2013

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Recommended Citation

Wood, Kelly L., "A critical period of development for auditory memory and the auditory scaffolding hypothesis" (2013). *Independent Studies and Capstones.* Paper 673. Program in Audiology and Communication Sciences, Washington University School of Medicine.
http://digitalcommons.wustl.edu/pacs_capstones/673

A CRITICAL PERIOD OF DEVELOPMENT FOR AUDITORY MEMORY AND THE AUDITORY SCAFFOLDING HYPOTHESIS

by

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An Independent Study
submitted in partial fulfillment of the
requirements for the degree of:

Master of Science in Deaf Education

Washington University School of Medicine
Program in Audiology and Communication Sciences

May 17, 2013

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Abstract: This paper discusses whether or not a critical period of development exists for auditory memory and the educational implications for children who are deaf or hard of hearing.

Acknowledgements

I would like to thank Ms. Ellie White for her continual support, enthusiasm, and dedication throughout the completion of this project. From start to finish, her wisdom and guidance were invaluable. I would also like to thank Dr. Heather Hayes for her contributions to this paper and for helping me develop my original ideas into a cohesive project. In addition, I am very grateful for the PACS staff, my classmates, my friends, and my family. Your support these past two years means more than I can express!

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Introduction

In the past several decades, a myriad of research has been done on the topic of critical periods of development. According to Robert Siegler, a critical period is a phase in the life span during which an organism has heightened sensitivity to external stimuli that are compulsory for the development of a particular skill. If the organism does not receive the appropriate stimulus during this critical period, it may be difficult, ultimately less successful, or even impossible to develop some functions later in life (2006). Critical periods of development have been researched across many fields, including language acquisition, the development of the visual cortex, and the development of the auditory system.

There is no doubt that children and adults who are born with profound hearing loss will experience, at least at some point in their lives, a period of sensory deprivation. If they receive access to sound via a cochlear implant, the brain has to adapt and learn how to process this new sensory input. Because of this, cochlear implant users provide researchers with a unique opportunity to study the effect of sensory deprivation on the development of the auditory system. In particular, the development of auditory memory in children with hearing loss has been a topic of interest to educators, especially as an increasing number of children have received cochlear implants in the past few decades. This is due to the fact that auditory memory is so important in educational tasks and a lack of auditory memory inhibits a child’s ability to progress in certain academic areas. Low test scores on auditory memory tasks were found in children who have specific reading and language learning disabilities (King, Warrier, Hayes, & Kraus, 2002).

The implications for auditory success for children with profound hearing loss are certainly notable and could possibly lead to major advancements in the way that children with hearing loss are educated. As more and more children learn to listen and talk using amplification devices, the bar continues to rise regarding the very definition of a successful education. With early intervention services, proper audiologic management, and a language-enriched education, children with hearing loss are no longer simply getting by in the hearing world— they are excelling. However, there are still some areas of development in which children with hearing loss continue to struggle.

Children with hearing loss have historically shown delays in measures of auditory memory (Dawson, Busby, & McKay, 2002; Pisoni & Cleary, 2003; Pisoni, Conway, Kronenberger, Horn, Karpicke, & Henning, 2008). Auditory memory is important to the development of speech and language, which are foundational for a child's academic progress (Geers, 2006). This paper discusses the relationship between the development of the central auditory system and auditory memory. The relationship between the critical period of development of the central auditory system and auditory memory is of particular interest. This is because the critical period of development of auditory memory is difficult to assess and has not been researched extensively. An additional component is the relationship of hearing loss to general memory and sequencing abilities. Research by Cleary, Pisoni, and Geers (2001) showed that children with hearing loss who wear cochlear implants have impaired measures of visual and spatial working memory in addition to impaired auditory memory functions. Auditory sequencing, a function of auditory memory, was researched by Conway, Pisoni and Kronenberger in 2009. Their findings showed that several modalities displayed sequencing delays, not just the auditory modality. Visual sequencing and tactile sequencing were delayed even though the participants in the study were typically developing despite their hearing loss. The implications of this for educators of the deaf, as well as classroom strategies, will be discussed as well.

Neuroplasticity

For hundreds of years, researchers viewed the brain as a static part of the body— an organ that functioned like a machine and never changed. It was thought that the brain remained the same from birth to death, permanently deteriorating over time like the rest of the human body. Initially, scientists supported the idea of localizationism which states that an area of the brain is dedicated to a certain function that occurs in the same location in every human brain. In the last 250 years, researchers have attempted to refute this notion, but it was not until the 1970's that any real evidence began to emerge to the contrary. A new idea began to materialize as medicine improved and brain imaging technology was developed. For the first time, using Magnetic Resonance Imaging, scientists could 'see' how a brain worked by studying it *while* it was actually working. The field of neuroscience exploded as the firing of neurons in the brain was recorded and analyzed in real-time. This firing was recorded in a systematic way called mapping and resulted in a brain map. The more researchers saw the brain in action, the more questions they asked.

Further studies were conducted with individuals who had experienced sensory deprivation, such as hearing, visual, and vestibular impairment as a result of syndromes and/or disorders present at birth. These individuals exhibited a brain map that looked very different from a brain that had developed typically. The same was true for people who experienced brain injury, stroke, or lesions that caused part of the brain to become ineffective. Research done by Paul Bach-y-Rita (1972) revolutionized neuroscience by retraining the brain in patients who had experienced sensory deprivation. One set of experiments he performed was on patients who experienced vestibular malfunction. An electrode array was placed on the tongue (where there is a high density of sensory receptors) and attached to a series of accelerometers. These accelerometers were worn on the head and detected movement in every plane, which was translated into vibrations felt on the tongue. Bach-y-Rita intended for this device to eventually be worn at all times, but after several trials with the device, he discovered something shocking. Patients remained balanced after the device was removed for increasingly extended periods of time. Bach-y-Rita hypothesized that the brain was processing the vestibular information in the same place that a typical brain would process the information, but the information reached that area of the brain in a different way.

In the last half-century, neuroplasticity has transformed from taboo conjecture to accepted science. In the realm of rehabilitative sciences, Edward Taub (1980) discovered that he could correct physical weakness caused by stroke through a rigorous training program which forced people to use their weak limbs. They were able to regain strength and movement coordination. Moreover, brain scans following training showed that the areas of the brain used for movement increased in size (Taub, 1980). Another major breakthrough in the field of neuroplasticity came at the hands of Michael Merzenich, a man who would later help develop the cochlear implant. Merzenich used a very precise technique called micromapping to map responses that occurred when different portions of the motor cortex of the brain were stimulated. He found that, over time, stimulating the same exact place could trigger a different result. This showed that the brain was not a machine that performed the same task over and over— it was constantly changing and reorganizing itself. In one of his well-known experiments, he mapped the three nerves in the hand of a monkey to see which area of the brain responded to which nerve. He then cut the nerve for the middle part of the hand. Two months later, he remapped the brain and discovered that the brain maps for the other two nerves had invaded the space previously occupied by the brain map of the middle nerve. This showed that the two nerves took over unused map space to process their input and strengthen their efficiency (Merzenich, Nelson, Stryker, Cyander, Schoppmann, & Zook, 1984).

In the auditory system, the implications of neuroplasticity in conjunction with hearing loss are endless. Bavelier, Dye, and Hauser (2006) demonstrated that cortical reorganization occurred in individuals born with profound hearing loss. Without auditory stimulus, the auditory cortex received input from other senses. For example, individuals with hearing loss performed better on peripheral vision tests than individuals with typical hearing. Neuroplasticity also explains how people with profound congenital hearing loss are able to process sound in the auditory cortex once they begin to receive auditory input as cochlear implant users — the brain, formerly devoid of auditory input, reorganizes itself according to the new presence of auditory information. With training, the brain can learn to make sense of this new input and begin to process the information efficiently and effectively.

Auditory Scaffolding Hypothesis

Sound has typically been thought of as domain-specific source of input, affecting only the parts of the brain that are related to auditory perception. Recent research suggests that these modality constraints are less stringent than originally thought because of the integrated functioning nature of the brain. Sensory processing is no longer thought of as autonomous from the rest of neurocognition. In 2009, Conway, Pisoni, and Kronenberger developed the Auditory Scaffolding Hypothesis— a new theory regarding the relationship between this notion and profound congenital hearing loss.

The Auditory Scaffolding Hypothesis states that “experience with sound may help bootstrap— that is, provide a kind of “scaffolding” for— the development of general cognitive abilities related to representing temporal or sequential patterns" (Conway, Pisoni, & Kronenberger, 2009). This research argues that because sound is the most basic temporal and sequential signal humans are exposed to (even before birth), the absence of auditory stimuli during the first few years of life could result in atypical development of general cognitive sequencing skills. This is evidenced by two different findings: modality specific constraints in subjects with typical hearing and non-auditory sequencing abilities in subjects with congenital deafness.

Modality constraints have been thoroughly investigated and results show that if people rely primarily on their hearing, performance is significantly better on recalling timing and order for tasks that require perception, learning, or memory of events. According to Collier and Logan (2000), adults can perceive and reproduce auditory patterns more accurately than they can reproduce visual patterns when sequences of either auditory tones or light flashes are presented at varying rates. Coding time for auditory events is also more accurate than it is for visual events (Glenberg & Jona, 1991).

In 2005, Conway and Christiansen tested participants' ability to repeat a sequence of events presented in various modalities. Participants were presented with auditory, visual, and tactile sequences generated using an artificial grammar. The pre-determined set of grammatical rules controlled the order in which stimuli could be presented. Participants were not aware of the artificial grammar before the study began, yet they actually demonstrated learning patterns as the stimuli were presented during testing. Conway and Christiansen found that participants performed significantly better on many aspects of the auditory tasks than on visual or tactile tests. They refer to this phenomenon as the auditory superiority effect. In another study from 2009, Conway and Christiansen showed that auditory information can be coded efficiently by the brain even when the presentation rate is relatively fast— a skill not present in other modalities of sequence learning. The results of these two studies lend support to the Auditory Scaffolding Hypothesis, providing evidence of the brain's highly efficient use of auditory input.

More support for the Auditory Scaffolding Hypothesis comes from Conway's research on non-auditory sequencing abilities in individuals with congenital hearing loss. Conway looked at the motor sequencing abilities of a group of children with cochlear implants. Due to their hearing loss, these children performed atypically when compared to a control group of children with typical hearing and when compared to normative data of children who are typically-developing (Conway, Pisoni, & Kronenberger, 2009). The 2010 study by Conway, Pisoni, Anaya, Karpicke, and Henning compared the visual sequence learning abilities of children with cochlear implants to visual sequence learning abilities in children who are typically developing. Twenty-five children with congenital deafness who wore at least one cochlear implant were compared to twenty-seven children who were typically developing. The visual sequencing task used an artificial grammar that was 'taught' for the first portion of the test. During this phase, the children were shown sequences of colored squares on a computer screen and had to reproduce the sequence by tapping the correctly colored squares on the screen. The two groups performed equally well on this task. The second part of the task, the test phase, revealed significant differences between the two groups. This portion of the test used new sequences generated from the same artificial grammar as the first task. This tested whether or not the children were able to learn the grammar rules and apply them to novel sequences. 54% of children with typical hearing showed some form of implicit visual sequence learning abilities compared to only 34% of the participants with hearing loss. The evidence regarding these non-auditory sequencing abilities in individuals with congenital hearing loss suggests a need for further investigation into the role sound plays in development of all cognitive sequencing abilities.

In summary, the Auditory Scaffolding Hypothesis suggests two different possible mechanisms for the disparity in the development of sequencing skills. First, the authors argue that listening to and automatically imitating sounds ‘bootstraps’ the skill of verbal rehearsal and “strengthens the development of domain-general implicit sequence learning abilities” (Conway, Pisoni, & Kronenberger, 2009, p. 278). In addition, research by Rosenblum shows that sound is unique in engaging the brain in decoding activities for higher-level patterns from birth (2008). These two mechanisms might help explain why sound is so integral to scaffolding sequence-learning abilities across multiple domains.

Critical Period of Development for Auditory Memory

Auditory learning is the ability to learn new information from listening alone. The process required for achieving auditory learning includes four different levels of auditory skill development. The first, detection, is the most basic auditory skill. It is the awareness of the presence or absence of sound. Detection occurs when the primary auditory cortex registers that a sound exists. The second level is discrimination, which is the ability to determine if two sounds are the same or different. Identification is the third level, and this occurs when a person is able to attach meaning to sound and label what is heard. The fourth and most complex skill required for auditory learning is auditory comprehension. Auditory comprehension is the ability to hear and listen to information provided from only auditory cues and, from there, successfully generate new ideas and novel responses based solely on information taken in through the auditory modality. Because auditory comprehension requires a person to store the auditory information while generating ideas or responses related to that auditory information, auditory memory is one of the most important factors in the development of auditory comprehension (Tye-Murray, 1998).

Auditory memory is the ability to process, store, and recall orally presented information. The task of auditory comprehension is complex and involves several mechanisms, including auditory memory. Though the development of auditory memory specifically in children with hearing loss has not been studied extensively, much time and effort has gone into the study of working memory (also known as short-term memory) in both children and adults. Many tests are commonly used to assess working memory. When a test is given using only auditory stimuli, the result is a good indication of auditory memory ability. The task that is most widely used to assess auditory working memory is the forward or backward digit-span test. The forward portion of this test assesses a person’s ability to repeat a series of numbers presented auditorily in the order of presentation. The backward portion of this test assesses a person’s ability to repeat, in reverse order, a series of numbers presented auditorily. Because digit span tests provide information through the auditory-only modality, these tests play a vital role in assessing auditory memory.

Because the development of auditory memory in children with hearing loss has not been studied extensively, there is a lack of information on the probable existence of a critical period for auditory memory development. The most prominent explanation for this is that the tasks required to assess auditory memory, like digit span, are far too advanced for young children. Since auditory memory can only be assessed through behavioral measures, children must be cognitively mature enough to complete the tasks. Children within the age range that a critical period most likely exists are not cognitively developed enough to complete the tasks.

Researchers and educators have been forced to rely on data from other measures in order to draw conclusions about whether or not this critical period exists.

The development of a critical period in relation to the maturity of the central auditory system has been studied extensively. The central auditory system is made up of two basic parts—the brainstem and the brain. When the auditory nerve is stimulated, a signal is sent from the nerve to the primary auditory cortex in the brain, passing through many points within the brainstem along the way. Sound is processed and manipulated in the primary auditory cortex. Studies have linked an underdeveloped central auditory system with a wide variety of learning difficulties. Research by Purdy, Kelly, and Davies (2002) has shown that children who have significant differences on central auditory development measures also showed major delays in both short- and long-term auditory memory. King, Warrier, Hayes, and Kraus (2002) found a correlation between children with delayed auditory brainstem responses and children with many learning impairments, including deficits in auditory memory. This connection between auditory memory and the development of the central auditory system provides insight into whether or not there is a critical period of development for auditory memory. If a critical period of development exists for the central auditory system, it can be assumed that auditory memory must develop before the ‘cutoff’ of central auditory system development since children with an immature central auditory system struggle with auditory memory tasks.

The maturity of the central auditory system is most commonly measured via the latency of auditory evoked potentials. Auditory evoked potentials are electrophysiological measures that can be taken regardless of the age of the person being tested because they are not behavioral measures. Two different measurements of the Auditory Brainstem Response (a specific type of Auditory Evoked Potential) will be discussed in this section. The first is P1 latency. This measures the delay between the onset of a signal (sound) and the perception of that signal by the primary auditory cortex. The second is measured by what is known as the N1-P2 complex. This comparison of two different evoked potentials demonstrates the synchronous firing of multiple neural structures required for speech perception. Increased N1-P2 values represent stronger, more synchronous neural connections. Stronger neural connections correlates to a better understanding of a complex signal, like speech. The pathways that sound takes to the primary auditory cortex mature and become more efficient with age. Electrically evoked potentials are good tools for inferring the maturity of central auditory pathways in children with congenital hearing loss since the central auditory system still develops with some, or even minimal, exposure to sound.

Children with congenital profound hearing loss give researchers a unique opportunity to study the development of a central auditory system that experienced sensory deprivation for an extended period of time. Many behavioral measures of central auditory system development cannot be done on young children due to their cognitive level, so children who receive cochlear implants at an older age are able to complete tasks that give insight into the maturation of a system that experienced auditory deprivation. Studies have shown that neuronal connections throughout the central auditory system are formed even in the absence of sound (Hartmann, Shepard, Heid, & Klinke, 1997), but that the deprivation of sound from birth leads to overall degeneration of the system and inefficient functioning of these connections (Hardie & Shepard, 1999). Examples of this include the reduced synaptic activity in these connections (Kral, Hartmann, Tillein, Heid, & Klinke, 2002) and a takeover of auditory cortical areas by visual function (Lee et al., 2001).

In a 2002 study by Sharma, Dorman, and Spahr, 104 persons with congenital hearing loss who used cochlear implants were compared to 136 age-matched peers with typical hearing. Their findings divided the participants with hearing loss into three separate groups based on when they received their first cochlear implant. These groups were defined as the early implanted group (57 children implanted at age 3.5 years or younger), middle implanted group (29 children implanted ate ages 3.5 to 6.5 years), and late childhood (18 children and three adults implanted at age 7 years or older). On average, children implanted before the age of four developed P1 latencies that were right on target for their chronological age. This means that the children who were implanted before the age of four developed a central auditory system that sent signals to the brain at the same rate, which is just as efficient as children who were born with typical hearing. The results of the study demonstrate that for children with congenital hearing loss, “there is a time period during early development of approximately 3.5 years when the auditory system is relatively nondegenerate and/or maximally plastic” (Sharma, Dorman & Spahr, 2002, p.532). Approximately two-thirds of the middle childhood group and almost every participant in the late childhood group had atypical P1 latencies that showed a delay when compared with age-matched peers. This indicates that the central auditory systems of these children are not processing sound at the same rate as the systems of age-matched peers with typical hearing. This delay, according to Purdy, Kelly, and Davies (2002) could lead to delayed or inefficient development of the mechanisms responsible for auditory memory.

In response to Hartmann, Shepard, Heid, & Klinke (1997), the researchers in this study hypothesize that the pathways only remain intact for approximately the first four years before beginning to degenerate. Research by Moore (1994) suggests that during the first four years of life, the neural dendrites experience massive growth and reorganization, with a peak in the density of these dendrites occurring between the ages of two and four. The plasticity of the neurons during this age was further investigated by Sharma, Dorman, & Kral in 2005. In this study, children who were implanted before the age of 3.5 years experienced a large and rapid decrease in P1 latencies within a week of their cochlear implant being activated and their latencies fell within the average range within 6-8 months. Children who had received their implant after the age of 3.5 experienced the same rapid decrease immediately post-implantation, but it took between 12 and 18 months for their latencies to fall within the average range. This suggests that the auditory pathway is overall less plastic after the age of 3.5 years once the initial burst of rapid change occurs. This indicates that after the initial stimulation, the central auditory system fails to develop the same efficiency as a typical system. Since the correlation between maturity of the system and the ability to be successful at auditory memory tasks is high, a child with an immature central auditory system would be expected to struggle with tasks involving auditory memory.

This data seems to contradict an earlier study by Ponton and Eggermont (2002). In this study, the age at which the critical period of development ends is much older than what Sharma and colleagues found. The researchers tested nine children and young adults between the ages of five and twenty years who wore cochlear implants. They looked at P1 latencies of these individuals and compared them to P1 latencies of age-matched peers with typical hearing. They found that cochlear implant users had similar latencies to their peers up to age 8. The researchers suggest that children who have profound congenital hearing loss and are not exposed to sound before the age of 8 (via a cochlear implant) will never develop a fully functional set of axons in the superficial layers of the auditory cortex. However, the limited number of subjects in this study could be a confounding factor.

Other researchers, however, argue that there is no critical period of development for the central auditory system. Tremblay, Kraus, Carrell, and McGee (1997) state that a fully functional set of axons in the auditory cortex is necessary for higher level auditory functions, such as discriminating between very similar novel speech stimuli. They suggest that the auditory cortex is always plastic and, regardless of age, is “capable of reorganization as a function of experiences” (p. 3762). They use measures of mismatch negativity cortical evoked potentials to determine whether or not discrimination training can have an effect on central auditory cortex efficiency. Eighteen adult participants with typical hearing exhibited improvement in their ability to discriminate and identify the unfamiliar stimulus after auditory discrimination training. The experiment took place over only nine days, showing a relatively rapid change in neural structure in order to accommodate skills gained from the auditory training. Not only was the auditory cortex able to discriminate more quickly and correctly after training, but electrophysiological responses show that a larger area of the brain was utilized for the task after training than before. Previous studies indicating that perceptual systems are plastic into adulthood were behavioral studies that could not conclusively measure the effect of the environment on the auditory system, but this study establishes the plasticity of this portion of the auditory cortex through both behavioral and electrophysiological measures.

Similar results were determined in a study by Tremblay, Kraus, McGee, Ponton, and Otis (2001). Their research is based on the notion that the N1-P2 complex of cortical evoked potentials is extremely important in determining efficiency of perceiving minute differences in speech. The subjects in this project were ten adults with typical hearing who were taught speech discrimination techniques. After ten days of exposure to difficult novel speech stimuli, behavioral measures of speech discrimination greatly improved. Electrophysiological measures also showed an improved N1-P2 response time, which correlates to a physical change in the ability to discriminate, not just a behavioral change.

Another study that supports these findings was performed by Kraus and colleagues (1995). Speech discrimination training was used to see if changes in the auditory cortex of adults would result when experience-related behaviors are elicited repeatedly over time. Speech perception “requires precise encoding in the peripheral auditory system and experience-dependent refinement of that encoding in the central auditory system” (Kraus, McGee, Carrell, King, Tremblay, & Nicol, 1995, p.25). The study also showed both behavioral (the ability to discriminate and identify minimally-different stimuli) and electrophysiological (more efficient mismatch negativity potentials) differences in twelve of the thirteen participants who received speech discrimination training. They found that training resulted in an increase in the number of neurons firing at the time of the stimulus, which resulted in more synaptic links between neurons, which led to more efficient processing of this information in the central auditory cortex. The responses did not result from simply being exposed to the stimuli, because mere exposure to novel stimuli without training did not lead to any changes.

Although research does not necessarily agree whether or not a critical period of development exists for the central auditory system, it seems to point towards a ‘sensitive’ period sometime before age 8. This sensitive period describes a more general time during which the brain is most primed to learn a new skill. Although adults with typical hearing are able to improve upon auditory discrimination skills following direct auditory training, research shows that children with hearing loss struggle to develop mature systems if exposure to sound via hearing devices (like hearing aids and cochlear implants) does not occur before age 8. The brain may be most capable of learning to efficiently encode auditory information during this wide time range. Although it may be possible for children amplified after age 8 to develop a mature central auditory system, the system may not be as efficient if the pathways to the primary auditory cortex are atypical. If the Auditory Scaffolding Hypothesis is accurate, the importance of exposure to sound at an early age cannot be underestimated. Research by Conway, Pisoni, and Kronenberger (2009) advocates for early decision-making and implantation of a cochlear implant for a child. If auditory sequencing and other auditory memory-related skills are foundational for 'bootstrapping' later developing visual and tactile sequencing abilities, then development of the central auditory system as early as possible is imperative. Further research is necessary before determining whether auditory skill development, which leads to the development of auditory sequencing skills, is highly correlated with the development of sequencing skills in other modalities, such as the visual and tactile modalities.

These findings are very important when considering the development of auditory memory in children with hearing loss. The development of a mature central auditory system is a necessary component for the eventual development of age-appropriate auditory memory capabilities. The implications of a long, 'sensitive' period of development or a system that can be 'retrained' into adulthood are positive. If a critical period exists, and it is true that the development of auditory memory is dependent upon a mature system, some inferences can be made. It can be assumed that if a critical period of development for auditory memory exists, it must occur in a time period after the development of the central auditory system, given the complexities of auditory memory. If one is unable to clearly detect, discriminate, identify, and comprehend an auditory-only stimulus, it is unlikely that the central auditory system can support an auditory memory task like sequencing. It can be further inferred that there are specific activities classroom teachers and early intervention providers can do in order to take advantage of the neuroplasticity of the central auditory system. Educators must provide as much support as possible to help overcome the implications of the Auditory Scaffolding Hypothesis.

Implications for Educators of the Deaf

If a mature central auditory system is necessary for achieving age-appropriate scores on auditory memory tasks, and if auditory memory ability is directly correlated to academic progress, then the importance of developing a mature central auditory system cannot be underestimated. Educators can acknowledge the importance of developing these auditory skills by teaching them with a systematic approach. Auditory training can be used to systematically develop auditory skills, specifically foundational auditory skills necessary for building auditory proficiency. For auditory development to be successful, appropriate amplification with hearing aids and/or cochlear implants is essential. The following explanations of auditory development techniques are all based upon the assumption that the child has appropriate audiologic management and is wearing amplification devices that fit well.

Though the task of true auditory training is not yet appropriate for the birth to three population, parents and educators can utilize many parts of the daily routine as opportunities to develop listening skills. Because parents are the primary educators of children at this age, the implications for the importance of auditory development apply primarily to them. Early intervention providers can coach parents on how to promote children’s auditory development. Beginning with detection, the most basic skill of auditory development, parents can help babies and toddlers learn to detect sound by acknowledging a sound when it occurs. This requires the parent to get the child’s attention and direct his attention to the sound. Furthermore, the parent can take this opportunity to use appropriate language to label and/or describe the sound. For example, when the dog barks, the parent or parent educator can get the child’s attention, pause, point to his or her ear, and say “I heard that! Did you hear that? That’s the dog.” Drawing the child’s attention to sound teaches him that sound is important and attention should be delegated to listening. Though speech is arguably the most important sound to which children should listen, attention should be drawn towards environmental sounds and music as well. All auditory information gives children the ability to learn from the world around them. Parents can monitor their children’s auditory development using one of many available checklists that list auditory development milestones for children with typical hearing. These checklists can be easily found by searching the Internet. They are extremely useful in that they provide a finite list of individual auditory skills as well as the order in which these skills are typically developed.

The next two phases of auditory skill development are discrimination and identification. They can be developed by using specific toys and objects to represent sounds. A child can demonstrate discrimination when he understands when two sounds are different or the same. Next, the child will learn to associate specific sounds with meaning, which is the foundation for the identification skill. This leads to the understanding that sounds, words, and language are useful symbols. This can also be accomplished through joint attention tasks, where the adult and child look at and attend to the same object while the adult talks about it. Research shows that auditory information is extremely useful in developing joint attention in children (Rossano, Carpenter & Tomasello, 2012). Signs that a young child is able to identify sounds include looking at the dog when it barks and looking expectantly at the door when the doorbell rings.

Comprehension, the final level of auditory skill development, requires more cognitive development than other levels, yet it is a skill that toddlers are typically able to demonstrate. One way to build comprehension skills is to include multi-step directions in the child’s daily routine. The directions can be simple but require auditory comprehension and sequencing skills for the child to correctly perform them. An example would be telling the child to take off his coat, hang up his coat, and then take off his shoes. Creating a game by changing up the order of simple routines can keep the child interested while creating situations in which he or she is forced to listen closely in order to perform the directions correctly. In addition to building auditory comprehension skills, the act of following directions specifically builds auditory sequencing skills.

During the preschool years, auditory development tasks such as the ones mentioned above can still be done at home by the caregivers. These techniques are also useful in the classroom or therapy setting in conjunction with true, direct auditory training from a teacher of the deaf, speech-language pathologist or auditory-verbal therapist. Auditory training tasks facilitate the development of foundational listening skills so a child can eventually learn to use more functional listening skills in real-world situations. Though auditory skills are taught during explicit auditory training sessions, they can also be incorporated into any lesson. There are multiple sets of auditory training curricula and materials available for teachers to use in the classroom (Table 1). These typically come with evaluation sheets that provide a listening hierarchy. They can be used to determine present levels of listening ability, set goals, track student progress and provide reports to parents and professionals. According to Nancy Tye-Murray, many of these materials are organized according to four design principles (1998). The first is auditory skill, which is the skill being targeted (detection, discrimination, identification, or comprehension). The second category is stimuli. There are two basic kinds of stimuli, analytic and synthetic. Analytic stimuli require focus on the different parts of an auditory message while synthetic stimuli focus on gaining overall meaning from the stimuli. The third aspect of organization is the activity type, which describes whether the activity is formal or informal (natural). The fourth principle of design is difficulty level, which assesses the difficulty of the task based on many factors, including the complexity and similarity of stimuli and the presence or absence of background noise.

In addition to explicit auditory training, teachers of the deaf can, like parents, incorporate listening tasks throughout the day in natural ways. These tasks expand upon the ones early intervention providers coach parents to use. In order to strengthen auditory memory, teachers can continually give multi-step directions in the auditory-only modality, which will give students practice listening for comprehension and delegating attention to information.

Another natural way to expand upon auditory memory for preschoolers is by capitalizing on something that is a core part of any preschool curricula— music. Singing songs and repeating nursery rhymes is a functional way to engage the auditory memory functions of a young child's brain. When singing, children are not simply engaging their auditory memory to recall the words heard— they must also use their auditory memory to incorporate all of the suprasegmentals involved in music such as pitch, intensity, and intonation. Songs and even nursery rhymes contain these suprasegmental elements that children with typical hearing typically pick up naturally. Children with hearing loss must often be explicitly taught that these changes in suprasegmentals carry meaning, so drawing attention to and remembering these key elements is important. This auditory memory task is complex because it requires recalling the words themselves and the suprasegmentals attached to them, but because it is a highly motivating task, young children are less likely to lose attention.

Direct auditory training can be done with school-aged children as well, but once the foundational skills have been developed, functional auditory skills should also be developed. As children age, their language levels improve and the curriculum becomes more diverse, so it can be easier to incorporate auditory memory and auditory sequencing tasks throughout the day. For example, verbally listing the procedures for a science experiment once and challenging the students to remember in what order the procedures occur can activate auditory memory and sequencing skills. Additional functional skills include memorizing important telephone numbers, recalling details from an orally presented story, and developing music appreciation skills. Music can again play a role in developing auditory memory because a typical school-aged skill is learning to play an instrument or developing singing skills in choir, both of which use auditory memory skills. For children who still receive speech therapy, the time dedicated to speech can also be used to develop auditory memory skills, especially for children who are working on speech at the conversational level. Speech corrections can be made as children play games which require recall of information presented only auditorily. An example of one of these games is the "I'm going on vacation and taking…" where each participant is required to remember what has already been said, in order. A mature central auditory system with a developed auditory memory is important for these and other situations where little visual information is present and orally-presented information must be processed and recalled efficiently.

Conclusion

In the last half century, the topic of neuroplasticity has transformed from taboo conjecture to a fascinating field of research that is almost universally accepted throughout academia. The brain is capable of changing as a result of experience, or lack of experience. Critical periods of development will continue to be explored as technology allows us to see the human brain function in real-time. No conclusive evidence can be drawn yet as to the existence of a critical period of development for auditory memory. But as researchers continue to study the implications of hearing loss on the development of auditory memory, educators are called to incorporate tasks that require the development of these skills into as many aspects of their school day as possible. If the development of auditory memory, specifically auditory sequencing skills, is important for the development of other sequencing skills, it is incredibly important to specifically target these skills. Auditory training in general is incredibly important for developing a mature central auditory system, which is the foundation for developing auditory memory. Regardless of the age of the students, teachers of the deaf are responsible for incorporating formal and informal activities that are the building blocks of a mature central auditory system that is capable of comprehending, manipulating, and recalling information presented in the auditory-only modality.

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Table 1

Auditory Training Curricula/Materials

Resource	Distributor	Target Age	Description
Contrasts for Auditory and Speech Training (CAST)	Linguisystems	Ages 3-12	An analytic training program for practice discriminating suprasegemental differences, dissimilar words, and similar words.
CHATS: The Miami Cochlear Implant, Auditory and Tactile Skills Curriculum	Intelligent Hearing Systems	Children who use amplification (any age).	A curriculum that uses a team approach to incorporate speech perception and speech production goals into classroom instruction.
Developmental Approach to Successful Learning II (DASL)	Cochlear Corporation	Children and adults	A curriculum that focuses on the development of sound awareness, phonetic listening, and auditory comprehension skills.
Speech Perception Instructional Curriculum and Evaluation (SPICE)	Central Institute for the Deaf	Children ages 3-12	Systematic curriculum that includes training in detection of sound, suprasegmental perception, vowel and consonant perception, and connected speech. As children progress through the curriculum, activities become less formal and more natural.
SPICE for Life	Central Institute for the Deaf	Children ages 5 and up	Auditory learning curriculum that focuses on functional auditory skills. Activities include practice with auditory memory, listening in noisy settings, listening to music, localizing sounds, listening in conversation, listening on the telephone.
SKI-HI	The SKI-HI Institute	Children birth to age 5	Home intervention program organized around all areas of development, including audition. Lessons are systematic and can be done by early interventionists. Skills targeted include localization, discrimination, and auditory comprehension.