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Auditory spatial localization: Developmental delay in children with visual impairments

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ABSTRACT

For individuals with visual impairments, auditory spatial localization is one of the most important features to navigate in the environment. Many works suggest that blind adults show similar or even enhanced performance for localization of auditory cues compared to sighted adults (Collignon, Voss, Lassonde, & Lepore, 2009). To date, the investigation of auditory spatial localization in children with visual impairments has provided contrasting results. Here we report, for the first time, that contrary to visually impaired adults, children with low vision or total blindness show a significant impairment in the localization of static sounds. These results suggest that simple auditory spatial tasks are compromised in children, and that this capacity recovers over time.

What this paper adds?

In agreement with previous studies (e.g., Doucet et al., 2005; Gougoux et al., 2004; King and Parsons, 1999; Lessard, Pare, Lepore, & Lassonde, 1998; Lewald, 2007; Roder et al., 1999), our results confirm that adults with visual impairments correctly localize sound source in the horizontal plane. Contrary to what expected from literature review (Ashmead et al., 1998; Bigelow, 1983; Fazzi et al., 2011), children with visual impairments show a significant developmental delay in the acquisition of auditory spatial localization if compared with age matched sighted controls. The developmental delay that we observed for auditory spatial localization supports the idea that vision is the most reliable sense to represent the spatial properties of the external world (Alais, Newell, & Mamassian, 2010), but it also suggests that a compensation mechanism occurs in late adulthood thanks non-visual spatial experiences that shape spatial perception (Fiehler, Reuschel, & Rösler, 2009).

1. Introduction

The ability to determine the location of perceptual objects in the space is essential to navigate and make interactive contacts with the others in the environment. Among the sensory modalities, vision seems to play a crucial role in spatial localization, mainly because it provides an immediate and complete representation of the surrounding layout in a single frame (Tinti, Adenzato, Tamietto, & Cornoldi, 2006). In absence of vision, specific auditory spatial skills result enhanced probably thanks to cortical organization (Collignon, Voss, Lassonde, & Lepore, 2009). For example, many studies report that

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visually impaired human adults can localize sound sources in the horizontal plane as well as or even better that sighted individuals (e.g., Doucet et al., 2005; Gougoux et al., 2004; King and Parsons, 1999; Lessard et al., 1998; Lewald, 2007; Roder et al., 1999), especially for peripheral regions of the space (King and Parsons, 1999; Rauschecker, 1995; Voss et al., 2004). Physiological works on animals confirm this result, indicating that in absence of visual experience the occipital regions, normally activated by vision, are involved in auditory processes (King and Parsons, 1999; Rauschecker, 1995). It has been demonstrated that the level of cortical organization is strongly related to the accuracy in auditory localization tasks, implying that the more visual regions are recruited the more auditory accuracy is displayed (Gougoux, Zatorre, Lassonde, Voss, & Lepore, 2005; Voss, Lepore, Gougoux, & Zatorre, 2011). Overall these results are in favor of the compensatory hypothesis, which states that, in absence of vision, the remaining intact sensory systems are structurally and functionally recruited to process spatial information, allowing blind individuals to develop an accurate sense of space (Collignon et al., 2009; Voss et al., 2004).

Although auditory spatial perception has been widely investigated in congenitally blind adults, less effort has been spent in understanding how this sense of space changes during development in children with visual impairment. Studies in children report conflicting results. For example, children with visual disabilities have excellent spatial hearing, measured as the ability to discriminate differences in sound localization in the horizontal and vertical plane, as well as the ability to reach or walk to the sound source position (Ashmead et al., 1998). On the contrary, several studies suggested that infants with severe congenital blindness have a developmental delay in sound localization abilities (Fraiberg, 1977) and motor responses to sound (Adelson and Fraiberg, 1974; Fraiberg, Siegel, & Gibson, 1966). For example, blind children do not reach for objects that produced sounds until the end of the first year while sighted children start around 5 months (Bayley, 1969). Similarly, blind children show worse performances than sighted children in auditory bisection, minimum audible angle tasks (Vercillo, Burr, & Gori, in press) and audio depth tasks (Cappagli et al. in press). Other studies show contrasting results, indicating that children with congenital visual disabilities show an initial neuromotor developmental delay but compensate for the lack of vision developing good manipulatory and walking skills exploring sounding objects in the environment (Fazzi et al., 2011).

Nonetheless, it is difficult to compare the studies that investigate the effect of vision loss on auditory spatial skills mainly because they use different methodological approaches and stimuli. For example, the auditory spatial tasks employed in many studies assess different aspects of auditory spatial perception for different age range. Moreover, most perceptual studies used motor responses, such as reaching, mixing the motor and the perceptual component (Bigelow, 1983; Fazzi et al., 2011). In addition, in some cases sighted and blind groups of children were not perfectly matched for age range, sometimes using also adults as comparison (Ashmead et al., 1998). Finally, the difference between early and later loss of vision has not been often considered. Many studies mixed data from children with no visual experience with those of children with partial visual experience in the first period of life (Ashmead et al., 1998).

To summarize, although compensatory mechanisms for spatial perception have been demonstrated in blind adults, it is not clear whether an early visual impairment might delay the development of specific auditory spatial skills. To investigate this point, starting from the considerations made in the previous paragraph, we think that a good approach is to replicate in children studies that have been previously widely investigated in adults, by using the same procedure and methodology. With this aim, here we replicate in children the static sound localization by using a similar approach previously used by other authors in adults (Collignon et al., 2009). Our results suggest that, contrarily to adults, children have worse performances than sighted children in performing this task, suggesting that this deficit recovers over time.

2. Material and methods

2.1. Participants

We compared the spatial performance between different age groups of sighted participants, and between a sighted and a visually impaired group of children and adults. The blind group consisted of 20 children (children with total blindness: age range 9–17, mean age 12.3, 8 females; children with low vision: age range 7–17, mean age 11.6, 6 females) and 11 adults who either lost their vision at birth (7 early blinds; age range 20–54, mean age 32, 4 females) or later in life (4 late blinds; age range 20–63, mean age 37, 2 females). The visual deficit was assessed according to the International Statistical Classification of Diseases and Related Health Problems (ICD)—10th revision. In each case the visual deficit was of peripheral origin; for blind individuals the visual deficit led to total blindness except for some residual light perception in 6 subjects (categories 4); (see Table 2 for clinical details). The main exams used for the functional assessment of visual abilities are electroretinogram (ERG), visually evoked potential (PEV) and pattern electroretinogram (ERP). The cognitive level of all the children tested was assessed with “The Reynell–Zinkin Scales: Developmental Scales for Young Visually Handicapped Children” and with the Verbal Comprehension and Working Memory Index’ s of “The Wechsler Intelligence Scale for Children (WISC)—Fourth Edition”. For this study, the mental development of the participants was qualified as normal, according to the total scores and the cut-offs proposed by the authors. None of the visually impaired subjects had additional sensory disabilities, including hearing disabilities tested with classical audiometer tests during the periodic neuro-ophthalmological assessment.

The sighted control group consisted of 57 children (age range 8–15, mean age 10.5, 27 females) and 12 adults (age range 22–65, mean age 35, 8 females). We also tested a group of younger sighted children (n = 20, age range 6–7, 12 females) to assess the developmental trend of the auditory spatial localization skill (see Table 1 for all demographic details). All the subjects in the control group were healthy volunteers and underwent the tasks blindfolded, so they had no notion of the