20 Integrated Language Intervention for Children with Hearing Loss

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Integrated Language Intervention for Children with Hearing Loss

Research on a variety of topics related to pediatric cochlear implantation has been discussed in this volume. Synthesizing results across these various topics allows us to make specific recommendations regarding how behavioral interventions should be implemented for children who receive CIs. Many of the ideas to come out of this effort are identical to those that would be recommended for any child born with any degree of hearing loss (mild to profound), or who might acquire such a loss early in life. Significant delays in language acquisition continue to be observed for children with only mild-to-moderate hearing loss, which is typically defined as auditory thresholds between 20 and 70 dB hearing level, in spite of advances in hearing aid technology (e.g., Briscoe et al. 2001; Davis et al. 1986; Delage and Tuller 2007; Wake et al. 2004). One finding of special interest coming out of that work is that mean performance levels obtained for children with mild-to-moderate hearing loss are commonly found to be one standard deviation below the means of typically performing children with normal hearing (e.g., Gilbertson and Kamhi 1995; Wake et al. 2004), which is strikingly similar to what is found for children with CIs: Consistently across studies of language acquisition for children with CIs, differences of that magnitude have been observed, as indicated by the studies listed in Table 11.1, as well as by others (e.g., Boons et al. 2012; Geers et al. 2003; Nittrouer et al. 2012). This level of mean performance marks significant improvement in language abilities for children with severe-to-profound hearing loss as a result of the availability of cochlear implants. But the finding that children with mild-to-moderate hearing loss are performing no better, on average, can be taken as evidence that improving implant technology alone should not be expected to close the gap in performance compared to children with normal hearing. These collective findings across studies emphasize that degree of hearing loss cannot predict language outcomes for children, a point explicitly discussed by several investigators (e.g., Davis et al. 1986; Gilbertson and Kamhi 1995; Norbury et al. 2001; Tuller and Jakubowicz 2004). In turn, that trend highlights the fact that there is more involved in learning language than simply being able to harvest linguistically relevant acoustic cues from the physical signal reaching the auditory system.

There are several ways in which hearing loss and subsequent cochlear implantation can negatively impact the development of language and literacy. The most obvious way is by diminishing the quantity and quality of the sensory input. As we move through our lives, we use sensations to inform us about events in our environment, as well as about the effects our actions have on that environment. Children recover information about the speech production patterns of others through their sensory systems, and refine their own production from the feedback they receive through those systems. Those interactions with the environment—both as perceiver and producer of spoken language—allow children to develop the linguistic elements that they will use in language and cognitive processes. Any degradation in sensory inputs can negatively impact the acquisition and refinement of these linguistic elements by diminishing the resolution of the representations. Where childhood hearing loss is concerned, degraded sensory input is responsible for the challenges children face in the acquisition of language. Accordingly, the dramatic improvements in language learning outcomes observed for severely to profoundly deaf children since cochlear implants became available are surely due to enhanced sensory inputs. Nonetheless, communication capabilities and language acquisition cannot be entirely explained

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by the quality of the input children have access to; if they were, degree of hearing loss would predict the lion's share of variance in the language capabilities of these children, and as was learned in the last paragraph, it does not.

Many more processes underlie communication and language learning than those associated with peripheral sensitivity to the sensory input. It is for this reason that factors related primarily to implants and implant surgery do not explain especially large amounts of variance in outcomes for children with severe-to-profound hearing loss. One nonsensory factor influencing communication abilities is that the perceiver must be able to attend to the information-bearing components of the sensory input, and ignore other inputs. Where speech perception is concerned, these strategies are known as *perceptual weighting strategies*. Investigations into this phenomenon reveal that listeners of different language backgrounds have different perceptual weighting strategies. What that means is that listeners selectively attend to different parts of the acoustic structure in the speech signal, depending on their native language background (Crowther and Mann 1992, 1994; Escudero et al. 2009; Flege and Port 1981; Iverson et al. 2003; MacKain et al. 1981). Because listeners in those experiments were all selected to have normal hearing, observed differences in attention could not be explained by differences in sensitivity to the relevant acoustic cues. In an especially stark demonstration of that discrepancy between sensitivity and weighting, Miyawaki and colleagues (1975) asked native Japanese speakers who learned English as a second language to discriminate a mid-frequency spectral glide that supports categorization of the phonemes [r] and [l] in English. They were found to be just as sensitive to this acoustic property as English speakers in a control group. However, when that short acoustic bit was merged with a more complete speech signal, the native Japanese listeners failed to use it to categorize [r] and [l]. That phonetic distinction is not present in Japanese, and apparently these speakers never learned to attend to the acoustic property on which it is based.

In addition to language background, the age of the listener plays a critical role in how the acoustic cues of speech get weighted. Much of the work demonstrating that point has been done in this laboratory, and shows that children initially attend strongly to the time-varying spectral structure of the signal arising from changes in shape and size of the vocal tract. That attentional strategy is different from what is generally found for adults, who attend more strongly to temporally restricted sections of acoustic structure. Illustrating these age-related phenomena are past experiments involving fricative-vowel stimuli. In a series of experiments, stimuli based on natural tokens of [ʃ]-vowel and [s]-vowel syllables were used (e.g., Nittrouer 1992; Nittrouer and Miller 1997; Nittrouer and Studdert-Kennedy 1987). Figure 20.1 displays these syllables with the vowel [ɑ], and shows that two kinds of acoustic structure, or cues, are clearly associated with the different places of constriction for these syllable-initial fricatives. First, the aperiodic fricative noise is lower in frequency for [ʃ] than for [s], a difference arising because the cavity in front of the constriction is larger for [ʃ]. In addition, the vocalic formants differ in onset frequency, direction, and extent of change, depending on place of constriction of the syllable-initial fricative. In particular, the second and third formants start at similar frequencies for [ʃ], but not for [s]. Consequently, the third formant rises after voicing onset for [ʃ], but falls following [s]; the second formant is higher at onset for [s] than for [ʃ]. Results of labeling experiments have consistently revealed that children weight the formant transitions more than adults when presented with these sorts of stimuli, and weight the static fricative noises less (Mayo et al. 2003; Nittrouer 1992; Nittrouer and Miller 1997; Nittrouer and Studdert-Kennedy 1987; Siren and Wilcox 1995).

Similar age-related differences in perceptual weighting strategies have been found for decisions regarding the voicing of syllable-final consonants (Greenlee 1980; Krause 1982; Nittrouer 2004; Wardrip-Fruin and Peach 1984). In this case, the two cues to voicing are the duration of the vocalic segment preceding the final consonant and the offset frequencies of the formants, especially the first formant. Children show the same preference for the time-varying formant patterns with these stimuli as they show with the fricative-vowel stimuli. Results across contrasts and experiments have led to the suggestion that children's perceptual attention changes with development and language experience, an idea termed the *developmental weighting shift* (Nittrouer et al. 1993). The explanation provided for this developmental change hinges on the notion that formant transitions span temporal stretches of the speech signal affiliated with more than one phonemic segment. One of the first tasks facing the child when it comes to language learning is discovering how to parse the signal into linguistic units such as words and syllables. Consistent patterns of formant change can mark these linguistic units, helping the young child learn how to divide the signal into meaningful units. As children get older, perceptual attention becomes increasingly focused on temporally discrete parts of the signal more closely affiliated with individual phonemic segments. That perceptual change accompanies the developmental enhancement of attention to word-internal phonemic structure observed for children across the first decade of life (e.g., Liberman et al. 1974; Walley et al. 1996).

Besides weighting acoustic cues according to language-specific strategies, it is essential that language users are able to integrate those cues in order to recover linguistic form accurately and efficiently. This process entails a phenomenon known as *perceptual organization*, defined as the strategies involved in blending sensory information into coherent

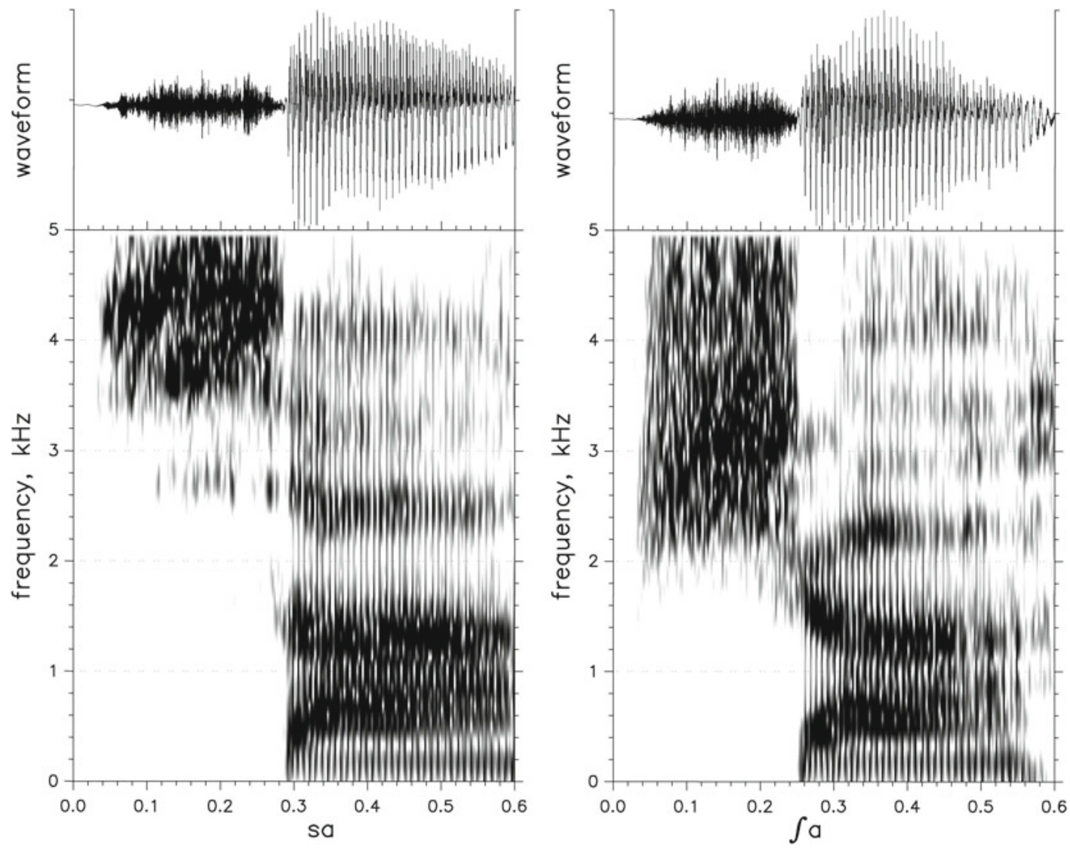

Fig. 20.1 Spectrogram of the syllables *sa* (*left*) and *sha* (*right*) spoken by a man, illustrating that both the spectral structure of the fricative noise and the formants differ depending on the initial fricative

units (Kimchi 2009). This phenomenon is the focus of a great deal of investigation in the visual domain where it can readily be illustrated. A simple example is provided by the well-known Rubin's vase. From the pattern of light and dark present in that simple drawing can be recovered either two faces in profile on either side of the image or a single vase in the middle. In either case the same sensory information is reaching the visual cortex; the form recovered is determined by how the perceiver organizes that information.

It is no coincidence that the visual images used to illustrate perceptual organization commonly involve degraded signals, typically patterns formed by various shades of gray. Degraded signals make is much easier to evoke alternative forms, and that point is relevant to appreciating what must be achieved by the child learning language through a cochlear implant because these prostheses provide only degraded auditory input. The child with normal hearing might not be totally immune to disorders of perceptual organization; in particular, a disorder of this nature has been suggested as underlying developmental dyslexia (Nittrouer and Lowenstein 2013). However, the probability of that kind of problem arising for children who have access to highly refined sensory information (i.e., those with normal hearing) is lower than it surely is for children with hearing loss, especially if they use cochlear implants. Thus, another challenge facing the child with a CI is learning appropriate perceptual organization strategies for speech. The emergence of such strategies cannot be assumed to be automatic for children with CIs because they have access only to a degraded representation of the speech signal.

The way in which sensory information comes to be organized is critically important. Among early theories of speech perception was the idea that listeners recover the articulatory gestures involved in producing the signal heard, with special reference to their own vocal tracts (Liberman et al. 1967). While that particular idea, known as the motor theory of speech perception, has not withstood the test of time, the general idea that speech perception is a sensorimotor process has received continued support (Kuhl 2010; Liberman and Mattingly 1985; Todd et al. 2006). In particular, there is clear evidence that the supplementary motor as well as the lateral premotor areas of the cortex are activated when listeners hear speech signals. Figure 20.2 illustrates that this process develops over the first year of life, with a concomitant diminishment in activation of the primary auditory cortex (Kuhl 2010). This figure shows images from magnetoenchephalography

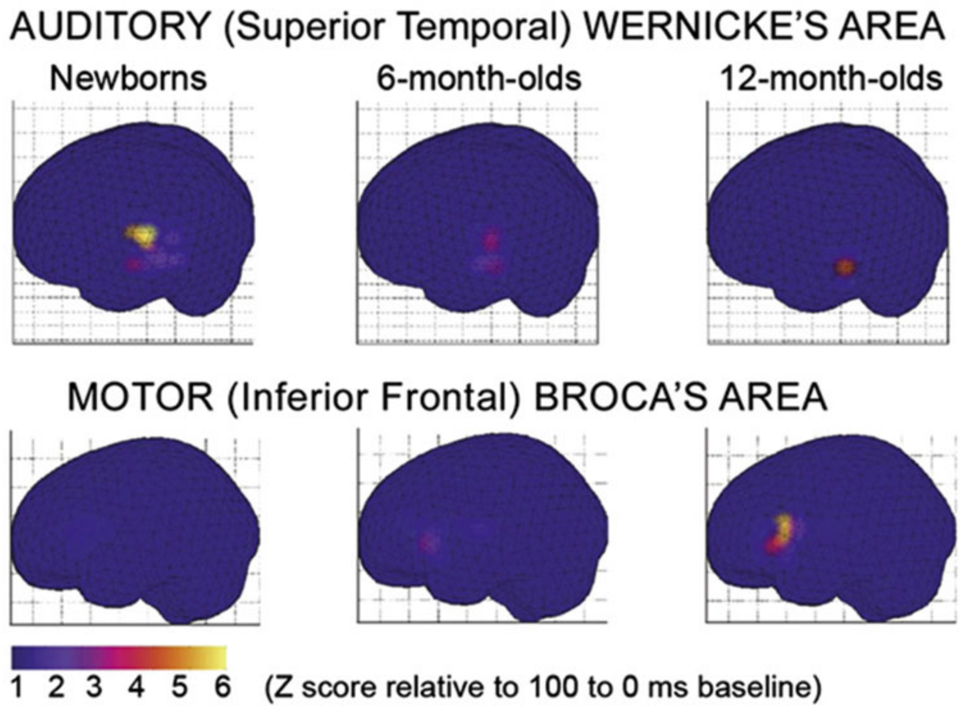

Fig. 20.2 Images from a magnetoenchephalography study of infants listening to speech across the first year of life, conducted by Imada et al. (2006). This image is reprinted from Kuhl (2010)

(MEG) recorded in the auditory (top) and motor (bottom) regions of the cortex in response to speech sounds. It shows how cortical responses to speech become isolated to the motor region. In that work, no similar shifts in the brain regions responding to nonspeech sounds were observed (Imada et al. 2006).

Behavioral evidence for the suggestion that perceptual organization of acoustic signals differs depending on whether those signals are processed as speech or nonspeech comes from several sources. For one, studies of sine-wave analogs of speech signals demonstrate the disparity in organizational strategies. These analogs eliminate most kinds of structure from the speech signal, except for the long-term trajectories of the first three formants. The center frequencies of these formants are tracked, and represented as separate sine waves in the generation of the analogs. Thus these signals are auditory analogs to ambiguous visual signals, such as Rubin's vase. In the very first experiment conducted with sine-wave speech, listeners were given no description of what they would be hearing prior to presentation. When queried after hearing them, many listeners reported hearing whistles or bird chirps or some other form of nonspeech sound. However, when listeners were instructed that they would be hearing degraded speech signals, they all were able to perceptually integrate these three disparate sine waves in such fashion as to recognize sentences (Remez et al. 1981). This dichotomy in how signals are organized as a function of expectations has been well replicated (e.g., Remez et al. 2001). Furthermore, patterns of phonetic labeling are rarely found to be explained by auditory sensitivity to the pertinent acoustic properties manipulated in the stimuli used in those experiments (e.g., Miyawaki et al. 1975; Nittrouer 1996; Nittrouer and Crowther 1998; Rosen and Manganari 2001).

In sum, three ways that hearing loss and subsequent cochlear implantation might hinder the development of age-appropriate language and literacy have been discussed. First, diminished access to sensory information can interfere with language learning. However, the finding of a lack of correspondence between degree of hearing loss and degree of language deficit reveals that other perceptual processes come into play. The second way that hearing loss and subsequent cochlear implantation might hinder the development of age-appropriate language and literacy concerns the fact that the child must discover what components, or cues, in the signal should be weighted strongly. That process requires a critical amount of experience hearing the ambient language, and such experience can be constrained by hearing loss. Finally, the child must be able to organize those cues appropriately in order to recover linguistic units, something that is a perceptually slippery undertaking when a degraded sensory input is involved. These considerations should help shape the way that we design intervention for children with CIs.

Principles of Integrated Language Intervention

The factors reviewed above concerning how speech signals are processed can and should be used to derive general principles for designing intervention programs for children with CIs. In this section, specific principles for designing integrated approaches to intervention are described that emerge from the basic science on how linguistic signals are processed, as well as from outcome studies of current language and literacy performance of children with CIs.

Use Sufficiently Long Signal Stretches

Some approaches to intervention for deaf children start by trying to elicit isolated segments or words from the children, and then seek to build language systems by training children to combine those smaller units. This approach fosters a concept known as *generalization*, meant to refer to a process in which the child first masters production of small units acquired in isolation and subsequently learns to incorporate those units into longer stretches of language. The speech therapist's job is seen as twofold: first, teaching children to produce isolated segments, and then training them to move each of those segments to broader language contexts. Unfortunately that approach is an example of the proverbial placement of the cart before the horse.

The first goal of intervention, especially with young children and infants, should be to generate attention to speech in order to facilitate the attainment of appropriate perceptual organization. Children with CIs must learn to recognize speech as such—a signal generated by human speakers—and learn to organize that structure according to speech-relevant strategies. These goals are best realized by using long signal stretches in clinical and educational efforts with children. Intervention to correct errors at the segmental level should be implemented only after a child demonstrates a desire to communicate with spoken language, and is producing—or attempting to produce—speech in order to express needs, feelings, and wishes. According to this approach, intervention to improve production of smaller units serves to polish what the child is already attempting to produce. Thus an appropriate conceptualization of the therapy process might be one of *progressive refinement*, indicating that children's attention should first be directed to global structure, with gradual redirection to increasingly detailed structure. This approach matches children's typical developmental refinement of attention from whole-syllable or word structure to word-internal phonological structure.

Use Speech Signals to Teach Language

Precisely because signal components are perceptually organized differently as a function of whether expectations are that they are part of speech or nonspeech signals, only speech should be used in language learning experiences with children with CIs. The use of nonspeech signals trains children only to be more attentive to some cues when listening to the signals as nonspeech structures.

Aids to Perceptual Organization

In 2009, Nittrouer and Chapman reported outcomes for a subset of children in the longitudinal study reported in Chap. 11 titled Early Development of Children with Hearing Loss, or EDCHL. In that study, it was observed that the children who wore a hearing aid on the ear contralateral to the ear that received a CI for a period of a year or more after receiving that CI demonstrated better language abilities across the board than children who discontinued use of a hearing aid upon receiving a CI. That was true, regardless of the degree of hearing loss in the ear with the hearing aid. Furthermore, these benefits were found to be long-term, with some positive effect of early bimodal experience seen in language abilities measured at kindergarten (Nittrouer et al. 2012).

In another experiment, one unaffiliated with the EDCHL study, we sought to verify the effect more generally (Nittrouer et al. 2014). To do that, stimuli were constructed to simulate the signal provided by a CI, both when presented alone and when presented in combination with an acoustic signal in just a very low-frequency range (i.e., below 250 Hz). Materials consisted of sentences and isolated words that were high-pass filtered with a low-frequency cutoff of 250 Hz and used to create four-channel, noise-vocoded signals that simulated CI inputs. Those signals were presented alone, as well as in combination with the original signal (i.e., not vocoded) below 250 Hz. In two separate diotic conditions, either just the CI-simulated signal was presented to both ears or the combination signal was presented to both ears. In two dichotic conditions, either the CI-simulated signal was presented to one ear only or it was presented to one ear with the low-frequency signal presented to the other ear. Both adults and children served as listeners. Results showed significant improvements in speech recognition for the combined signals, regardless of whether the two signals were presented diotically or dichotically, for adults and children alike.

Those findings might seem surprising because in all cases in the simulation experiment, and in many cases for the children wearing CIs, the limited spectral structure available through the hearing aid (or simulated hearing aid) was not sufficient to provide any explicit linguistic information. Listeners could not understand any words with the low-pass signal alone. Nonetheless, immediate improvements in speech recognition were observed in the simulation study, along with long-term benefits to children using the bimodal prosthetics. The most likely explanation for those benefits is that the very-low-frequency, naturalistic speech signal spurred recognition of the entire complex (low-frequency + vocoded signal) as speech. Consequently, perceptual strategies promoting the organization of the various signal components into speechlike form were easily invoked. That kind of effect means that the low-frequency acoustic signal can be viewed as an aid to perceptual organization: It reduces ambiguity about how signal structure should be organized.

Another factor that should similarly facilitate speechlike perceptual organization is audiovisual presentation. Being able to see the speaker's face should evoke speechlike strategies for the degraded signals provided by cochlear implants. But at least one approach to early intervention has long advocated against allowing infants and young children with hearing loss to see the talker (Beebe 1978; Estabrooks 2001; Luterman 1976; Pollack 1970, 1984; Power and Hyde 1997). It is an approach based on perspectives of sensory development and processing dating back to the nineteenth century contending that transmission of sensory information through each modality is encapsulated from the periphery to the brain, and any use of a different modality would diminish the entrainment of sensory processing through the primary modality (e.g., Goldstein 1897). However, more recent views of the nervous system, based on imaging and electrophysiological evidence, indicate that there is much more integrated processing of sensory information across modalities than the earlier perspective recognized (Kayser and Logothetis 2007). For example, some experiments have explicitly shown that neuronal responses in the primary auditory cortex are modulated (usually meaning they are enhanced) by simultaneous input from the visual system (Lehmann et al. 2006; Pekkola et al. 2005). At the same time, the evidence from the work of Imada et al. (2006), discussed by Kuhl (2010) and described earlier, indicates that input from any one modality can project to different parts of the cortex, depending on the nature of the signal: nonspeech signals are projected only to the primary auditory cortex, and speechlike signals tend to be projected to the motor cortex, as well. When it comes to training children with CIs to organize the degraded signals they receive through their implants according to speechlike principles, adding sensory input from the visual modality can surely promote the appropriate kind of organization.

The appeal made here for audiovisual speech input for children with CIs does not rest on traditional views of speechreading. Those older views suggested that listeners with hearing loss benefit from seeing the talker because specific features of phonemic categories can be obtained through vision that cannot be obtained through impaired audition (e.g., Erber 1972, 1975; Miller and Nicely 1955; Numbers and Hudgins 1948; Woodward and Barber 1960). According to that perspective, speechreading serves the purpose of providing information about place of articulation, which is hard to get through impaired hearing because it tends to be high frequency; amplified hearing provides information regarding voicing and manner of articulation, which can be derived from lower frequency signal components. Thus, according to that older perspective, listeners benefit from a process of sensory summation that increases the amount of information available. The argument made here is that providing the visual display of speech helps the child learn to perceptually organize the signal according to speech-appropriate strategies: the child becomes more certain that the signal is speech, so can process it accordingly. This latter effect was demonstrated in a study by Remez et al. (1998) in which visual information was supplemented by one of several sine waves, replicating either fundamental frequency or one of the three lowest formants. In that study, the greatest benefit of the audiovisual over the audio-alone condition was observed when the second formant was presented. That formant provides information primarily about place of articulation, which meant that the information provided by the visual signal and the audio signal was mostly redundant. Thus, the benefits of audiovisual presentation cannot simply be sensory summation. In this case, multisensory input led to sensory enhancement. Regarding their finding, Remez et al. concluded that "agreement between seen and heard speech promotes fusion" (p. 71), thus allowing the listener to process the stimulus as speech. That conclusion matches the notion of sensory integration proposed by Kayser and Logothetis (2007). These latter authors proposed that having redundant information from more than one modality can help perception by reducing uncertainty of the internal representation. It is critical that this kind of multisensory input is available to children with CIs who receive only a highly degraded signal through their prostheses. Rather than diminishing the integrity of the acoustic speech signal, providing a concomitant visual signal serves to strengthen that auditory representation.

Children Learn to Understand Speech by Producing Speech

The evidence presented above demonstrating that speech perception is a sensorimotor process can be used to support the suggestion that intervention with deaf children should involve ample opportunity to produce speech. This principle can also be illustrated with outcomes of the EDCHL study. At each age for which data were collected in that study, Pearson product-moment correlation coefficients were computed between measures of speech intelligibility and several measures of language ability. The metric of speech intelligibility used was the Children's Speech Intelligibility Measure (CSIM), an instrument originally developed by Wilcox and Morris (1999) to investigate motor control and organization for speech production by children at risk of articulation disorder. In this task, children imitate 50 words. The instrument itself consists of 200 such word lists that are constructed from a master list of 600 words (50 sets of 12 possible words). Most words are of single syllable, but a few have two syllables. In this study, each word to be imitated was presented as an audio-video sample of a woman talking. Including the visual display meant that errors in recognition were minimized. All children's productions were audio-video recorded at the time of testing. Later, each child's productions were downloaded to a hard drive, and the child's word productions were separated into individual audio files. The video signal was discarded so that only audio samples of children's productions remained. Listeners unfamiliar with the speech of deaf talkers came to the laboratory and listened to these samples. The task of the listener was to select the word that was produced from the set of 12 phonetically similar choices. Each listener heard productions from only three children (with a maximum of two children with hearing loss) so that no listener would have the opportunity to become familiar with the speech of children with hearing loss. Two naïve listeners scored the samples from each child. Here we used the mean score from the two listeners for each child, and report these scores as the percentage of words the listeners identified correctly. These scores may be viewed as an index of how well the children were able to produce and organize the articulatory gestures required for clear production.

Table 20.1 shows the Pearson product-moment correlation coefficients between these CSIM scores and scores obtained on five other measures from the children with CIs, collected at both 48 months and second grade. These measures were selected because they were ones obtained at both test times. The only difference in tasks was that the auditory comprehension scores obtained at 48 months were from the Preschool Language Scales—4 (PLS) (Zimmerman et al. 2002), and those from second grade were from the Comprehensive Assessment of Spoken Language (CASL) (Carrow-Woolfolk 1999). It is apparent from this table that language scores at 48 months were highly correlated with speech production abilities. That outcome highlights the sensorimotor nature of processing for speech signals. By second grade, the relationship has diminished, which might be expected as more children with CIs develop good speech intelligibility. For these children, the mean speech intelligibility score was 57 % correct (SD = 18 % correct) at 48 months of age and 89 % correct (SD = 8 % correct) at second grade. There is much less variability at the later test age, and that truncation in variability might explain the diminished correlation coefficients. Nonetheless, these analyses suggest that there is a relationship between early motor control abilities for speech production and language learning for these children with severe-to-profound hearing loss.

In approaches that handle especially well this recommended teaching style of emphasizing speech production, therapists and teachers require complete morphosyntactic forms from children in all communications. Not only does producing speech help children learn about the organization of articulatory gestures, but also generating morphosyntactic forms helps to solidify that structure for the child. Children need to create complete and accurate utterances as often as possible, even when it means that the child needs to repeat using an extended form an utterance originally produced as an abbreviated form. This aspect of a well-designed intervention program might be the component that feels most unnatural to novice speech-language pathologists and teachers, but it has great payoffs.

Closely tied to the principle of requiring children to produce complete morphosyntactic forms as often as possible is the idea of recasting. This term refers to the practice of recreating in more complete and syntactically accurate form an utterance that a child tried to say. Thus, a complete sequence of events combining this technique and the one above would consist of the child trying to produce an utterance

Table 20.1 Pearson product-moment correlation coefficients between speech intelligibility scores from the Children's Speech Intelligibility and other language measures for children with CIs in the Early Development of Children with Hearing Loss (EDCHL) study, described in Chap. 11

	Expressive vocabulary	NDW	Auditory comprehension	MLU	Pronouns
48 months ($N=58$)	0.698[a]	0.669[a]	0.638[a]	0.701[a]	0.552[a]
Second grade ($N=50$)	0.232	0.429[a]	0.254[b]	0.318[c]	0.353[c]

Expressive Vocabulary represents standard scores from the EOWPVT; NDW is the number of different words in the first 100 utterances of a narrative sample; Auditory Comprehension represents standard scores from the PLS at 48 months and the CASL at second grade; MLU is mean length of utterance from the 20-min narrative sample; and Pronouns are the number of pronouns in the first hundred utterance from that narrative sample

[a] $p<0.10$ (2-tailed test)
[b] $p<0.05$ (2-tailed test)
[c] $p<0.01$ (2-tailed test)

(*More milk*, or even just *more*), the adult recasting it (*Oh, you want more milk*), and finally the child reformulating the original utterance according to the recast version (*I want more milk*). This exchange can and should be as natural as possible. The process should not involve the adult producing the exact version of what the child should say by using a directive (*Say,* "*I want more milk*"). This latter approach is sometimes used by well-meaning practitioners, but it results only in imitation on the part of the child. In fact, the goal is for the child to generate the correct morphosyntactic form on his own, with some appropriate prompting in the form of a recast.

Direct Language Instruction

Although the general perspective taken in this chapter is that language emerges in the child as a result of maturation and experience, children with CIs require some explicit instruction. Largely due to the diminished opportunity to access high-quality sensory input, children with CIs have decreased opportunity for the kinds of language experiences most children have. Background noise, room reverberation, and simple distance can all hinder a child's ability to hear spoken language, and so to have opportunity to generate responses. That experiential deficit forms the basis of the suggestion that children with hearing loss need specially enhanced experiences. Nonetheless, it would be a mistake to presume that extra-enriched opportunities for language experience alone would be sufficient to help children with CIs attain the same levels of language performance as children with normal hearing. In addition to the relatively natural experiences described thus far, children with CIs require direct language instruction.

This term, *direct language instruction*, is often invoked to refer to methods used with students who are second-language learners of English. Although the population of children being discussed here differs, the principles are the same. Essentially the term indicates that phonological, lexical, and morphosyntactic structure needs to be introduced explicitly to the student. General educational policies have moved away from this approach, placing an emphasis instead on naturalistic learning of the language needed for both casual and academic communication. That naturalistic approach is appropriate and sufficient for typically developing children without sensory deficits, precisely because language acquisition is such a natural process for them. However, children with hearing loss need direct instruction in order for them to learn explicitly linguistic forms.

In the preschool years, this kind of instruction can appear informal, involving games meant to introduce new vocabulary or morphosyntactic structures. For example, snack time can serve as an opportunity to teach the difference between mass and count nouns by varying the kind of food that is available: *I want a lot of pudding* versus *I want three crackers.* In the school years, the instruction can be more overt, with activities meant to help these children focus on phonological or morphological forms, or enhance their vocabularies. For example, learning Latin roots for English words can help children with CIs expand their knowledge of morphological structure. At all ages, however, it is essential that the direct instruction supplements naturalistic experiences, and is begun only after a child has started producing spoken language of substantial quantity.

At one time a popular method of teaching sentence construction to deaf children was the Fitzgerald Key, first developed by Edith Fitzgerald (1929). Those of us who worked in schools for the deaf prior to the 1990s recall the symbols that formed the basis of the Key, which was on chalkboards in every classroom. Other readers might recall seeing the Key on the chalkboard in William Hurt's classroom in the movie *Children of a Lesser God*, which came out in 1986. The Key had six columns and each represented a component of sentence structure. The first column was the nominal clause (Who, Whose, What). The second column represented the verb clause, marked with a special symbol (┌─┐). The third column was the objective clause, and so on. Using the Key, deaf children were taught to construct sentences through protracted curricula extending over several years. Again we find the cart positioned before the horse with this approach. Historically, methods such as this one likely contributed to the highly stylized language patterns that were characteristic of the speech of deaf children. Clearly the Fitzgerald Key is a method of direct language instruction that is too formal and poorly timed with regard to language development. Children with hearing loss need to be given opportunities to generate language naturally, with appropriate recasting, while direct instruction well timed from a developmental perspective is provided in the curriculum.

Continued Intervention Throughout Childhood

In 1968, Carol Chomsky completed her dissertation, titled The Acquisition of Syntax in Children from 5 to 10 (Chomsky 1969). This work was a demonstration of the kinds of complex morphosyntactic structures acquired after the start of elementary school by children learning language in typical fashion. These constructions often have to do with meanings that cannot be derived from the surface form. For example, the two sentences in each pair below share the same surface form, but the meanings are different:

John is easy to please.
John is eager to please.

Donald promises Mickey to do a somersault.
Donald tells Mickey to do a somersault.

In her investigations, Chomsky found that typically developing 7- to 8-year-olds often failed to comprehend the differences in these kinds of sentence structures when semantic and external cues were removed. Thus these are samples of language skills that do not usually emerge until after children start school. In complement to those syntactic trends, Liberman et al. (1974) demonstrated that typically developing children do not have sufficient sensitivity to phonemic structure to enable them to count the numbers of phonemes in monosyllabic words until they are in second grade, even though they are capable of counting the numbers of syllables in multisyllabic words at kindergarten. When it comes to lexical development, the term *restructuring* is commonly used to refer to the process observed for children in that 5–10-year-old range. In early childhood, children enter words into the lexicon using holistic forms. Gradually, up to roughly the age of 10 years, the lexicon is reorganized until it is eventually structured according to word-internal phonemic units (e.g., Ferguson and Farwell 1975; Storkel 2002; Walley 1993). In sum, there is a lot of language development that is not expected to happen until after children enter school.

No one involved in the care of children with CIs discounts the importance of starting intervention as early as possible. When implemented properly, that intervention results in the acquisition of language skills in roughly the normal range (i.e., better than 1 SD below the mean of typical children) for half the children born with severe-to-profound hearing loss by the time they are ready to enter school. However, based on these outcomes, an equally common view has evolved that deaf children are ready to graduate from early intervention prepared to acquire on their own the language skills typically learned after the start of regular school. But there is no basis for that assumption. There is no reason to suspect that children with CIs who acquired early language skills only with strong support will stop needing that level of support once they enter school. Special teaching and language experiences beyond what is afforded children with normal hearing need to be provided during the toddler-preschool years for these children to develop the skills that they do during that time. Similar kinds of support are required once they start school, as well, in order for them to continue the learning process. In their chapter on the syntax of deaf children learning English according to the oral method, de Villiers et al. (1994) listed three factors that are needed for the acquisition of a first language: (1) innate language acquisition mechanisms; (2) the natural unfolding of biological and cognitive factors with maturation; and (3) experience with high-quality inputs. There is no reason to suspect that the first two of these factors would be deviant in children whose only problem is a sensorineural hearing loss. These children have typical language acquisition mechanisms, and maturation of biological and cognitive determinants of language should unfold at the usual rate. However, the third requisite factor is more difficult to provide. It is critically important that the nature and timing of language input and experience be kept as close to a natural timetable as possible, if these children are to develop as their peers with normal hearing. That requires the provision of adequate support for children with CIs after they start school.

Another way to conceptualize the need for ongoing support for deaf children with CIs is by viewing speech and language learning as a series of sensitive periods. Currently, the notion of a sensitive period for language learning is viewed as one single entity that starts at or before birth, and narrows dramatically sometime prior to the start of regular school age. A visual representation of this phenomenon was developed by Tomblin et al. (2007), and is shown in the top of Fig. 20.3. But different language skills emerge at different ages in typical children, coinciding with the ontogeny of various biological, cognitive, and even social factors. Consequently there is no reason to envision a single, monolithic sensitive period. The characterization of serial sensitive periods, shown on the bottom of Fig. 20.3, might be a more realistic perspective (e.g., Newport et al. 2001). According to this view, different language skills emerge at different stages of childhood. Ongoing, strong support for language learning is required by deaf children with CIs to help them through all of these emergent processes.

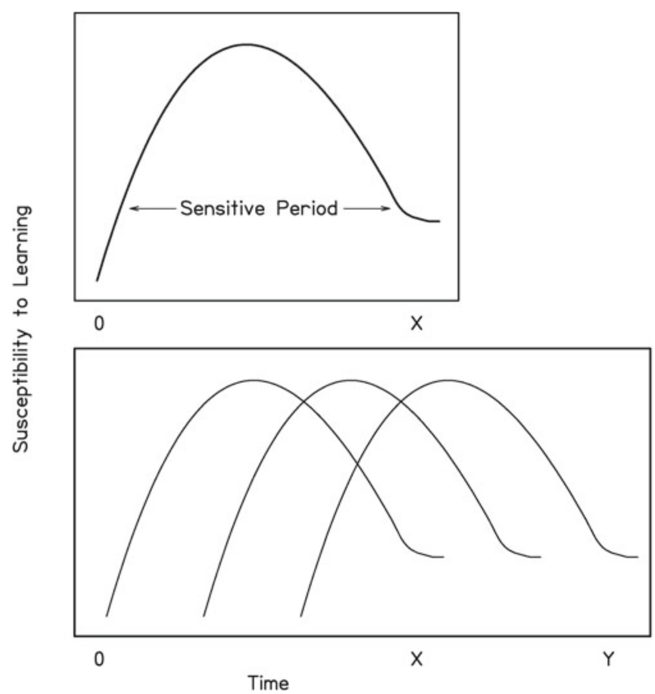

Fig. 20.3 Images illustrating the traditional conceptualization of a sensitive period for language learning, consisting of one such period extending from birth to roughly the start of school age (*top*), and a reformulation of this concept suggesting that a more appropriate perspective might view the phenomenon as serial sensitive periods extending into school age (*bottom*)

Other Treatment Considerations

Age of Implantation

One of the most highly debated treatment factors when it comes to children with CIs concerns how early a child should be implanted, specifically whether there is a need to push for very early implantation. There is widespread agreement that once unambiguous auditory thresholds have been obtained indicating hearing loss severe enough to warrant a CI, the child should receive it as soon as possible—assuming that there are no other medical considerations that might preclude implantation at that time. The issue in dispute specifically concerns how necessary it is to press to do the surgery very early—well before the first birthday—when there may be lingering diagnostic questions, medical concerns, or emotional issues on the part of family members.

Many studies of language acquisition in children with CIs report significant effects on outcomes as a function of the age of implantation for the first CI (Connor et al. 2006; Dettman et al. 2007; Kirk et al. 2000). For example, Geers and Nicholas (2013) showed that even after roughly eight and a half years of CI use, age of first implant still explained about 15 % of the variance in the latent language scores of a group of 60 children who received their first CIs between 12 and 38 months ($r = -0.396$). If there is a linear effect of age of first implant between 12 and 38 months, there is no reason to expect that relationship would be different below 12 months of age. Thus, "as early as possible" would seem the best policy when it comes to implants, and some investigators have explicitly reported benefits tied to implantation before the first birthday. For example, investigations by Houston and Miyamoto (2010) and Leigh et al. (2013) demonstrated better vocabulary scores for preschoolers who received first CIs before 12 months of age than for those who received first CIs between 12 and 24 months of age. However, these findings of significant effects of age of first implant are not consistently observed across studies. For example, Walker and McGregor (2013) failed to find any effect in a study of word learning by children with CIs.

In the EDCHL study, age of first implant was found to be a significant factor explaining language outcomes for children with CIs, but only for a subset of those children. Of the 50 children with CIs in that longitudinal study, 26 of them had continued to wear a hearing aid on the unimplanted ear for at least a year after they got their first implant. That group is referred to as the *some bimodal* group. The other 24 children ceased wearing a hearing aid around the time they received that first implant. Those children are referred to as the *no bimodal* group. Mean age of first implant was 22 months (SD = 14 months) for the children who had some bimodal experience at the time of their first implant, and 14 months (SD = 5 months) for the children who had no bimodal experience. The factor of whether children had some bimodal experience or not at the time of first implant turned out to be highly predictive of later language skills, and that effect could not be traced to other, potentially confounding factors such as socioeconomic status (Nittrouer and Chapman 2009). Table 20.2 shows Pearson product-moment correlation coefficients between each of the five language measures and age of first implant for each group. As can be seen, age of first implant explained significant amounts of variance only for the children with no experience wearing a hearing aid and a CI simultaneously. Based on these findings, the possibility presents itself that differences in whether or not age at first implant is found to explain significant proportions of variance in language outcomes across studies might be tied to whether the children included in the different samples tended to have some bimodal experience or not. That factor is rarely reported.

Bimodal Experience

The outcomes reported above regarding the effects of early bimodal experience are believed to reflect the important role that acoustic hearing—even if it is just a small amount—likely has on an individual's skill at perceptually organizing the degraded signal received through a CI. Even though the information provided is highly constrained, the amplified signal that infants with severe-to-profound hearing loss hear through high-powered hearing aids seems to be enough to help them learn to recognize speech signals as speech, and appropriately organize those signals. That experience with hearing aids may facilitate the shift in processing from the primary auditory cor-

Table 20.2 Pearson product-moment correlation coefficients between age of first implant and various language measures at second grade, for children who had some bimodal experience at the time of first implant and those who did not have any bimodal experience

	Expressive vocabulary	Auditory comprehension	MLU	Reading comprehension	Working memory
Some bimodal ($N = 26$)	−0.257	−0.339	−0.158	−0.094	−0.224
No bimodal ($N = 24$)	−0.404	−0.485*	−0.501*	−0.420*	−0.407*

Expressive Vocabulary represents standard scores from the EOWPVT; Auditory Comprehension represents standard scores from the CASL; MLU is mean length of utterance from the 20-min narrative sample; Reading Comprehension represents number of questions answered correctly about reading passages; Working Memory represents the number of words recalled in correct order. Correlation coefficients are all significant ($p < 0.05$) for the no-bimodal group; none are significant for the some-bimodal group

*$p < 0.05$ (2-tailed test)

tex to the motor cortex for speech signals, a shift observed by Imada et al. (2006) and described by Kuhl (2010) for children with normal hearing. It may be that children who either have only very limited experience with hearing aid use or discontinue wearing a hearing aid upon receiving a first implant must (re)learn how to organize the new signal they are hearing through their CIs, and (re)train the auditory system to project the input to the motor area of the cortex, starting from scratch. When no continued hearing aid use is provided, it makes sense that the earlier the first implant is received, the better. But children who continue to wear a hearing aid upon receiving a first implant may not have to go through the relearning process. It may be that consistent use of a high-powered hearing aid conditions the auditory system to handle acoustic inputs appropriately. As long as the new signal provided by the CI is accompanied by the hearing aid signal, it could be that the auditory system handles both inputs together, and according to the way the typically developing auditory system handles acoustic speech signals.

Of course, one potential challenge to the claim made above is that children who were given some amount of time with a bimodal configuration might have had better pre-implant auditory thresholds, thus biasing clinicians to provide that period of bimodal stimulation. And indeed that may have been the case for the children in the EDCHL study. Whereas the children who had no bimodal experience had mean pre-implant, three-frequency (0.5, 1.0, and 2.0 kHz) PTAs of 108 dB hearing level (SD = 11 dB), the children who had some bimodal experience had pre-implant PTAs of 97 dB hearing level (SD = 15 dB). Nonetheless, when Pearson product-moment correlation coefficients were computed between each of the language measures shown in Table 20.2 and pre-implant pure-tone average thresholds, none of these correlations were found to be significant. That lack of significance was observed when all children with CIs were included in the analysis. These correlation coefficients were also computed separately for the group of children who had some bimodal experience. Again, no significant relationships were obtained, indicating that even children with PTAs poorer than 100 dB hearing level stood to gain from a period of bimodal stimulation. Thus, in spite of the difference in pre-implant auditory thresholds, those thresholds are not able to explain any differences found for the two groups. It seems that even children with very little residual hearing in only the very low frequencies benefit from a period of wearing a hearing aid early in the language learning process.

Bilateral CIs

Another treatment option that is debated when it comes to children with severe-to-profound hearing loss involves bilateral CIs. There is a growing trend to give infants and toddlers with severe-to-profound hearing loss two CIs as soon as possible, a trend based at least partly on evidence from electrophysiological studies showing that having just one CI can lead to abnormal cortical organization in children (Gordon et al. 2007, 2008, 2013). However, where language is concerned, it is not clear what the effects of that abnormal organization might be. Certainly providing two CIs could be expected to promote auditory effects that derive from binaural listening, such as localization and spatial release from masking. Evidence of just those benefits has been observed, although these binaural effects are neither especially strong nor consistent across children with bilateral CIs (Grieco-Calub and Litovsky 2010; Misurelli and Litovsky 2012; Nittrouer et al. 2013). These diminished and inconsistent effects are likely attributable to problems with bilateral fitting (Kan et al. 2013), so research efforts are currently being undertaken to improve methods of bilateral fitting. Nonetheless, even if bilateral CIs are fit to maximize binaural effects, improvements in language acquisition are not assured. Each CI still provides spectrally degraded inputs. Children with unilateral CIs are already at risk for language delays, due precisely to the degraded quality of the input. It is not clear that having degraded signals at both ears should be expected to do anything to benefit language acquisition. Some studies have demonstrated better language scores for deaf children with bilateral CIs than for those with unilateral CIs (e.g., Boons et al. 2012), but that effect has not observed in this laboratory. Table 20.3 shows, in the top two rows, mean scores of language measures for children with one and two CIs at the time of testing. (Participant numbers in this table are fewer than in the last table because six children continued to use bimodal stimulation at the time of testing. Those children are not characterized as having either one or two CIs in Table 20.3.) In this table, a mean of the three phonological awareness tasks (initial consonant choice, final consonant choice, and phoneme deletion) was used as the metric of phoneme awareness, and is termed PA mean.

It appears from these data that children with two CIs performed better on most of the language measures. However, when scores from children with two CIs are separated into groups based on whether or not those children had some bimodal experience near the time of their first implant, shown in the bottom two rows of Table 20.3, it becomes clear that the advantage only extends to children with two CIs who had some bimodal experience. It is especially apparent from this table that scores for children with two CIs who had no bimodal experience, shown in the last row of the table, are similar to those for children with one CI, shown in the top row of the table. The children who performed the best on these language measures in this study were those who had some bimodal experience around the time of receiving a first implant and then went on to receive a second implant. These are the scores shown in the third row of Table 20.3.

Table 20.3 Means and *standard deviations* of language measures for children with one and two CIs are shown in the top two rows

	EOWPVT		CASL		MLU		PA		Comp.		W.R.		W.M.	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
One CI (*N*=13)	89	14	91	13	5.01	1.14	44	21	15	5	99	13	38	11
Two CIs (*N*=31)	99	20	105	22	5.68	1.40	55	25	18	7	103	17	45	17
Some bimodal (*N*=17)	106	20	114	20	5.97	1.49	60	23	19	6	106	15	50	20
No bimodal (*N*=14)	91	18	93	21	5.33	1.26	48	26	16	7	100	19	39	10

Scores for children with two CIs are separated based on whether or not those children had some bimodal experience near the time of receiving a first implant, and means and *standard deviations* for those groupings are shown in the bottom two rows

Sign Support

Although this chapter has focused on children with CIs who have been growing up with the expectation that spoken English would be their first language, some parents elected to send their children to early intervention programs that supplemented spoken language input with sign language, either an English-based system or American sign language. A total of 17 children with CIs were in sign-supported programs during the preschool years. By second grade, however, no child remained in a sign-supported program or had a sign-language interpreter in school. Nonetheless, *t* tests were computed to see if there were differences in language performance based on early sign experience. The measures examined were expressive vocabulary (EOWPVT), auditory comprehension (CASL), MLU, phonological awareness (PA mean), reading comprehension (QRI), word reading (QRI), and working memory (number of words recalled in the correct order). The only measure to show a significant effect of sign exposure was MLU, $t(48) = 2.55$, $p = 0.014$: children who were in oral-only programs prior to starting kindergarten had a mean MLU of 5.76 (SD = 1.03) and children who had some sign exposure during those early years had a mean MLU of 4.79 (SD = 1.65). Those results were not differentiated based on whether the early sign system used was American sign language or an English-based system. (Some children with NH were also exposed to sign language early in life through the popular *Baby Signs* programs, but no differences in language abilities at this second-grade testing were observed for these children based on that sign exposure.)

Summary

Several broad ideas for intervention were discussed in this chapter. Based on empirical outcomes, it was recommended that children with CIs need intensive support for language learning throughout childhood. A model that carefully integrates enriched, naturalistic experience along with direct language instruction was recommended. The need for providing high-quality sensory input at all times was discussed. It was specifically recommended that the sensory input through the implant be supplemented by amplified acoustic hearing, at least for a while near the time of first implantation. An argument was made for providing visual input (i.e., speechreading) whenever possible. The importance of requiring children with CIs to generate and produce linguistic structures was highlighted. While cochlear implantation as early as reasonably possible is recommended, age of implantation for these children was not found to explain especially large proportions of variance in overall language outcomes. At least where language acquisition is concerned, no special benefits of two implants over one have been observed. At present, an intervention approach that provides a robust sensory input with a rich language environment offers the strongest means of helping children with hearing loss achieve their full language potential.

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