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Research report

The neural development of the biological motion processing system does not rely on early visual input

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ABSTRACT

Naturally occurring sensory deprivation in humans provides a unique opportunity to identify sensitive phases for the development of neuro-cognitive functions. Patients who had experienced a transient period of congenital visual deprivation due to bilateral dense cataracts (congenital cataract, cc) have shown, after visual re-afferentation, deficits in a number of higher visual functions including global motion and face processing. By contrast, biological motion (BM) perception seemed to be spared. The present study investigated the neural correlates of BM processing in a sample of 12 congenital cataract-reversal individuals who had underwent visual restoration surgery at the age of a few months up to several years. The individual threshold for extracting BM from noise was assessed in a behavioral task while event-related potentials (ERPs) were recorded in response to point-light displays of a walking man and of a scrambled version of the same stimuli. The threshold of the cc group at detecting BM did not differ from that of a group of matched controls (mc). In both groups, the N1 was modulated by BM. These largely unimpaired neural responses to BM stimuli together with a lack of behavioral group differences suggest that, in contrast to the neural systems for faces the neural systems for BM processing specialize independent of early visual input.

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1. Main text

Brain development comprises phases of enhanced neural plasticity during which the effects of experience are particularly strong (Hensch, 2004; Knudsen, 2004). Such phases are termed sensitive periods (Knudsen, 2004; Lewis & Maurer, 2005). The time course and the degree of experience dependence of neuro-functional development differ across brain regions and even within functional domains, as, for example, for different aspects of vision (Maurer, Lewis, & Mondloch, 2005) or language (Schachter, 1996).

Sensitive periods are properties of emerging neural circuitries (Knudsen, 2004) and have mostly been investigated in animal research using a visual deprivation approach (see pioneer work of Wiesel & Hubel, 1965). In humans only few models exist that allow for a systematic investigation of the time course and neural mechanisms of sensitive periods: such opportunities arise for example, when the re-afferentation of a deprived modality is possible. Individuals born with bilateral dense cataracts (opaque lenses that prevent patterned light to reach the retina) and whose cataracts were surgically removed at different ages provide such a rare opportunity (see Maurer et al., 2005 for a review). Studies in humans have shown that visual deprivation from birth can results in permanent visual impairments at different levels of visual processing. For example, individuals with a history of congenital cataracts often show lower visual acuities, impaired peripheral vision and higher thresholds for the judgment of local motion direction (see Maurer, Mondloch, & Lewis, 2007 for a review). Furthermore, these individuals perform at a lower level compared to controls in tasks relying on an automatic binding of visual features including global motion perception (Ellemberg, Lewis, Maurer, Liu, & Brent, 2002), global form perception (Lewis et al., 2002), configural face processing (Robbins, Nishimura, Mondloch, Lewis, & Maurer, 2010), the ability to recognize faces from different perspectives (Geldart, Mondloch, Maurer, de Schonen, & Brent, 2002; Putzar, Hötting, & Röder, 2010), and the perception of illusory contours (Putzar, Hötting, Rösler, & Röder, 2007). Despite significant impairments at perceiving the direction of local motion (Ellemberg et al., 2005) as well as at extracting global motion (Ellemberg et al., 2002; Hadad, Maurer, & Lewis, 2012), recent evidence has suggested that the behavioral sensitivity to human biological motion (BM) is largely unaffected by periods of congenital visual deprivation (Hadad et al., 2012). However, to finally reject the idea of a sensitive period for BM processing, it must be demonstrated that congenital cataract-reversal individuals engage the same neural system for BM processing as controls rather than using alternative routes, as for instance a more controlled processing mediated by later visual processing stages (Fieger, Röder, Teder-Sälejärvi, Hillyard, & Neville, 2007). As an example, it has been shown that even though congenital and late permanently blind individuals show similarly enhanced auditory localization, they use different neural systems (Fieger et al., 2007).

In the present study we made use of the high temporal resolution of non-invasive event-related potential (ERP) recordings to investigate the effects of a transient visual deprivation on the development of the neural systems of BM: typically sighted controls detect BM within the first 250 msec post stimulus onset, resulting in an enhanced N1 response of the ERP (Hirai, Senju, Hirokata, & Hiraki, 2005; Hirai, Watanabe, Honda, & Kakigi, 2009; Jokisch, Daum, Suchan, & Troje, 2005; Krakowski et al., 2011). In a previous ERP study in a group of cataract-reversal individuals (Röder, Ley, Shenoy, Kekunnaya, & Bottari, 2013) we demonstrated a lack of a functional specialization of the neural systems for face processing. In the present study, we recorded ERPs to BM and scrambled BM stimuli in a sample of 12 individuals who had been totally deprived of patterned visual input from birth for a few months up to 16 years. Differences in the ERPs between cc individuals and matched controls (mc) despite a lack of behavioral group differences would suggest a sensitive period for the functional specialization of the neural systems for BM processing and an alternative route serving functional recovery. By contrast, if cc individuals and their controls would not differ, either at the behavioral or at the neural level, we would reject the hypothesis of a sensitive phase for the functional specialization of the BM processing system.

2. Methods

2.1. Participants

The cc group comprised 12 individuals with a history of congenital, bilateral, dense cataracts (cc: mean age = 17.8 years, ranging between 10 and 35 years of age, for details see Table 1). All cc individuals were recruited at the LV Prasad Eye Institute in Hyderabad, India. Cataract history was confirmed from the medical records. Cataracts presence was diagnosed at different ages, therefore, the following additional criteria were applied to guarantee that only individuals with total ccs were included in this group: the presence of a nystagmus, a density of the lenticular opacity, an invisibility of the fundus prior to surgery, a family history and family reports. Prior to surgery, most of the participants had only light perception (see Table 1). cc individuals underwent surgery on average at the mean age of 94 months (range: 4–192 months). The duration of visual deprivation (time since surgery) was on average 119 months (range: 12–396 months). Mean visual acuity, measured post surgery at the best eye, was on average .14 (range: .05–.50). All cc individuals took part in the BM EEG experiment. A subset of them, comprising 7 individuals (3 females, mean age: 18.5 years, range: 11–35 years, mean visual acuity: .2, range: .05–.50; mean age at surgery: 86 months, range: 4–168 months, see Table 1) was tested in an additional behavioral task which assessed the behavioral threshold for detecting BM (BM behavioral task; see Table 1). All cc participants were right-handed and neurologically healthy according to self report and medical examination by a physician.

A group of aged matched healthy participants was recruited as control (mc) in Hamburg, Germany, for the BM EEG experiment and the BM behavioral task. All mc participants had normal or corrected to normal vision and were neurologically healthy according to self report. A group of 12 individuals participated in the BM EEG experiment (6 females, mean age: 18 years, range: 8–37 years). In addition, a sample