Sustained Visual Attention in Deaf Children: A Deafcentric Perspective

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> "I call it *the law of the instrument,* and it may be formulated as follows: Give a small boy a hammer, and he will find that everything he encounters needs pounding." (Kaplan, 1964)

There is an ongoing debate in the field of early intervention and deaf education about the differences in executive functions between deaf and nondeaf children and what might give rise to them (Hall, 2020; Kronenberger & Pisoni, 2020; Morgan & Dye, 2020). Executive functions encompass cognitive abilities that allow a child to successfully perform tasks by planning and organizing their actions, and by maintaining focus on their goals and avoiding distraction (for a review see Diamond, 2013). Executive functions include a range of abilities, often studied in isolation, such as working memory (Baddeley, 2012), inhibition (Bari & Robbins, 2013), and sustained attention (Fisher, 2019). Studies of deaf children from nondeaf families who have received a cochlear implant have reported deficits and large variability in outcomes for a number of these executive functions (Castellanos, Pisoni, Kronenberger, and Beer, 2016; Kronenberger, Beer, Castellanos, Pisoni, and Miyamoto (2014); Lyxell, Sahlén, Wass, Ibertsson, Larsby, Hällgren, & Mäki-Torkko, 2008; Quittner, Barker, Snell, Cruz, McDonald, Grimley, Botteri, Marciel, & CDaCI Investigative Team, 2007). Several different proposals have been put forward to explain the large degree of variability in this population of children. Those proposals differ in what they see as the optimal approach to early intervention and/or remediation of executive function. Some argue that rehabilitation of hearing loss is the best approach (Kral, Kronenberger, Pisoni, & O'Donoghue, 2016), others that establishing healthy communication between caregiver and child is critical (Morgan & Dye, 2020), and yet others that early exposure to and acquisition of a natural sign language is the best approach (Hall, 2020). In this chapter we will focus on just one of the executive functions – *sustained attention* – and use that (a) to explore the evidence for and against different approaches, and (b) to consider how some of those approaches interpret data based upon what we claim is an audiocentric perspective that fails to acknowledge or appreciate the experience and authority of deaf people.

Sustained Attention

The study of *attention* is the study of how information is selected and/or filtered by the human brain (Carrasco, 2011). One aspect of attention is called spatial attention. This is concerned with how information from different physical locations in the external world is selected and filtered. Visual spatial attention is the process by which we select/filter information from different parts of our visual field (Carrasco, 2018; Yeshurun, 2019). For example, as we drive down the road, we take in information from across our visual field. But while light from the deer grazing at the side of the road may fall upon our retina, we do not necessarily "see" the deer unless we are paying attention to that part of the visual field, a phenomenon called inattentional blindness (Simons & Chabris, 1999). While visual spatial attention has been well researched in deaf children and adults (Dye, Baril & Bavelier, 2007; Daza & Phillips-Silver, 2013; Prasad, Patil & Mishra, 2015; Bavelier, Tomann, Hutton, Mitchell, Corina, Liu & Neville, 2000; Dye, Hauser & Bavelier, 2009; Loke & Song, 1991; Proksch & Bavelier, 2002; Stevens & Neville, 2006; Codina, Buckley, Port & Pascalis, 2011), far less work has considered *temporal* aspects of visual attention in these populations. Temporal visual attention is concerned with how we attend to events or objects over time. For example, consider a child attending to a video on a tablet PC. That child must direct their eye gaze towards and attend to the spatial location of the video in order to understand what is happening. They must also sustain that spatial attention over time, not allowing their mind to wander or eye gaze to be averted. Sustained attention is one form of temporal attention (Fortenbaugh, DeGutis, & Esterman, 2017). A closely related process is vigilance (Oken, Salinsky, & Elsas, 2006; sometimes referred to as alerting: Posner, 2008), which refers to staying ready and alert for something to happen or appear within the visual field.

Why would we expect these temporal aspects of visual processing to be different for deaf compared to nondeaf individuals? In the spatial domain, it is anticipated that an information processing system that does not use hearing to attend to the world will instead devote more resources to doing so visually – this is referred to as a *compensation* hypothesis (Bavelier, Dye & Hauser, 2006; Dye & Bavelier, 2010). Auditory systems are able to attend spatially to a larger field than visual systems, allowing nondeaf people to shift their visual attention to spatial locations that are prompted by peripheral sounds (Arnott & Alain, 2011). In deaf individuals, it seems that the visual system compensates by allocating more resources to the far visual periphery, making deaf people more "sensitive" to visual events occurring there (Bavelier, Dye & Hauser, 2006; Pavani & Bottari, 2012). It is also possible that such compensation can occur in the temporal domain, given the greater importance of vision for deaf children and adults. Contrary to this expectation, studies of temporal visual attention in deaf individuals have typically demonstrated performance in deaf children that is "worse" than that of nondeaf children, and have been used to support *deficit* hypotheses. These studies are summarized below.

Sustained Visual Attention and Deaf Children

One metaphor commonly used to discuss visual attention is that of the flashlight or spotlight of attention (Posner, Snyder & Davidson, 1980). The idea is that by shining the "attentional beam" on a stimulus, it can be processed more accurately and efficiently. Attention, however, is effortful, and must be actively sustained in order to be effective (deBettencourt, Norman & Turk-Browne, 2018). In the spotlight metaphor, one can think of the beam weakening in strength as resources are exhausted, with the amount of light on the target decreasing, and performance suffering. Sustained visual attention can be considered the ability to maintain that attentional beam over time. The ability to sustain visual attention over time has been assessed in deaf children using observational studies (Quittner et al., 2007) and surveys (Mitchell & Quittner, 1996; van Eldik, Treffers, Veerman & Verhulst, 2004; Karchmer & Allen, 1999). Here, however, we focus on computerized assessments.

Computerized assessments of sustained attention have used variants of the continuous performance test (CPT). The purpose of a CPT is to determine how well an individual can maintain their attention for a relatively long time (typically ~9 minutes) in a task that is repetitive and requires infrequent responses. In one version of this task – the Gordon Diagnostic CPT (Gordon & Mettelman, 1988) – individuals must pay attention to a sequence of 540 digits appearing on an LED display at a rate of 1 digit/second and respond to a specific sequence of digits (a 1 followed by a 9) that occurs only 45 times. If attention cannot be sustained, and the attentional beam weakens, then the sequence will be missed. Conversely, responses to non-target sequences will produce false alarms. By examining the pattern of misses and false alarms, an index of *vigilance* can be derived that serves as a measure of the construct of interest – sustained attention.

The first study to use such a CPT with deaf children was reported by Quittner, Smith, Osberger, Mitchell and Katz (1994) who compared three groups of children: nondeaf children, deaf children with hearing aids, and deaf children with cochlear implants. The deaf children were in educational settings that implemented oral or Total Communication (a combination of speech, supporting signs, gestures and drawing) approaches, so it is important to note that none of the children were proficient in, nor had they received early exposure to, American Sign Language (ASL). The children were further sub-divided into younger (6-8 years) and older (9-13 years) age groups: no *a priori* justification for this grouping was provided, although the two groups can be thought of as representing primary school and elementary school aged children in a US context. Results suggested that (a) deaf children had worse sustained attention than nondeaf children in both age groups, and (b) older deaf children looked more like their nondeaf peers if they had received a cochlear implant, but not if they used hearing aids. A subsequent study by the same research group recruited a larger sample and did not categorize based upon age (Smith, Quittner, Osberger & Miyamoto, 1998). They reported that while all children started to show gains in sustained attention around the age of 8-9 years, those gains were greater for deaf children with CIs than those with HAs and neither group caught up with their nondeaf peers. Of course, caution must be taken in inferring a causal effect of being deaf on visual sustained from cross-sectional data that also lacks random assignment to groups: pre-existing differences between the deaf and nondeaf children unrelated to their hearing levels may have led to differences in performance on the CPT, a critique that can be levelled at all studies employing causal-comparative (ex post facto) designs.

Subsequently, Horn, Davis, Pisoni and Miyamoto (2005) reported a retrospective longitudinal design that analyzed CPT performance prior to implantation (mean implantation age was 6.2 years), and at several time points 1-3 years post-implantation, in 88 deaf children. Again, these children used either oral communication or Total Communication (not ASL), and included a number of children who became deaf over time as a result of contracting meningitis in infancy. Due to a large amount of missing data, the researchers used a mixed effects model so that all of their data could be included. They reported the number of children for whom data was available at each age range, revealing that very few children provided data at three time points, and no children provided data at all four time points: this is a relatively sparse data set, and it is not clear that the missing data were missing-at-random (a key assumption of the statistical approach used). The authors reported that CPT performance improved each year following implantation, although the large amount of variability at pre-implant testing meant that there was no statistically significant improvement compared to that baseline score. While it is tempting to conclude that implantation led to improvements in sustained attention, there was no comparison group of deaf children who did not get cochlear implants, and comparisons to nondeaf children were based on published norms that were likely collected under very different testing and recruitment conditions.

A study by Tharpe, Ashmead and Rothpletz (2002) was the first to find no differences between 8-14 year old nondeaf children and deaf children with HAs or CIs. Their study was careful to control for nonverbal IQ differences between the deaf and nondeaf samples, and suggested that nonverbal IQ differences may have driven the effects observed in prior studies. This study, and prior work, recruited and tested deaf children who were learning English as a primary language, with no studies reporting the inclusion of deaf children fluent in a natural sign language or deaf children from deaf families. It is possible, therefore, that these deaf children were experiencing the effects of language deprivation (Chen, Roth, Halgren & Mayberry, 2019; Mayberry, Davenport, Roth & Halgren, 2018; Murray, Hall & Snoddon, 2019). The full effect of delayed and impoverished access to natural language is still being determined by scholars, although it would not be surprising that decrements in nonverbal IQ were one corollary of such deprivation.

In yet another CPT study, Yucel and Derim (2008) compared deaf children who had received cochlear implants at different ages with nondeaf children. All of the deaf children were enrolled in Auditory Verbal Therapy programs, and none used a sign language. The deaf children were split into two groups: those who received their implant before age 4 years, and those who were 4 years or older when they underwent the surgery – no *a priori* justification for dividing the children in this way was provided. While the performance of the two groups of deaf children with CIs did not significantly differ – suggesting age at implantation has little-or-no effect on sustained attention abilities – both groups were outperformed by a sample of nondeaf children. While the authors claimed that the deaf children who got implants later were "less mature" and "more careless" than their nondeaf peers, these claims appear to be both unsubstantiated by the data and reveal a logical fallacy in extending the results of a single CPT task to a population-level generalization about maturity and carelessness.

A study by Dye and Hauser (2014) recruited deaf children who used ASL as a first language, and compared their CPT performance with that of nondeaf children, in an attempt to determine whether being deaf was a necessary precondition for reported performance deficits on the CPT. In audiological terms, these signing deaf children were profoundly deaf, they did not use CIs, and all had acquired ASL as a first language from deaf parents. No differences were observed either for a younger (6-8 year) or older (9-13 year) age group – following the age grouping reported by Quittner et al. (1994). While it can be claimed that these children are not "typical" deaf children because they belong to the small proportion of deaf children with deaf parents (Mitchell & Karchmer, 2004), at a theoretical level they argue against the notion that a lack of audition alone is sufficient to bring about deficits in sustained visual attention.

Most recently, Hoffman, Tiddens, Quittner and the CDaCI Investigative Team (2018) reported data from a large-scale longitudinal project (Childhood Development after Cochlear Implantation; Fink, Wang, Visaya, Niparko, Quittner, Eisenberg, Tobey & CDaCI Investigative Team, 2007) that included CPT data from 106 deaf children who had received a CI five years previously. All of the deaf children were being educated using an oral-aural approach alongside nondeaf children. These children were compared with nondeaf children of the same age. The nondeaf children had mothers with higher levels of education and came from families with larger incomes – maternal education was controlled for, but family income was not. Their results suggested that the nondeaf children outperformed the deaf children, and that age of implantation was a predictor of sustained attention performance.

So, do deaf children have “deficits” in sustained visual attention? It would seem that some deaf children clearly do show performance decrements on computerized CPT assessments, yet some deaf children do not. In a recent article, Kronenberger and Pisoni (2020) highlight the importance of looking at both group differences and explaining individual variability within groups. All of the studies reported above have focused on between group comparisons. Most of the studies compare nondeaf children with a specific group of deaf children: those from nondeaf families, who use hearing aids or CIs, and who do not know a natural sign language such as ASL. It is often argued that these deaf children are the “typical” case, with very few deaf children born to deaf parents (or born to hearing parents and provided access to a sign language from an early age). However, that does not mean that studies of deaf children from deaf families are uninformative: they provide important insights into the development of visual attention *without* auditory input. The Dye and Hauser (2014) study started from the viewpoint that enhancements in sustained visual attention were more likely than deficits, especially for deaf children who did not undergo language deprivation. Despite sample sizes much larger than previous studies, they did not find any deficits (although there were no compensatory enhancements either). At face value, this suggests that while there are undoubtedly sustained visual attention deficits in deaf children, it may not be being deaf itself that caused those deficits. This is important, as we shall see, when it comes to determining what an effective early intervention for cognitive development might look like.

Audiocentrism and Deficit Theorizing

In the extant literature, there are four different (albeit related) proposals for why being deaf in and of itself might result in weaker sustained visual attention, with some of those proposals extending to executive functions more broadly. The first, proposed by Smith et al. (1998), is the *division-of-labor* hypothesis which claims that because deaf children cannot use hearing to attend to the world around them, they must spread their visual attention and use that to monitor their environment. This, the hypothesis proposes, results in a more diffuse spread of limited attentional resources. Restoring auditory inputs via cochlear implants, therefore, results in better visual attention skills as the children adapt to using the auditory channel to monitor their environment – an ironic claim that deaf children are better visual learners if they are given the ability to hear. This hypothesis is problematic in several ways. Firstly, it cannot account for the lack of sustained visual attention deficits in deaf signing children – it predicts that these children would perform worse than non-signing deaf peers rather than equivalently to nondeaf children. It also rests upon the notion of limited attentional resources that are spread thin, failing to consider possible compensatory mechanisms or the adoption of strategic behaviors by deaf children. Finally, its origins are in the notion of *deficit* and the idea that deaf children must "rely" upon vision in the absence of audition – the audist/linguicist equivalent of suggesting that deaf children are forced to "rely" upon a sign language for communication – betraying an audiocentrism that sees "hearing" and "speech" as aspirational and superior for deaf children (Bauman, 2004; Eckert & Rowley, 2013; Humphries, 1975).

Conway, Pisoni and Kronenberger (2009) proposed the *auditory scaffolding hypothesis*. Simply stated, the auditory scaffolding hypothesis explains poor spoken language outcomes in deaf children with CIs as resulting from both a lack of access to the sound structure of speech **and** from cognitive deficits that also stem from a lack of access to sound. The auditory scaffolding hypothesis considers sound to be crucial for the development and support of sequencing abilities, although it can arguably be extended to other cognitive functions. Inherent in this view is that vision is superior for spatial processing whereas audition is superior for sequential statistical learning. There is not the space here to discuss studies of statistical learning in deaf individuals in depth (see Hall, 2020). Suffice to say that whereas studies of non-signing deaf children with CIs reveal sequence learning deficits (Conway, Pisoni, Anaya, Karpicke & Henning, 2011; Lévesque, Théoret & Champoux, 2014), studies with deaf signing children fail to replicate those findings (Hall, Eigsti, Nortfeld & Lillo-Martin, 2017; von Koss Torkildsen, Arciuli, Haukedal & Wie, 2018; Giustolisi & Emmorey, 2018). Like the division-of-labor hypothesis, the auditory scaffolding hypothesis seeks to attribute observed deficits to a lack of access to sound on the basis that being deaf must result in some kind of problem or performance decrement. It is important to state that audition is not a prerequisite for language – deaf individuals who are native users of signed languages are an existence proof that language does not depend upon any specific sensory modality. However, these deficit approaches commonly start from the audiocentric premise that acquiring **spoken** language is to be prioritized – given that deaf children commonly struggle to successfully acquire proficiency in spoken language, there is already a deficit (poor language) that may be explainable by other deficits (poor cognition). As we will suggest below, if one starts from the assumption that deaf children do not struggle to acquire *language*, then one does not seek to theorize deficits but instead to consider the optimal linguistic and social environment to promote language acquisition. A philosophical difference, but one which also has significant impacts upon how we as scientists theorize about deaf children.

Kral and colleagues (2016) proposed the idea of being deaf as suffering from a "*connectome disease*". They argued that being deaf results in a disconnection of auditory processing regions of the brain from other brain areas that support memory, reasoning, language, and so on. The way that each deaf child's brain responds to this perturbation means that the disease may reveal itself differently in different children. However, all of those deaf children will essentially have an abnormal connectome, with a broad range of consequences for cognitive and linguistic functioning. Cochlear implantation, in this view, does more than restore sound, it rewires the brain and restores the normal equilibrium and balance between multiple, interconnected brain regions. Inherent in this approach is the view that the brain is supposed to be wired a certain way, and that deviations from that are abnormal and result in sensory, cognitive, linguistic and emotional deficits because the deaf child no longer has a brain that allows them to function successfully. Deaf children, then, are not neuro-diverse, they are neuro-compromised with widespread trauma to brain connectivity because their primary auditory cortex has been decoupled. The evidence presented by Kral et al. in support of the "deaf connectome" – a heavily neuroscientific model – is based almost entirely on clinical and cognitive outcomes of deaf non-signing children with CIs, and fails to consider any of the research on the neuroscience of language processing. In fact, the idea that higher-order neural processes are contingent on any particular input modality runs contrary to the vast array of neuroimaging evidence that the frontotemporal classical language network is supramodal (Arana, Marquand, Hultén, Hagoort & Schoffelen, 2020; Fedorenko, Behr & Kanwisher, 2011), and that the brain is highly plastic and adaptable to input in early life. Language activation has been observed in both the occipital cortex of congenitally blind people (Bedny, Richardson & Saxe, 2015) as well as frontotemporal neural areas commonly associated with audition and language processing in deaf people (Corina, Lawyer & Cates, 2013). Such extensive neuroplastic changes in response to altered input do not track with the idea that such changes would cause a *deficit* in higher-level cognition. Rather, they suggest the converse: that the human brain is remarkably adaptable to input and there is no one "correct" configuration of neural connectivity which confers cognitive superiority. In summary, we find the idea that to be deaf is to have a brain disease to be highly misguided, once again reflecting audiocentric and audist views of deaf people. Nor does the approach explain the lack of cognitive deficits in the large number of deaf children who have typical linguistic abilities as a result of natural sign language acquisition in infancy.

Kral et al.'s deaf connectome proposal is a limited form of *biopsychosocial systems theory* (Engel, 1977). Recently, Kronenberger and Pisoni (2020) and Kronenberger (2019) have articulated an auditory-neurocognitive model that emphasizes the interconnectedness of the human brain (the "bio"), but also takes into account the psychological and socio-cultural factors that are known to influence cognitive development. Kronenberger and Pisoni (2020) argue that a myriad of such biological (auditory experience), psychological (intelligence, reduced early language exposure, social maturity) and sociocultural (family communication challenges, educational environment) factors combine in order to produce the precise pattern of executive function deficits observed in each individual deaf child. However, they return to “hearing loss” as the primary driver of deficit, as hearing loss is seen as the culprit behind disrupted biological, psychological and sociocultural processes that bring about executive function deficits in deaf children.

Deafcentric Approaches to Cognitive Development

Interestingly, Kronenberger and Pisoni (2020) contrast biopsychosocial systems theory with arguments by others that early access to language is the primary driver of executive function deficits in deaf children. Ironically, in arguing against the importance of language for cognitive development, they describe studies in which *spoken* language accounts for little variability in executive function in Deaf children, ignoring the point that such “language based approaches” espouse the cognitive benefits of learning a *signed* language, as opposed to a spoken language. Furthermore, they argue, what they call “language based approaches” are just that – approaches and not theories. This is a mischaracterization of the arguments put forward by proponents of early language intervention for deaf children (Hall et al., 2017; Hall, 2020; Morgan & Dye, 2020). Indeed, Hall (2020) explicitly states that a “single factor view” that either auditory access or language access is the sole determinant of executive function development is a claim that no one has made. Similarly, Morgan and Dye (2020) propose a model of executive function development in deaf children that focuses on communication (rather than language) and which incorporates cascading interactions between multiple representational and processing systems.

Audiocentric approaches – such as the auditory scaffolding hypothesis and the auditory-neurocognitive model – see speech and hearing as the norm and the desired goal for deaf children. It is the fact that the children cannot hear that is the researcher's focus. If one can fix the hearing, then the child will develop as a "normal hearing" child. In contrast, deafcentric approaches do not see being deaf as a problem intrinsic to the child that requires fixing or repair. Under the right conditions, the healthy cognitive, linguistic and social development of the child is not seen as being at risk. Those conditions would include early access to a natural sign language such as ASL (not sign-and-speech, SimCom or Signed English), caregivers who can establish early communicative interactions with their deaf child, an educational system that understands the needs of a deaf child and provides an appropriate education, and a society that accepts the deaf child as a deaf child. Here, then, we start to see that Kronenberg and Pisoni's auditory-neurocognitive model is exactly what is being argued for by proponents of language-based approaches. Perhaps the only difference is that language-based proponents do not see the link between auditory access and language access in the same way. Indeed, from a deafcentric perspective, there is *no connection* between hearing and language. Language exists in the absence of audition – auditory access provides privileged access to but one form of human language: spoken language. Time and again, studies of deaf children who meet the optimal conditions from a deafcentric perspective reveal no deficits in executive function, sequence learning, or language development. The claim that auditory access is crucial for cognitive development is made despite these data, and by researchers whose field is speech and hearing science, or communication sciences and disorders. There is a failure to consider things from a deaf perspective, or to consider the inherent value of being deaf. This is perhaps most commonly revealed in the exhortation by clinicians that even if deafcentric sign language proponents are correct, nondeaf parents will never bother to learn sign language and, even if they did, could not do so well enough to support their deaf child's development. This reflects not just a lack of respect for the deaf child, but also a lack of respect for nondeaf parents of deaf children many of whom do choose to use a sign language to successfully communicate with their child and provide rich linguistic interactions as a result.

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