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Research report

The influence of preterm birth on structural alterations of the vision-deprived brain

Catherine Y. Wan [a,b,d,*], Amanda G. Wood [b,e], Jian Chen [b], Sarah J. Wilson [a] and David C. Reutens [b,c]

[a] Psychological Sciences, The University of Melbourne, Victoria, Australia
[b] Southern Clinical School, Monash University, Victoria, Australia
[c] Centre for Advanced Imaging, University of Queensland, Queensland, Australia
[d] Department of Neurology, Beth Israel Deaconess Medical Center/Harvard Medical School, MA, USA
[e] School of Psychology, University of Birmingham, UK

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ABSTRACT

Differences in brain structures between blind and sighted individuals have not been widely investigated. Furthermore, existing studies have included individuals who were blinded by retinopathy of prematurity, a condition that is associated with premature birth. Recent pediatric research has reported structural differences in individuals who were born prematurely, suggesting that some of the structural abnormalities previously observed in blind individuals may be related to prematurity rather than being specific to blindness. In the present study, we used voxel-based morphometry to investigate gray and white matter differences between 24 blind and 16 sighted individuals. Of the blind individuals, six were born prematurely and 18 at term. Compared to those born at term, blind individuals born preterm showed differences in gray, but not white, matter volumes in various brain regions. When the preterm individuals were excluded from analysis, there were significant differences between blind and sighted individuals. Full-term blind individuals showed regional gray matter decreases in the cuneus, lingual gyrus, middle occipital gyrus, precuneus, inferior and superior parietal lobules, and the thalamus, and gray matter increases in the globus pallidus. They also showed regional white matter decreases in the cuneus, lingual gyrus, and the posterior cingulate. These differences were observed in blind individuals irrespective of blindness onset age, providing evidence for structural alterations in the mature brain. Our findings highlight the importance of considering the potential impact of premature birth on neurodevelopmental outcomes in studies of blind individuals.

* *Corresponding author*. Department of Neurology, Beth Israel Deaconess Medical Center, Harvard Medical School, 330 Brookline Ave, Boston, MA 02215, USA.
E-mail address: cwan@bidmc.harvard.edu (C.Y. Wan).
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1. Introduction

Neuroimaging studies of blind individuals have revealed the effects of visual deprivation on the organization of the human brain. Over the past decade, there has been growing evidence that implicates the occipital cortex in the processing of non-visual stimuli by blind individuals. This cross-modal plasticity has been observed in a variety of studies using tactile (Burton et al., 2004, 2002; Gizewski et al., 2003; Sadato et al., 1998, 1996; Thompson et al., 2008), verbal linguistic (Amedi et al., 2003; Burton et al., 2003), and auditory stimuli (Stevens and Weaver, 2005; Voss et al., 2006; Weeks et al., 2000). The functional relevance of the occipital cortex in non-visual processing has been demonstrated by transcranial magnetic stimulation (Pascual-Leone and Torres, 1993) and lesion (Hamilton et al., 2000) studies. In addition, experiments with blindfolded sighted individuals have demonstrated cross-modal activation during non-visual task performance (e.g., Pascual-Leone and Hamilton, 2001), suggesting that plastic changes can occur throughout life.

In contrast to the vast literature on functional reorganization, only a handful of studies have examined structural changes in blind individuals. In sighted individuals, several studies have shown that structural changes are associated with environmental demands in terms of increased volumes of specific brain structures (e.g., the hippocampus in taxi drivers, Maguire et al., 2000; the mid-temporal area in practiced jugglers, Draganski et al., 2004; the posterior parietal region and hippocampus in students preparing for exams, Draganski et al., 2006). In blind individuals, studies investigating structural brain changes have shown that their visual areas are smaller, a change that may be detected with radiological inspection (Breitenseher et al., 1998). More sophisticated analysis such as voxel-based morphometry (VBM) has revealed a reduction in gray matter volume in the primary and secondary visual areas, as well as atrophy of the optic chiasm and optic radiation (Noppeney et al., 2005; Pan et al., 2007). In addition to these areas, Ptito et al. (2008) observed gray matter decreases in the precuneus and middle temporal regions. As a complement to the investigation of gray matter, diffusion tensor imaging (DTI) showed lower white matter densities in the visual cortices, and atrophy of the geniculo-calcarine tracts in five congenitally blind individuals (Shimony et al., 2006). In another DTI study (Schoth et al., 2006), no such differences were observed between sighted controls and six blind individuals. More recent structural imaging studies have reported decreased connectivity in the inferior frontal and occipital lobes (Shu et al., 2009), and thicker cortical surface of visual areas (Jiang et al., 2009) in blind compared to sighted individuals.

In non-visual brain areas, structural changes have not been consistently observed. For example, Shimony et al. (2006) reported white matter increases in the primary somatosensory and motor areas. In contrast, Ptito et al., (2008) reported white matter decreases in the splenium of the corpus callosum and the inferior longitudinal fasciculus, and Pan et al. (2007) observed white matter decreases in the temporal lobe. A possible reason for the mixed findings could be the inclusion of blind individuals born prematurely. One of the most common causes of congenital or early blindness is retinopathy of prematurity (ROP), which results from high levels of supplemental oxygen administered following premature birth (Smith, 2003). Recent studies on preterm sighted infants have revealed significantly smaller volumes of gray matter tissues compared to full-term infants (e.g., Boardman et al., 2006; Cheong et al., 2008; Thompson et al., 2008), a change which persists to adolescence (Nosarti et al., 2008) and adulthood (Parker et al., 2008). Some of the areas affected include the putamen, insula, cuneus, fusiform gyrus, thalamus, caudate nucleus, and lentiform nucleus. Given the effects of premature birth in sighted individuals, it is likely that premature birth would also lead to structural changes in blind individuals.

Most existing neuroimaging studies on blindness-induced brain reorganization have included individuals with ROP. It is therefore possible that prematurity, rather than blindness, contributes to some of the structural changes previously reported. For example, three of five participants in Shimony et al. (2006) and four of 11 participants in Ptito et al., (2008) suffered from ROP. In Noppeney et al. (2005), five of 11 participants were congenitally blind, and ROP was listed as one of the causes of blindness in their participants.

The present study used VBM to examine region-specific changes in gray and white matter as a result of complete blindness. In addition, because many studies have shown that premature birth can lead to considerable changes in brain structures, at least in sighted individuals, we were motivated to examine the effect of prematurity in blind individuals.

2. Methods

2.1. Participants

24 blind volunteers (mean age 42 years, age range 21–63) and 16 sighted controls (mean age 37 years, age range 22–53) participated in this study. All were right-handed. In all blind participants, blindness was caused by peripheral defects. At the time of testing, blind individuals had no pattern vision, and minimal (or no) sensitivity to light. Furthermore, they had no significant hearing loss, as assessed by an audiogram. All participants were reported to have no neurological or psychiatric disorders. Radiological reports from the MRI scans also indicated no neurological abnormalities.

Among the blind participants, six reported to be born prematurely and they all had prematurity of retinopathy (ROP) as their cause of blindness. All sighted individuals reported to be born at term. Table 1 presents the demographic characteristics of the blind participants. The study was approved by the Human Research Ethics Committee of Southern Health and all participants gave informed consent.

2.2. Data acquisition

A Siemens 1.5 T Symphony system was used to acquire T1 anatomical volumes yielding 144 sagittal slices with a voxel size of .5 × .5 × 1 mm^3 (MP-RAGE-sequence, TR = 1.98 sec, TE = 3.93 sec, matrix size = 256 × 256, FOV = 250 mm).