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Research Report

Deafness and visual enumeration: Not all aspects of attention are modified by deafness

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ABSTRACT

Previous studies have demonstrated that early deafness causes enhancements in peripheral visual attention. Here, we ask if this cross-modal plasticity of visual attention is accompanied by an increase in the number of objects that can be grasped at once. In a first experiment using an enumeration task, Deaf adult native signers and hearing non-signers performed comparably, suggesting that deafness does not enhance the number of objects one can attend to simultaneously. In a second experiment using the Multiple Object Tracking task, Deaf adult native signers and hearing non-signers also performed comparably when required to monitor several, distinct, moving targets among moving distractors. The results of these experiments suggest that deafness does not significantly alter the ability to allocate attention to several objects at once. Thus, early deafness does not enhance all facets of visual attention, but rather its effects are quite specific.

1. Introduction

The loss of a sensory system early in development causes profound neural reorganization, and in particular an enhancement of the remaining modalities, a phenomenon also termed cross-modal plasticity (Bavelier and Neville, 2002; Frost et al., 2000; Ptito et al., 2001; Ptito and Kupers, 2005; Rauschecker, 2004; Sur et al., 1990; Theoret et al., 2004). Support for cross-modal plasticity is often echoed in the proposal that blind individuals have more acute senses of audition and touch, and deaf individuals have a more acute sense of vision. Although this view is generally valid, recent research reveals that cross-modal plasticity is rather specific, in that only some aspects of the remaining senses appear modified after early sensory deprivation. For example, in the case of deafness, the available literature indicates comparable visual psychophysical thresholds, be it for brightness discrimination (Bross, 1979), visual contrast sensitivity (Finney and Dobkins, 2001), temporal discrimination (Mills, 1985), temporal resolution (Bross and Sauerwein, 1980; Poizner and Tallal, 1987), or sensitivity to motion processing (Bosworth and Dobkins, 1999; Brozinsky and Bavelier, 2004). This lack of population differences across several different measures of visual skill indicates that changes in visual performance after early deafness are not widespread.

One aspect of vision that has been reliably documented to be enhanced following auditory deprivation is peripheral visual processing, in particular during attentionally demanding tasks using moving stimuli. For example, deaf individuals exhibit a larger field of view than hearing controls when asked

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to detect the presence of moving light points at locations in the periphery (Stevens and Neville, 2006). Deaf individuals are faster and more accurate than hearing controls in detecting the direction of motion of a small square at an attended location while ignoring squares flashing at unattended locations (Neville and Lawson, 1987b). Electro-physiological recordings indicate an increased N1 component – associated with a modulation of visual attention – when deaf subjects performed this task. Similar increases in N1 amplitude have been noted when deaf individuals are presented with abrupt onset squares flashed at three possible locations randomly (Neville et al., 1983) or when monitoring drifting low-spatial frequency gratings for a rare target (Armstrong et al., 2002). In line with the proposal of enhanced peripheral visual attention, the N1 enhancement in deaf individuals is more pronounced for peripheral than central stimuli. Using fMRI, we and others have found greater recruitment of area MT/MST, specialized for motion processing, in deaf than in hearing participants when motion stimuli were monitored peripherally rather than centrally (Bavelier et al., 2001; Fine et al., 2005). These results highlight enhanced performance in deaf individuals in tasks using moving stimuli and manipulating the spatial distribution of attention. These studies mostly focused on Deaf native signers allowing for the possibility that signing rather than deafness leads to enhancements in peripheral vision. To disambiguate the role of signing from that of deafness, we and others have carried similar studies on hearing native signers. In all these studies (Bavelier et al., 2001; Bosworth and Dobkins, 2002; Neville and Lawson, 1987b; Proksch and Bavelier, 2002), hearing native signers performed like hearing non-signers and unlike deaf signers. Thus, signing in itself does not induce the peripheral processing change observed in deaf signers.

It is worth noting, however, that not all tasks that rely on motion processing or require peripheral processing show enhancement in the deaf population. We and others have found that sensory thresholds for motion direction and velocity are not altered by early deafness, even when tested in the visual periphery (Bosworth and Dobkins, 1999; Brozinsky and Bavelier, 2004). Similarly, recruitment of MT/MST, a brain area highly specialized for visual motion processing, was found to be similar in deaf and hearing individuals upon passively viewing moving stimuli at various eccentricities (Bavelier et al., 2001; Fine et al., 2005). The visual skills for which deaf individuals exhibit different performance compared to hearing individuals appear therefore relatively specific to conditions that engage spatial attention (Bavelier et al., 2006a,b).

This specificity is also illustrated by research on the effects of deafness on visual attention itself. A host of studies documents enhanced peripheral visual attention after early deafness as discussed above. In several studies, deaf individuals displayed greater distractibility from peripheral distractors than hearing individuals, revealing greater attentional resources in the visual periphery (Dye et al., 2007; Lavie, 2005; Proksch and Bavelier, 2002). In contrast, few population differences have been documented on standard attentional paradigms. Studies using the Posner cueing paradigm document no robust change in orienting, except in the presence of a competing central load (Bosworth and Dobkins, 2002; Dye et al., 2007; Parasnis, 1992; Parasnis and Samar, 1985). Although an early study of visual search reported a tendency for more effective visual search in deaf than in hearing individuals (Stivalet et al., 1998), recent reports have failed to replicate the effect (Bosworth and Dobkins, 2002; Rettenbach et al., 1999). The only population effect observed was that deaf adults terminated target-absent trials faster than hearing adults; this result may reflect differences in decision criterion rather than attention between the two populations (Rettenbach et al., 1999). Early deafness may therefore lead to changes in visual attention, but these appear quite specific to the spatial distribution of visual attention over the visual field.

The aim of the present paper is to document further which of the many aspects of attention may be modified after early auditory deprivation. Here we specifically investigate the effect of deafness on the ability to deploy visual attention to several different objects at once. One view is that compensatory plasticity allows deaf individuals to reach similar performance levels as hearing individuals on tasks which typically benefit from the integration of visual and auditory information. As a result, one may only expect those visual functions known to benefit from multisensory integration between vision and audition to change after early deafness. This view readily captures the findings reviewed above, that the most robust change in visual functions in deaf individuals is in the spatial re-distribution of visual attention over space. Indeed, cross-modal links between audition and vision have been repeatedly documented to control the deployment of spatial attention (Eimer et al., 2002; McDonald et al., 2003; Teder-Salejarvi et al., 2005). According to this view, we expect little if any changes in the ability to deploy visual attention to several objects at once, as this skill appears similarly limited to about 4 items whether tested visually or auditorily (Cowan et al., 2005). An alternative view holds that compensatory plasticity enhances many aspects of the remaining modalities, with deaf individuals possibly displaying enhancement on a wide range of visual skills. In the absence of audition, the remaining modalities, and in particular vision, are put under increasing demands, leading to the expression of use-dependent plasticity in visual functions. Under this view, an enhancement of the ability to monitor several objects may be expected as a way to enhance visual processing in deaf individuals. Although this latter proposal is at odds with the existing literature to date, the ability to maintain a high number of events in the focus of attention is certainly advantageous and, given that this skill can be modified by experience such as video game playing (Green and Bavelier, 2006), it remains possible that it could be changed in deaf individuals.

As in our past studies, the deaf individuals selected to participate in this study were born to deaf parents (genetic etiology) and raised in an environment that used a visual language at home (hereafter referred to as Deaf native signers) (Mitchell and Karchmer, 2002). This is important because deaf individuals from hearing families introduce possible confounds. First, they often experience a language delay (and associated delay in psycho-social development) because their hearing loss is usually not detected until around the age of 18 months and they are not exposed to a natural language that