Vision Research 105 (2014) 29–36

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Temporal entrainment of visual attention in children: Effects of age and deafness

Matthew W.G. Dye

Department of Speech and Hearing Science, University of Illinois at Urbana-Champaign, 901 S 6th St, Champaign, IL 61820, USA

ARTICLE INFO

Article history:
Received 5 March 2014
Received in revised form 2 September 2014
Available online 16 September 2014

Keywords:
Deafness
Visual attention
Rapid serial visual presentation
Attentional awakening
Temporal entrainment
Children

ABSTRACT

The major documented effect of auditory deprivation on visual processing is enhanced spatial attention, in particular to the visual periphery and to moving stimuli. However, there is a parallel literature that has reported deficits in temporal aspects of visual processing in individuals with profound hearing losses. This study builds upon previous work showing possible deficits in processing of rapid serial visual presentation streams in deaf children [Restorative Neurology and Neuroscience (2010), 28, 181–192]. Deaf native signers of American Sign Language and hearing children and adults were asked to perform a 2-AFC identification task with a visual target embedded in a stream of visual stimuli presented at 6 Hz. Both children and adults displayed *attentional awakening*, whereby target identification accuracy improved as the number of stimuli preceding the target increased. For deaf children, however, this awakening effect was less pronounced than that observed in hearing children, interpreted as difficulty sustaining entrainment to the stimulus stream. The data provide the first account of attentional awakening in children, showing that it improves across the 6–13 year age range. They also provide additional support to the possibility of domain-general alterations in the processing of temporal information in the absence of auditory input.

1. Introduction

It is now well documented that early profound deafness results in changes in visual functions (Dye & Bavelier, 2012; Pavani & Bottari, 2012). Studies of deaf adults have demonstrated that they are better able than their hearing peers to detect and localize targets in their visual periphery (Buckley et al., 2010; Dye, Hauser, & Bavelier, 2009; Loke & Song, 1991), and process visual motion (Armstrong et al., 2002; Hauthal et al., 2013a; Stevens & Neville, 2006). There is also some evidence that deaf adults are better able to orient their visual attention in response to external cues (Bosworth & Dobkins, 2002; Bottari et al., 2010; Colmenero et al., 2004; Dye, Baril, & Bavelier, 2007; Parasnis & Samar, 1985). At the behavioral level, it has been proposed that these changes in visual functions reflect enhanced visual perception or enhancements in visual attention to the periphery and to motion (Dye & Bavelier, 2012; Pavani & Bottari, 2012). At the neural level, a number of potential mechanisms have been postulated to explain the changes in visual function, including a redistribution of retinal ganglion cells (Codina et al., 2011b), enhanced responsivity of early visual processing areas (Bottari et al., 2011), changes in top-down connectivity within the dorsal visual pathway (Bavelier et al., 2000; Hauthal et al., 2013b), and cross-modal recruitment of functionally homologous areas in auditory cortex (Lomber, Meredith, & Kral, 2010).

In stark contrast to these studies demonstrating enhanced spatial properties of the visual system in deaf adults, the few studies that have been conducted with deaf children have suggested that they may suffer from deficits in these functions at earlier ages that transform to potential enhancements around the age of 11–13 years. One study administered a variant of the Useful Field of View to deaf children born to deaf parents aged 7–17 years and to Deaf native signer adults (Dye, Hauser, & Bavelier, 2009). This task required the participants to respond to a central target at fixation, and also indicate the on-screen location of a concurrent peripheral target (20 deg of visual angle) embedded within a field of distractors. Using the stimulus duration required in order to achieve 79% accuracy on the peripheral target as a measure, deaf adults significantly outperformed hearing adults. Looking at data from the children, this deaf advantage was only apparent from the age of 11 years onwards – prior to that there was no observed difference between the groups. A subsequent report by Codina et al. (2011a) looked at how accurately 5–15 year old deaf and hearing children could detect LED lights in the far periphery (30–85 deg of visual angle). They reported that deaf children

E-mail address: mdye@illinois.edu

http://dx.doi.org/10.1016/j.visres.2014.09.001
0042-6989/

outperformed hearing children in the 13–15 year age category. From 11 to 12 years, the two groups performed similarly, and from 5 to 10 years of age the deaf children performed worse than hearing children. Thus these two studies produced convergent findings – the visual peripheral enhancements observed in deaf adults are not apparent in young deaf children until they approach the teenage years.

A number of studies have focused upon temporal aspects of visual function in deaf children. Rather than examining how well deaf children can process information from across the visual field, they have looked at how well they are able to process rapidly changing visual information over time. Several studies have used continuous performance tasks, which are computerized measures of attention that typically require children to attend to a rapidly changing stream of visual stimuli. The Gordon Diagnostic System (Gordon & Mettleman, 1987) is one commonly used continuous performance task. In the Gordon Diagnostic System digits appear rapidly, one at a time, in the center of an LED display, and subjects are required to make a response to a target digit or to a specific sequence of target digits. Deficits in continuous performance tasks have been reported in deaf children in several studies (Horn et al., 2005; Quittner et al., 1994; Smith et al., 1998). This has led to the suggestion that deaf children are more impulsive (Quittner et al., 1994) and suffer from elevated levels of distractibility (Mitchell & Quittner, 1996). Furthermore, Smith et al. (1998) reported data suggesting that cochlear implantation alleviates these deficits, although the children with cochlear implants did not achieve the performance levels of hearing controls. These findings have led some to suggest that a lack of auditory input may prevent successful multi-modal integration, with one result being that the visual system does not benefit from the temporal information provided by the auditory modality (Conway, Pisoni, & Kronenberger, 2009). Recently, however, we reported a study using continuous performance tests in 6–13 year old deaf children who acquired American Sign Language (ASL) from birth (Dye & Hauser, 2014). We found that deaf and hearing children were comparable in terms of how well they could sustain attention to a sequence of centrally presented digits (see also Tharpe, Ashmead, & Rothpletz, 2002), but that the youngest deaf children had difficulty when distractor digits were presented to the left and right of the target stream. One interpretation given for this finding was that shifting attention from the periphery to the center was an effortful process for young deaf children, which taxed their age-limited cognitive resources.

It has also been reported that deaf children have difficulty implicitly learning transitional probabilities governing a temporal sequence of visual locations (Conway et al., 2011). Five to 10-year-old normally hearing children, and deaf children with a cochlear implant, were asked to reproduce sequences of colored squares appearing in quadrants of a touchscreen. The sequences were created on the basis of a set of transitional probabilities that specified the probability of a color appearing at time $t + 1$ given the identity of the color at time t. Two sets of sequences (set A and set B) were generated using different transitional probabilities. After observing a sequence from set A, the children were asked to repeat that sequence by tapping it out on the touchscreen. This was repeated for several sequences, and followed by a test in which sequences from set A were interspersed with sequences from set B. It was reasoned that if children learned the underlying transitional probabilities of set A, then they should be able to better reproduce test sequences from set A than from set B. Such an advantage was reported for normally hearing children (learning score = +5.8%, 14 out of 26 children with positive scores), but not for deaf children who had received a cochlear implant (learning score = −2.5%, 8 out of 23 children with positive scores). A marginally significant correlation was reported between a deaf child's learning score and the age at which they received a cochlear implant (after controlling for age at time of test). Further, the learning score was a significant predictor on two subtests of the CELF-4 (a standardized clinical measure of spoken language processing), suggesting that any impairment in temporal sequence processing may operate across domains. Conway, Pisoni, and Kronenberger (2009) have proposed an auditory scaffolding hypothesis, which posits that temporal sequencing skills are developed in the auditory modality and subsequently exploited in the visual modality – a lack of auditory input therefore results in deficits in temporal sequence processing in the visual domain.

We recently reported data from a rapid serial visual presentation (RSVP) task in young deaf children (7–10 years) and deaf adults (Dye & Bavelier, 2010). The task required observers to look at a series of colored shapes presented in the center of the visual field. The shapes appeared one at a time, at a rate of approximately 9 items/s. The observers' task was to monitor the stream of shapes for a target shape (for half of the subjects a red isosceles triangle pointing left or right, and for the other half a blue isosceles triangle pointing up or down). At the end of the RSVP sequence, they reported the direction (up-down, left–right) of the target shape. The data revealed that whereas most deaf adults achieved asymptotic performance (the same as all hearing adults), young deaf children performed significantly worse than young hearing children. An attentional blink task conducted with the same subjects revealed no differences between deaf and hearing subjects, suggesting that the deficit in the young deaf children was not due to impaired attentional recovery over time.

In this study we sought to build upon our earlier work by administering an RSVP task to a cross-sectional sample of deaf and hearing children aged 6 through 13 years and also to deaf and hearing adults. All deaf participants had at least a severe-to-profound hearing loss, and none had received a cochlear implant. They were all born deaf to culturally Deaf parents from whom they acquired American Sign Language as a first language in infancy. We reasoned that if the deficit was due to auditory deprivation – as suggested by the auditory scaffolding hypothesis – then the deficit would be apparent for these deaf children and adults alike. However, failure to find a deficit in either the deaf children or adults would suggest a need to revise the auditory scaffolding hypothesis to take into account other factors (for example, age of exposure to perceivable natural language).

2. Experiment 1: children

2.1. Methods

This study was conducted with the approval of the Institutional Review Board at the University of Illinois at Urbana-Champaign and in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans. Written consent was obtained from a parent of each child before obtaining written consent or verbal assent from all children.

2.1.1. Participants

A total of 75 deaf and hearing children aged between 6 and 13 years were recruited into the study. Screening questionnaires were used to exclude children who (1) played action video games, (2) wore cochlear implants, (3) reported a learning disability or visual impairment (other than being shortsighted), and (4) had a history of neurological or psychiatric disorder. The deaf and hearing groups did not differ in mean age ($t(73) = 0.64$, $p = .524$) or in gender distribution (χ^2 (1) = 0.224, $p = .636$).

2.1.1.1. Hearing children. Hearing children ($n = 54$) were recruited from schools in Champaign, IL, and paid for their participation.