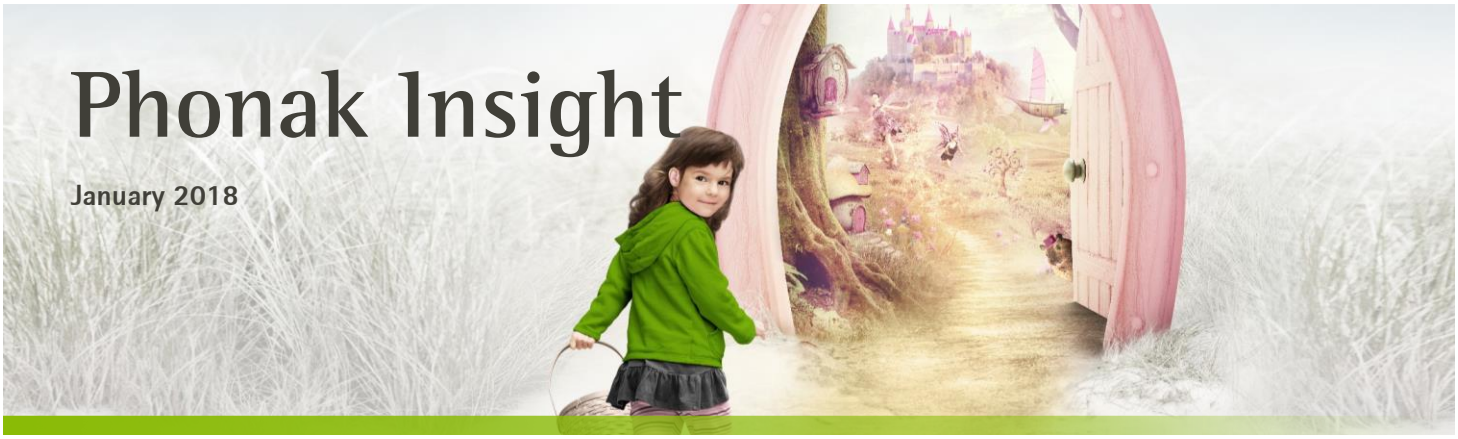

Phonak Insight

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The ears are doorways to the brain

Introduction

The world has changed for hearing healthcare; we are in a new era. Advances in knowledge about brain plasticity, auditory deprivation, and critical periods for language development have shifted the concentration of hearing management from the ear to the brain. Even though it is important to understand how the middle ear, cochlea, and auditory nerve process auditory signals/vibrations, it is more important to understand how the brain interprets linguistic elements. The ear is the structure that captures sound and directs that auditory information to the brain, but it is the brain that processes language. *Hearing, therefore, can be defined as brain perception of auditory information.*

Hearing management has leapt to a new level – now we recognize the brain as the endpoint of all auditory information. Although the source of hearing loss is almost always traceable to the outer, middle, and inner ear structures, actual "hearing" in the sense of the processing and constructing of a meaningful linguistic message requires many areas of the brain to actively participate and interact.

From this summary document, pediatric hearing care professionals will be able to take basic scientific knowledge of neuroplasticity and auditory deprivation, and transform that information into a counseling narrative that explains hearing loss and the benefits technology can provide in a way that is meaningful for families who choose listening and spoken language as their desired outcome.

The doorway-brain narrative: Hearing loss impacts more than just the ears

As approximately 95% of children with hearing loss are born to hearing and speaking families (Mitchell & Karchmer, 2004), our conversations with families, about hearing loss, could be transformed in this new era. Hearing healthcare professionals need to begin by connecting the dots between hearing loss, auditory neural deprivation, brain plasticity, and literacy development along with the use of hearing technologies – and explain the connection between these key concepts to families.

The conversation about hearing loss begins with a discussion of "sound". Sound is *an event* rather than a name or label. For example, you can "see daddy" but you cannot "hear daddy" if he is not actively doing something. You hear daddy walking, laughing, talking, typing on a computer, cooking and so on. You hear daddy performing an activity or an action – engaged in an event. An event creates vibrations. These vibrations are picked up by the "ear pathway" and sent to the brain as energy for coding and for information to be perceived as sound. Sound is a temporal event, not a spatial label (Boothroyd, 2014).

Humans are designed with many amazing sensory structures that capture environmental data and transform that information into chemo-electric and neuro-electric impulses that can be analyzed in the brain. For example:

- We smell with the brain; the nose is the pathway to the brain for olfactory stimuli, but the perception of the smell occurs in the brain.

- We see with the brain; the eyes are the entryway to the brain for visual/optic information, but actual understanding of our sights occurs in the brain.
- We hear with the brain; while ears are the doorways to the brain for sound/auditory information, the actual hearing occurs in the brain, not in the ear.

Consequently, hearing loss is primarily a brain issue – not an ear issue.

Continuing with this analogy in our ongoing conversations with families, hearing loss can be described as a doorway problem. Hearing loss obstructs that doorway in various ways and to varying degrees, from a small obstruction to complete obstruction, preventing clear auditory input from traveling the auditory pathway and reaching the brain. Learning to speak, read, and obtain knowledge about the world requires auditory information. A lack of clear information to the brain is a big problem that will interfere with the child learning to listen, talk, read, and develop social relationships. Fortunately, we have a way to break through the doorway — hearing technologies.

Hearing technologies (such as hearing aids, cochlear implants, bone-anchored devices, and remote microphone systems) are engineered to break through the doorway to allow activation, stimulation, and development of auditory neural pathways with auditory information, including spoken language. *Therefore, the purpose of wearing hearing technologies is to deliver auditory information through the doorway to the brain. There is no other reason.* The child's listening and spoken language outcomes in turn are not determined by 16,000 (or likely much fewer) hair cells or by 30,000 auditory nerve fibers, but by 100 billion neurons in the brain, processing 100 trillion instructions per second (Kral et al., 2016). Studies show that for the best possible listening, spoken language, and literacy outcomes for a child, the ear/doorway problem needs to be diagnosed and assisted by technology as soon as possible (Dettman et al., 2016; Dillon, Cowan and Ching, 2013; McCreery et al., 2015; Sininger, Grimes, and Christensen, 2010).

Once hearing technologies break through the doorway and deliver auditory information to the brain, the child's brain must be stimulated and enriched with knowledge (Hart and Risley, 1999; Hirsh-Pasek et al., 2015; Suskind, 2015). So, the fitting of the appropriate "doorway device" by an audiologist is only the first step in developing the child's neural network and knowledge-base. The child then must wear the device at least 10 hours per day, and be immersed in a family-focused language-rich environment through coaching by a listening and spoken language professional (McCreery et al., 2015). Encourage family members to speak, read, and sing to the child, in the family's home language, for optimal brain development. The bottom line is, infants and children must have brain access to intelligible speech and meaningful auditory information as early as possible in order to fully develop and connect all auditory areas of the brain for optimization of the child's spoken language, literacy capacity, and intelligence (Kral & Sharma, 2012). *Hearing is a stepping stone to cognition.*

Auditory brain development

Studies of brain development show that sensory stimulation of the auditory centers of the brain is critical and indeed influences the actual organization of auditory brain pathways (Kral et al., 2016). Helping parents and caregivers with the doorway/brain conversation empowers them with the knowledge of basic neural science.

Neuroplasticity refers to the brain's availability and malleability to grow, develop, and alter its structure as a function of external stimulation (Chermak, Bellis & Musiek, 2014; Kilgard, Vasquez, Engineer, & Pandya, 2007). Neuroplasticity is greatest during the first three and a half years of life (Sharma, Campbell & Cardon, 2015). The younger the infant, the more neuroplasticity the brain has (Kral, 2013). Rapid infant brain growth requires prompt intervention, typically including amplification and/or cochlear implantation and a comprehensive intervention program to promote the development of auditory skills. If clear and intact auditory information is received, then this is how the brain will be organized. Conversely, if unmanaged hearing loss filters some or all speech sounds from reaching auditory centers of the brain, then the brain will be organized differently and will experience a lack of necessary auditory information (Kral et al., 2016).

Basic science investigations show that when the brain does not have access to intelligible speech during the early years of a child's life, meaningful auditory input does not coordinate activity between the primary and secondary auditory cortex (Kral et al., 2016). Additionally, auditory stimulation beyond the critical period of language development finds disordered functional connections and interactions between the primary and secondary auditory cortex, further complicating auditory learning (Kral and Lenarz, 2015). The disconnection between the primary and secondary auditory cortex has significant functional implications for auditory and spoken language development. When auditory signals are not efficiently and effectively transmitted from the primary to the secondary auditory cortex, the secondary auditory cortex cannot distribute

spoken language and other meaningful sounds and information to the rest of the brain to create auditory meaning and knowledge; this negative process is called "downstream degradation". Kral uses this interconnected model of deafness to explain inter-individual variations in cochlear implant outcomes (Kral et al., 2016).

Auditory deprivation

The brain is a dynamic, self-organizing system that develops based on reciprocal experiences between neural activity and stimulation from the environment (Cardon, Campbell, & Sharma, 2012). Therefore, changes occur in brain structure when the brain is deprived of auditory information. Auditory deprivation has widespread effects on brain development, affecting the capacity to process information even beyond the auditory system (Kral & Sharma, 2012). If the ear/doorway remains closed, the brain's effective connectivity is altered within the auditory system, between sensory systems, and between the auditory system and centers serving higher order neurocognitive functions (Kral et al., 2016). As a result, limitations in auditory experience during development might affect neurocognitive functioning well beyond spoken language.

Organic evidence for the importance of auditory neural enrichment

Unlike with our eyes, we cannot "close" our ears. The brains of children with typical hearing are exposed to auditory stimuli 24 hours every day. The brains of children with hearing loss have access to sound only when they are wearing their hearing devices — far less than 24 hours. Unfortunately, none of our current hearing devices, including cochlear implants and hearing aids, are engineered for 24-hour use. Yet, our brains are organically designed for continuous auditory stimulation, even during sleep. Parents often report that their children with hearing loss request to wear their hearing devices when sleeping.

Further organic evidence of the power of hearing is that the inner ear is fully developed by the fifth month of gestation. Therefore, a typically developing human fetus potentially has 4 months of *in utero* auditory brain stimulation (Simmons, 2003). Moon et al. (2013) found that infant-phonetic perception can be measured shortly after birth by noting differences in responding to familiar versus unfamiliar vowels. Therefore, the ambient language such as the mother's speech, to which the brains of fetuses are exposed in utero, affects their perception of their family language at a phonetic level.

At approximately one year of age, or 16 months of meaningful and interactive listening (including before-birth auditory exposure), a child with typical hearing begins to produce words. The key point is that "listening time" cannot be skipped, and a child who misses months of brain access to auditory input needs to make up for it (Hirsh-Pasek et al., 2015). The brain requires extensive listening experience to properly organize itself around the speech signal. Importantly, infants also must hear their own vocalizations, creating an auditory feedback loop that is critical for motivating frequent early vocalizations (Fagan, 2014).

Hearing and listening – the same thing?

There is a distinction between hearing and listening. Hearing is the perception of auditory information by the brain as a result of auditory data received through the ear/doorway. On the other hand, listening is purposeful attention to auditory information as evidenced by activation of the prefrontal cortex (Musiek, 2009).

Hearing must be made available before *listening* can be taught or learned. In parent-focused listening and spoken language therapy, parents and practitioners focus on using intervention strategies to develop and enhance the child's listening, spoken language, and cognitive skills through technology that has been fitted and programmed by the audiologist (Cole & Flexer, 2016; Dornan et al., 2010; Estabrooks, MacIver-Lux & Rhoades, 2016).

In order for a child's brain to be both a hearing brain and a listening brain, attention and working memory must be fostered. Training needs to occur in acoustically favorable conditions (Doidge, 2007). Extensive auditory practice creates the neurobiological foundation not only for spoken language and literacy skills, but also for age-appropriate social and cognitive skills.

Brain enrichment is a necessity

Unlike any other organ, the brain is not fully developed when a child is born; brain development is completely dependent on environmental experience (Kral & Lenarz, 2015; Suskind, 2015). So that's why, in the first three years of life, the foundation for all thinking and learning is being built through parent talk and interaction (Caskey et al., 2011; Cole & Flexer, 2016).

Since language/information is learned best in social interaction and conversation with the people who love the

baby, it is the parents who generally become their child's first teacher, and teach the child the language and knowledge of the home (Chen et al., 2012; Hirsh-Pasek et al., 2015). Thus, families are guided to speak the language they know best right from the beginning, whether that language is English, Spanish, Russian, sign language, etc. in order to grow their child's brain with knowledge (Chen et al., 2012; Hirsh-Pasek, et al., 2015; Suskind, 2015).

Read aloud daily

All children, and especially children with hearing loss, should be read aloud to, daily. In fact, studies show that reading aloud is one of the most important activities we can do with our children (DesJardin et al., 2017). Why?

Robertson (2014) explains:

- Exposure to storybooks is the biggest factor in a preschooler's vocabulary
- More parent-child conversations occur during read-aloud time than during any other activity
- Children who receive read-aloud time show gains of more than twice as many new words

Summary

This paper has proposed a counseling narrative that explains hearing loss and technology in a way that is meaningful for families. Since approximately 95% of children with hearing loss are born to hearing and speaking families, listening and talking will likely be desired outcomes for the vast majority of families we serve. Families need support in understanding what it takes to attain their desired outcome.

Below are summary bullets for professionals and caregivers regarding this counseling narrative:

- The ears are the doorways to the brain
- Hearing occurs in the brain because we listen and understand with the brain, not the ear
- Sound = auditory information = knowledge
- Hearing is a stepping stone to cognition
- Hearing loss is often a fixable doorway problem
- Modern hearing technologies are designed to break through the ear/doorway to deliver auditory information to the brain
- Hearing technologies must be worn at least 10 hours per day
- Better quality and greater quantity of information delivered to the brain means stronger neural pathways are developed and more knowledge is gained
- Have many daily conversations with your child in your home language
- Reading aloud daily is one of the most powerful ways a parent can help develop a child's brain

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Author

Carol Flexer, PhD, FAAA; CCC-A; LSLS Cert. AVT
Distinguished Professor Emeritus, Audiology
The University of Akron, Akron, Ohio

cflexer@uakron.edu / www.carolflexer.com

Carol Flexer received her doctorate in Audiology from Kent State University in 1982. She is a Distinguished Professor Emeritus of Audiology, The University of Akron, and an international lecturer in pediatric and educational audiology. Dr. Flexer is an author of more than 155 publications including 14 books, and is a past president of the Educational Audiology Association, the American Academy of Audiology, and the AG Bell Academy for Listening and Spoken Language.