 1.1	2.8 ± 1.9	
Overall performance (% accuracy)*	95.7 ± 3.2	92.5 ± 7.9	87.1 ± 6.8
Non-word task performance (% accuracy)*	97.1 ± 2.7		
Word task performance (% accuracy)*	94.4 ± 4.0		

* Accuracy = (correct responses/number of presentations) × 100.

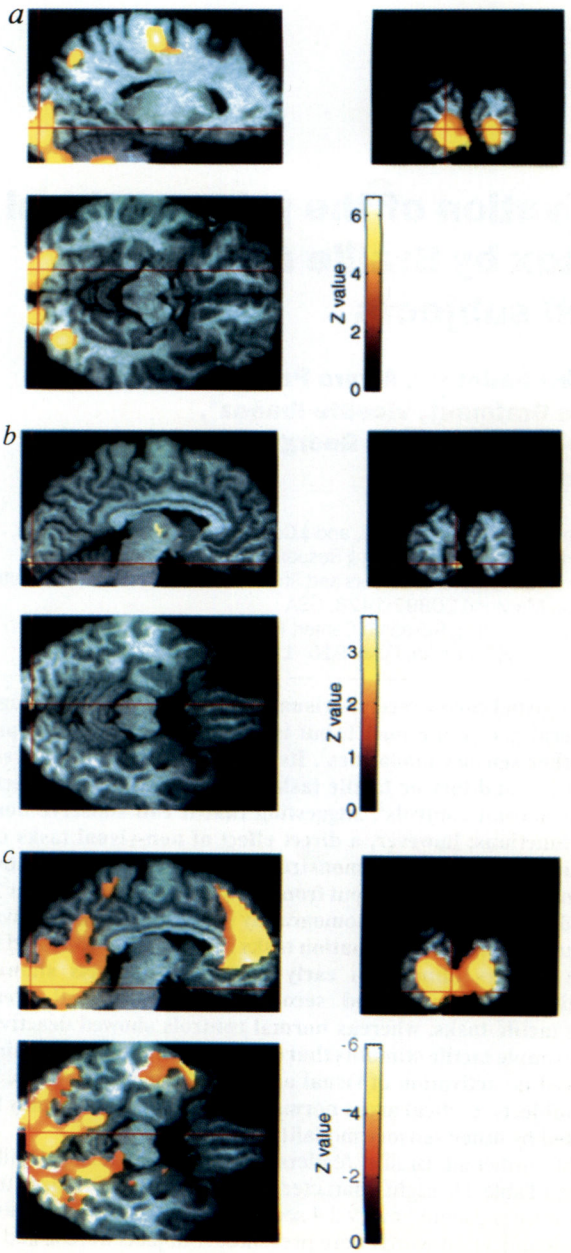

FIG. 1 *a*, Adjusted mean rCBF in blind subjects reading Braille with the right index finger compared with rest. A statistical parametric map of group analysis in three orthogonal sections was superimposed on a typical anatomical magnetic resonance image (MRI) unrelated to the study's subjects (as shown in *b* and *c*). All PET scans were normalized into the standard, proportional stereotaxic space of Talairach and Tournoux[19]. The red lines indicate the projections of each section that cross in the centre of the activation in the primary visual cortex; the Talairach's coordinates are: $x = -16$ mm, $y = -98$ mm, and $z = -8$ mm. The coronal section is 98 mm posterior to the anterior commissure, the transverse section is 8 mm below the anterior–posterior commissural line, and the sagittal section is 16 mm left of the mid-sagittal plane. Only pixels are shown that were significantly different between conditions at $P < 0.05$ with a correction for multiple comparisons[20] to keep the false-positive rate at the defined level for the entire brain. Activation of V1 during Braille reading was also shown by a functional MRI study[21]. *b*, Activation in blind subjects performing non-Braille discrimination tasks compared with rest. Activation in the primary visual cortex is seen with smaller *Z*-score than that observed with Braille reading (Table 2). Talairach's coordinates in the centre of the activated area are: $x = -6$ mm, $y = -98$ mm, and $z = -16$ mm. Only pixels that were significantly different between conditions at $P < 0.001$ without a correction for multiple comparisons are shown, as our search was restricted to the primary visual cortex by the results of the Braille-reading task by the blind subjects. *c*, Adjusted mean rCBF in sighted subjects performing non-Braille discrimination tasks compared with rest. There is a decrease of rCBF in the primary visual cortex. Talairach's coordinates in the centre of the deactivated area are $x = -6$ mm, $y = -98$ mm, and $z = -16$ mm. Only pixels that were significantly different between conditions at $P < 0.001$ without a correction for multiple comparisons are shown.

METHODS. PET scanning was performed with a Scanditronix PC2048-15B (Uppsala, Sweden) 15-slice tomograph with interslice spacing of 6.5 mm. Images were reconstructed to a full width at half maximum of 6.5 mm. Images of cerebral blood flow were obtained by summing the activity occurring during the 60-s period following the initial increase in cerebral radioactivity after an intravenous bolus injection of 30 mCi of ^{15}O-labelled water. Each task began 10 s (Braille task) or 30 s (non-Braille task) before the tracer injection, and continued for the duration of the scan. The order of presentation was counterbalanced. The initial and final scans of a series of 10 were done with the subject at rest. The data were analysed with statistical parametric mapping[22–24].

TABLE 2 Activation in the primary visual cortex by tactile discrimination tasks performed by the right index finger

	Non-discrimination ('sweep') task versus rest		Non-Braille tactile discrimination tasks versus rest		Braille reading vesus rest
	Sighted	Blind	Sighted	Blind	Blind
	($n = 10$)	($n = 6$)	($n = 10$)	($n = 6$)	($n = 8$)
Change in CBF (%)	−2.71	1.09	−3.87	6.48	9.73
Z-score	−1.98	0.37	−3.34*	3.64†	5.61‡
Talairach's coordinates (ref. 16)	(−6, −98, −16)	(−6, −98, −16)	(−6, −98, −16)	(−6, −98, −16)	(−16, −98, −8)

In the Braille-reading task, activation in the primary visual cortex was similar for reading with the right or left index finger, hence, data are shown only for the right index finger. There was no significant difference between reading words and reading non-words. In the non-Braille tactile discrimination tasks, the data for angle, width and character, compared with the rest condition, were pooled, because the results were similar to those obtained for comparison of the individual conditions. A Bonferroni-type correction was not applied to the results of the non-Braille tactile discrimination tasks because our search was restricted to the primary visual cortex by the results of the Braille reading task by the blind subjects.

* $P < 0.001$ (uncorrected for multiple comparisons).

† $P = 0.0001$ (uncorrected for multiple comparisons).

‡ $P < 0.05$ (with three-dimensional Bonferroni-type correction).

Neuronal mechanisms of cross-modal plasticity, such as unmasking of silent inputs, stabilization of normally transient connections, or axonal sprouting, are based mainly on cross-modal plasticity of neighbouring cortical regions[13]. It has been shown that in cat anterior ectosylvian cortex, where spatial processing is a common function, auditory representation increased in size after visual deprivation[14], which led to the hypothesis that two different inputs to the region were competitive, and that deprivation of one modality accelerated the expansion of the competing pathway. A PET study with sighted subjects[15] showed that a tactile discrimination task activated the parietal cortices, but not the occipital cortex. In the monkey, the posterior parietal association cortex (area 7) is interconnected with the visual association cortex (dorsolateral area 19)[16]. Early visual deprivation in the monkey made most neurons in areas 7 and 19 responsive to somatic exploration[17]. It is known that diffuse reciprocal projections link area 19 to the primary visual cortex[18]. These findings suggest that somatosensory input could be transferred to the primary visual cortex through the visual association areas during Braille reading by blind subjects.

In blind subjects, the primary visual cortex appears capable of reorganizing to accept non-visual sensorimotor information, possibly for further processing. Braille reading, which requires prolonged somatosensory tactile learning, may enhance this plasticity. □

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