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Research report

Failure in developing high-level visual functions after occipitoparietal lesions at an early age: A case study

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ARTICLE INFO

Article history:
Received 26 December 2012
Reviewed 4 February 2013
Revised 6 April 2013
Accepted 13 July 2013
Action editor Jason Barton
Published online 23 July 2013

Keywords:
Development
Object selectivity
Ventral visual pathway
Early visual cortex
Cortical lesion

ABSTRACT

Previous functional magnetic resonance imaging (fMRI) studies have identified several regions in the ventral visual pathway that are specialized for processing faces, words and general objects. However, little is known about the origin of the functional selectivity of these regions. Here, we reported a pediatric patient who suffered a left occipitoparietal lesion in the first year after birth from a subdural hematoma. After the hematoma was removed at the age of six, the hemianopia in the right visual field was alleviated, and no obvious deficits in low-level vision were observed in the patient at the age of twelve. In line with the behavioral observations, meridian mappings with fMRI showed that the early visual cortex of the left hemisphere was significantly activated, which was similar to that of the intact right hemisphere. However, the left ventral temporal cortex failed to show selective responses for faces, words and objects, which were in contrast to the normal selective responses for these objects in the right counterpart. Therefore, it is likely that the development of object selectivity in the ventral temporal cortex depends on visual inputs from the early visual cortex at an early age.

1. Introduction

Previous functional magnetic resonance imaging (fMRI) studies have identified multiple functionally specialized regions in the ventral visual pathway that respond selectively to particular object categories (e.g., faces, words and general objects) (Cohen et al., 2000; Grill-Spector et al., 1999; Kanwisher, McDermott, & Chun, 1997). Although adult-like object-selective responses are observed in children as early as the age of five (Golarai et al., 2007; Scherf, Behrmann, Humphreys, & Luna, 2007), only until adolescence does the object selectivity reach the adult level (Aylward et al., 2005; Brem et al., 2006; Gathers, Bhatt, Corbly, Farley, & Joseph, 2004; Golarai et al., 2007; Nishimura, Scherf, & Behrmann, 2009; Passarotti et al., 2003; Robbins, Shergill, Maurer, & Lewis, 2011; Scherf et al., 2007). During development, the size of the object-selective regions is expanded (Aylward et al., 2005; Golarai et al., 2007; Scherf et al., 2007), and the selectivity is

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0010-9452/$ – see front matter
http://dx.doi.org/10.1016/j.cortex.2013.07.009

increased (Pascalis, de Haan, & Nelson, 2002; Peelen, Glaser, Vuilleumier, & Eliez, 2009; Scherf et al., 2007). Even in adults, the visual cortex is still malleable, and short-term visual experiences are able to shape the functionality of these regions (Kourtzi & DiCarlo, 2006; Op de Beeck & Baker, 2010; Song, Bu, Hu, Luo, & Liu, 2010; Song, Hu, Li, Li, & Liu, 2010; Song, Tian, & Liu, 2012). These findings together suggest the important role of continuous visual experiences in the development of the functional selectivity of object-selective regions in the ventral pathway (Johnson, 2001; Lewis & Maurer, 2009). However, little is known about how critical visual experiences are in shaping the high-level visual cortex during development. Here, we reported a case in which a pediatric patient had experienced hemianopia in the right visual field since the first year after the birth and then recovered after surgery was performed when the patient was six. We examined whether the functional selectivity in the left temporal cortex developed properly in the absence of visual inputs at an early age.

Studies of visual deprivation and lesions have provided ample evidence for the critical role of visual inputs in functional development. The pioneering work of Hubel and Wiesel (1963, 1965) of testing visually deprived cats has shown that visual inputs are critical for the development of binocular vision. Studies have shown that high-level visual functions that develop later are more likely to be affected by visual experience (Daw, 2003; see also Lewis & Maurer, 2009) compared to low-level visual functions that usually develop at early ages (Crair, Gillespie, & Stryker, 1998; Horton & Hocking, 1996; Rathjen & Lowel, 2000). Bova et al. (2008) have described a pediatric patient who had an infarction of the bilateral occipital lobe at the age of two years and six months. After four years' recovery, most low-level visual functions had improved significantly, except for object recognition in a complex environment. Similar findings have been observed in studies of children with congenital or early-age cataracts. After surgical removal of the defective natural lenses of the eyes, visual inputs are largely restored, but patients are severely impaired in processing global form (Ellemberg, Lewis, Maurer, Brar, & Brent, 2002; Lewis et al., 2002), global motion (Ellemberg et al., 2005; and see Hadad, Maurer, & Lewis, 2012), and face configuration (Geldart, Mondloch, Maurer, de Schonen, & Brent, 2002; Le Grand, Mondloch, Maurer, & Brent, 2001, Le Grand, Mondloch, Maurer, & Brent, 2003). Even several years after their surgeries, the patients are still unable to process faces holistically (Le Grand, Mondloch, Maurer, & Brent, 2004; Mondloch, Le Grand & Maurer, 2003; Robbins, Maurer, Hatry, Anzures, & Mondloch, 2012).

The aforementioned behavioral studies have clearly demonstrated that the development of high-level visual functions, especially object recognition, requires visual inputs at an early age. However, it is unclear how the ventral visual cortex is affected by the disruption of visual inputs at an early age. In order to address this question, we used fMRI to investigate a pediatric patient (CGN) with right homonymous hemianopia from a subdural hematoma in the left occipitoparietal cortex that was observed when CGN was one year old. At the age of twelve years eight months, or six years and one month after the surgery, his low-level vision seemed to be fully recovered. To quantify the visual functions of the visual cortex, we first performed meridian mapping in order to examine whether the functionality of the early visual cortex was properly recovered. Then and more critically, we presented a variety of objects, including faces, words and objects, to the patient in order to characterize object-selective responses in the ventral pathway. If visual inputs at an early age are critical to the development of object-selective regions, we expected to observe underdeveloped selectivity to objects in the left ventral visual pathway. If not, after the visual inputs were restored after the surgery, we expected to observe normal or near normal selectivity for objects in the ventral pathway.

2. Materials and methods

2.1. *Case description*

CGN is a left-handed male child. He was born at term after a normal pregnancy and uneventful labor. He was diagnosed with encephalitis one and a half months after birth and was hospitalized for one month. After he was one year old, his right extremities started to involuntarily twitch. This symptom occasionally expanded to his left extremities.

When he was six years and seven months old, he participated in his first MRI scan at the First Affiliated Hospital of Jinan University, Guangzhou, China. The T1-weighted images revealed a subdural hematoma and underdeveloped occipitoparietal cortex in the left hemisphere. The hematoma was located between the left superior parietal lobule and the skull, and it caused significant atrophy around the left temporal–parietal–occipital junction (Fig. 1A). T2-weighted images showed abnormal hyperintense areas in the superior parietal lobule, precuneus, cuneus, intraparietal sulcus, and part of the superior temporal gyrus (Fig. 1B).

Besides the MRI scan, CGN participated in behavioral tests to examine his visual perception, including the rapid object naming test, clinical confrontation test, spontaneous painting test, and line bisection test (Barton & Black, 1998). In the rapid object naming test, a black fixation cross was first presented at the center of the visual field on a white background, and CGN was instructed to fixate on the cross. Then, a familiar object (e.g., car, frog or hat) was presented for 200 msec in one of nine squares that were evenly distributed in a 3 × 3 matrix, and CGN was asked to name the object (Fig. 1D). The size of a square was $4.6^\circ \times 3.4^\circ$, and the whole nine squares covered $13.7^\circ \times 10.3^\circ$ of the visual field. In Fig. 1D, the objects that CGN named correctly are marked in white, and those he failed are marked in gray. In the first trial, CGN correctly named the objects that were located in the lower left and upper center of the visual field. In the second trial, CGN correctly named the objects that were located in the upper left, lower left, and center. That is, CGN was only able to name objects that were shown in the left visual field in the rapid object naming test. In the spontaneous painting test, the picture was left centered with relatively complete left and right structures (Fig. 1C). In the line bisection test, CGN was instructed to estimate and mark the midpoint of various oriented lines that were shown on paper. He started from the upper left part of the paper and then completed all of the marking lines on the paper. All of the marks that he drew were at the center of the lines. These three