HEARING LOSS IN BABIES IS A NEUROLOGICAL EMERGENCY

Dimity Dornan A.M.
Ba.Sp.Th., F.S.P.A.A.,
LSLS Cert. AVT, Cp. SP.
Managing Director and Founder
Hear and Say Centre, Australia

EXECUTIVE SUMMARY

Background

Early auditory brain access is critical for the development of listening, spoken language and literacy skills. Recent neuroscientific research shows that the auditory brain commences its development in-utero, and is “pre-wired” to accept and process sound. If stimulated through meaningful sound, the auditory brain etches its neural pathways permanently. “Pre-wiring” that is not used (stimulated) is diminished (removed, truncated, reassigned for other functions or atrophied) over time until it is no longer available for stimulation. The brain’s optimal developmental period for audition is the time span during which this neural connecting and pruning of auditory nerves is at its maximum.

A baby born with significant hearing loss has already missed out on around 20 weeks of auditory stimulation and significant activation of auditory neural pathways. If the baby is to develop optimal listening and spoken language skills, then he or she needs to be diagnosed early, preferably before 6 months of age, and have early auditory brain access through prompt fitting of modern hearing technology, such as cochlear implants and digital hearing aids. If parents desire a listening and spoken language outcome for their child with hearing loss, an educational approach that emphasizes the development of auditory brain pathways through listening and spoken language is necessary (Cole & Flexer, 2007). It is important to note that infants and toddlers whose hearing loss is diagnosed later still have the opportunity to develop listening and spoken language. Although it will likely require a remedial approach to intervention, rather than the more efficient developmental model supported by the paper introduced here, it is not

impossible. Parents who have a child with hearing loss who was diagnosed late should not be discouraged from considering a spoken language communication option.

Evidence from Neurodevelopmental Research

- All babies are born with their brains pre-wired to learn listening and spoken language from birth (Flexer, 1999).
- The brain is the organ of hearing – the ears are only the vehicle through which sound is transmitted to the brain (Flexer, 1999).
- Learning to listen sets the stage for language development and if the outcome that is desired by the family of a child with hearing loss is listening and spoken language, the child's auditory brain centers must be accessed and developed (Cole & Flexer, 2007).

Development of Listening and Spoken Language in Babies with Typical Hearing

- Babies with typical hearing begin learning to listen in the last 20 weeks of gestation. Before they are born, babies can already discriminate:
    - ❖ Consonant types.
    - ❖ "Content" (e.g. nouns or verbs) as compared to "function" words (e.g. "and," "of," "with," or articles) (Vouloumanos & Werker, 2007).
- By birth, babies already have learned to prefer:
    - ❖ Their native language.
    - ❖ Speech over non-speech.
    - ❖ Their mother's voice.
    - ❖ Stories and songs heard prenatally.
    - ❖ Content words (e.g. nouns or verbs) (Vouloumanos & Werker, 2007).
- By 8 months of age, if babies hear a "content" word, they then expect a "function" word to follow (Vouloumanos & Werker, 2007).
- By 12 months of age, babies have learned to:
    - ❖ Tune into only their own language if they are monolingual (Rivera-Gaxiola, Silva-Pereyra, & Kuhl, 2005).
    - ❖ Tune into both languages if they are bilingual (Bosch & Sebastian-Galles, 2003).

- By 14 months of age, babies are capable of learning nonsense or real words in a laboratory situation (Werker, Cohen, Lloyd, Cassasola, & Stager, 1998).
- Difficulties in accessing auditory information (such as with hearing loss) can predict later language learning delays (Tsao, Liu, & Kuhl, 2004).
- Babies can tell the differences in lip shapes of different languages between 4 and 6 months of age, but lose this ability at 8 months because they can hear these differences and do not need to see them (Weikum et al., 2007).
- Between 14 and 20 months of age, babies learn to recognize mispronunciation of words. Babies in a bilingual environment take a bit longer to reach this goal, but eventually achieve it (Fennell, Byers-Heinlen, & Werker, 2007).

Language Delay

- The ability of babies to process speech predicts later language ability (Tsao, Liu, & Kuhl, 2004).
- Atypical listening and hearing ability may predict later language delays (Tsao, Liu, & Kuhl, 2004; Molfese, 2000).

Optimal Developmental Periods of the Auditory Brain

- Auditory brain development in babies is very rapid.
- Optimal developmental periods are limited windows of time, which usually close early in a child’s life and during which there is massive interconnecting of neural pathways and pruning of unwanted or unused neural pathways.
- There is a critical period of birth to 3.5 years during which the cochlear implant can be placed in a highly plastic system (Sharma, Dorman, & Spahr, 2002).
- After 7 years of age, a cochlear implant is placed in a system of highly reduced plasticity (Dorman, 2007).
- Evidence regarding neural development of the auditory pathways may be obtained from Auditory Evoked Responses, which have been found to serve as clinical indicators of central auditory maturation in children.

Development of Listening in Children with Hearing Loss

- Babies born with hearing loss are not starting from the same point as a child with typical hearing – as they have missed out on 20 weeks of development of their auditory brain pathways, as well as the neural development missed before they are diagnosed. Babies born with hearing loss are starting from a point of NEUROLOGICAL EMERGENCY because they have a limited window of time in which to catch up. Therefore, the focus must be on early detection, amplification and enhanced listening experiences to urgently develop auditory neural connections so that optimal developmental periods for brain growth can be maximized.

Literacy in Children with Hearing Loss

- Neuroimaging and research on dyslexia validates a critical role for phonological processing in literacy development and reading disorders.
- Brain development for phonological processing is the single best predictor of reading success and is likely to have very early closing windows for critical periods (Mody, 2003). Therefore, to achieve optimal literacy, a child with hearing loss needs to develop phonological processing early in life through auditory access.
- The early development of auditory brain pathways forms the basis of speech perception, spoken language and literacy skills.

Executive Summary

- Early development of auditory brain pathways is a necessary precursor for developing speech, spoken language and literacy skills.
- Because babies born with hearing loss have missed out on 20 weeks of auditory brain pathway development in-utero, in addition to the time before the hearing loss was diagnosed and a hearing device fitted, they need appropriate treatment urgently so brain development can catch up for time lost within the optimal developmental period.
- A baby with hearing loss must be diagnosed early, immediately fitted with a hearing device and begin therapy and education quickly (preferably before 6 months of age) so that his or her auditory brain pathways can be developed within the optimal developmental periods for listening (from birth to 3.5 months of age).
- The exact length of optimal developmental periods for various listening skills is unknown, but phonological processing, the precursor for literacy, is very likely to have early closing windows of time.
- The ability to hear and use auditory information early in life predicts later spoken language delay.
- An educational approach that emphasizes auditory brain access and development through the use of modern hearing technology (such as digital hearing aids or cochlear implants) is essential to maximize the optimal development of the brain and to establish listening, speaking and literacy skills.
- **A child with hearing loss is starting form a point of NEUROLOGICAL EMERGENCY, because learning to listen is time-bound.**

Early Auditory Brain Access is Critical for the Development of Listening and Spoken Language and Literacy Skills

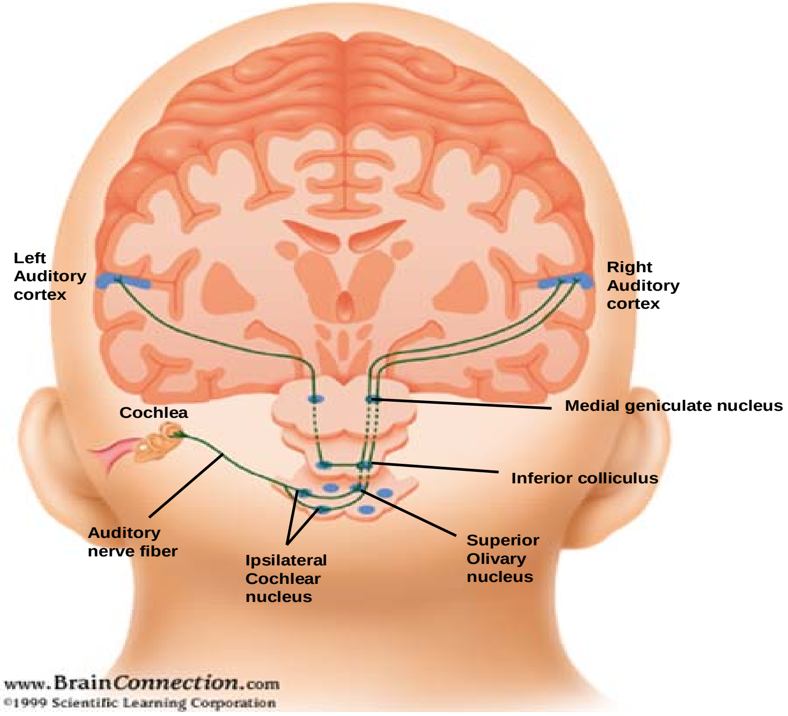
Recent neuroscientific research related to the neurodevelopmental foundations of spoken language, speech and literacy is revealing the importance of learning to listen early in the life of child with hearing loss. The auditory brain commences its development in-utero and is "pre-wired" to accept and process sound. If stimulated, the auditory brain etches the neural pathways permanently. "Pre-wiring" that is not used (stimulated) is diminished (removed, truncated, used for other functions or atrophied) over time until it is no longer available for stimulation. The optimal developmental phase is the time span during which this neural connecting and pruning is at its maximum for the auditory-area of the brain. This is a critical and sensitive period for listening.

Auditory Neural Pathways

The auditory nerve receives stimuli from the cochlea, which is situated in the inner ear. The stimuli are transferred to the spiral ganglion, and then travel via the dorsal and ventral cochlea nuclei to the superior olivary nucleus. This is the area where information regarding frequency and intensity of auditory stimuli is relayed, and input is given to the facial nerve (for the stapedial reflex) as well as a feedback loop to outer hair cells in order to fine tune sound. Stimuli then travel via the lateral meniscus to the inferior colliculus, a large area of unknown function. The auditory signal then reaches the thalamus, a critical centre for audition consisting of 12 distinct nuclei on each half of an egg shaped center in the heart of the brain. Virtually all neural impulses go through the thalamus and all auditory impulses are relayed through the medial geniculate nuclei, a pair of thalamic nodes. The thalamus is a dynamic, rich, interplaying system that connects, integrates and processes sound.

From the thalamus, impulses travel to the cortex of the brain. The cortex resembles a golf ball in-utero, but as it grows it is contained by the cranium and develops sulci and gyri (convolutions) in its surface in the last three months of gestation. Auditory stimulation travels to the auditory cortex, situated in the temporal lobe. Auditory sensations reach perception only if received and processed by a cortical area.

The auditory areas of the brain are "pre-wired" for listening at birth, but the brain connections that allow a child to understand speech are formed and shaped by auditory experience or disuse.



Because a baby with significant hearing loss has already missed out on around 20 weeks of auditory stimulation and significant activation of auditory neural pathways, early diagnosis and intervention through newborn hearing screening and appropriate follow-up, preferably before 6 months of age, is essential for optimal development of listening and spoken language (Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998).

During the early months of life, the brain is globally tuned to learn spoken language through listening. The listening ability of a baby with typical hearing undergoes a series of rapid changes in response to listening stimulation, and it is this ability of the baby's brain to learn through listening that sets the scene for acquiring spoken language. Atypical listening and learning may presage later language delays.

It is important to note that infants and toddlers whose hearing loss is diagnosed later still have the opportunity to develop listening and spoken language. Although it will likely require a remedial approach to intervention, rather than the more efficient developmental model supported by the paper introduced here, it is not impossible. Parents who have a child with hearing loss who was diagnosed late should not be discouraged from considering a spoken language communication option.

Hearing loss in babies is now considered a situation of “neurological emergency,” when a delay in auditory stimulation or a reduced auditory signal during the optimal developmental stage may cause permanent, irretrievable reassignment of auditory brain cells.

The rest of this document reports on the research evidence emanating from these new directions of study, which are indications that much more auditory neural development occurs in the early part of the child’s life than has been understood up to this point. Recent evidence for the impact of early listening focuses on the following main areas:

- Auditory maturation processes of the central nervous system.
- Capacity for plastic reorganization of the central auditory system.
- Importance of timing of intervention for children with hearing loss.
- Neurobiology correlates of literacy.
- Information from bilingual studies.
- Factors influencing auditory perception.

Tools for investigating structure-function relationships in the brain are:

- EEG : electroencephalography
- MEG: magnetoencephalography
- fMRI: functional magnetic resonance imaging
- PET: positive emission tomography
- NIRS: near infra-red spectroscopy

- DTI: diffusion tensor imaging

Auditory Maturation Processes of the Central Nervous System

The first auditory neurons appear at three weeks of an embryo’s development, and the auditory mechanism in a fetus is fully developed by 20 weeks of gestation (Eliot, 1999). The fetus may begin hearing early in the sixth month of gestation, and can discriminate sounds by the third trimester (Eliot, 1999; Graneir-Deferre, Lecanuet, Cohen, & Busnel, 1985; Rubel, 1985).

The early mechanisms of the brain that underpin changes during early infancy are still unknown (Vouloumanos & Werker, 2004). However, research has shown that specific neural substrates in the left hemisphere of adults as well as babies are used for speech perception (Binder & Price, 2001; Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002; Peña et al., 2003; Scott, Blank, Rosen, & Wise, 2000; Vouloumanos, Kiehl, Werker, & Liddle, 2001).

Babies are born with their brains prewired to learn spoken language through listening (Flexer, 1999). The neonate’s brain already shows that they are born with left brain superiority for processing the specific sounds of speech (Peña et al., 2003).

The detection of speech in an auditory stream is a prerequisite first step to processing spoken language. A simple speech detection task, in which no identification or linguistic analysis is required, elicits significantly greater activation than both complex and simple non-speech stimuli in classic receptive language, namely bilaterally in the middle temporal gyri – in a locus lateralised to the left posterior supratemporal gyrus and in a small area of the right inferior frontal gyrus (Vouloumanos et al., 2001).

Researchers have found that the instigation of brain function in a newborn requires sensory input (Kral, Hartmann, Tillein, Heid, & Klinke, 2002). Studies of the auditory development of the brain reveal that sensory stimulation of the auditory centers of the brain is critically important as it influences the organization of the auditory brain pathways (Boothroyd, 1997; Chermak & Musiek, 1997; Musiek & Berge, 1998). Auditory cells are highly tuned to receive and process auditory sensations, and the brain keeps rewiring itself after birth according to its experience (Gopnik, Meltzoff, & Kuhl, 1999).

Humans are born with a performance or bias for listening to speech, rather than non-speech sounds (Vouloumanos & Werker, 2007). This preference for the typical communication method of one’s own species is also apparent in the animal kingdom (Gould & Marler, 1987; Johnson, Bolhuis, & Horn, 1992; Ryan, Phelps, & Rand, 2001). In addition, human infants use different neural resources for speech and non-speech processing (Dehaene-Lambertz et al., 2002; Peña et al., 2003).

The types of sound that attract a newborn to listen are complex auditory stimuli, rich in spectral characteristics or patterned in temporal properties, which have been shown to elicit greater changes in electromyography (Hutt, Hutt, Lenard, van Bernuth, & Muntjewerff, 1968), electroencephalography (EEG) (Lenard, von Bernuth, & Hutt, 1969) and heart rate (Clarkson & Berg, 1983; Groome et al., 2000).

At birth, the perceptual system of a baby is already tuned to some of the dimensions of human speech that are exploited by the phonological and phonetic systems of spoken language (Bertoncini, Bijeljac-Babic, Blumstein, & Mehler, 1987; Christophe, Dupoux, Bertoncini, & Mehler, 1994; Jusczyk, Bertoncini, Bijeljac-Babic, Kennedy, & Mehler, 1990; Mehler et al., 1988; Nazzi, Bertoncini, & Mehler, 1998; Ramus, Hauser, Miller, Morris, & Mehler, 2000; Sansavini, Bertoncini, & Giovanelli, 1997; Shi, Werker, & Morgan, 1999). At 2 months of age, infants listen longer to speech sounds as compared to structurally similar non-speech sounds (Vouloumanos & Werker, 2004).

At birth, infants are already sensitive to word boundaries (Christophe et al., 1994), distinguish between rhythmically dissimilar languages (Mehler et al., 1988; Ramus et al., 2000), distinguish between stress patterns of multisyllabic words (Sansavini et al., 1997) and discriminate categories of lexical versus grammatical words (Shi et al., 1999).

During the first year of the baby's life, these initial sensitivities become increasingly tuned to the properties of the baby's native language (Werker & Tees, 1984). This refinement of listening skills is shown clearly in the decline of the baby's discrimination of aspects of the speech signal that are not pivotal for processing his or her native language (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Werker & Tees, 1984), and also in the gain of sensitivities that are pertinent to native language processing (Jusczyk, Cutler, & Redanz, 1993; Jusczyk, Hohne, & Bauman, 1999; Myers et al., 1996).

By birth, significant auditory brain development has occurred and infants already show a preference for their native language or languages (Werker, Weikum, & Yoshida, 2006). During the first year of life, there is a window of opportunity for perceptual re-organization in the auditory area of the baby's brain (Werker & Tees, 1984) with a baby's ability to discriminate between sounds of their own language and another language, which reduces later in the first year for monolingual babies. Many other authors have reported on the changes in the ability of babies to discriminate speech sounds over time (Anderson, Morgan, & White, 2003; Best, McRoberts, LaFleur, & Silver-Isenstadt, 1995; Bosch & Sebastián-Gallés, 2003; Cheour, Ceponiene, Lehtokoski, Luuk, & Allik, 1998; Polka & Werker, 1994; Kuhl et al., 2006; Riviera-Gaxiola, Silva-Pereyra, & Kuhl, 2005). Within 8-12 months of age, babies' will have an enhanced ability to recognize the distinctions used in their native language or language environment. **This ability to rewire the brain and learn through listening forms the basis of later spoken language learning**. Any disruption to this process of listening and learning may cause a language delay later (Molfese, 2000; Tsao, Lieu, & Kuhl, 2004).

During the first year of life, the auditory processing of the speech signal undergoes radical reshaping and becomes more specific and more sophisticated (Vouloumanos & Werker, 2004). By the end of the first year of life, studies have found that babies are able to integrate multiple cues and perform more complex analyses on linguistic input (Morgan and Saffran, 1995).

By 6 months of age, babies are able to associate words that are heard very frequently with familiar objects (Tincoff & Jusczyk, 1999) and can use recognition of highly familiar words to discriminate the boundaries of known words and unfamiliar words (Bortfeld, Morgan, Golinkoff, & Rathbun, 2005). Within 9-12 months of age, babies understand the meaning of many words and are able to perform associative word learning tasks. They are able to distinguish when word meanings have been purposely switched by 14 months of age (Werker, Cohen, Lloyd, Stager, & Cassasola, 1998; Stager & Werker, 1997). Babies succeed in learning phonetically similar words at 17 months of age (Mills et al., 2004; Werker, Fennell, Corcoran, & Stager, 2002). However, studies comparing monolingual and bilingual babies have found that although monolingual babies are able to learn to differentiate similar sounding words by 17 months of age, bilingual babies are not able to achieve this until 20 months of age (Fennell, Byers-Heinlein, & Werker, 2007).

The significance of being able to listen and develop the auditory brain early in life is particularly shown by findings that infant speech perception and the ability to learn early word-object associations can predict later language development. Furthermore, difficulties in using the rich information acquired auditorily can predict later language delay (Bernhardt, Kemp, & Werker, 2007; Molfese, 2000; Tsao et al., 2004).

Research results on Autism Spectrum Disorder (ASD) show that children with ASD fail to show a preference for speech when compared to non-speech or complex, superimposed voices (Klin, 1991; Kuhl, Coffey-Corina, Padden, & Dawson, 2005). The researchers conclude that not only does a preference for speech provide an advantage for learning language, it is also important for learning language through listening, which may be essential for developing typical language abilities. This initial bias may be enhanced by listening experience to refine the perceptual preferences of developing organisms (Werker & Tees, 1984). Vouloumanos & Werker (2007) maintain that a speech bias, combined with established experience-based preferences for the mother’s voice and native language(s), may provide human neonates with powerful tools for selecting and learning about communication signals.

In summary, the changing ability to rewire the brain through listening experiences forms the basis for later spoken language learning.

Capacity for Plastic Reorganization of the Central Auditory System

Evidence regarding neural plasticity of the auditory pathway may be obtained from cortical, auditory-evoked responses. These can be described as activity in response to sound stimulation, which can be recorded non-invasively from all levels of the auditory pathway using an EEG.

A particular cortical, auditory-evoked response, the P1 response, is generated at the levels of the primary and secondary auditory cortex (Ponton & Eggermont, 2001). The latency of the P1 component of the cortical evoked response to sound varies as a function of age and can be used as a biomarker for maturation of central auditory pathways (Dorman, Sharma, Gilley, Martin, & Roland, 2007).

The development of the P1 response in children with typical hearing follows an identifiable path, and is an index of the maturation of the central auditory pathways in these children (Eggermont & Ponton, 2003; Pang & Taylor, 2000; Ponton et al., 2000; Sharma & Dorman, 2006) and in children with hearing loss who use cochlear implants (Eggermont & Ponton, 2003; Ponton, Don, Waring, Eggermont, & Kwong, 1996; Singh, Liasis, Rajput, Towell, & Luxon, 2004). Sharma, Dorman, & Spahr (2002a) found that there is a sensitive period of three to four years after birth in which a child with hearing loss can receive a cochlear implant in a highly plastic central auditory system, and that after 7 years of age the central auditory system is already re-organized and is not as able to adapt to and process auditory information easily. This is reflected in cochlear implant outcome findings in which children receiving implants under ages 3-4 years show significantly better speech perception and language skills compared to children receiving implants later, after ages 6-7 years (Fryauf-Bertschy, Tyler, Kelsay, & Gantz, 1997; Kirk et al., 2002; Manrique, Cervera-Paz, Huarte, & Molina, 2004; Waltzman & Cohen, 1998).

Studies have also found that the auditory pathway changes very rapidly following the onset of auditory stimulation for children receiving implants early, around 2 years of age (Sharma, Dorman, & Spahr, 2002b), and that the P1 response can be within typical limits within 8 months of implantation. Sharma et al. (2004) have shown that receiving a cochlear implant at 13 or 14 months of age can result in a rapid increase in canonical babbling within the first three months of use. For children receiving implants after 8 years of age, there was greatly reduced plasticity and the P1 response plateaued early and did not reach the same limits as children with typical hearing (Sharma, Dorman, & Kral, 2005). Currently, research is emerging on the neural correlates of bilateral cochlear implants. Sharma et al. (2005) have studied late sequential bilateral implants, showing that the auditory neural pathways for this stimulation are not occurring in a highly plastic central auditory system.

The latency and morphology of the P1 response can serve as markers for the developmental status of the central auditory pathways in children with hearing loss who use either hearing aids or cochlear implants (Sharma et al., 2002b; 2005). Although artifacts in cochlear implant EEG recordings require some future adaptations of this method of assessing central auditory system maturity (Gilley et al., 2006), central, auditory-evoked potentials have been found to be powerful, objective bio-markers of central auditory system plasticity and maturation, and hence may serve as clinical indicators of central auditory development in children who receive early intervention through hearing aids and/or cochlear implants.

Cochlear implants provide a unique research opportunity for investigating the plastic re-organization capacity of the auditory brain. Fallon, Irvine and Shepherd (2009) studied the electrical stimulation of spiral ganglion neurons in neonatally deafened cats via a cochlear implant. This study provided a means of investigating the effects of the removal and subsequent restoration of afferent input on the functional organization of the auditory cortex. The absence of afferent activity had little effect on the basic response properties of the auditory-cortex neurons, but resulted in the complete loss of normal cochleotopic organization of the auditory cortex. This effect was almost completely reversed over seven months by chronic activation of the auditory pathway through the cochlear implant.

In summary, the maturation of the auditory neural pathways can now be monitored by objective physiological tests, and cochlear implant results allow researchers a unique view of this process.

Importance of Early Intervention for Children with Hearing Loss

The sound-deprived auditory cortex cannot mature typically in children who are congenitally deaf (Kral, Hartmann, Tillein, Heid, & Klinke, 2000). Deprivation of auditory sensory input results in serious central nervous system deficits (Hartmann, Shepherd, Heid, & Klinke, 1997; Klinke, Hartmann, Heid, Tillein, & Kral, 2001; Katz, 1999; Kral et al., 2000).

However, this maturation can be achieved through auditory experience within the optimal, auditory developmental phase. In the case of cochlear implants, it is well documented that children who are deaf and who use an implant can achieve typical levels of oral speech and language skills (Pisoni, Cleary, Geers, & Tobey, 1999; Svirsky, Teoh, & Neuburger, 2004). Timing of implantation is critical, and the earlier a child who qualifies for a cochlear implant receives one, the better the outcomes (Colletti et al., 2005; Connor, Craig, Raudenbush, Heavner, & Zwolan, 2006). This is also true of all children who are deaf and receive auditory stimulation, whether through cochlear implants or hearing aids.

There is a sensitive period during early development during which stimulation to the auditory brain must be delivered if high levels of spoken language skills are to be acquired (Dorman et al., 2007). Researchers have compared the maturation of the human auditory system, as assessed by auditory-evoked potential recordings, to the maturation of axon neurofilaments and critical stages in speech perception. There is a strong suggestion that the maturation of the axons in Layer II and upper Layer III of the auditory cortex occurs in conjunction with the emergence of the N_1 component of the auditory cortical response. The absence of N_1 in subjects with cochlear implants who have been deaf for three to six years suggests a critical period in the maturation of the upper cortical layers, and potentially poor performance in perception of masked and degraded speech in the future (Eggermont & Ponton, 2003).

Information on synaptic activity in different cortical layers suggests that there are substantial deficits in the primary auditory cortex of congenitally deaf cats (Kral et al., 2000). Post cochlear implant studies in animals and humans can provide some insight into neural reorganization following deafness. A cochlear implant has been found to boost the low metabolic activity of the auditory cortex (Naito, Hirano, Honjo, Okazawa, & Ishizu, 1997). If take-over of the auditory neural system (for example, by vision) has occurred through cross-modal plasticity in children who are prelingually deaf, and metabolism consequently is restored, the auditory cortex can no longer respond to signals from a cochlear implant received afterwards. Neural substrates in the auditory cortex might be routed permanently to other cognitive processes (e.g., vision as in lip reading or sign reading) in patients who are prelingually deaf (Jae Sung Lee et al., 2001).

Following a cochlear implant, visual regions, as well as the brain regions located within and outside the classical language-associated areas, are recruited in an experience-dependent manner during auditory language processing (Giraud et al., 2000; Giraud, Price, Graham, Truy, & Frackowiak, 2001a & b).

In summary, a child needs to have early auditory brain access to maximise the optimal developmental periods.

Neurobiology Correlates of Literacy

Reading is a complex skill, and there are many factors that may contribute to a child’s reading skills. However, studies have consistently reported that reading deficiencies are dependent on a child’s ability to process the phonological components of spoken language. This ability plays a critical role in literacy, and the degree of phonological awareness is the single best predictor of reading success (Report of the National Reading Panel, 2000). Phonological processing has been defined as the segmental analysis of words for typical speaking and listening skills, as well as the metaphonological skills required for explicitly analyzing the sound structure of speech into the phonemic components represented by the alphabet (Mody, 2003). It is one skill that is likely to have a very early closing window in the optimal developmental time period (Mody, 2003).

Language acquisition and reading development depend largely on early exposure to and full appreciation of the phonological characteristics or sound patterns of a child’s own language. Hearing loss in a child may cause delayed reading ability, particularly if the child does not speak well (Robertson & Flexer, 1993). Historically, the average reading skills of a child with hearing loss has been around the 4th grade level for 10-year-olds, and a reading delay of at least 5 years upon leaving school (Geers & Moog, 1989).

Evidence from research on dyslexia has provided neurodevelopmental evidence for the basis of literacy and for the benefits of accessing the auditory brain by developing listening skills early in a child’s life. It has been found that developmental dyslexia results from a breakdown in word recognition (accurate and fluent recognition of real words), decoding (rate of oral reading of non-words) and spelling (translation of phonemic information into an integrated code) (Lyon, Shaywitz, & Shaywitz, 2003). The characteristic deficits in dyslexia are poor:

- Speech perception under demanding conditions (e.g. speech in noise).
- Phonological awareness (e.g. sound/syllable segmentation, blinding, rhyme judgement).
- Verbal memory (e.g. non-word repetition).
- Lexical retrieval (e.g. rapid naming).

Research using functional neuroimaging for dyslexia shows that the brains of individuals with dyslexia are not wired the same way as individuals without dyslexia. Dysfluent readers have been shown to possess different central auditory abilities compared to typical readers, and different patterns of disruption in the posterior circuits for reading (Lyon, Shaywitz, & Shaywitz, 2003).

The neural components and networks for language and reading are a complex system**.** Such complex functions of the brain (e.g. syntax or semantics) do not relate to one particular brain area. Instead, a set of brain areas that form an interconnected, parallel and distributed hierarchy are initialized for any language task or function, and each area within the hierarchy makes a specific contribution to the performance of the task (Petersen & Fiez, 1993).

Phonology, Orthography, Semantics, Syntax and Pragmatics:
Inferior frontal areas (speech production/articulation), temporoparietal areas (phonologic/semantic analysis), and occipitotemporal areas (word form recognition).

Neural Signature of Dyslexia:
Reduced activation of posterior reading circuitry in the temporoparietal and occipitotemporal areas of poor readers.

It has been found that intensive phonological training has helped children with hearing loss and reading deficiencies approximate brain activation patterns similar to those of a control group of children with typical hearing, with accompanied improved reading ability (Aylward et al., 2003; Blachman, Schatschneider, Fletcher, & Clonan, 2003; Simos et al., 2002).

In summary, neuroimaging and dyslexia research appears to validate a critical role for the phonological processing in literacy development and reading disorders. This phonological processing is learned through early listening, further validating the critical nature of early auditory brain access.

Information from Bilingual Studies

For a child to develop listening skills and understand various languages, the different properties of multiple languages, speech sounds, rhythm, allowable sound sequences of a particular language, and syllable structure need to be differentiated and associated with meaning in order to extract various meaningful units of speech. Studies, such as cross-lingual and monolingual vs. bilingual research, are providing new knowledge and show how early a very young child is able to start this process. For example, bilingual studies have shown that at birth, babies already have a preference for speech over non-speech sounds (Vouloumanos & Werker, 2007), their own native language (Moon, Cooper, & Fifer, 1993) and their mother’s voice (DeCasper & Fifer, 1993), and can discriminate consonant types (Saffran, Werker, & Werner, 2006) and categorize “content” versus “function” words (Shi et al., 1999). These perceptual biases at birth prepare the infant for learning a particular language. The brain at birth is globally tuned to learn language through listening, and auditory experience changes the speech sound categories that children develop to make meaning out of what they hear.

Sebastián-Gallés, Echeverria, & Bosch (2005) have found that even in the case of bilingual speakers who are exposed to both languages from birth, a dominant language prevails. Simultaneous bilingual speakers also do not attain the same level of proficiency as early bilinguals in their first language.

It has been found that an infant’s early phonetic perception plays an important role in language development (Tsao et al., 2004). There are significant correlations between speech perception at 6 months of age and later language categories or word understanding, word production and phrase understanding.

Cross-lingual language studies have proved that language development in infants follows a set of universal stages both in speech production and speech perception, and this can be seen across cultures (Ferguson, Menn, & Stoel-Gammon, 1992). Change in a baby’s ability to discriminate phonetic differences in language input adjusts according to linguistic experience (Werker & Tees, 1984).

In summary, studies on bilingual children provide many insights into the way children learn language.

Factors Influencing Auditory Perception

The author investigated physiological changes in the auditory cortex of rats in various auditory stimulation trials. She found that the auditory cortex can change in response to stimulation as well as specific factors, including 1) relevance of the stimuli and 2) attention areas of the brain are important contributors to cortical plasticity. In relating the results to auditory training in humans, the authors suggest repetitive and meaningful stimuli be used. These findings demonstrate the importance of repetition and meaning for memory and learning and for effecting change in the physiology of the brain.

In summary, the relevance of what is heard and attention factors are important for a child learning listening and spoken language.

Summary

Research over the last 10 years has provided some evidence on how infants "crack the speech code" (Kuhl, 2007). There is more recent evidence that social interaction is essential for natural speech learning. Babies cannot crack the speech code alone, and parents are the critical component to their baby learning to understand what they hear through meaningful, enjoyable social interaction (Kuhl, 2004; 2007).

Therefore, for children with hearing loss, if listening and spoken language outcomes with optimal literacy is to ensue, an approach to education which advocates early identification and intervention in which parents are taught to maximise opportunities to develop auditory brain pathways in their babies is essential. Early auditory brain access encompassing meaningful auditory-verbal social interaction is crucial. The auditory-verbal approach to education offers this capability. Optimal intervention for hearing loss in babies is time-bound, and infants with hearing loss cannot afford to wait (Olusanya, 2005).

References

Anderson, J.L., Morgan, J.L., & White, K.S. (2003). A statistical basis for speech sound discrimination. *Language and Speech, 46*(2-3), 155-182.

Aylward, E.H., Richards, T.L., Berninger, V.W., Nagy, W.E., Field, K.M., Grimme, A.C., et al. (2003). Instructional treatment associated with changes in brain activation in children with dyslexia. *Neurology, 61,* 212-219.

Bernhardt, B.M., Kemp, N., & Werker, J.F. (2007). Early word-object associations and later language development. *First Language, 27*(4), 315-328.

Bertoncini, J., Bijeljac-Babic, R., Blumstein, S.E., & Mehler, J. (1987). Discrimination in neonates of very short CVs. *Journal of the Acoustical Society of America, 82*(1), 31-37.

Best, C.T., McRoberts, G.L.W., LaFleur, R., & Silver-Isenstadt, J. (1995). Divergent developmental patterns for infants' perception of two non-native consonant contrasts. *Infant Behavior and Development, 18,* 339-350.

Binder, J.R., & Price, C. (2001). Functional neuroimaging of language. In R. Cabeza & A. Kingstone (Eds.). *Handbook of Functional Neuroimaging of Cognition* (pp. 187-251). Cambridge, MA: MIT Press.

Blachman, B.A., Schatschneider, C., Fletcher, J.M., & Clonan, S.M. (2003). Early reading intervention: A classroom prevention study and a remediation study. In Foorman, B.R. (Ed.). *Preventing and Remediating Reading Difficulties: Bringing Science to Scale* (pp. 253-271). Timonium, MD: York Press.

Boothroyd, A. (1997). Auditory development of the hearing child. *Scandinavian Audiology, 26*(Suppl. 46), 9-16.

Bortfeld, H., Morgan, J.L., Golinkoff, R.M., & Rathbun, K. (2005). Mommy and me: Familiar names help launch babies into speech stream segmentation. *Psychological Science, 16*(4), 298-304.

Bosch, L., & Sebastián-Gallés, N. (2003). Simultaneous bilingualism and the perception of a language specific vowel contrast in the first year of life. *Language and Speech, 46,* 217-244.

Cheour, M., Ceponiene, R., Lehtokoski, A., Luuk, A., & Allik, J. (1998). Development of language-specific phoneme representations in the infant brain. *Nature Neuroscience, 1*(5), 351-353.

Chermak, G.D., & Musiek, F.E. (1997). *Central Auditory Processing Disorders: New Perspectives.* San Diego, CA: Singular Publishing Group.

Christophe, A., Dupoux, E., Bertoncini, J., & Mehler, J. (1994). Do infants perceive word boundaries? An empirical study of the bootstrapping of lexical acquisition. *Journal of the Acoustical Society of America, 95*(3), 1570-1580.

Clarkson, M.G., & Berg, W.K. (1983). Cardiac orienting and vowel discrimination in newborns: Crucial stimulus parameters. *Child Development, 61*, 1584-1595.

Cole, E., & Flexer, C. (2007). *Children with Hearing Loss: Developing Listening and Talking Birth to Six*. San Diego, CA: Plural Publishing.

Colletti, V., Carner, M., Miorelli, V., Guida, M., Colletti, L., & Fiorino, F.G. (2005). Cochlear Implantation at under 12 months: Report on 10 patients. *Laryngoscope*, *115*(3), 445-449.

Connor, C.M., Craig, H., Raudenbush, S., Heavner, K., & Zwolan, T. (2006). The age at which young deaf children receive cochlear implants and their vocabulary and speech production growth: Is there an added value for early implantation? *Ear and Hearing, 27*(6), 628-944.

DeCasper, A.J. & Fifer, W.P. (1993). Of human bonding: Newborns prefer their mothers' voices. *Science, 208*(4448), 1174-1176.

Dehaene-Lambertz, G., Dehaene, S., & Hertz-Pannier, L. (2002). Functional neuroimaging of speech perception in infants. *Science, 298*(5600), 2013-2015.

Dorman, M.F., Sharma, A., Gilley, P., Martin, K., & Roland, P. (2007). Central auditory development: Evidence from CAEP measurements in children fit with cochlear implants. *Journal of Communication Disorders, 40*, 284-294.

Eggermont, J.J., & Ponton, C.W. (2003). Auditory-evoked potential studies of cortical maturation in normal hearing and implanted children: Correlations with changes in structure and speech perception*.* *Acta Oto-Laryngologica, 123*(2), 249-252.

Eliot, L. (1999). *What's Going On In There? How the Brain and Mind Develop in the First Five Years of Life.* New York, NY: Bantam Books.

Fallon, J.B., Irvine, D.R.F., & Shepherd, R.K. (2009, in press). Cochlear implant use following neonatal deafness influences the cochleotopic organization of the primary auditory cortex in cats. *The Journal of Comparative Neurology*.

Fennell, C., Byers-Heinlein, K., & Werker, J.F. (2007). Using speech sounds to guide word learning. The case of bilingual infants. *Child Development, 78*(5), 1510-1525.

Ferguson, C.A., Menn, L., & Stoel-Gammon, E. (Eds.) (1992). *Phonological Development: Models, Research, Implications.* Timonium, MD: York Press.

Flexer, C. (1999). *Facilitating Hearing and Listening in Young Children (2nd ed*). San Diego, CA: Singular Publishing Group.

Fryauf-Bertschy, H., Tyler, R.S., Kelsay, D.M.R., & Gantz, B.J. (1997). Cochlear implant use by prelingually deafened children: The influences of age at implant and length of device use. *Journal of Speech, Language, and Hearing Research*, *40*, 183-199.

Geers, A. & Moog, J. (1989). Factors predictive of the development of literacy in profoundly hearing-impaired adolescents. *The Volta Review, 91*, 69-86.

Gilley, P., Sharma, A., Dorman, M., Finley, C., Panch, A., & Martin, K. (2006). Minimization of the cochlear implant stimulus artefact in cortical auditory evoked potentials. *Clinical Neurophysiology, 117*(8), 1772-1782.

Giraud, A., Price, C.J., Graham, J.M., Truy, E., & Frackowiak, R.S. (2001a). Cross-modal plasticity underpins language recovery after cochlear implantation. *Neuron, 30,* 657-663.

Giraud, A., Price, C.J., Graham, J.M., & Frackowiak, R.S. (2001b). Functional plasticity of language-related brain areas after cochlear implantation. *Brain, 124,* 1307-1316.

Giraud, A.L., Truy, E., Frackowiak, R.S., Gregoire, M.C., Pujol, J.F., & Collet, L. (2000). Differential recruitment of the speech processing system in healthy subjects and rehabilitated cochlear implant patients. *Brain, 123*, 1391-1402.

Gould, J.L., & Marler, P. (1987). Learning by instinct. *Scientific American, 256*(1), 74-85.

Gopnik, A., Meltzoff, A.N., & Kuhl, P.K. (1999). *The Scientist in the Crib: Minds, Brains, And How Children Learn*. Fairfield, CT: William Morrow.

Granier-Deferre, C., Lecanuet, J.P., Cohen, H., & Busnel, M.C. (1985). Feasibility of prenatal hearing test. *Acta Otolaryngologica (Stockholm), Supplement 421*, 93-101.

Groome, L.J., Mooney, D.M., Holland, S.B., Smith, Y.D., Atterbury, J.L., & Dykman, R.A. (2000). Temporal pattern and spectral complexity as stimulus parameters for eliciting a cardiac orienting reflex in human fetuses. *Perception and Psychophysics, 62*(2), 313-320.

Hartmann, R., Shepherd, R.K., Heid, S., & Klinke, R. (1997). Response of the primary auditory cortex to electrical stimulation of the auditory nerve in the congenitally deaf white cat. *Hearing Research, 112,* 115-133.

Hutt, S.J., Hutt, C., Lenard, H.G., van Bernuth, H., & Muntjewerff, W.J. (1968). Auditory responsivity in the human neonate. *Nature, 218*, 888-890.

Jae Sung Lee, Seung Ha Oh, Seok-Ki Kim, Jeung-Whoon Kim, June-Key Chung, Myung Chul Lee, Chong Sun Kim (2001). Deafness: Cross modal plasticity and cochlear implants. *Nature, 409*, 149 – 150.

Johnson, M.H., Bolhuis, J.J., & Horn, G. (1992). Predispositions and learning: Behavioural dissociations in the chick. *Animal Behaviour, 44*(5), 943-948.

Jusczyk, P.W., Bertoncini, J., Bijeljac-Babic, R., Kennedy, L.J. & Mehler, J. (1990). The role of attention in speech perception by young infants. *Cognitive Development, 5*(3), 265-286.

Jusczyk, P.W., Cutler, A., & Redanz, N.J. (1993). Infant’s preference for the predominant stress patterns of English words. *Child Development, 64*(3), 675-687.

Jusczyk, P.W., Hohne, E.A., & Bauman, A. (1999). Infant’s sensitivity to allophonic cues for word segmentation. *Perception and Psychophsyics, 61*(8), 1465-1476.

Katz, L.C. (1999). What’s critical for the critical period in the visual cortex? *Cell, 99,* 673-676.

Kirk, K.I., Miyamoto., R.T., Lento, C.L., Ying, E., O’Neill, T., & Fears, B. (2002). Effects of age at implantation in young children. *Annals of Otology, Rhinology & Laryngology, 189,* 69-73.

Klin, A. (1991). Young autistic children’s listening preferences in regard to speech: A possible characterization of the symptom of social withdrawal. *Journal of Autism and Developmental Disorders, 21*(1), 29-42.

Klinke, R., Hartmann, R., Heid S., Tillein, J., & Kral, A. (2001). Plastic changes in the auditory cortex of congenitally deaf cats following cochlear implantation. *Audiology and Neurotology, 6,* 203-206.

Kral, A., Hartmann, R., Tillein, J., Heid, S., & Klinke, R. (2000). Congenital auditory deprivation reduces synaptic activity within the auditory cortex in a layer-specific manner. *Cerebral Cortex 10,* 714-726.

Kral, A., Hartmann, R., Tillein, J., Heid, S., & Klinke, R. (2002). Hearing after congenital deafness: Central auditory plasticity and sensory deprivation. *Cerebral Cortex 12,* 797-807.

Kuhl, P.K. (2004). Early language acquisition: Cracking the speech code. *Nature Reviews, Neuroscience, 5,* 831-843.

Kuhl, P.K. (2007). Is speech learning ‘gated’ by the social brain? *Developmental Science, 10*(1), 110-120.

Kuhl, P.K., Coffey-Corina, S., Padden, D., & Dawson, G. (2005). Links between social and linguistic processing of speech in pre-school children with autism: Behavioural and electrophysiological measures. *Developmental Science, 8*(1), F1-F12.

Kuhl, P.K., Stevens, E., Hayashi, A., Deguchi, T., Kiritani, S., & Iverson, P. (2006). Infants show a facilitation effect for native language phonetic perception between 6 and 12 months. *Developmental Science, 9,* F13-F21.

Kuhl, P.K., Williams, K.A., Lacerda, F., Stevens, K.N., & Lindblom, B. (1992). Linguistic experience alters phonetic perception in infants by 6 months of age. *Science, 255*(5044), 606-608.

Lenard, H.G., von Bernuth, H., & Hutt, S.J. (1969). Acoustic evoked responses in newborn infants: the influence of pitch and complexity of the stimulus. *Electroencephalography and Clinical Neurophysiology, 27*(2), 121-127.

Lyon, G.R., Shaywitz, S.E., & Shaywitz, B.A. (2003). Defining dyslexia, comorbidity, teacher's knowledge of language and reading. *Annals of Dyslexia, 53,* 1-14.

Manrique, M ., Cervera-Paz, F.J., Huarte, A., & Molina, M. (2004). Advantages of cochlear implantation in prelingual deaf children before 2 years of age when compared with later implantation. *Laryngoscope, 114*(8), 1462-1469.

Mehler, J., Jusczyk, P., Lambertz., G., Halsted, N., Bertoncini, J., & Amiel-Tison, C. (1988). A precursor of language acquisition in young infants. *Cognition, 29*(2), 143-178.

Mills, D.L., Prat, C., Zangl, R., Stager, C.L., Neville, H.J. & Werker, J.F. (2004). Language experience and the organisation of brain activity to phonetically similar words: ERP evidence from 14 and 20-month olds. *Journal of Cognitive Neuroscience, 16*(8), 1-13.

Mody, M. (2003). Phonological basis in reading disability: A review and analysis of the evidence. *Reading and Writing, 16*(1-2), 21-39.

Molfese, D.L. (2000). Predicting dyslexia at 8 years of age using neonatal brain responses. *Brain and Language, 72,* 238-245.

Moon, C., Cooper, R.P. & Fifer, W.P. (1993). Two-day olds prefer their native language. *Infant Behavior Development, 16*(4), 495- 500.

Morgan, J.L., & Saffran, J.R. (1995). Emerging integration of sequential and suprasegmental information in preverbal speech segmentation. *Child Development*, *66*(4), 911-936.

Musiek, F.E., & Berge, B.E. (1998). A Neuroscience view of auditory training/stimulation and central auditory processing disorders. In Masters, M.G., Stecker, N.A., & Katz, J. (Eds). *Central Auditory Processing Disorders: Mostly Management.* Boston, MA: Allyn and Bacon.

Myers, J., Jusczyk, P.W., Kemler Nelson, D.G., Charles Luce, J., Woodward, A.L., & Hirsh Pasek, K. (1996). Infant' sensitivity to word boundaries in fluent speech. *Journal of Child Language, 23*(1), 1-30.

Naito, Y., Hirano, S., Honjo, I., Okazawa, H, & Ishizu, H. (1997). Sound-induced activation of auditory cortices in cochlear implant users with post and prelingual deafness demonstrated by position emission tomography: *Acta Otoloaryngology, 117*(4), 490-496.

Nazzi, T., Bertoncini, J., & Mehler, J. (1998). Language discrimination by newborns: Toward an understanding of the role of rhythm. *Journal of Experimental Psychology: Human Perception and Performance, 24*(3), 756-766.

Olusanya, B. (2005). Can the world's infants with hearing loss wait? *International Journal of Pediatric Otorhinology 69,* 735-738.

Pang, E.W., & Taylor, M.J. (2000). Tracking the development of the N1 from age 3 to adulthood: an examination of speech and non-speech stimuli. *Clinical Neurophysiology, 111*(3), 388-397.

Peña, M., Maki, A., Kovacic, D., Dehaene-Lambertz, G., Koizumi, H, Bouquet, F., & Mehler, J. (2003). Sounds and silence: An optical topography study of language recognition at birth. *Proceedings of the National Academy of Sciences of the United States of America, 100*(20), 11702-11705.

Petersen, S.E., & Fiez, J.A. (1993). The processing of single words studied with positron emission tomography. *Annual Review of Neuroscience, 16*, 509-530.

Pisoni, D., Cleary, M., Geers, A., & Tobey, E. (1999). Individual differences in effectiveness of cochlear implants in children who are prelingually deaf: Some new process measures of performance. *The Volta Review, 101*, 111-164.

Polka, L., & Werker, J.F. (1994). Developmental changes in perception of nonnative vowel contrasts. *Journal of Experimental Psychology: Human Perception and Performance, 20*(2), 421-435.

Ponton C.W., & Eggermont J.J. (2001). Of kittens and kids: Altered cortical maturation following profound deafness and cochlear implant use. *Audiology & Neurootology, 6,* 363-380.

Ponton, C.W., Eggermont, J.J., Don, M., Waring, M.D., Kwong, B., Cunningham, J., & Trautwein, P. (2000). Maturation of the mismatch negativity: Effects of profound deafness and cochlear implant use. *Audiology & Neuro-Otology*, *5*, 167-185.

Ponton, C.W., Don, M., Eggermont, J.J., Waring, M.D., & Kwong, B. (1996). Auditory system plasticity in children after long periods of complete deafness: Auditory and vestibular, lateral line. *Neuroreport, 8*(1), 61-65.

Ramus, F., Hauser, M.D., Miller, C., Morris, D., & Mehler, J. (2000). Language discrimination by human newborns and by cotton-top tamarin monkeys. *Science, 288*(5464), 349-351.

Report of the National Reading Panel (2000). Teaching children to read: An evidence based assessment of the scientific research literature on reading and its implications for reading instruction. Vol NIH, Pub. No. 00-4754: Washington DC: Department of Health and Human Services, National Institute of Child Health and Human Development.

Rivera-Gaxiola, M., Silva-Pereyra, J., & Kuhl, P.K. (2005). Brain potentials to native and non-native speech contrasts in 7 and 11 month old American infants. *Developmental Science, 8*, 162-172.

Robertson, L., & Flexer, C. (1993). Reading development: A parent survey of children with hearing impairment who developed speech and language through the auditory-verbal method. *The Volta Review, 95*, 253-261.

Rubel, E.W. (1985). Strategies and problems for future studies of auditory development. *Acta Otolaryngologica (Stockholm), 421*, 114-128.

Ryan, M.J., Phelps, S.M., & Rand, A.S. (2001). How evolutionary history shapes recognition mechanisms. *Trends in Cognitive Sciences, 5*(4), 143-148.

Saffran, J.R., Werker, J.F. & Werner, L.A. (2006). The infant's auditory world: Hearing, speech, and the beginnings of language. In Kuhn, D., & Siegler, M. (Eds.). *The Handbook of Child Psychology (6th Ed)* (pp. 58 – 108). Hoboken, NJ: John Wiley & Sons, Inc.

Sansavini, A., Bertoncini, J., & Giovanelli, G. (1997). Newborns discriminate the rhythm of multisyllable stressed words. *Developmental Psychology, 33*(1), 3-11.

Scott, S.K., Blank, C.C., Rosen, S., & Wise, R.J. (2000). Identification of a pathway for intelligible speech in the left temporal lobe. *Brain, 123*(12), 2400-2406.

Sebastián-Gallés, N., Echeverría, S., & Bosch, L. (2005). The influence of initial exposure on lexical representation: Comparing early and simultaneous bilinguals. *Journal of Memory and Language, 52*(4), 240-255.

Sharma, A., & Dorman, M. (2006). Central auditory development in children with cochlear implants: Clinical implications. *Recent Advances in Otorhinolaryngology, 64*, 66-68.

Sharma, A., Dorman, M. & Kral, A. (2005). The influence of a sensitive period on central auditory development in children with bilateral and unilateral cochlear implants. *Hearing Research, 203*, 134-143.

Sharma, A., Dorman, M., & Spahr, A.J. (2002a). A sensitive period for the development of the central auditory system in children with cochlear implants: Implications for age of implantation. *Ear and Hearing, 23*, 532-539.

Sharma, A., Dorman, M.F., & Spahr, A.J. (2002b). Rapid development of cortical auditory evoked potentials after early cochlear implantation. *Neuroreport, 13*, 1365-1368.

Sharma, A., Tobey, E., Dorman, M., Bharadwaj, S., Martin, K., Gilley, P., & Kunkel, F. (2004). Central auditory maturation and babbling development in infants with cochlear implants. *Archives of Otolaryngology Head and Neck Surgery, 130,* 511-516.

Shaywitz, S., & Shaywitz, B. (2005). Dyslexia (specific reading disability). *Biological Psychiatry,* (*57*)11, 1301-1309.

Shi, R., Werker, J.F., & Morgan, J.L. (1999). Newborn infants' sensitivity to perceptual cues to lexical and grammatical words. *Cognition, 72*, B11-B21.

Simos, P.G., Fletcher, J.M., Bergman, E., Breier, J.I., Foorman, B.R., Castillo, E.M., et al. (2002). Dyslexia-specific brain activation profile becomes normal following successful remedial training. *Neurology, 58*, 1203-1213.

Singh, S., Liasis, A., Rajput, K., Towell, A., & Luxon, L. (2004). Event-related potentials in pediatric cochlear implant patients. *Ear & Hearing, 25*(6), 598-610.

Stager, C.L. & Werker, J.F. (1997). Infants listen for more phonetic detail in speech perception than in word learning tasks. *Nature, 388,* 381–382.

Svirsky, M., Teoh, S.W., & Neuburger, H. (2004). Development of language and speech perception in congenitally, profoundly deaf children as a function of age at cochlear implantation. *Audiology & Neuro-Otology, 9,* 224-233.

Tincoff, R., & Jusczyk, P.W. (1999). Some beginnings of word comprehension in 6-month-olds. *Psychological Science, 10*(2), 172-175.

Tsao, F.M., Liu, H.M., & Kuhl, P.K. (2004). Speech perception in infancy predicts language development in the second year of life: A longitudinal study. *Child Development, 75*, 1067-1084.

Vouloumanos, A., Kiehl, K.A., Werker, J.F., & Liddle, P.F. (2001). Detection of sounds in the auditory stream: Event-related fMRI evidence for differential activation to speech and nonspeech*. Journal of Cognitive Neuroscience, 13*(7), 994-1005.

Vouloumanos, A. & Werker, J.F., (2007). Listening to language at birth: Evidence for a bias for speech in neonates. *Developmental Science, 10*(2), 159-164.

Vouloumanos, A. & Werker, J.F., (2004). Tuned to the signal: The privileged status of speech for young infants. *Developmental Science, 7*(3), 270-276.

Waltzman, S.B., & Cohen, N.L. (1998). Cochlear implantation in children younger than two years old. *American Journal of Otology, 19*(2), 158-162.

Weikum, W.M., Vouloumanos, A., Navarro, J., Soto-Faraco, S., Sabastian-Galles, N., & Werker, J.F. (2007). Visual language discrimination in infancy. *Science, 316*, 1159.

Werker, J.F., Cohen, L.B., Lloyd, V., Stager, C.L., & Cassasola, M. (1998). Acquisition of word-object associations by 14-month old infants. *Developmental Psychology, 34*(6), 1289-1309.

Werker, J.F., Fennell, C.T., Corcoran, K., & Stager, C.L. (2002). Infants' ability to learn phonetically similar words: Effects of age and vocabulary size. *Infancy, 3,* 1-30.

Werker, J.F., & Tees, R.C. (1984). Cross-language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant Behavior and Development, 7,* 49-63.

Werker, J.F., Weikum, W.M., & Yoshida, K. (2006). Bilingual speech processing in infants and adults. In McArdle, P.D., & Hoff, E. (Eds.). *Childhood bilingualism: Research on infancy through school-age* (pp. 1- 18). London: Multilingual Matters.

Yoshinaga-Itano, C., Sedey, A.L., Coulter, D.K., & Mehl, A.L. (1998). Language of early- and later-identified children with hearing loss. *Pediatrics, 102*(5), 1161-1171.