An Introduction to Cortical Auditory Impairment After Hemispherectomy

TAMMY RIEGNER, AUD, CCC-A
NEMOURS/ALFRED I. DUPONT
HOSPITAL FOR CHILDREN
WILMINGTON, DE

AUDREY VERNICK, COPAA/SEAT
MONIKA JONES, JD
THE BRAIN RECOVERY PROJECT:
CHILDHOOD EPILEPSY SURGERY
FOUNDATION

INTRODUCTION

It is anatomically impossible for a child to have completely normal auditory processing skills after hemispherectomy surgery; however, the ***extent*** of the cortical auditory impairment **will vary from child to child**. A comprehensive auditory processing assessment is critical to understand the child's auditory processing skills.

If the child is unable to participate in an assessment, it should be assumed that:

1) the child has some impairments related to dichotic listening, sound lateralization, and potentially sound localization; and,

2) the ear opposite of the removed/disconnected hemisphere is massively suppressed in dichotic listening environments.

Observation and parent report may also reveal misophonia (i.e. extreme aversion to sound) and/or hyperacusis (i.e. abnormal increase in sensitivity to sound of different intensities). Accommodations, aids, and appropriate services to help the child access his/her educational environment should be made by the school team.

HEARING AND LISTENING

Auditory function is broadly described as the ability to hear and listen. Hearing is a **passive** sensory process where a person detects sound. Generally, a person does not have to try to hear something. Listening is an **active** process involving detection and interpretation. A person must actively attend to and discriminate different sounds, particularly speech. The ability to hear and listen provides us with an enormous source of information and forms a bridge between the world and how we interact with it. In school, hearing and listening allow a child to maintain a high level of concentration with little effort, communicate effectively with instructors, and register information accurately. In social situations, listening allows us to participate in conversations and interact with others in both loud and quiet settings.

After hemispherectomy (including functional hemispherectomy and hemispherotomy), hearing and listening can be dramatically affected. This guide explores cortical auditory processes after surgery and how the procedure can affect a child's sensory and learning processes.

WHAT IS AUDITORY PROCESSING?

How sounds of varying frequencies are transmitted and perceived into and through the brain is known as auditory processing. It's a rigorous way of describing the combined working of hearing and listening.

More than just hearing, the filtering, attenuating and perceiving of auditory processing can be described in various ways, including but not limited to:

Speech in noise

In typically-developing individuals, deciphering speech in a noisy environment is done by suppressing background noise via efferent brainstem pathways, compensatory speech sound processing, and increased attention to the signal of interest. Research shows that *both* hemispheres of the brain are needed to process sound in a noisy environment.

Dichotic listening

Dichotic listening is the ability to decipher competing meaningful speech or sounds presented to each ear at the same time. In typically-developing individuals, there is a right ear advantage for speech and a left ear advantage for non-linguistic stimuli until early to mid adolescence wherein there is almost no difference between the ears.

Sound lateralization

Lateralization is the ability to perceive from which specific side a sound is originating, either when presented by headphones or a bone conduction oscillator.

Localization

Localization is the ability to determine the location of a sound source that is present within a person's environment.

Temporal processing

Temporal processing is how the brain interprets timing cues, which allow the auditory cortices to distinguish between phonemes (i.e. speech sounds) as well as understanding pitch differences and intonation of conversational speech. This involves the timing of the spoken message, and requires accurate ordering, or sequencing, abilities. Problems with temporal processing can include misunderstanding conversations, responding inappropriately, misinterpreting the incoming message, and misunderstanding sarcasm.

Auditory closure

Auditory closure is the child's ability to fill in and recognize an acoustic signal when parts of the signal are missing or modified. It assesses whether or not the child is able to fill in missing information when the incoming signal is not clear. Children with auditory closure difficulties may have problems understanding the incoming message when talking on a cell phone or in a noisy restaurant.

ABOUT CORTICAL AUDITORY IMPAIRMENT

Central Auditory Processing Disorder reflects difficulties in the perceptual process of auditory information in the central nervous system and in the neurobiological activity underlying those processes that gives rise to electrophysiological auditory potentials. Central Auditory Processing Disorder can act like an acoustic filter that distorts the reception and/or interpretation of verbal language. There are multiple skill areas that fall into the category of CAPD, and evaluation helps to determine which areas are not functioning age appropriately.

Cortical auditory impairment, also known as central hearing loss, is a condition wherein the brain is unable to effectively detect and interpret incoming sounds or speech. **Central Auditory Processing Disorder** (CAPD), also known as Auditory Processing Disorder, is a type of cortical auditory impairment which results from a neurological deficit in the auditory centers of the brain. CAPD can affect the same areas of the auditory cortex but is a more specific diagnosis related to a set of behavioral characteristics associated with the brain's ability to interpret and effectively use sounds. Both are similar diagnoses but are not considered interchangeable. CAPD involves central auditory nervous system processes, but central hearing loss (i.e. cortical auditory impairment) is not always as specific in the skills sets that are adversely affected.

Children with any central auditory nervous system impairment show frequent mishearing of speech sounds, difficulty following a verbal message, and/or increased difficulty understanding speech in the presence of competing speech or background noise. They may also be hypersensitive to certain sounds or show distress or discomfort in some sound environments.

How Hemispherectomy Affects How The Brain Interprets What The Ears Hear

The brain's auditory centers are located in the temporal lobes located on both sides, or hemispheres, of the brain. These two auditory centers communicate with one another by interhemispheric transfer across a thick band of neural fibers called the corpus callosum. Because hemispherectomy surgery removes or disconnects one temporal lobe, and also severs the corpus callosum, listening is adversely affected but hearing, as it pertains to the sensory system, is often intact. This is why many children after hemispherectomy will show normal hearing test results.

Children After Hemispherectomy Are At Risk Of Cortical Auditory Impairment and CAPD

It is anatomically impossible for a child to have normal auditory processing skills after hemispherectomy; however, the *extent* of the impairment will vary from child to child. Research shows that children after hemispherectomy can do well on "speech in quiet" tests (where they listen to different environmental sounds and speech in a sound-treated booth); however, when there is competing noise within the environment (speech in noise) or meaningful speech coming into both ears at the same time (dichotic listening), auditory function is known to be severely impaired. Dichotic listening, specifically, is adversely affected when the corpus callosum is severed because there is no longer interhemispheric transfer (i.e. communication between the two sides of the brain) and coordination of the competing speech.

Differences Depending On Side Of Surgery

After left hemispherectomy the *right ear* is massively suppressed and the left ear has the hearing advantage. The instructor, tutor, or aide should sit to the left of the child so that the left ear hears lessons clearly.

After right hemispherectomy, the *left ear* is massively suppressed and the right ear likely has the hearing advantage. The instructor, tutor, or aide should sit to the right of the child so that the right ear hears lessons clearly.

Regardless of side of hemispherectomy, recognizing speech in noise is also known to be significantly impaired. Additionally, the main language center for most children is located on the left side of the brain, therefore, left hemispherectomy can cause even greater difficulty with recognizing fast or distorted speech and overall processing of language, especially if the child spoke prior to surgery.

The child with hemispherectomy may have numerous factors that raise concerns around deficits in attention, cognitive ability, memory, and language. While Central Auditory Processing Disorder can co-exist with other disorders such as Attention Deficit Hyperactivity Disorder (ADHD), Sensory Integration Dysfunction, learning disabilities or intellectual disability, CAPD is a specific deficit in the neural processing of auditory stimuli at the level of the central nervous system.

DIAGNOSIS

Children with cortical auditory impairments often exhibit a wide variety of academic and communicative complaints, including: inability to follow complex verbal directions; poor verbal cognitive performance as compared to non-verbal performance; spelling and reading difficulties; receptive language disorder; unwillingness to engage in classroom discussion or, alternatively, inappropriate or off-topic contributions to conversational exchanges; poor sound blending, discrimination, and segmentation skills, and difficulty maintaining attention to information presented auditorily. These same children frequently request many repetitions, may be easily distracted, and may exhibit signs of frustration, especially in language-based courses such as social sciences and language arts.

Accurate diagnosis is critical because verbal information processing problems can arise from a variety of areas including auditory processing or language processing as well as higher executive deficits in cognitive decision making, memory, attention, behavioral controls, or emotional factors. While testing of the peripheral hearing system is important to rule out potential sensory hearing loss, the traditional behavioral central auditory processing tests stress the higher auditory system at the level of the brain, which evaluates more than a peripheral hearing evaluation alone.

The Assessment Process

Only a trained audiologist can conduct the tests needed to evaluate cortical auditory function. It is imperative that a qualified examiner (using a sound booth) performs separate testing of each ear, binaural testing, and testing in the sound field.

The screening portion of the SCAN tests, for example, can be by administered by qualified school professionals (such as a speech-language pathologist or a certified school psychologist), but none of the test tools used by these professionals are diagnostic tools for CAPD. The actual diagnosis of CAPD must be made by an audiologist as mandated by the American Speech and Hearing Association (ASHA) and American Academy of Audiology (AAA).

If an audiological evaluation to confirm normal hearing sensitivity has not previously been done, a peripheral audiological evaluation including middle ear muscle reflex testing (also called acoustic reflex testing), otoacoustic emissions, and speech-in-noise testing should be completed prior to the tests of central auditory processing. Peripheral hearing loss has a known association with auditory processing deficits due to the deprivation of sound signals to the brain; however, Central Auditory Processing Disorder is not an automatic diagnosis when peripheral hearing loss is present. Recommendations and accommodations for hearing loss should be similar to those of a child diagnosed with CAPD and should always be aggressive in optimizing the listening environment for the child with hearing loss.

Prerequisites for a traditional central auditory processing evaluation include normal hearing sensitivity, normal cognitive abilities (IQ of 80 or higher), age appropriate speech and language skills, and a minimum age of seven years due to the age norms used to determine normal function; however, *if a child does not meet these criteria*, then a battery of electrophysiological and electroacoustic tests may be able to determine if the central auditory nervous system is a main contributor to some of the difficulties the child has shown.

Although these tests are not able to give a formal diagnosis of CAPD, they are valuable in looking at the central auditory nervous system (i.e the brain and the brainstem) without potential interference from other diagnoses that may adversely affect the accurate diagnosis using behavioral testing. But remember - *every child after hemispherectomy will have some deficits of central auditory function as a result of the auditory centers of the brain being removed.*

Evaluations

Evaluations after hemispherectomy should include:

- Speech in noise (also known as auditory figure-ground) tests assess a child's ability to understand specific speech in variety of reverberant, ambient noise environments. This taxes the auditory and attention systems more due to the amount of sound information that has to be effectively filtered by the brain. Children with attention deficits often also struggle with this testing due to the added auditory distraction of the noise.

- Dichotic listening tests present a different but meaningful stimulus to each ear simultaneously in order to assess binaural integration (i.e. repeating everything heard in both ears) or binaural separation (i.e. ignoring what is heard in one ear while repeating what is heard in the other ear). Dichotic listening tests are selected with varying language complexities to assess whether language itself is the underlying concern. Some of these tests are:

    - Competing words
    - Competing sentences
    - Staggered compound words
    - Dichotic digits

- Temporal tests often use non-speech stimuli in order to have the listener discriminate sound based on a sequence to assess pattern perception, pitch recognition, and timing recognition abilities. Temporal skills allow a child to interpret the contours of speech such as rhythm, intonation, syllabic stress, and keyword detection. Some of these tests include:

    - Pitch discrimination
    - Pattern sequence
    - Gap detection in quiet and in noise

- Binaural lateralization and or localization tests assess the ability to accurately find the side or origin of a sound.

- Monaural low-redundancy tests (also called tests of auditory closure) present modified speech in order to assess the brain's ability to fill in the missing components of the speech signal. The speech is modified by filtering it, making it faster, or adding reverberation like noise to reduce the signal's redundancy. Some of these tests include:

    - Filtered words
    - Time compressed speech
    - Speech in noise

- Non-central auditory processing supplemental tests may also be included to evaluate the child's phonological awareness, auditory vigilance, and/or auditory memory.

General Guidelines for Assessment

Both the American Speech Language Hearing Association and the American Academy of Audiology recommend a set of principles that should be applied when determining the composition of a test battery, which include:

(a) CAPD assessment should be multidisciplinary;

(b) diagnosis and management should be guided by case history and diagnostic findings;

(c) diagnostic test batteries should include both verbal and nonverbal stimuli to assess different levels of the central auditory nervous system (CANS);

(d) the test battery should examine different processes, regions, and levels of CANS;

(e) behavioral tests and other screening tools (including questionnaires) should be well validated, have good test-retest reliability, and demonstrate high sensitivity and specificity;

(f) testing should be completed within a reasonable period of time;

(g) the audiologist needs to be sensitive to subject-related attributes that may influence the individual's test performance, such as chronological age and mental age, attention to task, fatigue, and native language; and,

(h) testing should not be test driven but rather motivated based on the referring complaint.

In addition, the American Speech Language Hearing Association recommends the following test principles for central auditory processing assessment:

(a) audiologists should have the knowledge, training, and skills necessary to perform the testing;
(b) the test battery should be driven by referring complaint;

(c) audiologists should use "good tests" (i.e., established validity, reliability, and efficiency);

(d) audiologists should use tests that tax different auditory processes;

(e) audiologists should use tests with verbal and nonverbal stimuli;

(f) testing should be sensitive to attributes of the individual;

(g) normative data should be available;

(h) the audiologist should be aware of influences of age, especially on electrophysiologic tests;

(i) test methods should be like those in the manual/literature;

(j) the patient should be monitored and an appropriate duration of test session should be selected;

(k) other professionals should collaborate with the audiologist. if another deficit is suspected, the audiologist should refer on
the (C)AP evaluation should be one part of a multifaceted evaluation and the audiologist should relate the findings to the referring complaint.

The Importance of Multidisciplinary Assessment

After evaluation by an audiologist, a multidisciplinary team approach should be used as there is often a cluster of related challenges accompanying the auditory processing concerns. Parents, teachers, speech-language pathologists, psychologists, and neurologists are often partners in the management of a child who has multiple concerns that include Central Auditory Processing Disorder.

Teachers and other educational specialists can help relate the child's academic difficulties and effectively navigate the classroom modifications and accommodations. A psychologist can evaluate cognitive functioning and recommend strategies for improving or compensating areas of deficit. A speech-language pathologist assesses the child's functional speech and overall speech and language capabilities and recommends therapy as appropriate.

A multidisciplinary team approach should be utilized to help manage the various interventions, the timing of intervention strategies, how they can be delivered in a complementary manner, and how to measure the efficacy of the interventions. However, the actual diagnosis of CAPD must be made by an audiologist.

MANAGEMENT

There are many management options to address Central Auditory Processing Disorder. These can include therapeutic and environmental interventions and compensatory strategies to help the child to be as successful as possible, many of which may be helpful after hemispherectomy. Some examples are:

Training to build auditory and related skills:

- Computer-assisted therapy programs to assist with phoneme (i.e. speech sounds) awareness such as Earobics and Hearbuilder (helps to emphasize the development of phonics skills and temporal aspects of auditory development);
- Noise desensitization exercises for children with the added complaint of auditory sensitivity or demonstrate behaviors of being overwhelmed in noisy environments for children with the added complaint of auditory sensitivity or demonstrate behaviors of

being overwhelmed in noisy environments (e.g. Sound Eaze, Vital Sounds, to be used in conjunction with an occupational or vestibular therapy program);
- Auditory training such as Dichotic Interaural Intensity Difference (DIID) training (a therapeutic approach for patients with dichotic listening deficits);
- Auditory Integration Training (AIT);
- Interactive Metronome therapy can be used for children with temporal processing concerns but also has been utilized for children with attentional concerns, cerebral palsy, and some higher executive functional concerns.
- CAPD Online Therapy System (CAPDOTS)
- FastForWord also has been used to address temporal processing deficits. Although this requires some interhemispheric communication via the corpus callosum, some post-hemispherectomy families have reported a level of success with it.
- Integrated Listening System (iLs) and other Tomatis-based therapeutic models;
- Soundstorm or a similar therapy to work on developing the ability to localize sounds in space and build an appropriate auditory spatial map.

(Please note that that none of the above interventions are research-based after hemispherectomy. We do not know if any of these programs will work for children after hemispherectomy due to the damage to their neuroanatomy. If you try any of these methods, proceed very cautiously with frequent data collection and progress monitoring).

Therapy and Specialized Instruction

Various therapies and specialized instruction methods should be use to help the child access information presented auditorily. These include:

- Reading instruction: one-on-one or small group instruction in reading skills, targeting any areas of weakness; reading aloud; pre-teaching new concepts and vocabulary; listening to audiobooks in conjunction with visual assignments. The child may require a phonics-based reading program to assist with difficulties with phonemic decoding. A detailed reading assessment from a certified reading specialist can help the team understand specific reading deficits and tailor a program to the child strengths and deficits.

- Intensive speech and language therapy: one-on-one training with a speech therapist to provide exercises and training to build kids' ability to identify sounds and develop conversational and listening skills; i.e. phonological awareness and discrimination training (including speech-to-print skills); auditory closure activities; prosody training (including rhythm and stress perception); speechreading.

- Therapy to work on sound localization and sound lateralization. This may be performed by an auditory therapist, a speech-language pathologist who works with auditory complaints, or an occupational therapist who specializes in sensory integration dysfunction techniques related to auditory complaints;

- Occupational therapy to work on developing skills that will allow child to combine auditory and visual information and to work on desensitization strategies when needed.

Compensatory Strategies

Compensatory strategies are designed to assist individuals with techniques that they can apply to help overcome some of the daily struggles that they may face. For example, a child may need to "chunk" important information together to understand the message being conveyed.

Usually, compensatory strategies consist of suggestions for assisting listeners in strengthening central resources (language, problem-solving, memory, attention, other cognitive skills) so that they can be used to help overcome the auditory disorder. In addition, many compensatory strategy approaches teach children with CAPD to take responsibility for their own listening success or failure and to be an active participant in daily listening activities through a variety of active listening and problem-solving techniques.

Environmental Modifications

Certain environmental modifications can be made to improve access to information presented auditorily. They include:

- Use of large-group or individual FM systems to maximize the signal-to-noise ratio;
- Provide preferential/strategic seating (toward speech source and away from noise sources, such as large windows, playground, construction noise, HVAC units, pencil sharpeners, etc.);
- Reduce competing speech and distracting background noise;
- Reduce ambient reverberation in the room with sound-absorbing materials (carpet on floor, stoppers on chair legs, curtains on windows, corkboard bulletin boards on walls, etc.);
- Avoid open classrooms or multiple-use community rooms (which may increase ambient noise and unwanted visual distractions). Instead, instruction should be provided in contained rooms with permanent wall structures that reach to the ceiling, and closed doors;
- Improve lighting to maximize visual cues;
- Minimize visual distractions, or use a study carrel.

Accommodations

Various accommodations should be made to improve the child's access to auditorily presented information. These include:

School-based strategies

- Small group instruction - Due to the complexities of listening environments for hemispherectomy, smaller group instructional setting of approximately 6 children or less is recommended. For children with significant higher executive function deficits as well as listening and language deficits, one-on-one intervention may be needed for more language based- and computationally-driven subjects;
- Pre-teach new information, particularly new subject vocabulary;
- Provide written outlines or study notes/study guide before a lecture;
- Multimodal presentation of instructions and new subject matter, i.e. visual reinforcers, visual aids, and written instructions to augment the verbal where applicable; explain verbally while showing visually;
- Allow use of a recorder for meetings or lectures;

- Auditory cueing, which is gaining the child's attention by calling his/her name, using a previously assigned visual cue, or gently tapping the child on the shoulder before addressing him/her;
- Assign a visual cue to signal the teacher when the child needs repetition of instructions;
- Frequent checks for understanding of verbal information which may include asking the child to paraphrase or repeat instructions;
- Break up complicated or multi-step directions into smaller steps. This technique is called "chunking"; instructions should be short, simple and repeated if necessary;
- Alter assignments to minimize the area of weakness;
- Rephrase or repeat misunderstood information;
- Allow extra response time for oral testing and any activities with verbal instructions;
- Use metacognitive techniques designed to strengthen memory and aid in recall (such as verbal rehearsal, tag words, and organizational aids);
- Use of audiobooks (to augment any visual reading assignments to increase reading comprehension, and to exercise listening skills and auditory memory);
- Reduce rate of speaking: the understanding of verbal information for the average child is approximately 124 words a minute. Given that the average adult speaks using over 200 words a minute, a child often needs a slower rate of speech, deliberate pauses, and a clear voice. Reduce the instructional information to smaller units and present with a slower rate of speech to increase the child's ability to effectively listen to and follow verbal instruction; faster rates of speech may cause more difficulty for the child to accurately follow new instructions and unfamiliar topics;
- Develop and maintain routines and use consistent vocabulary and formats;
- Allow the child to have several breaks between class so that he/she has a recovery period during the day. In most cases, breaks of 5 minutes of quiet activity are recommended for 15-20 minutes of sustained attention to instruction but may need to be adjusted based on the individual child's needs and abilities;
- Encourage the child to self advocate; for example, s/he can request a quiet environment in which to work or take a break if feeling overwhelmed;
- Avoid more complex auditory tasks when the child is already fatigued.

Home-based strategies

- Play games that assist in further development of overall language and vocabulary use, such as: Scattergories, Taboo, Apples to Apples, Brain Quest, Password, Jeopardy, Knock Knock Jokes, Rags to Riches, Mad Libs;
- Encourage active participation in games that develop the ability to think several steps ahead, such as chess, backgammon, checkers, and Blokus;
- Use electronic games such as Splingo's Language Universe to develop skills in working on multiple step instructions; other language and educational games can be found at www.superduperinc.com;
- Use memory games and exercises such as Bop It or Simon, the card game Concentration, video games like Brain Age and Mind Games, and online resources targeted toward developing working memory (e.g. junglememory.com);
- Incorporate checklists and schedules in daily tasks to assist with organization and memory skills;
- Read aloud daily for 40 minutes with special emphasis on animation to increase reading aptitude, to reinforce the use of rhythm, stress, and intonation in expressive language, and to strengthen overall comprehension as well as increase auditory memory skills.

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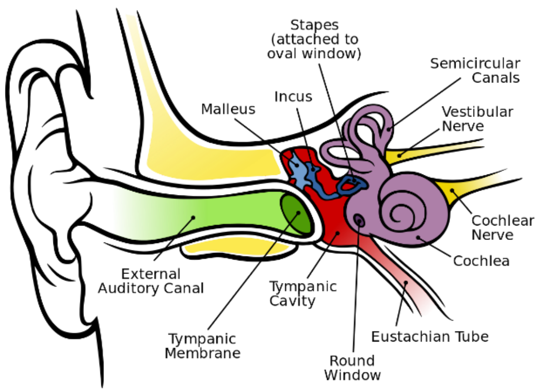
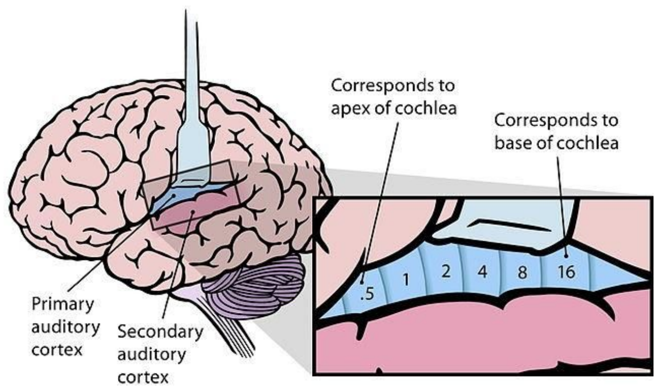
APPENDIX

HOW A HEALTHY BRAIN HEARS

Sound travels into the ear through the auditory canal where it hits the eardrum (tympanic membrane). The eardrum vibrates and transmits the vibrations through the tiny bones (the malleus, incus, and stapes) attached to it. The bones transfer the vibrations to the fluid-filled inner ear organ (the cochlea) where the vibrations, now in the form of little waves in the fluid, move tiny hair cells. Different hair cells receive different frequencies of sound waves. Each hair cell is connected to a neuronal axon which, bundled together, form the auditory nerve.





The auditory nerve carries the sound waves, now expressed as electrical impulses, to a band of highly specialized neurons in the brain called the **primary auditory cortex**. This auditory cortex is located on each side of the head in a lobe of the brain called the temporal lobe.

Each side of the brain has its own primary and secondary auditory cortex - **a strip of neurons dedicated to detecting and organizing sound**. Similar to how the cochlea is sensitive to various frequencies, the primary auditory cortices are also sensitive to sounds of various frequencies. Each part of the auditory cortex receives specific information from hair cells that are frequency specific. This is how the brain is able to distinguish between various sounds.

Although each side of the brain has its own auditory cortex, the main area that understands language is primarily only on one side of the brain. In most typically-developing people, that is the left side. The corpus callosum has an interesting role in the processing of sound, particularly speech. This wide, flat bundled band of over 250 million neuronal axons, which connects the two hemispheres of the brain, is important for language transfer and processing of auditory information.

Speech spoken into the right ear crosses over the brainstem via the auditory nerve to the language center in the left hemisphere of the brain. Speech presented in the left ear crosses over the brainstem to the right side; however, due to the location of the major language center on the left, the signal must then cross over the corpus callosum to access language interpretation in the opposite hemisphere. This pathway is very immature in younger children, which is why many children have a right ear preference. As children reach early-to-mid adolescence, the corpus callosum becomes very efficient in sending the auditory information at the same speed as the other ear. By that time, there is no longer a significant ear difference.

For additional resources about brain surgeries to stop seizures in childhood and information about the services of The Brain Recovery Project, please contact: The Brain Recovery Project: Childhood Epilepsy Surgery Foundation, 115 California Blvd., Suite 1024, Pasadena, CA 91105