Tactile vision: neuroimaging and brain-reorganization in the blind; implications for learning and adaptive-technology

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INTRODUCTION

Sensory impairment raises interesting questions regarding the brain's ability for functional reorganization. One particularly interesting instance of this reorganization is the remarkable remapping (called cortical plasticity) of visual areas in the blind population. Previous neuroimaging studies have demonstrated activation in visual areas of blind subjects in response to feeling tactile stimuli (Sadato et. al, 1996, 1998; Cohen et. al, 1997; Buchel et. al 1998). In this experiment, we further investigated the role of the traditional visual areas of the brain in tactile pattern recognition and shape discrimination in blind and sighted people. While the literature demonstrates some level of functional reorganization in the brains of blind individuals, many questions remain unresolved. In particular does tactile stimulation result in:

1. A difference in primary visual cortical activity between sighted and blind populations?
2. A difference in activity of other visual brain regions between sighted and blind populations?
3. Different activation patterns across visual cortices due to different types of tactile patterns?

By making use of the high spatial resolution of functional magnetic resonance imaging (fMRI), we hope to find out if the traditional visual (occipital) and other higher level visual regions show different patterns of activity in blind participants in response to presentation of different types of tactile stimuli

(Braille, embossed Roman letters, tactile shapes, tactile noise and smooth conditions). Since all but the braille reading conditions can be similarly discriminated or recognized between the blind and sighted groups, we can directly compare brain activation sequences across groups.

METHODS

Participants

The experiment incorporated three blind subjects and three sighted controls. All three of the blind subjects were early-onset. The blind were all proficient Braille readers, as measured by an earlier psychophysical experiment (Legge, Madison and Mansfield, Visual Impairment Research, in press).

Stimuli and procedure

Tactile stimuli were embossed on 11 X 11.5-inch cards. For each scan participants were presented with one of the cards and asked to read or identify the tactile stimuli with their dominant index finger, moving it along the line at approximately the speed of normal Braille reading.

Imaging

Imaging was performed on a standard clinical 1.5 T Siemens Vision MR system. Functional MRI data were obtained over the entire brain and overlaid on anatomical images of the same regions.

RESULTS

The most obvious finding of this experiment is the difference in patterns of occipital cortex (the traditional visual region in sighted people) activation between the blind and sighted groups. Blind participants demonstrated activation in primary visual, extrastriate and higher level visual cortices in response to tactile stimulation, whereas sighted subjects showed no such consistent "visual" activation to the same tactile stimuli. An important new finding is the observation of functionally relevant reorganization in all three blind participants. That is, while meaningful stimuli, like the Braille, embossed roman letters and tactile shapes showed the greatest and most defuse occipital activation in the blind subjects, the presentation of tactile noise alone showed little activation in these regions. In concert with this progression of salience and functional relevance is a fairly consistent pattern of areas associated with higher visual processing being activated by the more meaningful tactile stimuli across the blind participants.

Another unexpected result was the finding of similar, although weaker, patterns of visual activation in the sighted participants. Taken together, it seems that tactile information processing does occur in the visual regions of blind people and the loci of activation seem related to the meaningfulness or functional relevance of the stimuli. Where tactile noise and difficult to discriminate shapes activated extrastriate visual regions, the more meaningful roman and Braille words showed more primary and higher level visual activation, with bilateral inferior temporal (a visual face recognition area) activation observed in all three blind participants during Braille reading. The sighted participants demonstrated some occipital activation in response to tactile shape recognition but these activation sequences were much weaker and less robust than those observed in the blind subjects.

DISCUSSION and future implications to adaptive technology

The most significant result of this paper is the finding of stimulus specific reorganization. That is, tactile stimuli activate visual areas differently, with meaningful stimuli showing the most dynamic activation in visual regions. Another new finding is that higher-level areas of visual cortex (area IT) are active during tactile pattern recognition in blind subjects. The finding that a few of the sighted participants also show some visual activation in the "meaningful" condition was initially surprising but is congruent with several recent studies implicating the visual cortices in tactile object recognition in sighted participants. Work by Deibert and colleagues (1999) has shown that tactile object recognition in sighted subjects involves striate and extra-striate regions.

In future experiments, it will be important to determine if this kind of brain remapping in the blind is age-dependent or if it can occur later in life. If functional reorganization is possible in older people who are losing their vision (a growing percentage of our aging population) it will be critical to establish which types of learning paradigms and what kind of technology best help to facilitate this neural reorganization.

Adaptive technology presents viable possibilities for both training and testing in the development of such compensatory learning strategies. For instance, my main interest is blind/low-vision navigation. Traditional experiments investigating navigational performance with neuroimaging tasks use so called first-person virtual reality games. These are not accessible to blind people.

The advantage of these games is that they involve strategies and processes involved in real navigation (and thus activate the brain regions associated with navigation), are easy to score and tweak via the computer and can be run both in the lab and inside the MRI machine. Thus, both training and testing can occur under controlled conditions but with a feeling of real-time presence. There are several currently available adaptive technologies that may be very useful for the training/testing of spatial knowledge and navigation in blind people and which may also allow us to determine the best way to teach spatial information. Efficient navigation is crucial for independence and establishing how to get the most "neuro-hardware" to be allocated to the task is important. We are interested in finding the optimal techniques for behavioral performance and finding out how to "work" with the brain to facilitate these changes. Devices like the VirTouch tactile mouse or Emersion's haptic force feedback mouse provide excellent possibilities for presentation and learning of spatial layouts. Such devices could be used very much like the VR mazes that have been used in past studies of navigation in sighted people. In addition, assessment of other spatial information devices and the effectiveness of the information they provide can be addressed both from a practical and neuro level, through combined behavioral/neuroimaging experiments. In this way, multiple sources of converging evidence can be used to determine the most optimal method for providing spatial directions, as with devices like Sendero's GPS-Talk or other low-vision/blind navigation aids that are being developed by our labs and others. The comparison of behavioral performance with neuro-activation and cortical change also allows us to investigate the utility and underlying mechanisms of sensory substitution devices, such as Peter Meijer's vOICe or sonic devices such as Lesley Kay's Kaspa. This understanding not only helps us to know the efficacy of these devices and determine if it is reasonable for a person to take on the steep learning curve but also provide important information about the brain's ability to organize and reorganize with sensory loss. Thus, hopefully this information will aid in development of the best compensatory strategies by designing learning paradigms and adaptive technologies that maximize our brain's amazing plastic ability to adapt and utilize tecniques that best lend themselves to this process. It remains to be known what devices will play the most important role in providing spatial information and which will lead to the most intuitive and effective use, but this study provides some of the much needed groundwork for understanding the brain's role and setting the scope for future experimentation.