Chapter 9

Visual Attention in Deaf Children and Adults

Implications for Learning Environments

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> *Think you of the fact that a deaf person cannot hear. Then, what deafness may we not all possess? What senses do we lack that we cannot see and cannot hear another world all around us?*
>
> —Frank Herbert, *Dune*

The world we live in is overwhelmingly rich and complex. As human agents living in such a world we are constantly bombarded with large amounts of sensory information through multiple channels such as vision, audition, and olfaction. Our ability to filter, select, and focus upon different aspects of the environment is termed *attention.* Indeed, an initial level of filtering occurs at the sensory level—our senses are only able to process some of that information which bombards us. We cannot see the infrared light emitted by our remote controls, or hear the sound of a bat as it echo-locates in search of food. Some species, of course, can detect such signals—however, the human visual system has evolved in such a way that it cannot. When psychologists talk of attention, however, they do not refer to this kind of information selection. Rather, the emphasis is on selecting information that is made available to us via our senses.

Attention can be construed as the mechanism or mechanisms that allow us to select from the information those aspects we need in order to act appropriately—detect an oncoming vehicle in order to cross a road safely—or simply as a way to reduce incoming information to make it manageable for a brain that is limited in its capacity to process that information. Whatever the role of attention, it is clear that an ability to filter out irrelevant information and focus upon specific aspects of our environment in a goal-directed manner is an essential tool for survival. In this chapter, we focus upon visual attention—the ability to select and concentrate on information entering the brain via the visual pathway—and how significant hearing loss may have an effect upon how visual information is selected and attended.

Attention and Behavior Problems in Deaf Children

Deaf children have been reported to have behavioral problems related to impulsivity and an inability to focus attention. These reports have come from both subjective ratings of teachers and caregivers, as well as from clinical tests of attention skills. For example, mothers have been reported to rate deaf children as having greater distractibility–hyperactivity problems than hearing children using the Parenting Stress Index (Quittner, Glueckauf, & Jackson, 1990), and Reivich and Rothrock (1972) suggested that impulsivity and lack of inhibition accounted for a significant amount of the problem behavior in deaf pupils reported by teachers in their study. On the other hand, Altshuler et al. (1976) noted that teachers demonstrated little agreement in their ratings of impulsivity in their deaf adolescent pupils. Meadow (1976), using the Behavior Symptom Checklist with mothers of deaf and hearing children, reported little evidence of deaf–hearing differences in short attention spans, with few mothers reporting problems eliciting and maintaining eye gaze and joint attention with their deaf children. The lack of consistent findings is perhaps not surprising given the subjective nature of such rating scales.

Of more interest then, are the results obtained using more objective, clinical measures of attention. Altshuler et al. (1976) report that deaf children in their study performed on average worse than hearing controls on the Porteus Mazes and the Time to Draw a Line tests. Specifically, deaf children tended to make more wrong turns in the maze task and took significantly less time to draw a straight line across a sheet of paper, suggesting a lack of planning and an inability to consider decisions.

Other studies have examined lower-level visual skills underpinning attention behavior and the visuo-motor skills that may also influence problems coordinating action within the environment. An early study by Myklebust and Brutten (1953) reported that deaf children had low-level visual deficits, as measured by the Keystone Visual Survey, as well as poor levels of performance on visual tasks such as the marble boards test, a test of visuo-motor skills developed by Werner and Strauss (1941). Attempts to replicate these findings, however, found either no difference between deaf and hearing children (Keystone Visual Survey; Hayes, 1955) or slightly better performance by deaf children (marble boards test; Larr, 1956; McKay, 1952). Finally, Hauser and colleagues (Hauser, Cohen, Dye, & Bavelier, 2007) reported no differences between deaf and hearing college students on a range of tests of visuo-motor tasks, including the Rey–Osterrieth Complex Figure Test (Osterrieth, 1944; Rey, 1941) and the Wechsler Memory Scale Visual Reproduction subtest (Wechsler, 1997).

Recently, deficits in continuous performance tasks (CPTs) have been reported in deaf children (Mitchell & Quittner, 1996; Quittner, Smith, Osberger, Mitchell, & Katz, 1994; Quittner, Leibach, & Marciel, 2004; Smith, Quittner, Osberger, & Miyamoto, 1998). Continuous performance tasks are computerized measures of attention that typically require children to sustain their attention to a rapidly changing visual display and make responses to targets while withholding responses to nontargets. In one commonly used CPT, the Gordon Diagnostic System (Gordon & Mettleman, 1987), digits appear one at a time in rapid succession in the center of a display—children are usually required to make a response to a target number when it is preceded by a specific number, but not otherwise. For example, children may be asked to press the response button upon seeing the target number 9 if it has been preceded by the number 1, but not otherwise. In this case, the sequence 1–9 would require a response to the 9, whereas the sequence 4–9 would require the child to withhold a response to the 9 and the sequence 1–4 would require the child not to make an impulsive response on the basis of seeing the number 1 alone.

Several different versions of this CPT have been used with deaf children. In one version, a *delay* task, children are required to press a button and then wait before pressing it again in the absence of any numerical stimuli. If they wait long enough, they receive a reward (a point), providing a measure of the efficiency with which children obtain rewards, taken as an index of impulsivity. In a second version, a *vigilance* task, correctly pressing the button to a 9 preceded by a 1 is an index of vigilance or sustained attention, whereas pushing the button at any other time (a commission error) is taken as a measure of impulsivity. A third version of CPT, a *distractibility* task, involves irrelevant numbers appearing to the left and right of the central numbers. Poor performance is attributed to the child being distracted by the flanking numbers. Using these tasks, deaf children have been reported to be more impulsive (Quittner et al., 1994) and to suffer from increased distractibility (Mitchell & Quittner, 1996). Furthermore, Smith et al. (1998) reported data suggesting that cochlear implants (CIs) diminish the strength of these deficits, although the children with CIs did not achieve the performance levels of hearing controls. The authors suggest 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.

Parasnis, Samar, and Berent (2003) administered another version of CPT—called the Test of Variables of Attention (T.O.V.A., Leark, Dupuy, Greenberg, Corman, & Kindschi, 1999)—to deaf and hearing college students. In the T.O.V.A., targets and nontargets are randomly presented to observers in quick succession, and they are asked to respond to the targets only. Their data suggested that deaf observers had increased impulsivity when selecting the appropriate response, accompanied by decreased perceptual sensitivity (i.e., they found it harder to distinguish between targets and nontargets). Parasnis et al. argued that both of these factors contributed to the apparent increased impulsivity in deaf samples, but that both reflect adaptations to the environment and not attentional pathology. Specifically, a less conservative response selection reflects a reliance upon vision for alerting in the absence of auditory input. In the absence of auditory cues to objects and events in the environment, more reliance is placed upon visual information for bringing such objects and events to the attention of the deaf observer. The decreased perceptual sensitivity in central vision, they argue, results from redistribution of attention away from the center and toward peripheral vision, as initially proposed by Neville and her collaborators (Neville, Schmidt, & Kutas, 1983; Neville & Lawson, 1978a,b). This possibility was also considered by Mitchell and Quittner (1996) in regard to their findings on distractibility. This idea, that a redistribution of attention occurs across visual space in deaf individuals, is the focus of the next section. However, before considering that hypothesis, it is important to consider other limitations in the work just reviewed, with a particular focus upon the selection of appropriate stimuli and careful consideration of what is meant by a "deaf child" in the context of such studies.

The Importance of Etiology and Communication

Lesser and Easser (1972) suggested that the impulsivity that had been reported in early studies of behavior problems in deaf children might have been a result of a lack of self-regulation stemming from difficulties in communication and expressing needs. Thus, early on, the importance of language in the development of attentional skills had been acknowledged (see Hauser, Lukomski, & Hillman, this volume). Furthermore, Meadow (1980) cited a study by Chess, Korn, and Fernandez (1971) that showed that maternal rubella was related to hyperactivity, thus establishing the importance of examining comorbidity in deaf children. That is, many deaf children have learning and other disabilities, in addition to their hearing losses, that are often associated with the same etiological cause. Indeed, deaf individuals in general vary greatly in the etiology of their deafness, its severity, and age of onset.

Over 20 million people in the United States have been diagnosed with hearing loss, representing a prevalence rate of 9% (Ries, 1994). The etiology of hearing loss can be hereditary (~50%) or acquired by several mechanisms such as prenatal or perinatal infections (cytomegalovirus, rubella, and herpes simplex), postnatal infections (meningitis), premature birth, anoxia, trauma, or as a result of ototoxic drugs administered during pregnancy. Many of these causes have been associated with other, sometimes severe, neurological sequelae that affect behavioral, cognitive, and psychosocial functioning (Hauser, Wills, & Isquith, 2006; King, Hauser, & Isquith, 2006). Hereditary deafness is associated with over 350 genetic conditions (Martini, Mazzoli, & Kimberling, 1997), and about a third of these genetic conditions are associated with syndromes (Petit, 1996). Although not all hereditary cases of deafness are nonsyndromic, hereditary-deafened individuals are more likely to have unremarkable neurological and psychiatric histories.

In the United States, many individuals who have severe to profound hearing loss before the age of 3 years use American Sign Language (ASL) as their first language, and thus may also be less likely to have self-regulatory issues resulting from communicative stress and an inability to express themselves. This group relies on visual routes to learning and language access, and has similar values, beliefs, and behaviors that usually reflect Deaf culture. The community of ASL users is often referred to in the literature as a *linguistic minority community* because of the similarities it has with other minority communities in terms of language and culture (Ladd, 2003; Padden & Humphries, 2005). The body of research considered next has focused largely upon such deaf individuals, often referred to as *deaf native signers*, minimizing potential confounds due to comorbid disorders or difficulties and problems stemming from communication problems in early childhood.

Altered Distribution of Visual Attention in Deaf Individuals: Behavioral Studies

In contrast to studies reporting examples of visual deficits, studies using homogenous samples of deaf native signers have demonstrated changes in visual function that could be considered more adaptive, in that they show a compensation in the visual modality for the lack of auditory input. In such individuals, a selective enhancement for stimuli that are peripheral or in motion and require attentional selection has been demonstrated using a variety of paradigms.

One of the key attributes of attention is that, when allocated to a position in space, an object occupying that space receives enhanced processing. Put another way, when attention is allocated to an object, an observer demonstrates increased sensitivity to that object. An early study by Loke and Song (1991) demonstrated that deaf observers responded more rapidly to targets flashed at locations in the periphery, a finding replicated recently by Chen, Zhang, and Zhou (2006). Importantly, in these studies, the location of the peripheral target is unpredictable (i.e., they do not always appear at the same peripheral location), and the targets are presented for brief durations so that the observer cannot make a visual saccade and redirect their fixation to the target location. The conclusion, therefore, is that the deaf observers had allocated more of their attention to the whole of the peripheral field prior to the onset of the target.

Another common technique for analyzing how attention is distributed across the visual field is the *flanker compatibility paradigm.* In this paradigm, participants are required to identify a target (usually presented at fixation in the center of a screen). The decision is typically a two-alternative forced choice, using stimuli such as shapes (square or diamond), letters (H or S), or arrows (← or →). Accompanying the target are peripheral distractors, located at varying degrees of visual angle (usually to the left and right of the target). These distractors can be congruent with the target (e.g., square target and square distractors), incongruent (e.g., square target and diamond distractors), or neutral (e.g., square target and circle distractors). By measuring how long it takes an observer to respond accurately to the target and how many mistakes they make, the degree of processing of the distractors can be measured. Typically, congruent distractors will speed responses (or have little effect), whereas incongruent distractors will slow down responses and lead to more errors. The more attention that an observer allocates to peripheral vision, the greater their sensitivity to the distractors, and the greater the influence of those distractors on response times and errors. Although this greater influence can be considered as a sign of greater distractibility, fundamentally it reflects greater processing resources allocated to the distractors.

In a task employing a flanker compatibility paradigm, enhanced processing of peripheral distractors located at 4.2 degrees of visual angle from a concurrent target has been reported for deaf native signers relative to hearing participants (Proksch & Bavelier, 2002). In this experiment, participants were asked to identify shapes positioned in a circular pattern around fixation, while ignoring distractors placed peripherally to the circular pattern. The proposal that deaf individuals have greater attentional resources in the periphery predicts that peripherally located distractors will receive more attentional resources and thus be more distracting for deaf than for hearing individuals. This peripheral condition was contrasted with a condition in which the distractor was presented centrally. Results confirmed the known finding that, in hearing individuals, central distractors are more distracting than peripheral distractors. In contrast, deaf individuals were more distracted by peripheral distractors than were hearing individuals, and, interestingly, less so by central distractors.

These findings establish that, whereas in hearing individuals attention is at its peak in the center of the visual field, deaf individuals show greater attention at peripheral locations. Subsequently, Sladen et al. (2005) confirmed greater processing of peripheral distractors in deaf individuals by showing that the responses of deaf individuals were more influenced by distractor letters positioned at ~1.5 degrees from a letter target than were hearing controls. Following the same logic, Dye, Baril, and Bavelier (2007) recently showed that nonletter distractors (arrows) positioned at increasing eccentricities (1.0, 2.0, and 3.0 degrees) increasingly affected target performance in deaf individuals as compared with hearing individuals. Finally, using peripheral kinetic and foveal static perimetry—where observers are asked to respond when they can see a moving or static light point, respectively—deaf individuals were reported to be better than hearing controls at detecting moving lights in the periphery, manifested as a difference in field of view (Stevens & Neville, 2006). No difference was observed in their sensitivity to static points of light presented in central vision. What all of these "compensation" studies have in common is that they focus upon visual attention skills—how the deaf individuals allocate limited processing resources to the visual scene—and report enhanced attention to the periphery for deaf native signers across a range of visual angles (from 1.5 to over 60 degrees).

In the previous literature, this greater peripheral processing has often been interpreted as greater distractibility in deaf individuals. Here, we argue that it is better understood as a difference in allocation of attentional resources between deaf and hearing observers, with enhanced peripheral processing in deaf people and enhanced central processing in hearing people. This view predicts that deaf individuals should be more distracted by irrelevant peripheral information, but hearing individuals should be more distracted by irrelevant central information. Accordingly, in tasks where the target is slightly off-center, deaf individuals are more distracted by peripheral distractors but hearing individuals by central distractors (Proksch & Bavelier, 2002). In terms of adaptation to the environment, the attentional change observed in deaf individuals makes intuitive sense—a redistribution of visual attention to the periphery can compensate for the lack of peripheral auditory cues provided by the environment, such as the sound of an approaching vehicle or the creak of an opening door.

Importantly, such enhanced peripheral attention has been observed in deaf signers, but not in hearing individuals who are native signers (Bavelier et al., 2001; Neville and Lawson, 1987c; Proksch and Bavelier, 2002). The lack of a similar effect in hearing native signers demonstrates that using a visuo-manual signed language such as ASL is not sufficient to induce changes in peripheral attention. Rather, deafness appears to be the leading factor in this reorganization of the attentional system.

In contrast to these changes in visual attention, in which the onset and location of stimuli are unknown, attempts to demonstrate changes in basic visual skills among deaf native signers using psychophysical methods (where target location and onset are known a priori) have been unsuccessful. For example, in a task measuring contrast sensitivity thresholds across different spatial frequencies, temporal frequencies, and spatial locations, Finney, Fine, and Dobkins (2001a) reported no differences between deaf and hearing individuals. An absence of overall population effects has also been found in measures of visual flicker (Bross & Sauerwein, 1980), brightness discrimination (Bross, 1979), and temporal discrimination (Mills, 1985; Poizner & Tallal, 1987). Even psychophysical thresholds for motion processing have been found to be equivalent in deaf and hearing individuals. Sensitivity for motion direction and for small changes in motion velocity was compared in deaf native signers and hearing individuals, and no detectable difference was reported (Bosworth & Dobkins, 2002a,b; Brozinsky & Bavelier, 2004). This lack of effect stands in contrast to other studies, such as the kinetic perimetry study mentioned earlier, which document enhanced processing of motion information in deaf native signers when presented under conditions of attention.

The same dissociation between attentional changes but little to no perceptual change has been observed in the domain of touch: deaf individuals have been shown to have equivalent thresholds for detecting differences in vibration frequency, but a superior ability to detect a change in vibration frequency under conditions of attention, when the time of onset of the change in vibration is unknown (Levanen & Hamdorf, 2001). One working hypothesis is that a sensory loss leads to changes in higher-level attentional processing, especially in domains in which information from multiple senses is integrated (Bavelier, Dye, & Hauser, 2006; Bavelier & Neville, 2002). It thus appears that early deafness results in a redistribution of attentional resources to the periphery, most commonly observed when input from peripheral and central space competes for privileged access to processing resources.

Altered Distribution of Visual Attention in Deaf Individuals: Imaging Studies

Given the observed changes in the distribution of visual attention that have been observed behaviorally among deaf native signers, it makes sense to ask whether we can observe associated neurological changes. There is now a substantial body of work looking at compensational changes in brain activation following early auditory deprivation. One well-studied brain area is the medial temporal area/medial superior temporal area (MT/MST), an area of visual cortex involved in the detection and analysis of movement. When viewing unattended moving stimuli, deaf and hearing individuals do not differ in the amount of activation in MT/MST cortex. However, when required to attend to peripheral movement and ignore concurrent central motion, enhanced recruitment of MT/MST is observed in deaf native signers as compared with hearing controls (Bavelier et al., 2000, 2001; Fine, Finney, Boynton, & Dobkins, 2005). This pattern echoes a general trend in the literature, whereby the greatest population differences have been reported for motion stimuli in the visual periphery under conditions that engage selective attention, such as when the location or time of arrival of the stimulus is unknown or when the stimulus has to be selected from among distractors (Bavelier et al., 2006).

There are several potential ways in which cross-modal reorganization could support the changes observed in the spatial distribution of visual attention in deaf individuals. One possibility is that an expansion occurs in the representation of the peripheral visual field in early visual cortex. However, currently, little data supports this hypothesis (Fine et al., 2005). Another possibility is that, in deaf individuals, multimodal associative cortex—parts of the brain that combine information from different sensory modalities—may display a greater sensitivity to input from remaining modalities such as vision and touch. Evidence for this hypothesis comes from studies reporting changes in the posterior parietal cortex of deaf individuals (Bavelier et al., 2000, 2001), an area known to be involved in the integration of information from different sensory modalities. Finally, it is possible that in deaf individuals the lack of input from audition causes the auditory cortex—which is multimodal in nature—to reorganize and process visual information. Indeed, there is some evidence that auditory areas in the superior temporal sulcus show greater recruitment in deaf than in hearing individuals for visual, tactile, and signed input (Bavelier et al., 2001; Finney, Fine, & Dobkins, 2001b; Finney, Clementz, Hickok, & Dobkins, 2003; Levanen, Jousmaki, & Hari, 1998; Neville et al., 1998).

To conclude, behavioral studies suggest that a redistribution of attentional resources occurs in deaf individuals, with an enhancement of peripheral space that can be accompanied by a reduction at competing central locations. These behavioral differences are accompanied by neural changes suggesting cross-modal reorganization in areas that integrate information from different modalities and possible recruitment of multimodal cortex in auditory regions for the processing of visual information.

Summary and Implications

Deaf children have been reported to be inattentive and easily distracted. However, this may be a reflection of how they allocate attentional resources, as well as other factors such as linguistic competence and teacher–parent attributions, as opposed to a state of inattentiveness and attentional pathology per se. With respect to attentional allocation, problems may arise when there is a conflict between the demands of the environment and the default allocation of resources. For example, in structured learning environments, such as classrooms, a deaf child's attention has to be focused upon an instructor or an interpreter. When sources of visual distraction occur in the periphery, a deaf child may appear to be inattentive, as their attention is constantly being drawn toward those peripheral events. Note, however, that in other environments such an adaptation in resource allocation may be beneficial. For example, a research report published by the California Department of Motor Vehicles suggested that deaf drivers had driving records the same as or better than hearing drivers,[1] and the ability to better process peripheral information may also confer certain advantages in team sports (Knudson & Kluka, 1997), although reports to date are only anecdotal.[2]

The concern, here, is with learning environments and how best to construct learning environments in which deaf children are less distracted by events in the periphery, allowing them to focus their resources upon the task at hand. The behavioral research cited here suggests that deaf individuals cannot help but be distracted by visual information in their peripheral vision. This is perhaps unintuitive for the hearing reader, who experiences distraction more commonly from visual input in the center of their visual field. Imagine your frustration, for example, if every word on this page were to change color as soon as you fixated upon it. But for the deaf individual, inattention may occur more easily as a result of visual activity that is away from the direction of their overt gaze. It is not that they are being inattentive toward what they are looking at directly, but rather that they cannot help but allow peripheral input to draw their covert attention away from the task at hand, in much the same way that hearing individuals cannot help but be distracted by central distractors.

Any modification of the learning environment that aims to counteract these sources of visual distraction must also be sensitive to the psychological and cultural needs of the deaf child. It appears that the change observed in their attentional system is an adaptive change—it allows them to adapt to their environment, given the lack of an auditory sense to inform them about the environment and guide the focus of their attention. Thus, positioning a deaf child at the front of the classroom with their classmates behind them, or in a position where they cannot see out of windows or

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[1] State of California DMV Research Report No. 42, see http://www.dmv.ca.gov/about/profile/rd/rde2.htm.

[2] See Stiles, J. (March 24–30, 2004) Deaf player excels through field vision and skill. *The Villager, 73* (47), published online at http://www.thevillager.com/villager_47/deafplayersexcels.html.

through the classroom door, may actually exacerbate the difficulties they encounter in the formal learning environment. Positioning of the child in this manner will in effect serve to counter the adaptation that has arisen in their visual system and may be disconcerting and lead to greater distraction. This is because the enhancement in their peripheral vision is attentional and thus more evident when the timing and location of events in the periphery is unknown. Indeed, when the onset time and location of a peripheral stimulus is known a priori, deaf and hearing individuals do not differ in their sensitivity to those stimuli.

With this in mind, one approach may be allowing the deaf child or college student to "learn" their visual environment. Small class sizes, with a semicircular arrangement of seats, and consistent seating positions for each student across the term of instruction may result in a more predictable learning environment, one in which the deaf student can successfully learn to ignore abrupt onset stimuli at specific locations in their peripheral space. Unpredictable distraction may also be minimized by reducing the ebb-and-flow of traffic through the learning environment. Further classroom research involving the active participation of deaf children, deaf adults, and teachers will be required in determining how best to arrange the physical layout of learning environments to maximize the ability of the deaf child to attend to formal instruction. The literature on visual attention in deaf children and adults suggests, however, that the best practices will be those that produce a visually predictable environment in which deaf students can learn to predict and therefore ignore task-irrelevant stimuli that may distract them from attending to their instructor or other learning resource.

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