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Research paper

Sustained attention, selective attention and cognitive control in deaf and hearing children

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ABSTRACT

Deaf children have been characterized as being impulsive, distractible, and unable to sustain attention. However, past research has tested deaf children born to hearing parents who are likely to have experienced language delays. The purpose of this study was to determine whether an absence of auditory input modulates attentional problems in deaf children with no delayed exposure to language. Two versions of a continuous performance test were administered to 37 deaf children born to Deaf parents and 60 hearing children, all aged 6–13 years. A vigilance task was used to measure sustained attention over the course of several minutes, and a distractibility test provided a measure of the ability to ignore task irrelevant information – selective attention. Both tasks provided assessments of cognitive control through analysis of commission errors. The deaf and hearing children did not differ on measures of sustained attention. However, younger deaf children were more distracted by task-irrelevant information in their peripheral visual field, and deaf children produced a higher number of commission errors in the selective attention task. It is argued that this is not likely to be an effect of audition on cognitive processing, but may rather reflect difficulty in endogenous control of reallocated visual attention resources stemming from early profound deafness.

1. Introduction

Recently, there has been much interest in the relationship between audition and cognition. The new field of *cognitive hearing science* (Arlinger et al., 2009) has highlighted the important role of domain-general cognitive processes, such as working memory (Rönnberg et al., 2008), attention (Wild et al., 2012), and sequence processing (Conway et al., 2009) in supporting spoken language comprehension and production. In instances where auditory systems are compromised (for example, in age-related hearing loss, or noisy environments), these cognitive systems have been shown to play a pivotal role in supporting successful spoken language processing. One approach to identifying which cognitive processes support auditory processing in the context of language comprehension is to study individuals who are profoundly deaf. Indeed, such studies have lead to theories that articulate the role of audition in *shaping* those cognitive processes (Conway et al., 2009). This has lead to the claim that the deleterious effect of profound deafness on spoken language development is compounded – deafness makes access to the sound structure of the language difficult, and at the same time leads to deficits in the cognitive skills needed to support spoken language comprehension under adverse conditions (Conway et al., 2009).

However, there are some profoundly deaf children who do not struggle to acquire language. These are deaf children born into culturally Deaf families where they are exposed in infancy to a natural signed language such as American Sign Language (ASL). Sign languages are the natural languages of Deaf communities and possess phonological systems, morphological systems and syntactic rules, operating within complex grammatical systems (Sandler and Lillo-Martin, 2006). Whatever cognitive processes are required for modality-independent language processing are clearly not impaired by deafness in these children, who achieve typical language and social milestones in infancy (Bonvillian et al., 1983; Marschark, 1993; Peterson and Siegal, 2000; Petitto and Marentette, 1991). However, it is remains possible that the cognitive processes required to support spoken language are negatively impacted by a lack of auditory stimulation. One such process that

Abbreviations: ADD/ADHD, Attention Deficit Disorder/Attention Deficit-Hyperactivity Disorder; ANCOVA, Analysis of Covariance; ASL, American Sign Language; CI, cochlear implant; CPT, continuous performance task; GDS, Gordon Diagnostic System; SES, socio-economic status; SLI, Specific Language Impairment; T.O.V.A., Test of Variables of Attention

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has been demonstrated to play a role in audio-visual speech comprehension (Kushnerenko et al., 2013) and word-to-world mapping (Yu and Smith, 2011) is visual attention. Here we focus upon two aspects of visual attention thought to be compromised in deaf children: the ability to sustain attention over a significant period of time, and the ability to select task-relevant stimuli and avoid distraction – selective attention.

1.1. Attentional deficits in deaf children

Deaf children have been reported to have behavioral problems related to impulse control, distractibility, and an inability to sustain attention in the visual modality. Quittner et al. (1990) reported that parents of deaf children indicated that their children had greater distractibility-hyperactivity problems compared with the parents of hearing children. In a study of teacher-identified problem behaviors in deaf children, Reivich and Rothrock (1972) suggested that impulsivity and a lack of inhibitory control accounted for a significant amount of the problem behaviors reported. Chess and Fernandez (1980) reported elevated levels of impulsive behavior in deaf children manifest as aggressive acts such as kicking, hitting, and biting. Theirs was a study of deaf children whose mothers had Rubella during gestation, and the aggressive behaviors were more prevalent in those with multiple disabilities, than in the healthy children with deafness alone.

Parental and teacher reports, however, are by nature a subjective approach. Other researchers have adopted clinical measures that assess cognitive control by measuring how long it takes a child to complete a task, and how many errors they make – fast completion coupled with a large number of errors is taken as an indicator of an impulsive response style. Several studies have shown that deaf children of hearing parents perform more poorly than hearing children on these types of clinical measures, including the Porteus Maze Test (Best, 1974; Eabon, 1984; O'Brien, 1987), the Matching Familiar Figures Test (Eabon, 1984; O'Brien, 1987), and the Draw-a-Man Test (Harris, 1978). Interestingly, the study by Harris (1978) revealed an effect of parental hearing status on the Matching Familiar Figures and Draw-a-Man Test, with deaf children born to deaf parents outperforming those born to hearing parents.

1.2. Continuous performance tests

More recently, deficits in visual continuous performance tasks (CPTs) have been reported in deaf children (Horn et al., 2005; Mitchell and Quittner, 1996; Quittner et al., 2004, 1994; Smith et al., 1998; Yucel and Derim, 2008). CPTs are computerized measures of attention that typically require children to attend to a rapidly changing stream of stimuli. They have advantages over the clinical measures discussed in the previous section, including less subjectivity in the rating of performance and determination of errors, ease of administration, and the existence of large data sets providing norms across a large range of ages.

In one commonly used CPT, the Gordon Diagnostic System (GDS; Gordon and Mettleman, 1987), digits appear rapidly, one at a time, in the center of an LED display. Children are usually required to make a response to a target digit or to a specific sequence of target digits. The GDS can be administered as a visual task, with no auditory component, and has therefore been used with deaf children. In one version of the task, correctly pressing a button in response to the digit 9, but only when a 1 precedes it, is an index of *sustained attention*. Pushing the button at any other time (a commission error) is taken as being indicative of impulse control problems, reflecting poor *cognitive control*. In another version, irrelevant digits appear to the left and right of the central target digit stream. Poor performance is attributed to the child being distracted by the flanking digits; in other words, a failure of visual *selective attention*. In studies using these tasks, deaf children have been reported to have poorer cognitive control (Quittner et al., 1994) and to suffer from an inability to select targets appropriately (Mitchell and Quittner, 1996) relative to hearing age-matched controls. Furthermore, Smith et al. (1998) reported data suggesting that cochlear implantation alleviates these deficits, although the children with cochlear implants (CIs) did not achieve the performance levels of hearing controls. The authors suggested that their data indicate a deficit in visual selective attention stemming from poor multimodal sensory integration as a result of early, profound hearing loss. Such a position can be termed a deficiency hypothesis and, generally stated, it proposes that integration of information from the different senses is an essential component to the development of normal attentional functioning within each individual sensory modality.

An alternative view holds that attention-related deficits in deaf children may be related to their limited exposure to language and impoverished social communication early in life (Dye and Bavelier, 2013). Whether auditory loss, delays in language exposure, or abnormal socio-emotional development leads to attention deficits in deaf children remains a poorly understood issue. Other confounds are also worthy of consideration. For example, Parasnis et al. (2003) administered the Test of Variables of Attention (T.O.V.A.; Leark et al., 1999) to deaf and hearing college students. Their data suggested that deaf observers had decreased cognitive control when selecting the appropriate response, accompanied by decreased perceptual sensitivity. Parasnis et al. (2003) argued that this reflected appropriate adaptations to the environment for someone who cannot hear and was not an attentional pathology. Specifically, they argued, a less conservative response criterion reflects reliance upon vision for alerting in the absence of auditory input. The decreased perceptual discrimination ability, they argued, resulted from redistribution of attention away from the center and toward peripheral vision, as initially proposed by Neville and her collaborators (Neville and Lawson, 1987a, 1987b; Neville et al., 1983). In the absence of audition, a key modality in the detection of events in an individual's immediate environment, visual selection attention becomes enhanced in deaf individuals in the periphery of their visual field (Bavelier et al., 2006). This possibility should also be entertained when considering the Mitchell and Quittner (1996) findings. In sum, the existing body of evidence points to weaker cognitive control and poor visual selective attention in deaf individuals, but the source of these effects remains controversial.

1.3. Continuous performance tests and cochlear implantation

Horn et al. (2005) reported a retrospective longitudinal study of CPT performance in deaf children who had undergone CI surgery. These implanted children demonstrated poor sustained attention, which improved little with increasing years of CI use. A study by Yucel and Derim (2008) looked at the effect of age of implantation on sustained attention in 6–11 year old deaf children. They reported elevated levels of inattention and impulsivity in deaf children compared to hearing controls, with performance poorer in those deaf children who received CIs after the age of 4 years compared to those who received their implants at a younger age. Interestingly, Shin et al. (2007) reported the opposite in a prospective longitudinal study of Korean deaf children receiving a CI at 6–7 years of age: they demonstrated more inattention and impulsivity following surgery than they did pre-implant.

In studies of recovery of function following cochlear implantation there is a confound between restoration of auditory input, age of implantation, and the acquisition of language. It is unclear to