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Motion processing after sight restoration: No competition between visual recovery and auditory compensation

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A B S T R A C T

The present study tested whether or not functional adaptations following congenital blindness are maintained in humans after sight-restoration and whether they interfere with visual recovery. In permanently congenital blind individuals both intramodal plasticity (e.g. changes in auditory cortex) as well as crossmodal plasticity (e.g. an activation of visual cortex by auditory stimuli) have been observed. Both phenomena were hypothesized to contribute to improved auditory functions. For example, it has been shown that early permanently blind individuals outperform sighted controls in auditory motion processing and that auditory motion stimuli elicit activity in typical visual motion areas. Yet it is unknown what happens to these behavioral adaptations and cortical reorganizations when sight is restored, that is, whether compensatory auditory changes are lost and to which degree visual motion processing is reinstalled. Here we employed a combined behavioral-electrophysiological approach in a group of sight-recovery individuals with a history of a transient phase of congenital blindness lasting for several months to several years. They, as well as two control groups, one with visual impairments, one normally sighted, were tested in a visual and an auditory motion discrimination experiment. Task difficulty was manipulated by varying the visual motion coherence and the signal to noise ratio, respectively. The congenital cataract-reversal individuals showed lower performance in the visual global motion task than both control groups. At the same time, they outperformed both control groups in auditory motion processing suggesting that at least some compensatory behavioral adaptation as a consequence of a complete blindness from birth was maintained. Alpha oscillatory activity during the visual task was significantly lower in congenital cataract reversal individuals and they did not show ERPs modulated by visual motion coherence as observed in both control groups. In contrast, beta oscillatory activity in the auditory task, which varied as a function of SNR in all groups, was overall enhanced in congenital cataract reversal individuals. These results suggest that intramodal plasticity elicited by a transient phase of blindness was maintained and might mediate the prevailing auditory processing advantages in congenital cataract reversal individuals. By contrast, auditory and visual motion processing do not seem to compete for the same neural resources. We speculate that incomplete visual recovery is due to impaired neural network turning which seems to depend on early visual input. The present results demonstrate a privilege of the first arriving input for shaping neural circuits mediating both auditory and visual functions.

Introduction

Studies in humans with either permanent total blindness or profound deafness have often shown that neural systems implicated in the analysis of the deprived modality are activated during the processing of stimuli of the intact sensory modality (e.g. Bavelier and Neville, 2002; Murray et al., 2016; Pavani and Röder, 2012; Renier et al., 2014). This phenomenon has been called crossmodal plasticity. At the behavioral level,

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blind humans have been observed to be superior in auditory motion processing as compared to sighted controls (Lewald, 2013). Brain imaging studies have repeatedly found an activation of what are typically visual motion sensitive areas such as MT+ and V3A during the processing of auditory motion (Poirier et al., 2006; Bedny et al., 2010; Wolbers et al., 2011; Collignon et al., 2013; Jiang et al., 2014). In contrast, typical sound motion related areas as the posterior planum temporale (PT) have been shown to be less active in response to sound motion in congenitally blind individuals than in sighted controls (Jiang et al., 2014; Dormal et al., 2016). Indeed, multivariate pattern analyses of MRI data have suggested that visual motion areas might take over some decoding tasks for sound motion in congenitally blind individuals (Dormal et al., 2016).

Based on these results it could be speculated that, if sight could be restored, the functional recovery of visual motion processing is compromised due to the crossmodal plasticity following a transient phase of blindness. Moreover, it could be hypothesized that after sight restoration the auditory and the visual system might compete for the same neural resources, resulting not only in an incomplete recovery of visual motion processing but additionally in a decline of sound motion processing. In accord with the first hypothesis permanent deficits in both local and global visual motion processing have been observed in sight recovery individuals with a history of congenital dense bilateral cataracts (Ellemberg et al., 2002; see Maurer et al., 2007 for a review; Hadad et al., 2012). Furthermore, Saenz and colleagues (Saenz et al., 2008) provided first evidence for a parallel activation of the visual motion area MT + by auditory and visual motion stimuli in two sight recovery individuals, one with a history of a transient congenital blindness. Moreover, Guerreiro et al., (2016a) demonstrated that auditory motion is capable of influencing visual motion processing in congenital cataract-reversal individuals but not in visual impaired or normally sighted controls suggesting a higher influence of audition on vision in sight-recovery individuals. Interestingly, a recent fMRI study has suggested that intramodal changes in auditory cortex, as have repeatedly been observed in congenital blind individuals (Elbert et al., 2002; Röder et al., 1996, 1999; Starlinger and Niemeyer, 1981), seem to prevail in sight recovery individuals (Guerreiro et al., 2016b). These data would suggest that crossmodal compensation, that is, improvements in auditory perception associated with blindness (Pavani and Röder, 2012) might not be lost after sight restoration but might rather be maintained (see Guerreiro et al., 2016a; de Heering et al., 2017).

The present study used a combined behavioral and electrophysiological assessment of visual and auditory motion processing in individuals born blind due to bilateral dense cataracts, which were removed a few months to several years later. In order to test for the presence of sensitive phases and to control for the effect of visual impairments as well as for peripheral differences due to cataract surgery, we additionally tested a group of individuals with a history of developmental (late onset) cataracts or incomplete (not dense) congenital cataracts. The neural correlates of both visual and auditory motion processing were assessed with electroencephalographic recordings. In particular, we analyzed event-related potentials (ERPs) known to be modulated by the level of visual global motion coherence (N1 wave; Niedeggen and Wist, 1999; Nakamura et al., 2003) as well as oscillatory activity in the alpha (8–12 Hz) and beta band (13–35 Hz). Alpha band activity has been linked to the regulation of visual cortex activity (Jensen et al., 2012) and beta band activity has been associated with auditory spatial processing such as sound localization (Kaiser et al., 2002a, 2002b; Senkowski et al., 2014). Alpha and beta oscillatory activity are used here to assess the recovery of neural processing in the visual system and intramodal plasticity as a consequence of a transient phase of congential blindness associated with the auditory system, respectively.

Material and methods

Participants

A group of 18 individuals born with congenital, bilateral, dense cataracts was tested between 12 months and 33 years after cataract surgery (cc, see Table 1). All cc individuals were recruited at the LV Prasad Eye Institute in Hyderabad (India). The presence of cataracts prior to surgery was affirmed by medical records. Since the cataracts were diagnosed at different ages, additional criteria including the presence of nystagmus, the density of the lenticular opacity, an invisibility of the fundus prior to surgery, a family history of congenital cataract, and family reports were adopted to maximize the chance that only individuals with congenital total cataracts entered this group.

An additional control group of 19 individuals who had suffered from developmental cataracts or congenital incomplete cataracts (dc individuals) prior to surgery was recruited at the same institute. All cc and dc participants were right handed and neurologically healthy according to self-report and a medical examination by a physician. Moreover, a sample of 43 healthy control participants (mc) matched in age, sex and handedness was recruited in Hamburg, Germany. In order to get a reliable estimate of behavioral and electroencephalographic parameters a larger number of mc individuals, as compared to the other two group, was recruited. All mc participants had normal or corrected to normal vision and were neurologically healthy according to self-report or the report of a legal guardian. Participants and/or their legal guardians gave written informed consent after the scope and details of the study had been explained. The study was approved by the ethical committee of the German Society of Psychology and the ethical committee of the Hyderabad Eye Research Foundation.

Due to time limitations not all participants were able to take part in each of the three experiments (see Table 1). See Supplementary materials for a detailed description of the samples who took part in each Experiment.

Behavioral visual global motion coherence task: 14 cc individuals took part (4 females); mean age: 16.8 years, range: 9-35. Cc individuals underwent surgery for cataract removal of the first eye at a mean age of 82.6 months (range: 2-204). The time since surgery (indicating the duration of visual experience) was on average 9.4 years (range: 1-33). At the time of data collection, the visual acuity of the best eye of the cc participants was on average 0.24 decimals ranged between 0.03 and 0.50 as assessed by the Snellen Visual Acuity Chart. A group of 14 dc individuals (6 females) with a mean age of 16.1 years (range: 8-38) participated. On average dc individuals underwent surgery for cataract removal of the first eye at a mean age of 108 months (range: 24-420). The time since surgery was on average 6.1 years (range: 1-18). At the time of data collection, the visual acuity of the best eye was on average 0.42 decimals ranged between 0.08 and 1 as assessed by the Snellen Visual Acuity Chart. Visual acuity did not significantly differ between the cc and the dc group ($t(26) = -1.7$, $p > 0.1$). A group of 20 mc (9 females) were tested; mean age: 17.4 years, range: 7-39.

Visual Global Motion EEG experiment: 10 cc individuals (2 females) with a mean age of 20.6 years, range (11-35) participated. On average cc individuals underwent surgery for cataract removal of the first eye at a mean age of 71.1 months (range: 4-204). The time since surgery was on average 14.8 years (range: 2-33). At the time of data collection, the visual acuity of the best eye was on average 0.15 decimals and ranged between 0.05 and 0.5. A group of 12 dc individuals (5 females) with a mean age of 17.75 years (range: 8-38) participated. Dc individuals underwent surgery for cataract removal of the first eye at a mean age of 103.2 months (range: 2-252). The time since surgery was on average 8.1 years (range: 2-18). The visual acuity at the best eye was on average 0.4 decimals and ranged between 0.1 and 1. Cc group displayed a lower visual acuity compared to the dc group ($t(20) = -2.2$, $p < 0.05$). In order to match the sample size and visual acuity across groups, two participants of the dc group displaying the highest visual acuity were excluded from the analysis (see result section). Thus, the cc and the dc groups (both $N = 10$ participating in the global motion EEG experiment did not differ in visual acuity (cc: mean = 0.15, SE = 0.04; dc: mean = 0.28, SE = 0.07); $t(18) = -1.6$, $p > 0.14$). Moreover, a group of 23 mc (11 females) with a mean age of 21.3 years (range: 9-36) participated.