Language and Literacy Skills in Children with Cochlear Implants: Past and Present Findings

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Introduction

The topic of language acquisition in deaf children is one that can easily evoke visceral responses from clinicians and researchers in the field when it arises, a situation that might surprise anyone who does not have regular interaction with deaf individuals. To laypeople, hearing loss is seen as a problem of just that—hearing. But for those of us who work in deafness-related fields, it is more closely characterized as a problem of communication. Where children are concerned—especially since cochlear implants arrived on the scene—the problem of hearing loss is viewed primarily as a load placed on language learning, rather than as a problem of auditory sensitivity. In fact, the major challenge faced by scientists and clinicians is finding ways to facilitate language learning so that deaf children can progress through childhood unscathed by the deleterious consequences that can result from hearing loss. (Throughout this chapter the terms *deaf children* and *children with severe-to-profound hearing loss* are used more or less interchangeably to refer to children with average auditory thresholds no better than 70 dB hearing level, and generally much worse.)

Regardless of one's particular view concerning what language deaf children should be learning (the omnipresent question of whether it should be spoken or signed language) or how that learning should be facilitated, most professionals would agree that two key ingredients need to be provided in order for language to blossom: clear sensory input and adequate experience. Both of these ingredients are in short supply for deaf children, regardless of which language they are being encouraged to learn. (Throughout this chapter, terms referring to the *teaching* of language are avoided because of the philosophical perspective taken by the authors that language is not taught, for the most part. Rather, language emerges, or blossoms within children as part of the natural developmental process, facilitated by appropriate nurturing.)

If the decision is made that a child born with severe-to-profound hearing loss should be brought up learning a spoken language, strong constraints are imposed on the sensory inputs available because of that hearing loss. Although vision provides some access to the signals generated in the course of spoken language production, that information is limited because many articulatory gestures are not observable visually. Acoustic signals serve as the primary vehicles of transmission for sensory information generated during spoken language production. And even though cochlear implants have done a tremendous job of providing access to acoustic signals—effectively solving the problem of sensitivity—they nonetheless provide only degraded versions of natural speech. Spectral detail is greatly constrained by signal processing and delivery with cochlear implants, hampering access to many acoustic cues to phonemic categorization. Temporal structure arising from the actions of the larynx is largely absent, as is the harmonic structure generated by those actions. That factor accounts at least partly for the tremendous decrements in speech recognition observed when implant users must function in poor listening environments, such as noise or reverberation. And the problems associated with trying to listen in those tough environments serve to constrain the amount of language experience deaf children with cochlear implants (CIs) can obtain because many natural listening environments consist of some noise, arising from other speakers, the environment or reverberation. In the final analysis, both input and experience with spoken language are constrained for children with CIs.

Where sign language is concerned, it is true that deaf children have no sensory restriction on their access to the structure of that language: all components of sign language are available visually. Input is adequate for children who are

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deaf, but have no visual impairments, at least in principle. However, that point is only relevant for deaf children born to deaf/Deaf parents who are proficient signers themselves. Those children, who constitute about 5 % of all children born deaf, acquire sign language in a manner similar to how hearing children acquire spoken language (Lederberg et al. 2013). Generally speaking, though, deaf children are born to parents with normal hearing who have no proficiency in sign language. Even with the sincerest of intentions on the part of parents to facilitate their children's acquisition of sign language, these children will have highly constrained access to appropriate models of sign language. In the home, parents are unable to provide the kinds of rich language input that is usually provided to children. And it is extremely difficult to provide enough time in intervention to foster adequate exposure to sign language to make it a true first language.

This chapter is focused on the acquisition of spoken language by children with CIs; in particular, the acquisition of spoken English. Depending on the source of the estimates, something in the range of 93–96 % of children born with hearing loss are born to parents with normal hearing (Gallaudet Research Institute 2011). When those hearing losses are severe enough to warrant a cochlear implant, parents with normal hearing typically reach the decision to give their children implants for the specific purpose of facilitating the acquisition of spoken language, not sign language.

This chapter is divided into two sections. First, a review is provided of relevant data on language and literacy outcomes of children with severe-to-profound hearing loss who use CIs. Where language is concerned, both receptive and expressive language abilities are reviewed, providing a benchmark of how well children are faring with CIs. Where literacy is concerned, only reading is discussed in this chapter. Although of interest, there are not sufficient data on the writing abilities of deaf children to make conclusive statements at this time. A greater research effort needs to be dedicated to studying the writing skills of these children before we will have a collective account as comprehensive in nature as the one we have for their abilities in the areas of speech production and recognition, and reading.

Data of two sorts are discussed in this first section: (1) data from tests that are standardized in nature and meant to provide overall pictures of how children with CIs are performing with respect to language development, and (2) data from experimental protocols focusing on specific language-learning mechanisms. This review is largely restricted to school-age children.

In the second section of this chapter, a description is provided of data collected in our laboratory. These data come from a longitudinal study of children, both with hearing loss and with normal hearing. Specifically, performance levels will be described for children in this study at the age of 8 years. In this study, both standardized measures as well as experimental protocols have been incorporated in order to examine which specific language and cognitive mechanisms support the acquisition of spoken language and literacy.

Review of Research by Others

Anyone who is old enough to recall working with severely to profoundly deaf children before cochlear implants were available will readily recall the idiosyncratic language patterns of these children. There were, of course, the ubiquitous speech production errors that severely diminished intelligibility. Some of these speech production errors were problems with source support, such as breathy voice or deviant nasality. Other problems in production had to do with a failure to generate and coordinate the movements of the vocal tract, so omissions, epenthesis, and substitutions were frequent. But even when a listener could "hear through" those errors, the morphosyntactic and lexical constructions of the utterances were peculiar (e.g., Baumberger 1986; de Villiers et al. 1994; Quigley et al. 1976; Wilbur et al. 1976). Sentence structures were typically simple, with a lack of "sparkle" features such as adjectives beyond the ordinary or compound constructions of any kind. Inflectional morphemes (such as plural -s) were often missing. Contractions were rarely used. Function words were frequently absent. The pattern of language production and accompanying errors were recognizably unique to deaf children, a fact that might be attributable to the very formal approach taken to teaching these children language or to the late age at which most language skills were acquired. When tests standardized on hearing children could be implemented, deaf children of school age generally achieved age equivalency scores of roughly 3 or 4 years (Bishop 1983; Watson et al. 1982). When elicited productions of deaf and hearing children were analyzed, similarly low age equivalencies were observed for the deaf children (de Villiers 1988). These extremely delayed language abilities made the very information obtained by these assessment tools of little value for helping school-age deaf children acquire better language. Because they were cognitively well past the maturational levels of the children with whom they were matched in terms of language, typical language learning mechanisms could not be engaged. These qualities of the language of severely to profoundly deaf children (i.e., very low age equivalency scores and highly stylized structures) led to the development of evaluation instruments specifically designed for deaf children, such as the Scales of Early Language Communication Skills for Hearing-Impaired Children (Moog and Geers 1975). From these instruments teachers were able to get the kinds of data they needed to develop effective intervention programs for school-age deaf children. However, outcomes of these specialized tools made it difficult to gauge the language performance of deaf children, relative to that of children with normal hearing.

Once CIs were introduced to the treatment arsenal for deaf children, outcomes immediately improved, which meant that assessment tools could be modified. Many of the speech and language qualities so recognizable in deaf children before CIs were available have all but disappeared, with perhaps the most salient change involving speech production. The numerous source problems previously heard in the speech of many deaf children are rarely found any longer. Expressive language has improved for deaf children, as well, to the point where it is commonplace to use assessment tools designed for children with normal hearing. With the goal of early intervention set as having these children ready to enter mainstream classrooms with normal-hearing children by the traditional start of school it is important that we have an idea of how proficient deaf children with CIs are in terms of language skills, relative to same-age peers with normal hearing. Assessment tools designed for children with normal hearing suit that purpose. Overall, the question now becomes whether deaf children with CIs have the language skills required to keep up in regular classrooms. To help answer that question, data were examined from recent studies evaluating the spoken language abilities of children with CIs.

Review of Research by Others: Standardized Measures

For this chapter, we searched the literature for published reports of studies that made use of standardized assessment instruments to evaluate the performance of children with CIs on five kinds of language skills.

Lexicality

Results for tests of both receptive and expressive vocabulary measures are reviewed. This skill refers to the number of individual words a child has in her lexicon. Although slightly different from semantics, the two skills—vocabulary and semantics—are closely related. Semantics refers to how a speaker is able to convey word meaning in connected discourse. Naturally, the larger one's lexicon is, the more precisely that word meaning can be conveyed. Standardized evaluations of vocabulary can take two forms. Tests of receptive vocabulary involve having children listen to words in isolation and identify the picture from a small set that represents each word. Tests of expressive vocabulary require children to look at a picture and provide a word to label it. An example of a receptive vocabulary measure is the Peabody Picture Vocabulary Test (PPVT) (Dunn and Dunn 2007). An example of an expressive vocabulary measure is the Expressive One-Word Picture Vocabulary Test (EOWPVT) (Brownell 2000).

Grammar (Morphosyntax)

Results of both receptive and expressive morphosyntactic abilities are reviewed. These skills refer to how well a child can use syntax to combine words into sentences, and appropriately incorporate morphological units into those words and sentences. Several standardized tests have been developed to quantify the language level of children in general, including the Test of Language Development (TOLD) (Hammill and Newcomer 2008), the Clinical Evaluation of Language Fundamentals (CELF) (Semel et al. 2013), and the Comprehensive Assessment of Spoken Language (CASL) (Carrow-Woolfolk 1999). These tests provide robust metrics of morphosyntactic abilities, both receptive and expressive.

Phonology

This level of structure refers to the actual sound patterns of the language; in particular, how phonemes are arranged. Having well-developed sensitivities to this level of linguistic structure is critical to a wide variety of language processes. For example, phonemic units form the substance used to store language in short-term memory buffers. Without strong sensitivity to the phonological level of linguistic structure, it is difficult to store sufficiently long sequences of language material to support the comprehension of sentences with complex syntax, which are often long. It is also important to have well developed sensitivity to phonological structure in order to acquire awareness of some morphological structures because morphemes can consist of single phonemes, such as the plural –s. And because words are stored in the lexicon according to phonemic structure, at least for adults (Luce and Pisoni 1998), refined sensitivity to this level of structure is a prerequisite for eventually developing large vocabularies. Finally, it is critical that a child develop adequate sensitivity to phonemic structure in order to learn to read because the symbols of our writing system largely represent individual phonemes. A commonly used standardized test of phonological sensitivity and abilities is the Comprehensive Test of Phonological Processing (CTOPP) (Wagner et al. 1999).

Reading

Two kinds of skills are often evaluated when it comes to reading: the ability to recognize isolated words and the ability to comprehend passages that are read. Reports concerning the emergence of both of these skills in deaf children were sought for this review. One other kind of skill is sometimes measured in regard to children's reading acquisition, and that has to do with fluency, which is measured by tallying the number of words a child can correctly read in a specified amount of time. That skill has not been examined extensively for children with CIs, but an earlier report from this laboratory showed no differences in fluency between children with CIs and those with normal hearing

(Nittrouer et al. 2012). Consequently, fluency was not considered in this review of research by others. However, it is examined in the second section of the chapter.

Several tests of word reading are available. For example, in our laboratory we frequently use the Word Reading subtest of the Wide Range Achievement Test (WRAT) (Wilkinson and Robertson 2006). In these assessments, the child is asked to read a sequence of unrelated words that become increasingly harder as the list progresses. When it comes to reading comprehension, this skill is usually assessed by asking children to read a passage, and then answer questions to assess comprehension of that passage. Generally speaking, several passages and associated questions are used, of increasing difficulty. In our laboratory, we have used the Qualitative Reading Inventory (QRI) (Leslie and Caldwell 2006), which contains several passages at each grade level and comprehension questions related to each passage. That structure is typical of reading assessments.

Working Memory for Speech

Finally, recent reports on working memory for speech (or phonological working memory, as it is also called) were sought. Although not exactly a language skill, this cognitive function so strongly underlies language performance that it was considered important to examine. Typically, the concept of working memory refers to how efficiently an individual can preserve a sequence of phonologically relevant items in a short-term memory buffer, although the additional ability of performing some sort of action on those items is often incorporated into the definition. In order to assess working memory by the first of these definitions (i.e., simple storage of verbal items), a child may be asked to repeat a sequence of digits in the order in which they were produced. The number of digits the child can correctly recall is used as the dependent variable, and is known as forward digit span. To assess the second description of working memory (i.e., storage and processing of verbal items), the child is asked to repeat a sequence of digits, but backwards. Thus, the process that must be performed on the digits is to reverse the order. This task is known as backwards digit span.

Criteria for Including Reports

In our search to find reports related to each of the five skills listed above, certain constraints were imposed. First, the report had to concern children with CIs who did not use sign language as a primary communication mode. There are intervention and educational programs that use signing systems, usually English based, to support the acquisition of spoken language. Studies including children in those sorts of programs were not excluded from the review because the goal of those programs is steadfastly to facilitate the development of spoken language in deaf children; it just happens to be the educational philosophy of the programs that a signed language can facilitate the acquisition of a spoken language in children who are unable to hear speech clearly. Nonetheless, all dependent measures used in the studies reported here had to involve spoken language. If a study granted children the option of responding in sign language, that study was not included in this review.

All studies had to involve school-age children, meaning they were in roughly grades kindergarten through high school. There was also the presumption that most, if not all, children in any study selected had been born with severe-to-profound hearing loss or lost their hearing very early in life. The children in the studies included in this review must have received their CIs relatively early in life, as well. In particular, most children in any single study must have received them before the age of 3 years. And only studies with English-learning children were included in this review. We also restricted the range of publication dates, from 2008 to 2013, a 5-year span.

The studies themselves had to adhere to specific procedures that underlie rigorous research. In particular, the study had to include at least 20 children with CIs in order to provide any reasonable degree of power. There needed to be some evidence of the validity of the assessment tools used, and the reliability of measurement procedures.

Outcomes for Literature Review

Table 11.1 lists the set of reports culled from the literature matching the selection criteria established for this review. A general conclusion that may be drawn from these studies is that, regardless of which language skill is examined, children with severe-to-profound hearing loss who use CIs are performing, on average, one standard deviation below the mean of age-matched children with normal hearing. That means that children with CIs obtain mean standardized scores of roughly 85 or mean scaled scores of 7. An irrepressible optimist might view these outcomes as clear evidence that CIs have changed the landscape completely for children with severe-to-profound hearing loss. These kinds of scores would not have been possible before CIs became available. This collective finding means that roughly half of the children with that degree of hearing loss are in what may be described as the normal range of language abilities for their age. That is a tremendous advance over performance levels of the past. The glass truly may be seen as half full.

The realist, on the other hand, looks at these scores and recognizes that children with severe-to-profound hearing loss still are not attaining the levels of language proficiency that they presumably would have attained had they not been born with those hearing losses. One standard deviation below the mean is the 16th percentile in terms of population ranking. This means that half of the children born with severe-to-profound hearing loss are displaying language abilities in the lowest 15th percentile rankings of children with normal

Table 11.1 Summary of outcomes of standardized testing with children with cochlear implants

Authors (year)	Numbers	Measures	Results
Lexicality (Vocabulary)			
Schorr et al. (2008)	39 CI and 37 NH matched for age and gender, ages 5–14	PPVT and EVT	CI means were ≈1 SD below control means PPVT: NH-112, CI-87 EVT: NH-106, CI-91
Geers et al. (2009)	153 CI, ages 5–7	PPVT, EOWPVT, EVT	CI means were ≈1 SD below normative mean PPVT: 86 EOWPVT/EVT: 91
Johnson and Goswami (2010)	39 CI (20 early implant, 19 late implant) and 19 NH matched for reading level, ages 5–15	EOWPVT	CI means in both groups were ≈2 SDs below control means EOWPVT: NH-108, CI-80 and 76
Conway et al. (2011)	23 CI and 26 NH matched for age, ages 5–10	PPVT	CI mean was ≈2 SDs below control mean PPVT: NH-114, CI-86
Fitzpatrick et al. (2012)	21 CI, age 10	PPVT	CI means were >1 SD below normative mean PPVT: 77
Grammar			
Schorr et al. (2008)	39 CI and 37 NH matched for age and gender, ages 5–14	TOLD	CI mean was >1 SD below control mean TOLD: NH-12.3, CI-8.4
Geers et al. (2009)	141 CI, ages 5–7	CELF	CI means were >1 SD below normative mean CELF: 79
Fitzpatrick et al. (2012)	21 CI, age 10	CELF	CI means were ≈2 SDs below normative mean CELF: 71
Tobey et al. (2013)	160 CI, ages 6–12	CASL	CI means were >1 SD below normative mean CASL: 76 and 78
Phonology			
Schorr et al. (2008)	39 CI and 37 NH matched for age and gender, ages 5–14	CTOPP	CI mean was ≈1 SD below control mean CTOPP: NH-12.3, CI-8.7
Geers and Hayes (2011)	112 CI, ages 15–18	CTOPP	CI mean was ≈1 SD below normative mean CTOPP: 6.9
Fitzpatrick et al. (2012)	21 CI, age 10	CTOPP	CI means were between 1 and 2 SDs below normative mean
Reading			
Spencer and Tomblin (2009)	29 CI and 29 NH matched on mother's education and word comprehension, ages 6–17	WRMT	CI means on both tasks were at least 1 SD below control mean WRMT-WA: NH-117, CI-101 WRMT-WC: NH-108, CI-93
Johnson and Goswami (2010)	39 CI (20 early implant, 19 late implant) and 19 NH matched for reading level, ages 5–15	NARA-R	CI means were ≈1 SD below control mean NARA: NH-99, CI-85 and 81
Geers and Hayes (2011)	112 CI, ages 15–18	PIAT	CI total mean was ≈1 SD below normative mean PIAT: 83
Working memory			
Pisoni et al. (2011)	108 CI ages 8–9 and 112 CI ages 15–16	WISC-III Digit Span	CI means were <1 SD below normative means WISC: 6.44, 6.38
Harris et al. (2013)	66 CI, ages 6–12	WISC-III Digit Span	CI means were 1 SD below normative means

Note: Numbers: shows numbers in CI group and control group, if applicable, and age range in years; *Measures*: *PPVT*, Peabody Picture Vocabulary Test (Dunn and Dunn 1997); *EVT*, Expressive Vocabulary Test (Williams 1997); *EOWPVT*, Expressive One Word Picture Vocabulary Test (Brownell 2000); *TOLD*, Test of Language Development (Hammill and Newcomer 1997); *CELF*, Clinical Evaluations of Language Fundamentals (Wiig et al. 2004); *CASL*, Comprehensive Assessment of Spoken Language (Carrow-Woolfolk 1999); *CTOPP*, Comprehensive Test of Phonological Processing (Wagner et al. 1999); *WRMT*, Woodcock Reading Mastery Tests (Woodcock 1987): Word Attack (WA) and Word Comprehension (WC); *NARA-R*, Neale Analysis of Reading Ability-Revised (Neale 1997); *PIAT*, Peabody Individual Achievement Test (Dunn and Markwardt 1989); *WISC-III*, Wechsler Intelligence Scale for Children, 3rd Ed. (Wechsler 1991); *Results*, given relative to means of normative sample or specific control group in study, and as standard or scaled scores when possible; standard scores have normative means of 100 with SDs of 15; scaled scores have normative means of 10 with SDs of 3 hearing. That kind of language proficiency makes it difficult to compete in the mainstream. We, as a profession, cannot be satisfied with these outcomes. The glass remains half empty. Strong research efforts need to continue in order to find ways to improve these outcomes.

Review of Research by Others: Nonstandard Measures

The clear conclusion to be drawn from the studies reviewed above is that in spite of the beneficial effects accrued by deaf children from CIs, they still are not performing as well as children with normal hearing in terms of their language abilities. The half of children with CIs whose standardized test scores are within the normal range—defined as better than one standard deviation below the mean of children with normal hearing—are in all likelihood not performing at the levels that they would attain, if they did not have severe-to-profound hearing loss. Even at that, comparing scores from standardized instruments to published norms underestimates the true magnitude of the average deficit for these children with CIs. Parents who choose to participate in research studies tend to be heavily involved in their children's upbringing, and are often well educated. Both these factors positively influence language development and are associated with high scores on standardized tests. Evidence of this claim is provided by the findings shown in Table 11.1. Means for children in the control groups of almost every study were above the normative means, often by as much as one standard deviation. That trend suggests that the children with CIs in these studies would have been performing comparably, if it were not for their hearing loss. The goal of current research efforts must be to move the language performance for children with severe-to-profound hearing loss who wear CIs to the levels they would achieve if it were not for the hearing loss.

In addition to studies that make use of standardized instruments are ones that investigate the mechanisms underlying each language skill considered above. These studies point us to the kinds of underlying skills that need to be measured and sharpened in order to improve the overall language performance of individual children with CIs. For these reasons, several experiments on the mechanisms that underlie the language skills discussed above are reviewed here.

For the selection of experiments to be discussed in this section, criteria were again imposed. Any study that is discussed had to focus on a specific mechanism, using nonstandard assessment methods. That meant that scores could not be standardized on a larger sample. Accordingly, each study had to include its own control group of children with normal hearing in order to be included in this review section. Again, participants in the studies selected for review had to be learning language primarily through an oral method of instruction, although sign support was permissible as long as there was a clear focus on spoken language. Dependent measures had to consist of spoken language. Not every study meeting these criteria could be included, but a representative sample was selected.

For this review, a restriction regarding date of publication was not imposed. It is reasonable to restrict date of publication when considering benchmarks of how well children with CIs are doing in order to ensure that performance with current devices and intervention procedures are being taken into account. However, when it comes to understanding the mechanisms that underlie the skills measured, those principles would not be expected to change over time or as a function of changes in treatment for a specific group of individuals.

Vocabulary Acquisition

Looking first at vocabulary skills, Table 11.1 reveals that both the receptive and expressive vocabularies of deaf children with CIs are smaller than the vocabularies of their age-matched peers with normal hearing. It appears that vocabulary growth is slowed. In our longitudinal study (e.g., Nittrouer 2010), we have found that vocabulary growth is roughly 2 years delayed for children with CIs. This factor can make it difficult to function in school settings and can hinder the acquisition of literacy because it is affected by lexical knowledge (Wise et al. 2007).

Because of these observed deficits in vocabulary, it is reasonable to ask how children with CIs learn words. Broadly speaking, learning a word to the point where it is a stable and readily accessible element in the lexicon involves three processes. The first stage of this learning is termed *fast-mapping*, which happens when a learner makes a connection between the sensory input and the referent (object, action, attribute, etc.). At first, these fast-mapped representations are not stable and not well specified in terms of meaning. At this point, the learner is able to pick the referent out of a closed set of pictures upon hearing the word, as is the protocol for receptive vocabulary tests, but likely could not retrieve the item from the lexicon in order to label the referent, according to the protocol for tests of expressive vocabulary.

The second step in word learning involves extending the word to other exemplars. Thus, the learner comes to recognize the group of referents that may be labeled with that word, as well as those that do not fit in the category. For example, many furry quadrupeds fit the category of *dog*, but not all of them. Discovering which ones are legitimate members of that category is the process of *extension*. Finally, the learner's experience hearing and producing the word must be sufficient so that the word is retained in the lexicon and can be retrieved at much later times. That process is termed *retention*.

There have been several studies looking at word learning in children with CIs, or children with severe-to-profound hearing loss more broadly (Lederberg and Spencer 2009; Tomblin et al. 2007; Walker and McGregor 2013). Two of these studies included children with normal hearing as control groups (Tomblin et al. 2007; Walker and McGregor 2013). In both cases, it was observed that children with CIs performed more poorly in terms of fast-mapping than age-matched peers with normal hearing. Walker and McGregor further observed poorer skills at extension and retention of new vocabulary items. These authors were able to show that the performance of children with CIs matched that of children with normal hearing who were roughly 14 months younger. Still another study traced the largest share of variance in fast-mapping abilities for children with CIs to their sensitivities to phonological structure in the speech signal, $r^2 = 0.72$ (Willstedt-Svensson et al. 2004). This finding can explain observed deficits in receptive and expressive vocabularies in children with CIs. If the word-learning process depends in large part on sensitivity to phonological structure, children with CIs could be expected to have difficulty because CIs do not provide a signal rich in the kinds of spectral and temporal detail that are thought to underlie phonemic representations. Consequently, their vocabularies suffer.

Sensitivity to Phonological Structure

The lack of sensitivity to phonological structure predicted for children with CIs likely poses problems for other kinds of language learning, as well. Beyond deaf children, this lack of sensitivity is often suggested as a critical deficit underlying problems in reading and working memory skills: In both cases, evidence shows that proficiency in these areas depends strongly on children's abilities to recover phonological structure (primarily phonemic) from the acoustic signal. In fact, one predominant view is that developmental dyslexia can be explained by a single (core) deficit in sensitivity to phonological structure (Snowling 1998; Stanovich 1986; Wagner and Torgesen 1987; but cf., Pennington 2006). Children with normal hearing who get diagnosed as having dyslexia have also been found to demonstrate poorer working memory skills than their typically reading peers (Brady et al. 1983; Nittrouer and Miller 1999; Savage et al. 2007), a finding that has similarly been traced to poor sensitivity to phonological structure (Mann and Liberman 1984; Shankweiler et al. 1979; Spring and Perry 1983). Thus, it is reasonable to propose that much of the deficit in reading and working memory observed for children with CIs may be explained by poor sensitivity to phonological structure in the acoustic speech stream, which in turn arises because of the highly degraded signal they receive through their CIs.

Evaluating children's sensitivity to phonological structure in the acoustic speech signal can be accomplished with a variety of tasks, each tapping into different sorts of phonological skills. The terms *phonological awareness* and *phonological processing* are generally used to refer to slightly different phenomena, although the exact phenomenon to which each refers can vary across reports. In reality, the two terms might be seen as anchoring two ends of a continuum, with the boundary between awareness and processing being somewhat fuzzy. Strictly speaking, phonological awareness refers to the ability to recognize phonological structure—inflectional, syllabic, onset/rimes, and individual phonemes—in the acoustic speech signal. The term *phonemic awareness* is also used to refer to awareness, but strictly of phonemic structure. Phonological awareness tasks usually consist of asking children to explicitly judge similarity or difference in the phonological structure of words, assess whether words rhyme or not, count elements of one type or another, or blend or remove elements from target words or syllables. Phonological processing refers to children's abilities to take structure and use it in further processing, such as in the storage of words in a short-term memory buffer or in repeating non-words. In principle, children may be able to recognize phonological units in the signal, without being able to bring that recognition to the level required for conscious inspection and manipulation known as meta-linguistic awareness. In examining phonological awareness and processing, investigators need to take care to ensure that any differences found between experimental and control groups are not actually due to differences in that meta-linguistic component of testing. One way to do that is to include a range of phonological awareness or processing tasks in the experimental protocol. Patterns of variability across tasks can help identify where any observed problems reside. In particular, if group differences are smaller for tasks with low processing demands, then concern is heightened that children in the poorer performing group have difficulties with meta-linguistic awareness.

Phonological awareness can be further grouped according to the level of structure in the signal being examined. Children acquire sensitivity to various levels of phonological structure at different times during development. Evidence of this maturational effect was first offered by Liberman et al. (1974). They showed that typically developing children were able to count the numbers of syllables within words with better than chance accuracy by kindergarten, but it took until second grade for them to be able to count the number of sounds (or phonemes) in those syllables. The developmental hierarchy of phonological skills was further explicated by Stanovich et al. (1984), who tested kindergarten children on ten separate phonological awareness tasks. By ranking tasks according to mean accuracy of responses they established a developmental hierarchy.

A fundamental point that is easily forgotten when thinking about phonological awareness and processing skills in children is that the acoustic signal of speech is not comprised of sequences of isolable phonemes. Clinical and experimental protocols ask children to perform chores such as counting or matching phonemes, or removing one from a sequence. The implementation of these tasks can reinforce natural impressions that speech signals consist of strings of separate phonemes. But that is not the case. Figure 11.1 shows the sentence *Everybody knows the story of Winnie the Pooh*, and illustrates that it would be impossible to place markers on the *x* axis indicating where one phoneme ends and the next begins. (Spectrograms display time on the *x* axis and frequency on the *y* axis. Energy distribution across frequencies is represented by the darkness of the tracings.) That situation represents the attribute of speech known as a lack of segmentation. Figure 11.2 illustrates another relevant attribute of speech signals, known as a lack of acoustic invariance. This figure shows a single word, *bug*, spoken by a man and by a child. It is apparent in this figure that the acoustic structure affiliated with that production differs drastically for each talker. Thus, not only is it hard to identify individual phonemes in the continuous speech signal, but the acoustic structure affiliated with each phoneme differs depending on factors such as who the talker is. These attributes of speech signals emphasize the fact that speech perception involves more than just the harvesting of either phonemes or acoustic cues from the signal. Several separate processes must be undertaken and coordinated. The listener must know which components of the signal require attention for the perceptual task at hand: recovering phonemes or recognizing the speaker, for example. Those signal components need to be organized appropriately and interpreted within the current linguistic and social context. These considerations emphasize the fact that phonemic structure is highly encoded in the acoustic signal. Consequently, tasks of phonological awareness tap into processes much more complicated than simply recognizing phonemes in the signal. They require appropriate attentional and organizational strategies, as well.

Phonological awareness is an especially important mechanism to evaluate in children with CIs if we want to understand the underpinnings of their language and literacy skills. There is very good reason to suspect that children with CIs will have diminished sensitivity to phonological structure in the speech signal: the signal processing of CIs does not preserve the kind of spectro-temporal structure that strongly supports recognition of phonological structure. At the same time, phonological awareness has reliably been shown to underlie the development of many other language skills: in particular, working memory and reading. In turn, working memory plays a role in the acquisition of morphosyntactic abilities, especially those related to complex syntactic structures. Sentences with embedded clauses tend to be long, so it is important that a child can store long strings of linguistic material in order to discover clause structure in those sentences.

The CTOPP is very commonly used to evaluate phonological awareness and processing. As Table 11.1 shows, when a standardized measure of phonological awareness and processing is needed, the CTOPP is often the test of choice. Nonetheless, there have been some experiments

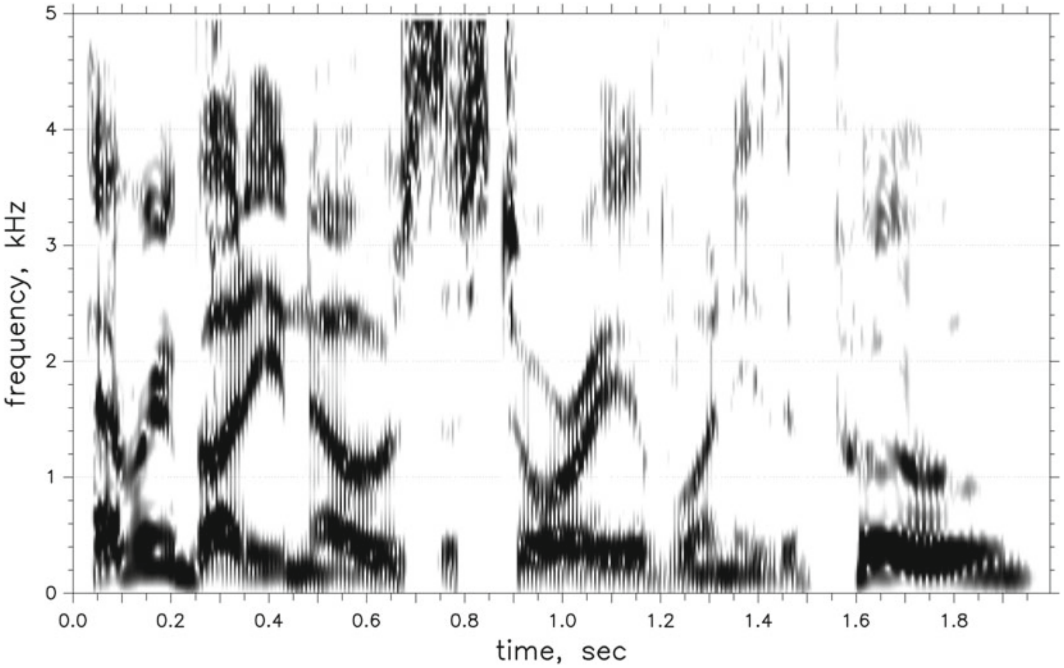

Fig. 11.1 A spectrogram of the sentence *Everybody knows the story of Winnie the Pooh* spoken by a man, illustrating the lack of clear segmental boundaries

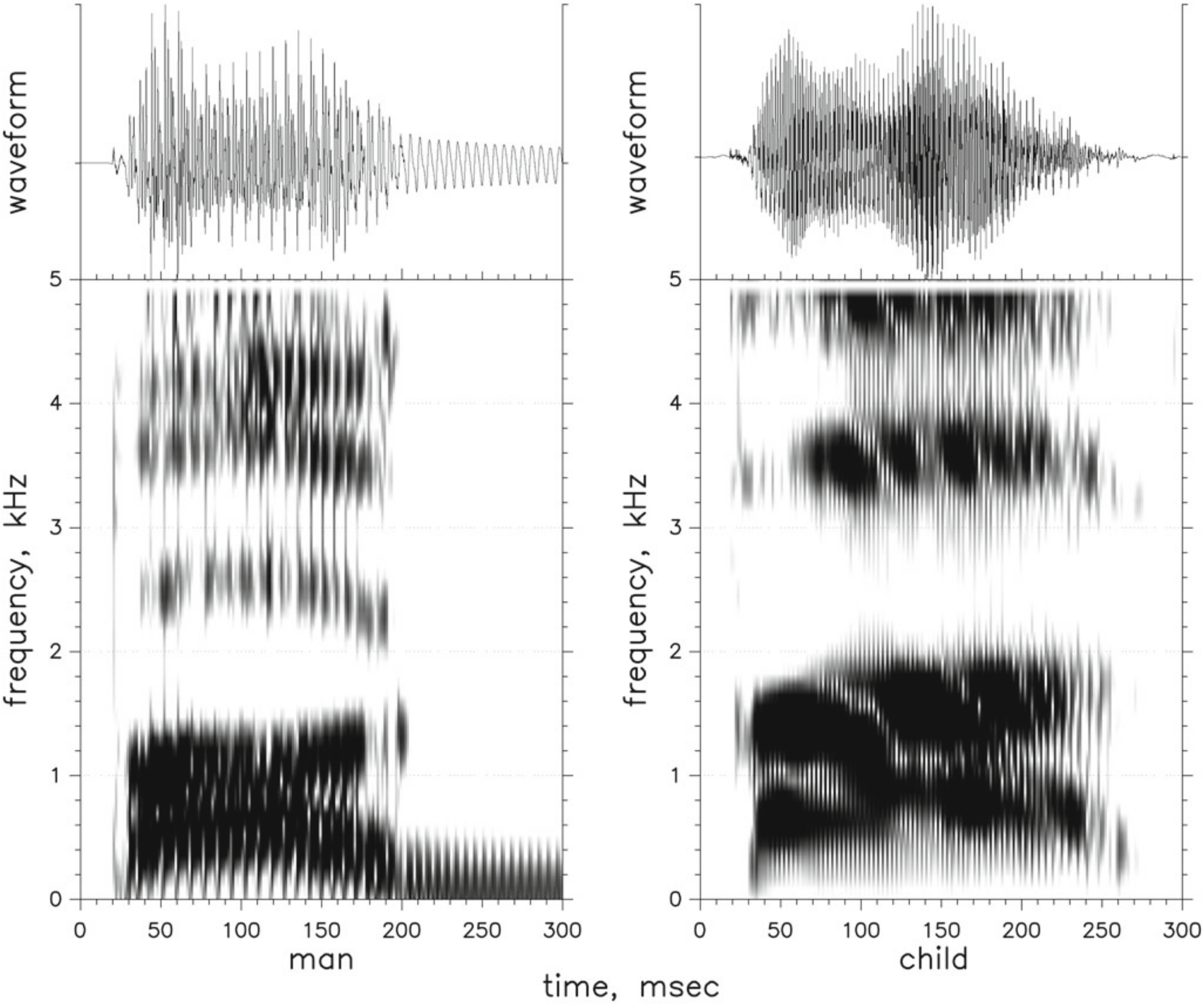

Fig. 11.2 The word *bug* spoken by a man (*left*) and a child (*right*), illustrating the lack of invariant acoustic structure

conducted that used nonstandardized measures of phonological awareness, and met the criteria for inclusion in this review. For example, James et al. (2009) examined phonological awareness in 19 eight-year-olds with CIs, 19 reading-level matched peers, and 19 chronological-age matched peers. These authors examined children's sensitivity to three kinds, or levels, of phonological structure: syllable, rhyme, and phoneme. The tasks were all visual, with pictures representing target words. The children with CIs performed as well as children in the two control groups on syllable awareness, but more poorly on rhyme and phonemic awareness. That finding would be predicted from the fact that syllable structure at the linguistic level is discernible from amplitude structure at the acoustic level. Recognizing phonemic structure, on the other hand, requires access to detailed spectro-temporal structure, precisely what is impoverished in cochlear implant processing strategies.

Grammar

Other studies have investigated the relationships among skills that are not strictly phonologically based. For example, Spencer et al. (2003) examined the relationship between reading comprehension and morphosyntactic skills for 16 nine-year-olds with CIs and 16 age-matched peers, for each group separately. To evaluate reading comprehension, the passage comprehension subtest of the Woodcock Reading Mastery Tests (WRMT) (Woodcock 1987) was used. To evaluate receptive and expressive language, the Concepts and Directions and Formulated Sentences subtests of the CELF were employed. Results demonstrated that the relationship between reading comprehension and oral language abilities was stronger for children with CIs than for the children with normal hearing: $r=0.8$ vs. $r=0.5$, respectively. A separate study by Connor and Zwolan (2004) replicated the general result. Taken together, those findings are important because they suggest that the extent to which non-phonological language factors explain literacy acquisition may differ for children with normal hearing and those with CIs. Robust evidence supports the claim that children with normal hearing develop literacy skills largely through a phonological route. Any reading proficiency children with CIs manage to acquire may depend to a greater extent on language abilities not necessarily related to phonological knowledge. The reason for that difference in underlying mechanisms is likely the diminished access to acoustic structure that supports phonemic structure experienced by children with CIs. Unfortunately, it is generally agreed that in order to read much above a fourth grade level, sensitivity to phonemic structure is required (Goldin-Meadow and Mayberry 2001). Thus, the reliance on extra-phonological factors observed for the literacy skills of young school-age children with CIs might be a harbinger of limited proficiency to be found in their later literacy achievements.

There have been fewer investigations of the morphosyntactic skills of children with CIs using nonstandard measures than of other sorts of speech and language abilities. That may be due to the arduous nature of analyzing morphosyntax in language samples; it is much more efficient to use standardized test instruments. Nonetheless, one report using a measure that is not strictly standardized was conducted by Geers et al. (2003). It included 181 children with CIs, and 24 age-matched peers with normal hearing, all tested at 8- to 9-years of age. As the measure of morphosyntax, the Index of Productive Syntax (Scarborough 1990) was used. With this instrument, trained listeners review language samples from children. Occurrences of 56 syntactic and morphological forms are evaluated, providing scores in four categories: complexity of noun phrases, verb phrases, questions/negations, and sentence structures. When Geers et al. applied this index, the average score of children with CIs was 1.13 SDs below the mean of the control group. Thus, this study replicated the general finding that children with CIs are performing, on average, roughly one standard deviation below the means of children with normal hearing.

Summary

Results from several laboratories have been reviewed in this first section of the chapter, but it is far from an exhaustive set of studies on the topic of language and literacy in children with CIs. Over the past two decades there has been a well-focused effort on quantifying language outcomes in children with severe-to-profound hearing loss who use CIs, and measure how those outcomes have improved since CIs became available for children. Entering the search terms *language*, *cochlear implants*, and *children* together into the *PubMed* database produces more than a 1000 results. In this review section, we focused on a select few of those studies, using specific criteria. Nonetheless, the outcomes reported here generally match those of the numerous papers that we were unable to include. The data overwhelmingly indicate that CIs have allowed many children with severe-to-profound hearing loss to acquire language and literacy skills in the range of children with normal hearing, but the influences of that hearing loss have not yet been eliminated. The goal of future research and intervention efforts must be to find ways to more effectively ameliorate those influences. One approach that could facilitate that effort would be to construct a better model of the factors that underlie language acquisition for these children, and how those factors may differ for children with CIs and children with NH. That is what we are seeking to do in the research conducted in our laboratory.

Review of Outcomes at Second Grade from a Longitudinal Study of Children with CIs

In this next section, outcomes are reported for a sample of children in a longitudinal study conducted for 10 years in our laboratory. The project is titled Early Development of Children with Hearing Loss (EDCHL). In this chapter, language and literacy outcomes are reported for these children from data collected when they were all 8 years of age (mean age = 8 years, 6 months; SD = 5 months). They were tested during the summer following second grade in all cases. More detailed information about the original sample and procedures can be found elsewhere (e.g., Nittrouer 2010).

Participants

The children on the EDCHL project came from across the USA, and all had been tested as part of this project between four and eight times since their first birthdays. Forty-eight of these children had normal hearing (NH), and 50 of them had severe-to-profound hearing loss and wore one or two CIs. In order to participate in the study, children, their families, and their early intervention programs (in the case of the children with CIs) needed to meet specific criteria.

Criteria for Participation for Children

In order to participate, there could be no evidence of any physical, cognitive, or emotional deficit other than hearing loss (in the case of children with CIs) that could on its own be expected to impact development. While the first of these three requirements was easy to verify from clinical records, the last two were less transparent. Consequently, assessments were made at each test time to confirm that none of these children had any disabling conditions other than hearing loss. The children in the NH group had their hearing screened each time they were tested, with octave frequencies between 0.25 and 8 kHz presented at 20 dB hearing level. All children were administered four subtests on the Leiter International Performance Scale—Revised (Roid and Miller 2002), which is a completely nonverbal test of cognitive functioning. The four subtests administered were Figure Ground, Form Completion, Sequential Order, and Repeated Patterns. From these four subtests an estimate of nonverbal intelligence can be computed that is labeled by the test authors as the Brief IQ. That metric is given as a standardized score, with a mean of 100 and a standard deviation of 15.

Emotional stability—defined here as the lack of emotional problems—was assessed using the Child Behavior Checklist (CBCL) by Achenbach and Rescorla (2001). This is an instrument completed by each parent separately and by the classroom teacher. Each of these three responders read 113 individual statements, such as *Argues a lot* and *Stubborn, sullen, or irritable* and had to rate how strongly the statement describes the child being assessed using a three-point scale (0–2). Weighted sums across items are computed to obtain two general indices, one of internalizing and one of externalizing tendencies. These weighted sums are given as standardized T scores, which have means of 50 and standard deviations of 10. Scores above 70 are considered to be in the clinical range. Internalizing problems refer to difficulties such as being emotionally reactive, withdrawn, or anxious. Externalizing problems refer to difficulties with rule breaking or aggressive behavior.

Finally, all children were screened with the Short Sensory Profile (SSP) by McIntosh et al. (1999), which is an abbreviated version of the Sensory Profile (Dunn 1999). This instrument is completed by parents, who rate according to a five-level scale how frequently 38 separate statements describe their children. Each statement concerns a specific kind of sensory processing, such as *Avoids going barefoot, especially in sand or grass* and *Responds negatively to unexpected or loud noises.* Impairments in the ability to process sensory inputs—such as defensiveness or over-responsivity—are widely reported for children with autism spectrum disorders (e.g., Kientz and Dunn 1997; Ornitz 1989; Osterling and Dawson 1994; Watling et al. 2001). By administering this instrument, we were able to screen the children in this study for tendencies that would place them on the autism spectrum. Scores on the SSP load on seven separate clusters: Tactile Sensitivity, Taste/Smell Sensitivity, Movement Sensitivity, Underresponsive/Seeks Sensation, Auditory Filtering, Low Energy/Weak, and Visual/Auditory Sensitivity. Results are not given as standardized scores. Instead, three ranges of scores are used that group children into three categories: Typical Performance, Probable Difference, and Definite Difference. Summing across the seven categories provides a total score that can be used, as well. Children on the autism spectrum have reliably been found to score lower than typical children in each category separately and on the total score, and reliably in the third category of Definite Difference (e.g., Tomcheck and Dunn 2007).

Table 11.2 shows means and standard deviations for pertinent scores from these screening measures. For the Brief IQ, it is clear that means for both groups were at the means for the normative sample, and standard deviations were similar, as well. A t test revealed no difference in scores across the groups.

For the CBCL internalizing and externalizing scores, two-way, repeated-measures ANOVAs were performed on each set of scores with respondent (mother, father, or teacher) as the repeated measure and group (NH or CI) as the between-subjects factors. Only for the externalizing scores was a significant effect found, and it was for respondents, $F(2, 162) = 3.86$, $p = 0.023$. That finding reflected the fact that mothers rated their children as having slightly fewer problematic externalizing behaviors than either fathers or teachers. But the differences were small: mean externalizing T scores were 46, 48, and 49 for mothers, fathers, and teachers, respectively. No Hearing Group × Respondent interaction was found. Consequently, means across the three responders were computed and are reported in Table 11.2, for both internalizing and externalizing behaviors.

Table 11.2 Group means and *standard deviations* for children with normal hearing ($N = 48$) and children with CIs ($N = 50$) for cognitive, emotional, and sensory processing measures

	Brief IQ		CBCL internalizing		CBCL externalizing		SSP auditory filtering		SSP total	
	M	*SD*	M	*SD*	M	*SD*	M	*SD*	M	*SD*
Normal hearing	105	*14*	48	*7*	47	*6*	24	*3*	168	*13*
Cochlear implants	100	*18*	47	*8*	48	*9*	22	*5*	166	*18*

Note: Brief IQ = standardized scores with a mean of 100 and *SD* of 15; CBCL (Child Behavior Checklist) = T scores with a mean of 50 and *SD* of 10; and SSP (Short Sensory Profile) = categorized into ranges describing performance. For SSP Auditory Filtering these are: Typical Performance (23–30); Probable Difference (20–22); and Definite Difference (6–19). For SSP Total Score these are Typical Performance (155–190), Probable Difference (142–154), and Definite Difference (38–141)

For the SSP, mean scores for both groups were in the Typical Performance range on all subtests and *t* tests revealed no differences between scores for children with NH and those with CIs, with one exception. Children with CIs scored significantly lower in the category of Auditory Filtering, $t(1,96) = 4.07$, $p = 0.046$, reflecting the fact that children with CIs did not attend to auditory input as well as children with NH. That difference could be predicted due to children in the CI group having hearing loss. Nonetheless, because of that difference, scores for this category are reported, as well as total scores.

In general it can be seen from Table 11.2 that mean scores for both groups were well within the average ranges on these screening instruments. That means that any group differences found for language and literacy measures can be fairly attributed to differences in hearing status, and the fact that children with CIs were learning language with a degraded signal.

For the children with hearing loss, further criteria had to be met in order for them to participate. There could be no evidence that the hearing loss was progressive in nature. As closely as could be determined, it needed to be present since birth. Better-ear pure-tone average thresholds for the frequencies of 0.5, 1, and 2 kHz (better-ear PTAs) needed to be poorer than 50 dB hearing level. The children needed to have been identified with hearing loss, received appropriate amplification, and started an intervention program by the time they were 2 years of age in order to be included in the study. For this group of children with CIs, mean age of identification was 6 months (SD = 7 months); mean age at which they received their first hearing aids was 8 months (SD = 6 months), and they began early intervention by a mean age of 9 months (SD = 7 months). Mean better-ear PTAs before receiving CIs was 100 dB hearing level (SD = 17 dB).

A few children are exceptions to the descriptions offered above, and they are the children who received their CIs late. Forty-three of the 50 children in this CI group received a first CI before 3 years of age, with a mean age of 16 months (SD = 5 months). Those children all had better-ear PTAs poorer than 80 dB hearing level, with a mean of 105 dB (SD = 13 dB). The seven children who received a first CI after 3 years of age (with a mean age of 58 months), all had better-ear PTAs better than 80 dB hearing level, with a mean of 71 dB. (SDs are not listed here because the group is so small.) These late-implanted children are also distinguished by the fact that they were identified with hearing loss and started intervention later than the early-implanted children: mean age of identification for the late-implanted children was 10 months and mean age of starting intervention was 12 months. These factors raise the specter that these late-implanted children form a distinct group. Because of that possibility, two-group *t* tests were performed on all 13 measures reported in this section of the chapter. Mean scores for the early- and late-implanted children were remarkably similar, and were not significant in any instance. Consequently, data at second grade from these seven late-implanted children are included with the larger group of children with CIs in this report.

Criteria for Parents and Early-Intervention Programs

In order for a child to participate in the EDCHL study, their parents and early intervention programs needed to meet certain requirements. All children had parents with normal hearing, and the language spoken in the home was predominantly English. In a few cases, grandparents visited who spoke a language other than English with each other and with the child's parents. However, in all cases parents spoke English with each other and with the children in this study. At every test session, parents were asked to reconfirm that it was their goal that their children would be fully mainstreamed in a regular educational setting by the start of traditional school age, without the need for a sign language interpreter. Some children, both with NH and with CIs, were exposed to a manual sign system from infancy through preschool. In all those cases, the stated purpose of using a sign system was to facilitate the acquisition of spoken language and/or to provide a means for the child to communicate wants and needs while learning to talk.

The early intervention programs in which children and their parents participated needed to provide services at least once per week during infancy and the toddler years. Those programs needed to be staffed by individuals with at least a Master's degree, and that educational background needed to be in a discipline related to communication and the needs of children with hearing loss. That typically meant that early intervention was provided by speech-language pathologists or teachers of the deaf. All of the children with CIs for whom data are reported in this section received early intervention services along with their parents at least once per week up to age 3 years, and then they attended preschool programs for children with hearing loss for an average of 16 h/week. They were generally mainstreamed into regular classrooms starting at kindergarten, but for a couple children, mainstreaming did not start until first grade.

Method

Children and one parent traveled to Columbus, Ohio for a day and a half of testing during the summer following second grade. Four to six children were tested during each of these "camps" in six sessions. Children had a minimum of 1 h between test sessions. In each session, several tasks were combined to make between 40 and 60 min of data collection. Undergraduate and graduate students were involved in data collection in each of the six sessions. These students were thoroughly trained during the spring preceding the summer camps, and were required to practice procedures on at least 15 children with normal hearing whose data are not included in this report. Training emphasized testing details, such as how to provide verbal reinforcement for staying on task and working hard without providing reinforcement for giving correct answers. During the training of experimenters as well as during data collection itself, the program manager observed test sessions and reviewed video recordings to make sure that no experimenter strayed from standard protocol.

All procedures for stimulus presentation were made standard and automated. Any test instrument that is typically presented with live voice by a clinician or experimenter was presented on a computer monitor with audio presented on a high-fidelity speaker at 0° azimuth. All materials were presented at a 68 dB sound pressure level. Materials for these presentations were created by video recording a member of the laboratory staff producing test instructions and test items. High-quality audio was ensured on these videotapes by having the staff member wear a FM transmitter, and the signal from the receiver was fed into the video camera. With the exception of two tasks, children were videotaped as they were responding, and care given to recording the relevant dimension of the responses. When responses involved pointing, for example, the video camera was positioned so those responses could be seen on the video recording. When responding involved verbal responses, clear shots of the children's faces were obtained. Figure 11.3 shows the setup for data collection for the passage comprehension subtest of the CASL. In this case, the video camera recording children's responses was positioned behind them in order to capture the pointing responses. All tasks used in data collection were preceded by appropriate training. Scoring was done using the video records at a later time, with the stipulation that the staff member who collected a specific kind of data could not score responses for those data. All scoring was done by two independent staff members so that reliability could be checked.

The two tasks that were not video-recorded were the phonological awareness and the working memory tasks. In these cases, responses were entered directly into the computer by the software that controlled the experiments.

Outcomes are presented for the same set of language skills reviewed in the previous section: lexicality, grammar, phonological awareness, reading, and working memory. In sum, there were 13 measures that were examined.

Lexicality

Two measures were used to assess the size of children's lexicons and their abilities to use words in spoken language. Expressive vocabulary was assessed with the EOWPVT. This task requires the child to provide the words that label a series of pictured items shown one at a time on separate pages. Standardized scores were used as dependent measures.

Children's skill at using their lexical knowledge as part of spoken language (i.e., semantics) was evaluated by the number of different words they used in a 20-min narrative sample consisting of a story retelling. For this narrative, each child entered the sound booth and the experimenter explained that she had been called away for a few minutes. The equipment was set up for the child to view and hear a video of the book *The Day Jimmy's Boa Ate the Wash* (Noble 1980). This story was video-recorded with a narrator reading the printed material, but with separate staff members saying the material that appeared in quotes in the book. Full images of each face were

Fig. 11.3 Setup for testing

shown to ensure optimal opportunity for speech reading. Illustrations from the book were shown when appropriate. The experimenter explained that she hadn't seen the video story yet, and asked the child to watch carefully so it could be told to the experimenter when she returned. After the story was finished, the experimenter reentered the sound booth, and asked the child to tell her the story in as much detail as possible. If the story retelling did not take a full 20 min, the experimenter supplemented the time by asking questions about personal experiences the child had that paralleled some of those of the children in the story. Later the story retelling was transcribed by members of the laboratory staff. Those transcriptions were submitted to the Systematic Analysis of Language Transcripts (SALT) software (Miller and Iglesias 2010) for analyses of morphosyntactic structures, including the number of different words (NDW). For most SALT measures, including NDW, the first 100 utterances were used in the analysis. The NDW score indexes how well children use their vocabulary knowledge in their generative language.

Grammar

Children's abilities to understand morphosyntactic structure was assessed using the paragraph comprehension subtest of the CASL. In this task, children listen to progressively more complex stories, and have to answer comprehension questions by pointing to one of four choices on an easel. The stories and questions were video-recorded by a staff member. It is characterized by test authors as a measure of receptive syntax.

Generative grammar was assessed by three measures obtained with SALT analysis: mean length of utterance in morphemes (MLU), number of pronouns, and number of conjunctions. Although MLU is frequently criticized for being insensitive to language differences once children reach MLUs of roughly 5, we have found it continues to distinguish between syntactic capabilities for children with hearing loss and those with NH past that stage.

Phonological Awareness

Three measures of phonological awareness were used. Multiple measures are always used in our laboratory so that differences among groups will not be diminished by selecting a task that is either so easy that even children with phonological delays can perform it, or so hard that even children who are developing typically have difficulty. Using multiple tasks also provided an opportunity to evaluate whether children with CIs seem to have any special difficulties with meta-linguistic analysis. For these second graders, the three tasks used were the initial consonant choice, final consonant choice, and phoneme deletion tasks. Again, all test stimuli were video-recorded using laboratory staff members as talkers. In the first two tasks, children saw and heard a target word that they were required to repeat correctly. They were given three opportunities. If they could not repeat it correctly, that test item would not be included. However, all these children were able to understand the target words without difficulty. After repeating the target word, children saw and heard three word choices and had to select which of the three started or ended with the same sound, depending on which task was presented. In the phoneme deletion task, children saw and heard a non-word and had to repeat it correctly. Next they were asked to say the non-word without one of the segments. They needed to delete the correct segment and blend the others to create a real word. This task involved more phonological *processing* than the first two tasks, so required greater meta-linguistic awareness. In order to complete the phoneme deletion task, the child not only needed to be sensitive to phonological structure, but also needed to be able to manipulate segments within the non-word. By including this task, we were able to get an indication of whether any differences between groups would best be attributed to deficits in sensitivity to segmental structure, or to diminished capacities to engage meta-linguistic awareness. Each task had many items (i.e., 32 or 48), and all have been used extensively in this laboratory and others so they were known to be reliable (e.g., Nittrouer and Burton 2005; Nittrouer et al. 2012; Pennington et al. 1990; Stanovich et al. 1984). The percentage of items answered correctly was the dependent measure for each task.

Reading

The Qualitative Reading Inventory (QRI) was used to assess word reading, paragraph comprehension, and fluency. Although this last measure had not been found to distinguish children with NH and those with CIs when they were tested at kindergarten, it seemed worthwhile to examine it again because fluency is commonly used in educational settings to assess reading skill.

The QRI has both narrative and expository passages written at various levels of reading ability. In this study, children read each passage and were asked ten comprehension questions about each one. Three passages were used at each test age. One passage was a narrative written at one level below grade level, one was a narrative at grade level, and one was an expository at grade level. Children were video-recorded reading each story and responding to questions. Staff members scored the number of words read correctly and the number of questions answered correctly. Finally, the time required to read the passage was computed from the videotape, and the number of correct words read per minute was used as the metric of fluency.

Working Memory

On this task, children were asked to recall the order of strings of six monosyllabic nouns presented as auditory lists. In this case, video presentation was not used. A single set of words served as stimuli, and recognition was checked for each child both prior to testing and after testing was completed. If a child had difficulty recognizing even a single word auditorily, testing would not have been conducted (if it happened during the pre-test) or data would have been removed from analysis (if it happened on post-test). However, all children readily recognized these simple nouns.

This test procedure has been used often to examine short-term memory (e.g., Brady et al. 1983; Spring and Perry 1983), and this particular task with these particular words has been shown to have good test-retest reliability (Nittrouer and Miller 1999). In this procedure, pictures of each noun are shown at the top of a touch screen monitor, and the words are played in random order at a rate of one per second. The child's task is to touch the pictures in the order that the words were heard. Ten lists are presented. The dependent measure is the percentage of words recalled in the correct order.

Results

Data for the 13 measures described above were screened for normal distribution and homogeneity of variance. Data on all measures met the criteria.

Overall Performance

Means and standard deviations for the measures described above were computed. Two-group *t* tests were performed, and Cohen's *d*s were obtained. These last values index effect sizes by representing group differences according to standard deviations. Thus, a Cohen's *d* of 1.00 represents a group difference of one standard deviation.

Looking first at lexicality, means and standard deviations of those measures are shown in the two left-most columns of Table 11.3, with statistical outcomes shown below. The EOWPVT scores indicate that the expressive vocabularies of children with CIs were not as large as those of children with NH. Based on NDW, it is clear that using those lexical items to represent semantic variation in spoken language was not a skill that was as well developed for children with CIs as it was for children with NH. However, the difference in performance between the two groups of children is not as great for NDW as for EOWPVT. Thus, although the lexicons of children with CIs were not as large as those of children with NH, their skills at using those vocabulary items were less delayed.

Looking next at grammar, results for those measures are shown in the right-most columns of Table 11.3. Here it is seen that children with CIs were not performing as well as children with NH, but none of these effect sizes are as large as that found for expressive vocabulary with the EOWPVT.

Scores for the measures of phonological awareness are shown in the left half of Table 11.4, with statistical outcomes shown below. These measures reveal some of the largest effect sizes observed in this study, with the final consonant choice task showing the single largest effect. Of pertinence is the finding that children with CIs performed better on the phoneme deletion than on the final consonant choice task, $t(47) = 3.232$, $p = 0.002$, whereas children with NH performed indistinguishably on the two tasks. That finding for children with CIs provides support for the suggestion that they do not have diminished capacities for meta-linguistic awareness or phonological processing because they were able to do relatively well on the phoneme deletion task, the more meta-linguistically challenging of the tasks. Rather, it is recovering phonological structure that remains a challenge for them. (These were the only measures that could not be collected for all 98 children. One child with CIs was not able to understand the instructions for phoneme deletion, and another child with CIs became ill part way through testing, and could not complete the initial consonant choice or phoneme deletion tasks.)

Reading scores are shown in the right half of Table 11.4, with statistical outcomes shown below. Of these, fluency shows the weakest effects, making it a less sensitive metric of group difference than the other two measures. Paragraph comprehension shows the greatest difference between children with NH and those with CIs.

Scores for working memory are not shown in the tables described above. However, mean recall was 56 and 43 % correct for children with NH and those with CIs, respectively (SD = 16 % for each group). The *t* test performed on these data showed a significant group effect, $t(1,96) = 3.97$, $p < 0.001$, with a Cohen's *d* of 0.81. Thus, children with CIs are poorer at retaining verbal material in short-term memory, which could interfere with their learning of syntactic structures.

In summary, all 13 of these measures revealed significantly poorer abilities for children with CIs than for those with NH. The magnitude of those differences was generally between three-quarters of a standard deviation and one standard deviation, matching effect sizes found in the data of other investigators and summarized in the first section of this chapter. Consequently it seems fair to conclude that even with early identification, good intervention, and CIs, children with severe-to-profound hearing loss still experience significant delays in language acquisition because of that hearing loss. The challenge facing clinicians and scientists is to enhance our understanding of the mechanisms underlying the acquisition of spoken language for children with CIs in order for us to appropriately modify intervention techniques so that these children may one day reach their full potential.

Computing Latent Variables

Analyses of sorts other than those that merely measure differences in abilities between children with NH and those with CIs were performed to help us understand how spoken language skills interact with each other for these

Table 11.3 Group means and *standard deviations* for children with normal hearing ($N=48$) and children with CIs ($N=50$) for measures of lexicality and grammar. Results of two-group *t* tests performed on the measures, along with Cohen's *d*s are shown below. Degrees of freedom were 1, 96 for all analyses

	Lexicality				Grammar							
	EOWPVT		NDW		CASL		MLU		Conjunctions		Pronouns	
	M	*SD*	M	*SD*	M	*SD*	M	*SD*	M	*SD*	M	*SD*
Normal hearing	110	*14*	292	*56*	112	*12*	6.27	*1.35*	106	*41*	231	*70*
Cochlear implants	95	*19*	248	*65*	99	*21*	5.43	*1.34*	79	*41*	177	*72*
t value	*4.56*		*3.61*		*3.61*		*3.11*		*3.17*		*3.70*	
p value	*<0.001*		*<0.001*		*<0.001*		*0.002*		*0.002*		*<0.001*	
Cohen's *d*	*0.90*		*0.73*		*0.76*		*0.62*		*0.66*		*0.76*	

Note: EOWPVT (Expressive One-Word Picture Vocabulary Test) and CASL (Comprehensive Assessment of Spoken Language) = standardized scores with means of 100 and *SD*s of 15; NDW (Number of Different Words), Conjunctions, and Pronouns = count of occurrence of each in 100-utterance sample; MLU (Mean Length of Utterance) = count across the language sample

Table 11.4 Group means and *standard deviations* for children with normal hearing ($N=48$) and children with CIs ($N=50$) for measures of reading and phonological awareness. Results of two-group *t* tests performed on the measures, along with Cohen's *d*s are shown below. Degrees of freedom were 1, 96 for all measures, except for Initial Consonant Choice (1, 95) and Phoneme Deletion (1, 94)

	Phonological awareness						Reading					
	Initial consonant		Final consonant		Phoneme del.		Comprehension		Word read		Fluency	
	M	*SD*	M	*SD*	M	M	M	*SD*	M	*SD*	M	*SD*
Normal hearing	87	*13*	70	*18*	71	*22*	21	*3*	200	*5*	122	*32*
Cochlear implants	65	*26*	36	*26*	50	*31*	16	*6*	191	*15*	104	*38*
t value	*5.45*		*7.34*		*3.84*		*4.16*		*4.05*		*2.62*	
p value	*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*0.010*	
Cohen's *d*	*1.07*		*1.52*		*0.78*		*1.05*		*0.80*		*0.51*	

Note: Initial Consonant Choice, Final Consonant Choice, and Phoneme Deletion = percent of correct responses on each phonological awareness measure; Comprehension = number (out of 30) of comprehension questions answered correctly on the Qualitative Reading Inventory (QRI); Word Reading = number of words read correctly on the QRI; and Fluency = mean number of words read per minute on the QRI

children. In particular, factor analysis was performed to see if data across the 13 separate measures described above could be reduced to reveal a smaller set of latent variables. Specifically, factor analysis with varimax rotation was done on these measures. Although not strictly confirmatory in approach, this analysis was not exploratory, either. Predictions about how these measures might combine to create a few components could be made based on traditional models of linguistic structure. In particular, linguistic structure is generally viewed as having duality of patterning, in which a limited set of phonemic elements get combined to create almost an infinite variety of words and those words can be combined according to a finite set of rules to create sentences with almost infinite meanings (e.g., Hockett 1958; Studdert-Kennedy 2005). According to that model of duality, it was reasonable to expect prior to this analysis that the separate measures might reveal two latent variables based on these levels of structure: phonological and morphosyntactic. Thus the resulting variables would reflect language abilities associated with sensitivity to and processing of phonological structure or morphosyntactic structure.

Table 11.5 shows the standardized component matrix that resulted from the analysis, with significant effects indicated by bolded text. As expected, the variance in each of the individual measures is well explained by one of the components, but not the other. Furthermore, it seems appropriate, based on the measures associated with each component, to label the first of these a phonological component and label the second one a morphosyntactic (grammar) component. In this analysis, the number of participants relative to the number of measures was slightly less than optimal, but the strength of the components derived and the fact that those resolved components are conceptually sound militate against rejecting the outcomes because of that concern. Tabachnick and Fidell (1989) argue that in a situation such as this one (i.e., resolved components are strong and conceptually sound) five cases per measure is sufficient.

Table 11.5 The proportion of variance on each measure explained by the principal component

	Components	
	1	2
EOWPVT—expressive vocabulary	***0.814***	0.166
NDW—semantics	0.222	***0.875***
CASL—receptive syntax	***0.711***	0.346
MLU	0.235	***0.825***
Conjunctions	0.055	***0.890***
Pronouns	0.144	***0.761***
Initial consonant choice	***0.838***	0.104
Final consonant choice	***0.693***	0.153
Phoneme deletion	***0.823***	0.105
QRI—paragraph comprehension	***0.746***	0.383
QRI—word reading	***0.762***	0.071
QRI—fluency	***0.763***	0.221
Working memory	***0.622***	0.065

Note: *bolded text* indicates significant effects, with a $p < 0.05$

Scores for the two latent variables derived from this analysis were computed for each child, using the children with NH as the standard. Consequently, the mean for children with NH was 0.00 and the standard deviation was 1.00 on both the variables of phonological processing and of morphosyntax. It was found that means for the children with CIs were −1.86 (SD = 2.01) for the phonological processing variable and −0.87 (SD = 1.20) for the morphosyntactic variable. That means that the children with CIs in this study were trailing the children with NH in acquisition of both phonological and morphosyntactic skills, but they were further behind in phonological skills. That outcome could have been predicted from the fact that CIs provide signals that are highly degraded, allowing only limited access to the acoustic properties that underlie phonemic categories. Morphosyntactic structure can more readily be learned from how words are combined and knowing when to use each word. Even if the representations of those words are more global (i.e., less phonemically differentiated) for children with CIs than for children with NH, the rules for combining and using words may be learned.

Explaining Variance

Finally, Pearson product-moment correlation coefficients were computed for all pairwise combinations of the dependent measures examined, with one exception. Reading fluency was not included in this analysis because it was not found to be especially sensitive to differences between children with NH and those with CIs.

The primary motivation for this particular analysis was that by examining relationships among separate language measures, ideas should be derived concerning which skills would best be targeted in intervention. Table 11.6 shows correlation coefficients for each group separately: those for children with NH are on the top in each cell and those for children with CIs are on the bottom. Computing correlation coefficients separately for each group allowed us to examine whether the same pattern of relationships across skills could be observed for children in both groups. Again, that should help in designing interventions. A serious risk to the design of effective treatment options is encountered when strategies are based on patterns of language development found for children with NH because those patterns may or may not hold for children with CIs. In fact, examining Table 11.6 reveals that the most striking outcome is that many more of these correlations were significant for the children with CIs than for those with NH. Out of the 65 correlations performed, 51 were found to be significant for the children with CIs, while only 19 were significant for the children with NH. Fisher's z tests for the difference between correlation coefficients were performed on all pairs of coefficients in order to see if the strength of the relationship between individual pairs of measures were different for the two groups of children. In 28 cases, Fisher's z was significant, and in all those cases it was because the relationship was stronger for children with CIs than for those with NH. In Table 11.6, significant z scores are indicated by bolding. These outcomes indicate that language skills are less diversified for children with CIs than for children with NH.

Summary

This second section of the chapter reported data for second graders that come from an ongoing longitudinal study. All results are consistent with the pattern of outcomes reported in the first section of the chapter, from other studies. Even though the children in the longitudinal study have no risk

Table 11.6 Pearson product-moment correlation coefficients for pairs of dependent measures computed for children with NH (*top rows*) and children with CIs (*bottom rows*) separately

	E.V.	NDW	CASL	MLU	Conj.	Pro.	IC	FC	PD	Comp.	W.R.	W.M.
EOWPVT	1	–	–	–	–	–	–	–	–	–	–	–
NDW	***0.099*** ***0.456*****	1	–	–	–	–	–	–	–	–	–	–
CASL	***0.437***** ***0.722*****	***0.135*** ***0.483*****	1	–	–	–	–	–	–	–	–	–
MLU	***−0.018*** ***0.433*****	***0.541***** ***0.820*****	0.349* 0.524**	1	–	–	–	–	–	–	–	–
Conjunctions	−0.179 0.189	0.706** 0.771**	−0.051 0.274	0.681** 0.680**	1	–	–	–	–	–	–	–
Pronouns	−0.014 0.265	***0.214*** ***0.857*****	0.182 0.321*	***0.274*** ***0.693*****	***0.283*** ***0.845*****	1	–	–	–	–	–	–
Initial consonant	***0.171*** ***0.700*****	0.089 0.205	***0.214*** ***0.568*****	0.056 0.251	0.073 0.092	0.218 0.060	1	–	–	–	–	–
Final consonant	***0.144*** ***0.468*****	***−0.137*** ***0.259***	0.141 0.439**	***−0.139*** ***0.343****	−0.092 0.156	0.071 0.200	0.559** 0.424**	1	–	–	–	–
Phoneme deletion	***0.232*** ***0.690*****	***−0.284*** ***0.441*****	0.309* 0.502**	***−0.142*** ***0.470*****	***−0.304**** ***0.359****	−0.055 0.244	0.438** 0.667**	0.590** 0.531**	1	–	–	–
Reading comprehension	***0.496***** ***0.713*****	0.350* 0.536**	***0.561***** ***0.788*****	0.268 0.528**	0.143 0.330*	0.151 0.354*	***0.178*** ***0.637*****	0.068 0.378**	***0.196*** ***0.644*****	1	–	–
Word reading	***0.183*** ***0.574*****	***−0.038*** ***0.327****	0.140 0.375**	***−0.053*** ***0.384*****	−0.015 0.263	−0.039 0.224	0.543** 0.583**	0.401** 0.331*	0.508** 0.633**	***0.202*** ***0.527*****	1	–
Working memory	0.193 0.473**	***−0.074*** ***0.321****	0.251 0.342*	***0.005*** ***0.362*****	−0.025 0.197	0.023 0.165	0.351* 0.563**	0.311* 0.303*	0.299* 0.501**	0.253 0.315*	***0.124*** ***0.534*****	1

*Individual correlation coefficient is significant at the 0.05 level

**Individual correlation coefficient is significant at the 0.01 level

Bolded text indicates that Fisher's *z* showed a significant difference between groups in correlation coefficients, at a minimum of the 0.05 level (one-tailed test), but in many cases significance levels were higher factors for language delay other than hearing loss, and they all received appropriate and early treatment for that hearing loss, they trail behind their peers with NH by a substantial margin when it comes to language learning. Across the 13 measures reported in this section, the mean Cohen's *d* was 0.84. It was specifically found that children with CIs are further behind on skills requiring sensitivity to the phonological structure of the speech signal, rather than morphosyntactic abilities. That strong demonstration of phonological deficit surely reflects the fact that even with technological advances, CIs still provide degraded representations of spectro-temporal structure in the speech signal. Consequently these children have diminished access to some important cues to phonemic categories.

One piece of good news to come from these analyses is that morphosyntactic skills appear to be learned quasi-independently from the other language skills examined in this study, which are all strongly dependent on phonological structure. That outcome seems consistent with the proposal that young children with NH are less sensitive to word-internal segmental (phonemic) structure than are adults (Jusczyk and Derrah 1987; Locke 1988; Nittrouer 1992; Studdert-Kennedy 1981; Walley and Carrell 1983). For example, kindergartners have been found to judge similarity of non-word pairs based primarily on overall syllable shape, rather than on shared phonemes; by second grade, similarity is judged based on shared phonemes (Walley et al. 1986). As another example, the organization of the lexicon for 6-year-old children seems less clearly based on phonemic structure than are those of adults; instead children's lexicons seem based more on global acoustic patterns (Charles-Luce and Luce 1990). So although the rate of lexical acquisition is influenced by children's sensitivity to phonological structure (Willstedt-Svensson et al. 2004), children with normal hearing who are slightly younger than those for whom data are reported here acquire vocabulary items with less than adult-like sensitivities to phonological structure. It seems fair to suggest that the second graders with CIs in the EDCHL study may still be acquiring new vocabulary with those global representations. The independence of phonological and morphosyntactic skills revealed by the factor analysis reported in this section suggests that children with CIs can learn how to combine and when to use those lexical items in spite of having diminished sensitivity to phonological structure.

Finally, the results of correlational analysis reported in this section show that the language skills evaluated by the separate measures used in the EDCHL study are more interdependent for children with CIs than for those with NH. That finding emphasizes the need for enriching the language environments of children with CIs in a broad sense, rather than only working on separate language skills in piecemeal fashion, as might occur in pull-out intervention sessions.

Conclusions

This chapter has reviewed language and literacy outcomes for children with severe-to-profound hearing loss who receive CIs. Work by other investigators was reviewed, as well as work from an ongoing longitudinal study taking place in this laboratory. Outcomes were found to be consistent across studies, and reveal that children with CIs are performing on most language measures at roughly the 15th percentile of performance for children with NH. These findings suggest that language outcomes have not substantially improved for children with CIs since those devices first became available. Looking at the patterns of relationship across skills, it appears that morphosyntactic skills are not as affected by hearing loss and subsequent implantation as are skills dependent on sensitivity to phonological structure. Because the degraded nature of signals available through CIs likely diminishes access to the kinds of acoustic information needed to develop sensitivity to phonological structure, these language problems can be traced specifically to the nature of the signal children receive through their CIs. This situation means that ultimately solutions to the problems faced by children with CIs must involve the types of auditory prostheses we provide to them, but behavioral interventions should help, as well.

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