Functional neuroimaging studies of Braille reading: cross-modal reorganization and its implications

A frequent criticism of functional neuroimaging is that it offers limited additional information to that obtained with lesion studies. However, there are many cases in which lesion studies are not sufficient to study principles of cortical organization. One such case is cross-modal reorganization in the human brain after sensory deprivation. Vision is the dominant human sense and its loss leads to a major disability. However, the advent of modern information technology has made life easier for blind people. Spatial orientation in natural environments can be aided by a novel mobile satellite based Global Positioning System with a voice synthesizer, allowing blind subjects to reach a location by electronic guidance through the auditory modality. Another, well known sensory substitution is the tactile letter system Braille. Although attributed to Louis Braille, this system has its roots in the military field. In the early 18th century, Charles Barbier, a French soldier, invented a tactile reading and writing system that coded sounds as tactile patterns. Its intended use was silent communication in complete darkness along trenches. However, it quickly transpired that the system was too complicated to be of practical use. In 1821, Charles Barbier met Louis Braille, who was blind from the age of 4 years. Louis Braille immediately realized how useful this system of raised dots could be and simplified it from the original 12 to six dots. From then on it only took 6 more years until the first book in Braille was published.

Early research on Braille reading in blind subjects from the 1960s to the 80s has mainly focused on hand preference. The first experimental data on possible cortical reorganization in blind subjects came from experiments conducted by Wanet-Defalque et al. (1988). They used PET and [18F]fluorodeoxyglucose to investigate the effects of early onset blindness on cortical metabolism. Surprisingly, they observed vastly elevated glucose metabolism in the visually deprived occipital cortex of early blind subjects which was comparable to metabolism seen in sighted subjects studied with their eyes open. The most interesting question arising from this result was whether metabolic activity is task dependent. Unfortunately this question could not be answered by this initial experiment. Several groups (Sadato et al., 1996; Büchel et al., 1998) followed up on this question, now using H215O PET which allowed assessment of more subtle differences in regional activity. Both studies showed that occipital cortex activation is indeed task dependent and is related to tactile processing in congenitally and early blind subjects. In this issue of Brain, Sadato et al. (1998) present a broader view of their data, especially the role of the secondary somatosensory area (SII) in the context of Braille reading. The authors report activations in SII in sighted subjects, whereas the same region shows deactivations in the blind. Conversely, blind subjects show activation of occipital areas during tactile reading whereas in sighted subjects these areas are deactivated in a comparable tactile reading task.

This leads on to a crucial question first raised by electro-physiologists (Rosler et al., 1993) of whether occipital activations in blind subjects are necessary for Braille reading or represent an epiphenomenon. This issue has been subsequently addressed by an experiment using repetitive transcranial magnetic stimulation (rTMS) (Cohen et al., 1997a). In this study rTMS was used to functionally ‘lesion’ different brain regions to isolate regions that are necessary for Braille reading in early blind subjects. Transient inactivation of the occipital cortex led to impairment of Braille reading and even to the perception of ‘phantom dots’. Surprisingly, stimulation of somatosensory cortex contralateral to the reading hand did not interfere with reading abilities. This finding is in accord with results from the study by Sadato et al. (1998) showing that in blind subjects secondary somatosensory cortex is deactivated during Braille reading. The authors suggest that instead of SII, blind subjects activate a ventral occipital area that might be analogous to area TEO in the monkey. This is an interesting hypothesis because SII and this ventral occipital area share the functional property of shape discrimination, the former for tactile shapes and the latter for visual shapes.

Although speculative, the finding that rTMS over somatosensory regions does not disrupt Braille reading could point towards a different mechanism of cross-modal visuo-tactile reorganization. So far, it has been assumed that cross-modal plasticity, similar to within modality reorganization (Merzenich and Kaas, 1982) is based on corticocortical connections to reroute information. In the case of occipital cortex activations in blind subjects it is assumed that information reaches the cortex through the somatosensory thalamus and is then relayed through primary somatosensory cortices via parietal cortex to occipital cortex. A more parsimonious approach would be to postulate cross-modal reorganization at the thalamic level. Changes at the thalamic level have
been observed in the congenitally blind mole rat. In this subterranean animal the somatosensory thalamus almost reaches the dorsolateral surface, mirroring the advantage of tactile over visual processing for a life in darkness (Rehkamper et al., 1994).

Another important issue in the context of cross-modal plasticity is the time window in which such plastic changes can occur. This question has recently been addressed by Cohen et al. (1997b) studying blind subjects who lost their sight later in life (i.e. at age 15 years) than those reported in the study by Sadato et al. (1998) in this issue of Brain. Similar to their first experiments, Cohen et al. used PET and rTMS to investigate cross-modal reorganization. In accord with the notion that plastic changes are more likely to occur during early development, they could neither find activations in the occipital cortex with PET, nor disturb Braille reading by stimulation of the occipital cortex by rTMS in these subjects. This study highlighted that age of onset of blindness is a critical variable in cross-modal reorganization. However, there are other factors of similar importance. A previous PET study also on subjects who had lost their sight after puberty was reported by Büchel et al. (1998). The subjects in this study had deteriorating vision early in life and were told that they would become completely blind, which led them to start learning Braille at the age of 5 years, when their eyesight still allowed them to read visually. In these subjects cross-modal reorganization of the occipital cortex was demonstrated, indicating that intensive tactile experience early in life might be another important factor for cross-modal reorganization. Moreover, these results imply the coexistence of visual and tactile processing in the occipital cortex before the onset of complete blindness. These results also have major implications for the future education of visually impaired children who are likely to develop complete blindness.

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References