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Effects of attention and laterality on motion and orientation discrimination in deaf signers

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ABSTRACT

Previous studies have asked whether visual sensitivity and attentional processing in deaf signers are enhanced or altered as a result of their different sensory experiences during development, i.e., auditory deprivation and exposure to a visual language. In particular, deaf and hearing signers have been shown to exhibit a right visual field/left hemisphere advantage for motion processing, while hearing nonsigners do not. To examine whether this finding extends to other aspects of visual processing, we compared deaf signers and hearing nonsigners on motion, form, and brightness discrimination tasks. Secondly, to examine whether hemispheric lateralities are affected by attention, we employed a dual-task paradigm to measure form and motion thresholds under "full" vs. "poor" attention conditions. Deaf signers, but not hearing nonsigners, exhibited a right visual field advantage for motion processing. This effect was also seen for form processing and not for the brightness task. Moreover, no group differences were observed in attentional effects, and the motion and form visual field asymmetries were not modulated by attention, suggesting they occur at early levels of sensory processing. In sum, the results show that processing of motion and form, believed to be mediated by dorsal and ventral visual pathways, respectively, are left-hemisphere dominant in deaf signers.

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1. Introduction

Studies have shown that deaf individuals who use American Sign Language (ASL) have altered or enhanced attentional capacity and visual processing abilities, by virtue of their different auditory and visual sensory experiences during development. Generally, deaf individuals are believed to have enhanced visual detection of targets that move or appear in the parafovea or periphery (Bottari, Nava, Ley, & Pavani, 2010; Chen, Zhang, & Zhou, 2006; Colmenero, Catena, & Fuentes, 2000; Dye, Hauser, & Bavelier, 2009; Loke & Song, 1991; Neville & Lawson, 1987a, 1987b; Reynolds, 1993). This advantage is believed to be stronger under conditions of attentional load, such as when targets in peripheral and central space compete for attention (Dye et al., 2009; Proksch & Bavelier, 2002). In studies using peripheral precues that direct spatial attention towards the location of the upcoming stimulus, deaf signers benefit less with a valid cue, compared to hearing signers and nonsigners (Bosworth & Dobkins, 2002a). When attention is diverted away from the target with an invalid cue, deaf signers' performance was less hindered than hearing nonsigners (Parasnis & Samar, 1985). Together, these results are interpreted to mean that deaf people are able to orient covert attention more efficiently and faster to peripheral events, compared to hearing people (and see Stivalet, Moreno, Richard, Barraud, & Raphel, 1998 for a similar conclusion with a visual search task). These findings are complemented by brain imaging studies showing enhanced neural activity when deaf signers direct attention to peripheral, but not central, targets (*ERP*: Neville & Lawson, 1987a; Neville, Schmidt, & Kutas, 1983; fMRI: Bavelier et al., 2000). Moreover, superior attention to peripheral stimuli is reported in deaf native signers but not in hearing native signers (who have early ASL exposure from their deaf signing parents but normal hearing), indicating the effect is attributed to auditory deprivation and not sign language experience (Dye et al., 2009; Proksch & Bavelier, 2002). In fact, this peripheral attention advantage in deaf individuals may even make peripheral stimuli more distracting, which can hinder performance for irrelevant concurrent tasks (Dye, Hauser, & Bavelier, 2008a). One ecological explanation for these results is that, in the absence of informative auditory cues about changes in one's extrapersonal space, deaf individuals need to rely upon visual cues, and as a result, this experience makes them more efficient at allocating attention to peripheral changes, compared to hearing individuals.

Other visual capacities such as visual shape memory (Cattani, Clibbens, & Perfect, 2007), face processing (Corina, 1989; McCullough & Emmorey, 2009; McCullough, Emmorey, & Sereno, 2005), and mental rotation (Emmorey & Kosslyn, 1996) are altered in deaf

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signers, and these effects are believed to be a result of early exposure to and daily use of a visual sign language. Most relevant to the current study, with respect to motion processing, several studies have reported a consistent right visual field advantage, suggesting a left hemisphere dominance, in deaf signers, while hearing nonsigners show either no asymmetry or a small right hemisphere advantage. This effect for motion processing has been shown using lateralized stimuli for a leftward vs. rightward direction-of-motion discrimination task (Bosworth & Dobkins, 1999, 2002b; Samar & Parasnis, 2005), an apparent motion task (Neville & Lawson, 1987a, 1987b), and a speed discrimination task (Brozinsky & Bavelier, 2004). Hearing native signers also exhibit a similar right visual field advantage for motion processing as do deaf signers suggesting that the asymmetry is attributable to sign language experience, and not to deafness (Bavelier et al., 2001; Bosworth & Dobkins, 2002b; Neville & Lawson, 1987a, 1987b). Supporting these behavioral results, deaf and hearing signers show greater brain activation in the left hemisphere while viewing moving stimuli compared to hearing nonsigners (*ERP*: Neville & Lawson, 1987a; *fMRI*: Bavelier et al., 2001).

The dominant hypothesis in the literature explaining the alteration of lateralization is that it reflects an adaptive developmental reorganization to meet the functional processing demands of sign language. That is, because ASL comprehension is highly dependent on the ability to process moving hands, then perhaps the left, language dominant hemisphere has usurped some visual functions, such as motion processing, needed for language processing (Neville & Bavelier, 2002). In addition to motion cues inherent in hand movements of ASL, other form cues – orientation, position, and configuration of the hands – are also important for sign language comprehension. The purpose of this study is to test this hypothesis by extending previous findings of motion processing asymmetries to other sensory dimensions believed to be relevant to sign language processing, specifically form processing. A critical implication of the hypothesis in the existing literature is that, in addition to motion cues, other sensory cues that are linguistically distinctive for sign language processing (such as form and orientation) should also become left lateralized, whereas sensory dimensions that are not linguistically distinctive for sign language processing (such as brightness) should not.

The first goal of the current study was to investigate left vs. right visual field laterality in deaf signers and hearing nonsigners for three different aspects of visual processing, which differ in the extent to which they provide important cues for sign language comprehension. *First,* we tested *direction-of-motion* discrimination, which allowed us to replicate the finding of left hemisphere dominance for motion processing in deaf signers and not in hearing nonsigners. As opposed to previous studies which used stimuli containing opposite directions of motion (Bosworth & Dobkins, 2002a, 2002b; Fine, Finney, Boynton, & Dobkins, 2005; Finney & Dobkins, 2001), in the current study subjects discriminated between small differences in the directional angle of motion. We reasoned that this might be closer to the types of finer discriminations signers make during sign language comprehension, since the differences across hand movements in sign language are often relatively subtle. *Second*, we tested *orientation* discrimination, with the prediction that because discrimination of finger and hand orientation is important for sign language comprehension, we might also find a left hemisphere dominance for this aspect of visual processing in deaf signers but not hearing nonsigners. We also used these motion and orientation tasks to ask, more generally, whether the deaf signers and hearing nonsigners differ in processing of stimuli/tasks that are thought to be mediated by the dorsal and ventral pathways. It is believed that the dorsal pathway supports spatial and motion processing and visuo-motor integration while the ventral pathway supports form processing and object recognition (see Desimone & Duncan, 1995; Milner & Goodale, 2008; Ungerleider & Pasternak, 2004 for reviews). It has been previously suggested that the dorsal pathway may be more greatly affected by deafness (Bavelier, Dye, & Hauser, 2006; Samar & Parasnis, 2005; Stevens & Neville, 2006). One recent study compared brain activation in hearing nonsigners, deaf signers, and hearing signers while they performed a spatial matching task that activated the dorsal pathway and an object-matching task that activated the ventral pathway (Weisberg, Koo, Crain, & Eden, 2012). They confirmed differential effects of both deafness and sign language on each pathway. *Finally*, as a control, we tested *brightness* discrimination, with the prediction that since brightness is not important for sign language comprehension, our deaf signers and hearing nonsigners should not show differences in laterality.

A second goal of the current study was to investigate effects of *attention* on visual performance, which we addressed by measuring performance under *full* vs. *poor* attention conditions. This attentional manipulation allowed us to ask two main questions. One, we asked whether any observed left vs. right laterality effects were dependent upon the amount of attention devoted to the stimulus/task. Two, we asked whether effects of attention for central vs. peripheral visual fields differed for deaf vs. hearing subjects, motivated by previous reports that attention effects in deaf individuals are greater in the peripheral than in central visual field (Bavelier et al., 2000; Dye et al., 2009; Neville & Lawson, 1987a; Neville et al., 1983; Proksch & Bavelier, 2002). To manipulate attention, we used a dual-task paradigm, i.e., obtaining visual thresholds for the main task (motion, form, or brightness) under conditions of full attention (main task alone) vs. poor attention (main task with a concurrent foveal task). We and others have previously observed elevated thresholds under poor attention conditions using the dual-task paradigm (Bonnel & Miller, 1994; Bonnel, Possamai, & Schmitt, 1987; Bosworth, Petrich, & Dobkins, 2012; Braun, 1994; Braun & Sagi, 1990, 1991; Huang & Dobkins, 2005; Lee, Koch, & Braun, 1997, 1999; Sperling & Melchner, 1978). The intention of the poor attention condition was to require subjects to maintain endogenous spatial attention at fixation, providing less attention for the main task. Here, we reasoned that if deaf subjects have enhanced attention (i.e., better at shifting or distributing attention amongst multiple tasks), then they would be less impaired by the poor attention condition, compared to hearing subjects, and this effect could differ for left vs. right visual fields, and/or for central vs. peripheral visual fields.

2. Methods

2.1. Subjects

Subjects included 15 hearing (6 males, average age = 22.0 ± 1.0 years) and 9 deaf (3 males, average age = 26.0 ± 1.9 years) adults. Deaf subjects had uncorrected hearing loss greater than 80 Decibels in both ears. Based on self-report, all participants were deaf from birth, with the exception of one who lost hearing at 15 months of age due to uncertain etiology. Two indicated the cause was congenital rubella, all others indicated unknown or genetic causes. Only two had deaf parents or older deaf siblings. All deaf participants reported that they began signing between 6 months and 3 years of age and used ASL on a daily basis in their interactions at school, work, or at home. Hearing subjects had normal hearing and no ASL experience. All subjects were right-hand dominant. The difference in age between the two subject groups was not significant ($t(23) = 1.71$; $p = 0.10$). A subset of the hearing individuals participated in an additional study of visual attention (Bosworth et al., 2012). All subjects gave informed consent before