Visual Attention and Hearing Loss: Past and Current Perspectives

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Abstract

Background: It is reasonable to expect that deaf individuals require the use of vision for purposes other than those needed by hearing persons. For example, without the use of hearing, one would need to scan the environment visually to determine if someone was approaching rather than listening for footsteps or a name being called. Furthermore, these experiential differences could alter the development of neural organization of sensory systems of deaf persons.

Purpose: To review the evidence-based literature in the area of visual attention and deafness with an emphasis on a series of visual attention studies utilizing several paradigms including the Continuous Performance Task, the Letter Cancellation Task, the Flanker Task, and a self-designed task of target identification in the periphery under distracter and nondistracter conditions conducted at Vanderbilt University.

Research Design: Systematic review

Results: Collectively, the Vanderbilt studies pointed to a compensatory role that the visual system plays for deaf individuals. Specifically, the visual system appears to play an important role in directing a deaf individual's attention to the near visual periphery.

Conclusions: Studies of visual attention in deaf individuals have been mixed in their conclusions about whether altered neural organization results in better or worse visual attention abilities by those who are deaf relative to those with normal hearing. The notion of across-the-board deficits or enhancements in the visual function of deaf individuals is not supported by the literature, nor is there support for the idea that fundamental visual sensory abilities such as acuity or light detection differ between deaf and hearing persons.

Key Words: Deafness, neural organization, visual attention

Abbreviations: CPT = Continuous Performance Task; LED = light emitting diode; UHL = unilateral hearing loss

Sumario

Antecedentes: Es razonable esperar que los individuos sordos requieran del uso de la visión para propósitos diferentes de aquellos necesitados por la persona oyente. Por ejemplo, sin el uso de la audición, uno podría necesitar la revisión del ambiente en forma visual para determinar si alguien se está acercando, en lugar de escuchar pisadas o el llamado de un nombre. Más aún, estas diferencias de experiencia podrían alterar el desarrollo de la organización neurológica de los sistemas sensoriales de las personas sordas.

Propósito: Revisar la literatura basada en evidencia en el área de atención visual y sordera, con un énfasis en una serie de estudios de atención visual que utilizan varios paradigmas, incluyendo la Tarea de Desempeño Continuo, la Tarea de Cancelación de Letras, la Tarea de Flanqueo, y una tarea auto-

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diseñada de identificación de blancos en la periferia bajo condiciones de distracción y no distracción, desarrollado en la Universidad de Vanderbilt.

Diseño de la Investigación: Revisión sistemática.

Resultados: Colectivamente, los estudios de Vanderbilt apuntaron hacia un papel compensatorio que el sistema visual juega en los individuos sordos. Específicamente, el sistema visual parece jugar un importante papel en dirigir la atención del individuo sordo hacia la periferia visual cercana.

Conclusiones: Los estudios de atención visual en individuos sordos han tendido a confundir en sus conclusiones sobre si una organización neurológica alterada genera capacidades de atención visual mejores o peores entre los sordos y los individuos con audición normal. La noción de deficiencias en varios sistemas o el aumento en la función visual de los individuos sordos no está apoyada por la literatura, y tampoco hay apoyo a la idea de que las capacidades sensoriales visuales fundamentales, tales como la agudeza visual o la detección de la luz difieran entre personas sordas y oyentes.

Palabras Clave: Sordera, organización neural, atención visual

Abreviaturas: CPT = Tarea de Desempeño Continuo; LED = diodo emisor de luz; UHL = pérdida auditiva unilateral

The study of how the development of neural organization is affected by sensory deficits has fascinating implications for the disciplines of audiology and deaf education. Most neural connections are laid out during human fetal development and undergo continued refinement throughout childhood, with strong influence from prevailing patterns of neural activity and synaptic transmission (Bear et al, 2001). It is easy to imagine that a congenital sensory deficit in one modality might lead to an altered organization of neural connections that affects perception by other modalities. These variations in neural organization are commonly viewed in terms of compensatory or deficiency models (Reynolds, 1978; Parasnis, 1983). The deficiency model supposes that sensory systems complement each other and function optimally when all systems are intact. Therefore, a deficit in one sensory system, such as deafness, might detract from the function of another sensory system, such as vision. This might occur, for example, if the intact sensory modality were “burdened” with carrying out a function for which the system with a deficit normally excels. In contrast, the compensatory model suggests that a deficit in one sensory system could result in added proficiency in another sensory system, as the latter system is engaged in functions for which it is not typically called upon. Thus, for example, someone with an auditory deficit could have enhanced visual processing (Parasnis, 1983). Although the deficit/compensation distinction is important from a rehabilitation perspective, it has a teleological underpinning that probably does not accurately characterize the developing nervous system. Rather, the system is organized to make effective use of its available resources for the activities in which the person engages. For example, the brain areas involved in reading appear to differ considerably between deaf and hearing persons (Aparicio et al, 2007).

Because the life experiences and perceptions of a congenitally deaf person are very different from those of an individual with normal hearing, it is reasonable to speculate that the visual system of someone who is deaf could be organized in such a way as to reflect such differences. Numerous studies have been conducted to investigate both the compensatory and deficiency models by examining the visual perceptual skills of normal hearing and deaf individuals (Reynolds, 1978). The notion of across-the-board deficits or enhancements in the visual function of deaf individuals has not been supported by the literature, nor is there support for the idea that fundamental visual sensory abilities such as acuity or light detection differ between deaf and hearing persons. However, our work has been guided by the idea that the auditory system’s role in directing attention to events in one’s surroundings might be “delegated” to the visual and tactile systems. For example, when another person approaches you from out of your field of view, the sense of hearing usually provides ample information from their footsteps or voice. In the absence of hearing, people may acquire capabilities for getting this information through visual scanning, enhanced attention to the visual periphery, and tactile sensitivity to vibrations. Our work has focused on the visual aspects of this scenario.

STUDIES OF VISUAL ATTENTION AND DEAFNESS

Numerous studies have documented enhanced performance of deaf adults on visual search tasks and visual detection of peripheral stimuli relative to normal hearing adults (Parasnis, 1983; Parasnis and Samar, 1985; Loke and Song, 1991; Reynolds, 1993; Stivalet et al, 1998; Rettenbach et al, 1999). For example, Stivalet and colleagues (1998) demonstrated that adults with severe-to-profound hearing loss were faster than adults with normal hearing in identifying visual targets amid distracting visual stimuli. In addition, deaf adults were faster than adults with normal hearing at detecting stimuli in the periphery, particularly in the presence of foveal information (Parasnis and Samar, 1985; Loke and Song, 1991; Reynolds, 1993). Visual evoked potential studies have also supported this compensatory effect in deaf individuals (Neville et al, 1983; Neville and Lawson, 1987). Neville and colleagues recorded waveform components in response to peripheral stimuli that were one and a half to three times larger in the frontal and anterior regions of the cortex in deaf adults than in adults with normal hearing (Neville et al, 1983; Neville and Lawson, 1987). Furthermore, behavioral data from those studies demonstrated that deaf adults were significantly faster than individuals with normal hearing at detecting the direction of motion in the right visual field (Neville and Lawson, 1987).

In contrast to these studies that support the compensatory model, the results of several studies suggest that deafness may contribute to inferior visual selective attention skills in children (Quittner et al, 1994; Mitchell and Quittner, 1996; Smith et al, 1998). All three studies examined visual selective attention in small groups of children with prelingual deafness and with normal hearing. The children who were deaf used hearing aids or cochlear implants. The Continuous Performance Test (CPT; Gordon, 1986), a visual vigilance task, was used to measure sustained attention to a relatively tedious task. Young children with deafness performed significantly worse than children with normal hearing, and older children with a few years of cochlear implant experience outperformed their peers with deafness who did not have cochlear implants.

Quittner and her colleagues (1994) posited that the development of attention depends on integration of multimodal sensory information. That is, while children with normal hearing learn to focus their visual attention selectively on a task while monitoring their environment auditorily, children with severe-to-profound hearing loss may develop visual attention strategies that are more distributed because they must also use their vision to monitor their environment. By this account, there is a cost to using vision for event monitoring that would otherwise be carried out through hearing. The authors speculated that children with cochlear implants in these studies may have performed better than their peers who used hearing aids because they were able to focus their visual attention exclusively on the computer screen while using auditory input from their implant to monitor their environment. It should be noted that there were no significant differences in aided auditory thresholds in these studies between the children who used hearing aids and those who used cochlear implants. However, Quittner et al (1994) suggested that auditory stimulation via cochlear implants may provide an auditory processing advantage over that offered by hearing aids.

These studies triggered an interest on our part in exploring further the relationships among amplification status, off-task visual scanning, nonverbal intelligence, and performance on visual selective attention tasks. The first in our series of studies examined visual attention in deaf and normal hearing children (Tharpe et al, 2002). Specifically, we chose to examine visual attention by using the CPT, the same test employed by the aforementioned studies. The CPT is a monotonous task that requires sustained attention to a series of numbers presented on a screen but has no auditory demands. We also administered the Letter Cancellation Task, a measure of visual attention and visual-spatial scanning abilities (Diller et al, 1974). The Letter Cancellation Task consists of a printed matrix containing 12 capital letter Us embedded in a background of capital letter Os. The children were instructed to cross out all the target letters (U) with a pencil as quickly as possible. The dependent variable for this measure was the time it took the child to complete the task.

Recall that Quittner et al (1994) surmised that amplification enhanced vigilance to visual attention tasks. To evaluate this experimentally, we assessed visual attention skills with amplification devices on and off. We also positioned the participants in such a way as to require them to turn their heads in order to see if someone entered the room to determine if, in fact, they scanned their environment visually throughout the test session as previously speculated. That is, if the children were nonattentive to the task, we wanted to observe if they were visually scanning their environment during periods of inattentiveness. Finally, a measure of nonverbal intelligence was included to provide information on how general intellectual abilities affect performance on this type of task.

Twenty-eight children (aged 8–14 years) participated in the study. They comprised three groups: children with normal hearing, children with prelingually acquired or congenital severe-to-profound deafness who wore hearing aids, and children with prelingually acquired or congenital severe-to-profound deafness who wore cochlear implants. The CPT consisted of watching a series of numbers appearing one at a time on a computer screen at one-second intervals, and pressing a button when the number *9* appeared following the number *1*. During the nine-minute task, 540 semirandomized numbers were presented at a rate of 1/sec, with each number displayed for 0.2 sec. Despite our efforts to replicate the methods of previous studies, we found very few differences in performance between children with and without deafness on either of the visual attention tasks. Furthermore, we did not observe superior performance by the cochlear implant group over the hearing aid group, as had been reported in previous studies. In fact, all children, those with hearing loss and their normal hearing peers, performed quite well on both visual attention tasks. Although children with cochlear implants had significantly lower scores on the CPT than the normal hearing group, even the children with cochlear implants did very well. It is noteworthy that a significant association was found between CPT performance and nonverbal intelligence. It is possible that differences in CPT performance between normal and deaf groups in previous studies reflected intellectual differences rather than hearing status. Another point of interest was that other researchers hypothesized that the differences found between children with and without deafness on tasks of visual attention were related to differences in strategies for monitoring their environment. That is, there may be more distributed visual attention in children with deafness than children with normal hearing (Smith et al, 1998). However, results of the Tharpe et al (2002) study did not support this conjecture. Most of the children, deaf and normal hearing, kept their eyes fixated on the computer screen over the entire duration of the tasks. Therefore, on at least these two tasks of visual attention, the CPT and the Letter Cancellation Task, few differences among deaf and normal hearing children were noted.

The visual attention tasks utilized in the Tharpe et al (2002) study examined central vision in that children were looking directly at the numbers or letters. We speculated that differences between deaf and normal hearing individuals might emerge on tests of parafoveal, or peripheral vision, tasks. After all, being attentive to sign language, or even body language and hand gestures, requires visual attention beyond the foveal region. Furthermore, as previously discussed, individuals with limited hearing must use their vision to monitor their surroundings, as opposed to those with normal hearing who can rely on auditory as well as visual monitoring. This speculation led to the next study of visual attention that examined reaction times of deaf and normal hearing adults to visual targets in the periphery in distracting and nondistracting conditions (Rothpletz et al, 2003). Reaction times were measured by examining head orientation toward the visual stimuli. Specifically, 20 adults participated in this study and were divided into those with bilateral severe-to-profound deafness and those with normal hearing. All of the deaf adults communicated through sign language. Peripheral stimuli were red and green light-emitting diodes (LEDs) positioned at eye level and mounted on an arc at several eccentricities (i.e., 10, 40, and 65°) to the left and right of a center fixation point. The target light at one of the six locations would illuminate, and participants were instructed to look toward only the target color (red or green) LED when illuminated. For the nondistracter condition, only a target LED would illuminate. In the distracter condition, extraneous LEDs of the nontarget color would illuminate sequentially in the visual field, followed at some point in time by the target. The green lights served as distracters for the red targets, and the red lights served as distracters for the green targets.

Although previous studies concluded that deaf individuals respond faster to visual targets in the periphery than normal hearing individuals (Neville et al, 1983; Parasnis and Samar, 1985; Neville and Lawson, 1987; Loke and Song, 1991), Rothpletz and colleagues (2003) found equivalent reaction times between the deaf and normal-hearing participants to visual targets in the periphery in the nondistracter condition. However, in the distracter condition, the deaf participants were slower to respond to targets at several eccentricities than the normal hearing participants. Weber and Fischer (1994) suggested that the presence of nontarget stimuli in the visual field engages foveal attention and inhibits responses to peripheral events. Rothpletz et al (2003) theorized that the presence of distracting stimuli could result in greater inhibition in deaf individuals than in normal hearing individuals, thus resulting in slower, or more deliberate, responses to peripheral stimuli. Because deaf individuals must rely on their vision almost exclusively for communication and for monitoring their surroundings, in environments with numerous visual distracters, it may be necessary to focus intently on their immediate task. Therefore, deaf individuals may tend to emphasize accuracy of response at the cost of responding more slowly.

STUDIES OF THE FLANKER EFFECT AND DEAFNESS

The results of the Rothpletz et al (2003) study led to an interest in further examination of potential parafoveal differences between deaf and normal hearing individuals. The parafovea is the visual field within just two or three degrees of the fovea, which is known, for example, to play a role in guidance of eye movements during reading. One way to examine such differences is through the use of visual search tasks that require participants to recognize targets embedded among a display of visual elements (Eriksen and Schultz, 1979). A popular method of evaluating central visual filtering was first described by Eriksen and Eriksen (1974) and is referred to as the Flanker Task. Rather than requiring participants to search for visual

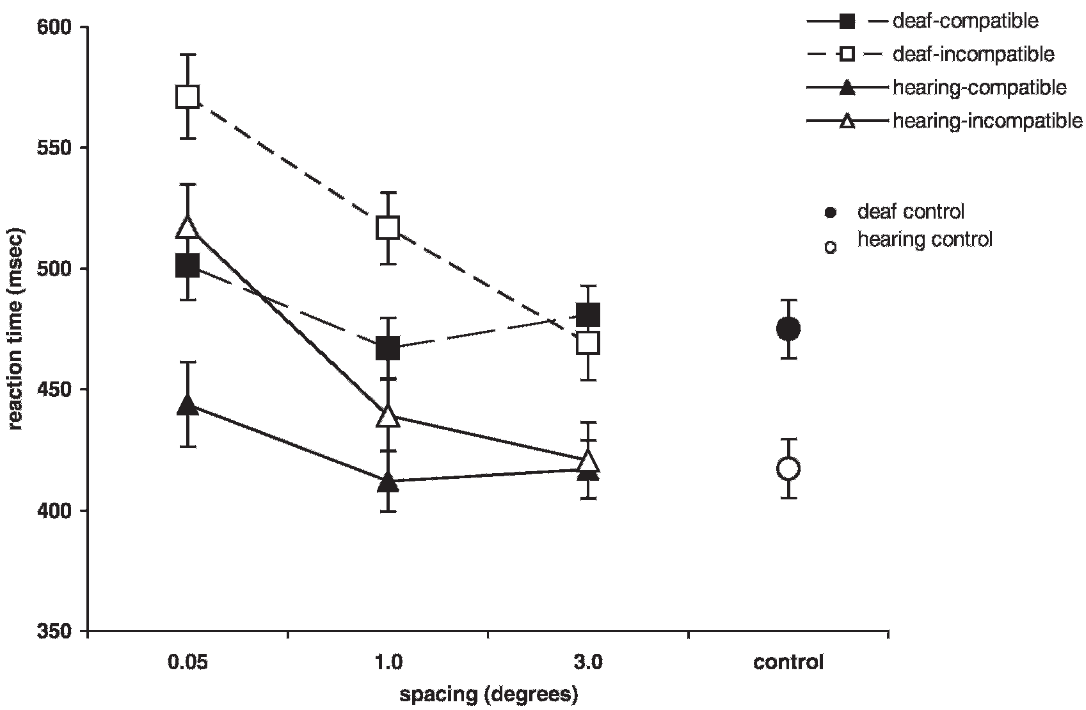

Figure 1. Average reaction times (±1 standard error) for the deaf and hearing groups as a function of compatibility and target-flanker spacing. From Sladen et al, 2005. Reprinted with permission.

targets, this paradigm requires participants to make a judgment about a target stimulus (e.g., a letter) in a fixed location on a computer screen when it is flanked by compatible (i.e., same letter as the target) or incompatible elements (i.e., different letter than the target). These compatible or incompatible elements, or flankers, are controlled to appear in varying proximity to the targets. Reaction time serves as an index of performance on this task. The reaction time on this task is dependent on the distance between the target and the flankers, and whether the flankers are compatible or incompatible with the target; that is, whether the flankers are the same as or different from the central target. Eriksen proposed that the visual system has a minimal channel capacity that is larger in spatial extent than that required for selecting a single letter. As a result, if other letters are present in close proximity, they are processed along with the target letter, even though the person viewing the display is consciously aware of only the central letter. If the letters surrounding the target are different from the central letter, then the time needed to identify the central letter is longer. This is called the flanker compatibility effect.

Using the Eriksen Flanker Task, Sladen and colleagues (2005) examined the central visual filtering of deaf and normal hearing adults. Again, given that deaf individuals rely on visual information to communicate and monitor the world around them, it was reasonable to propose that they allocate their visual resources over a wider area than hearing individuals. Therefore, we presumed that deaf adults would show more interference from incompatible flankers than normal hearing adults, especially when the flankers were spaced far from the target letter. Twenty adult participants were divided into two groups, ten each with normal hearing bilaterally and with prelingual severe-to-profound deafness bilaterally. The deaf participants used sign language as their primary mode of communication.

The results across groups supported previous findings of the flanker compatibility effect. This is, the flanker compatibility effect decreased with increased spacing between the target letter and the incompatible flankers for all participants, deaf and normal hearing alike. In fact, the median reaction times by the normal hearing subjects in this study were comparable to those reported by Eriksen and Eriksen (1974) in their original description of the task. As also noted in the reaction times reported in the Rothpletz et al (2003) study, the hearing participants were faster than the deaf participants for each of the experimental conditions as well as the control condition. This may constitute evidence for a deliberate response tendency of deaf individuals. In other words, because deaf individuals potentially have a lot to lose in some situations by redirecting their attention (i.e., missing conversation), they may be more careful about doing so than normal hearing persons.

But, as seen in Figure 1, the most interesting result of the Sladen et al (2005) study was the interaction among target spacing, compatibility, and group. Eriksen and Eriksen (1974) previously reported that when the display letters were separated by 1.0°, reaction times of typical adults for compatible and incompatible arrays were essentially the same. However, in the Sladen et al (2005) study, with 1.0° of spacing between the target and flanker, the flanker compatibility effect existed for both groups but was significantly larger for the deaf group. In other words, incompatible flankers caused less of an interference effect for the normal hearing group at 1.0° of spacing than they did for the deaf group. Again, this finding might be explained by the visual demands placed on deaf individuals. Deaf individuals must focus centrally on the lips and face of the person with whom they are communicating. To turn or glance away at an event in the periphery may come at a cost of missing an important piece of dialogue. Therefore, one could speculate that deaf individuals learn from an early age to focus their visual attention over a wider area than normal hearing individuals in order to monitor the visual periphery without having to shift visual attention away from the frontal region. This might explain why in the present study, deaf participants demonstrated a greater flanker effect for the 1.0° target-flanker spacing condition than the normal hearing participants.

There is some, albeit indirect, support for this notion that enhanced peripheral attention in deaf individuals may be part of a composite strategy of increased visual scanning of the environment. A series of studies are currently underway at Vanderbilt University examining the relationship between head elevation and angle (of children) and important sound sources, such as brief utterances, in a classroom environment (Ricketts and Galster, 2008). Specifically, they examined head orientation of children with and without hearing loss to determine if orientation accuracy was similar between these two groups across age range (i.e., five to seven and eight to twelve years of age). Preliminary data from 20 children, conducted in multiple educational settings, suggested that children with hearing loss turned their heads toward the source of brief utterances more often than their age-matched, normal hearing peers (Ricketts and Tharpe, 2005).

FUTURE DIRECTIONS

To date, research conducted at Vanderbilt University in the area of visual attention and deafness has focused on the effects of bilateral, congenital deafness on visual abilities. However, past research has demonstrated that even congenital, unilateral hearing loss (UHL) can have a significant affect on one's academic performance and speech perception (Bess and Tharpe, 1986; Bess et al, 1998; Lieu, 2004). Of particular relevance to this discussion is research by Bess and Tharpe (1986) and Humes et al (1980) that has shown UHL in children to affect performance on localization tasks. That is, those with UHL have significantly more difficulty on tasks of auditory localization than peers with normal hearing. If, as speculated by Sladen et al (2005), the visual periphery is expanded in congenitally deaf adults in part because these individuals use their vision to monitor their environments, then it is logical to assume that those with UHL, who do not have good auditory localization ability, will also use their vision to monitor their environments. Certainly, those with UHL may not have the need to scan their environments to the extent that individuals with bilateral hearing loss do. After all, those with UHL can detect sounds in their environments. However, they cannot identify the location of these sounds as adeptly as those with normal hearing. Therefore, they presumably scan their environments more often than those with normal hearing but not as often as those who are deaf. The next study in our series examining deafness and visual abilities will include individuals with UHL in a flanker effect task. We hypothesize that individuals with UHL, similarly to those with bilateral deafness, will demonstrate an allocation of visual resources further into the periphery than those with normal hearing.

Taken together, studies of visual attention support the notion of altered visual organization in deaf individuals. Moreover, this visual organization involves the widening of attention allocation into the visual periphery. Our studies suggest that these alterations serve a compensatory function by directing the attention of deaf individuals to their immediate surroundings for purposes of monitoring, a function typically shared by the auditory, visual, and, perhaps, tactile systems.

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