Brain Development & Hearing Loss

How the brain develops

The ability of a baby's brain to change with learning is what is known as *neuroplasticity.* During normal brain development the first information to be processed by the baby's young brain is sensory information. Baby's brains are "pre-wired" to accept and process sound. Babies with typical hearing, actually begin to "hear" before they are born - at 20 weeks gestation. At birth, babies already prefer listening to their mother's voice, to their native language, to people talking rather than noise, and to songs or stories that they heard before they were born.

Following birth, the brain of the newborn is flooded with information from the baby's sense organs – their eyes, ears, skin, mouth, nose. This sensory information must somehow get to the brain where it can be processed. To do so, maturing nerve cells make connections with one another, sending out multiple branches ("axons", which send out information, and "dendrites", which take in information). Each of these connections is a "synaptic contact" – where the branches of different nerves contact each other. At birth, each neuron in the brain has approximately 2,500 synapses, or connections. As a result of constant sensory stimulation and experiences with the world, the number of synapses grows to 15,000 synapses per neuron by the time an infant is 2-3 years old. This amount is about twice that of the average adult brain! Then something called "synaptic pruning" starts to happen and the weaker synaptic contacts are eliminated while stronger connections are kept and strengthened. A baby's experiences determine which connections in the brain will be strengthened and which will be pruned away. The connections that have been activated most often by the baby's repeated experiences are preserved. Ineffective, unused or weak connections are "pruned" in much the same way a gardener would prune away parts of a tree or bush, to encourage the plant to grow into the desired shape. Neuroplasticity enables this process of developing and pruning neural connections, allowing the brain to adapt itself to its environment and allowing the baby to *learn*.

Brain development and hearing loss from birth

The brain is the true organ of hearing – the ears only transmit sounds to the brain. Babies born with hearing loss are not starting from the same point as a child with typical hearing:

(1) they have missed out on 20 weeks of typical development of their auditory brain pathways before birth
(2) they have missed out on auditory neural development that could have occurred after birth, before their hearing loss was diagnosed, and
(3) they have missed the typical development of the auditory brain pathways that could have occurred after birth up until the time a child hears sound consistently by wearing hearing aids during all waking hours.

Hearing loss in babies has been called a "neurodevelopmental emergency." This is because there is an optimal time in a baby's brain development for important, meaningful auditory neural connections to form – and that time is during the first three years of life (especially the first year). The baby's brain must be exposed to meaningful sounds consistently in order for these auditory neural pathways in the brain to develop. If a baby does not hear sounds well, or is only exposed to just a little bit of sound or speech during his/her early years of life, a permanent, reassignment of the child's auditory brain cells. If the brain is not stimulated by sound it will reorganize itself through synaptic pruning to maximize processing through other senses – primarily vision. The visual centers of the brain will compete for 'real estate', eventually also using the space of the auditory brain centers unless consistent auditory stimulation is received by the auditory brain pathways. In other words, the baby's brain continues to develop and use the meaningful sensory information that it gets. However, if there is no sound information getting to the brain, those auditory neural branches will be pruned away and the neural branches that support the available vision information will be strengthened. This competition continues throughout the first three years of life. After about 3 ½ years of age, the brain has considerably less flexibility to develop effective skills to process auditory information. This is why children who have hearing loss that is identified late have a much harder time learning to listen and speak proficiently.

How brains develop directly relates to a child's development of communication skills. The brains of children born with severe to profound hearing loss who do not use hearing aids or a cochlear implant(s) will naturally become organized so that the children can use their vision as efficiently as possible to develop a visual mode of communication. If the communication occurring consistently around them from a young age is a meaningful visual language, like American Sign Language, their brains will quickly learn ASL as their native language. The "pre-wiring" in the brain for listening and spoken language learning will be reassigned – or changed - for other functions over time, until the auditory brain centers are no longer readily available to receive and use sound stimulation. Those neural connections and "brain space" are then typically used for processing the available and meaningful visual information.

Conversely, babies with hearing loss that is identified in the first weeks of life and who begin hearing optimally through amplification by 2-3 months (no later than 6 months) have a good chance of being able to develop the neural connections in their auditory brain pathways that are necessary to lay the foundation for spoken language development. This is especially true if they are provided with enhanced listening experiences. The best predictors of verbal language skill development are the child's age when full time hearing aid use started, the degree of the child's hearing loss and the amount of his/her exposure to meaningful listening experiences. Hearing aids, FM systems and cochlear implants are "brain access" tools. To take advantage of the critical period of optimal auditory brain development, the ability of the brain to perceive sound as much as possible must be provided as soon as possible after birth. Using technology, hearing ability must be provided as close to the typical hearing level as possible if the family wants the child to learn to listen and use spoken language.

Babies born with typical hearing already have a head start on language development. About 90% of what very young children know about the world is learned incidentally, casually and passively. Children with hearing loss require 3 times the exposure to learn new words and concepts due to their reduced ability to easily overhear the language used around them. Only through concerted effort on the part of families, can children with permanent hearing loss catch up and learn language at a rate similar to children without hearing loss. Regardless of the family's choice of communication mode, the key to children's communication development depends on intensive language exposure as early as possible throughout all of their daily activities. In other words, families are the key.

Brain development and hearing loss in only one ear

In a recent study (2010), researchers tried to find out if there were lasting effects from temporary hearing loss in one ear. They wanted to find out if hearing loss that comes and goes could affect the actual "neural wiring" of the brain. They tested rats of different ages, blocking the sound in just one ear for a couple of months and then unblocking the ear. They found that in young rats, the part of the brain associated with the normal hearing ear made a sort of 'real estate grab' in the auditory cortex, developing richer brain connections that resulted in changes to the way the brain processed sound. Even after the ear was unblocked and both ears were hearing typically, this imbalance in how the brain processed sound continued. We need to hear equally well from both ears to figure out the location of sound sources and to process speech as well as possible in background noise. With hearing in only one ear, the brain cannot combine the signals of both ears together to process sound in noisy conditions or to locate sound. What these researchers found was that, once hearing was restored to the previously blocked ear, the brain eventually developed workarounds that resulted in the ability to effectively process sound from both ears. With restored hearing, the brain can eventually catch up. For children with permanent hearing loss in one ear, the auditory cortex associated with the better hearing ear will develop richer brain connections to process sound, but this cannot make up for the loss of the ability to hear in both ears.

Brain development and hearing loss due to ear infections that come and go

Over 30 years ago, researchers wanted to find out if inconsistent hearing could affect the actual wiring of the brain. In a study where the ears of young mice were blocked and then unblocked the researchers found that 45 days of blocked hearing followed by 45 days of typical hearing ability affected the development of neurons in different parts of the brain. This is one reason why we believe that a critical period exists for consistent sound stimulation to fully develop the auditory center in the brain. Other studies have found that the extent to which animal brains are changed by fluctuating hearing depends on the type, degree, and similarity of the hearing loss from one ear to another. A study of human infants (0-2 years) also found that early fluctuating hearing loss caused brain differences. Another study followed children with histories of ear infections and fluctuating hearing loss during their first year of life and tested them at 4 years of age. They found that the children with ear problem histories were not able to do listening tasks in noise as well as children without a history of ear problems.

Taken together, there is some evidence that inconsistent hearing due to ear infections that come and go can influence the development of the auditory connections in the brain. Some children experience substantial hearing loss (i.e., 50 dB) in both ears due to chronic ear infections. However, most children experience middle ear problems in one ear at a time or in both ears at varying levels of hearing loss. Based on the available research, inconsistent hearing may result in delay in maturation of some parts of the brain. Due to neuroplasticity, the brain is likely to catch up resulting in improved neural processing by school age, however some challenges listening in noise may remain for some of these children.

What the family can do to 'grow' the auditory brain centers

- Ensure that your child is hearing as well as possible. In the case of fluctuating hearing due to middle ear infections, be sure to follow up with your child's doctor and have the child's hearing tested frequently. If your child has permanent hearing loss, aim to have him wear his hearing aid(s) or cochlear implant(s) 12 hours a day, or during all the time that they are awake. Check his or her hearing technology at least once a day to be sure it is working appropriately. Praise your child when he lets you know when he is having trouble hearing as well as usual.

- Minimize the background noise in your home and the child's other daily learning environments. Young children can't effectively separate noise from speech and this interference can slow language learning.
- Language is learned from meaningful interactions with the family and caregivers (not TV). Call your child's attention to sounds heard in the environment. Use complete sentences, talk about everything you and your child do and see, name objects using as many varied vocabulary words as possible as you care for your child and spend time with him daily.
- Play and have fun with your child. Sing songs to him or her often. Strive to read 10 books a day!

Resources and information:

- Brain Plasticity: What Is It? Erin Hoiland. http://faculty.washington.edu/chudler/plast.html
- Hearing Loss in Babies is a Neurological Emergency. Dimity Dorman. http://agbell.org/NetCommunity/Document.Doc?id=356
- Auditory Brain Development and How it Affects Listening, Language and Literacy. Carol Flexer. http://www.txsha.org/_pdf/Convention/2011Convention/2011SpeakerHandouts/Flexor,%20Carol%20-%20Auditory%20Brain%20Development%20and%20How%20it%20Affects%20Listening,%20Language,%20and%20Literacy.pdf
- Temporary Hearing Loss May Rewire Kids' Brains. Dan Polley & Maria Popescu. http://www.npr.org/blogs/health/2010/03/temporary_hearing_loss_in_kids.html?ps=rs http://www.ncbi.nlm.nih.gov/pubmed/20223206
- Effects of Neonatal Conductive Hearing Loss on Brain Stem Auditory Nuclei. Webster & Webster. http://www.ncbi.nlm.nih.gov/pubmed/496200
- Conductive Hearing Loss During Infancy: Effects on Later ABR Electrophysiology. Gunnarson & Finitzo. http://jslhr.asha.org/cgi/content/abstract/34/5/1207
- Listening and Language at 4 Years of Age. Gravel & Wallace. http://jslhr.highwire.org/cgi/content/abstract/35/3/588

Developed by Karen L. Anderson, PhD for the Minnesota Department of Education Parents Know website, 2011 (http://parentsknow.state.mn.us).