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ARTICLE

Child Development Perspectives

A framework for understanding the relation between spoken language input and outcomes for children with cochlear implants

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Abstract

Spoken language outcomes after cochlear implantation are highly variable. Some variance can be attributed to individual characteristics. Research with typically hearing children suggests that the amount of language directed to children may also play a role. However, several moderating factors may complicate the association between language input and language outcomes in children with cochlear implants. In this article, I present a conceptual framework that posits that the association between total language input directed to children and language outcomes is moderated by factors that influence what is accessible, attended to, and coordinated with the child. The framework also posits that children with cochlear implants exhibit more variability on those moderating factors, which explains why the relation between language input and language outcomes may be more complex even if language input is more important for successful language outcomes in this population.

KEYWORDS
cochlear implants, deaf children, hard-of-hearing children, language input

INTRODUCTION

Cochlear implants provide children with access to sound but do not guarantee successful spoken language outcomes. Even among deaf children who receive cochlear implants at young ages and who have no comorbid conditions, the degree of unexplained variability in outcomes is high (Niparko et al., 2010). Although some variability is due to differences in how well children's perceptual and cognitive systems can encode the highly degraded auditory input from the implants and integrate it with other sensory modalities (Houston et al., 2020), we need to also understand the role language input plays in supporting the acquisition of spoken language in children with cochlear implants. Language input is important for development and is something parents can influence in their interactions with their children. However, few studies have examined the association between language input and language development in children who use cochlear implants. In this article, I review what little is known and discuss factors that might complicate the association between spoken language input and spoken language outcomes for children with cochlear implants. Having a firmer understanding of this association is critical for providers who seek to support families of children with cochlear implants in optimizing children's spoken language development.

Unless otherwise indicated, the studies reviewed in this article were conducted primarily in the United States with socioeconomically diverse samples that are fairly representative of the country (e.g., with a broad range of maternal education levels that are, on average,

Abbreviations: LENA, language environment analysis; TAAC, total language that is accessible, attended to, and coordinated.

equivalent to an associate's degree). However, the samples in these studies were 80% to 85% non-Hispanic White, which partly reflects the limited ethnic/racial diversity in the geographic regions where the data were collected.

LANGUAGE INPUT

A language cannot be acquired without exposure to it, but how much exposure is needed or optimal remains an open question. In research involving detailed transcriptions of home recordings conducted in the 1990s, the number of words adults spoke to children was correlated with children's vocabulary growth and later educational outcomes (Hart & Risley, 1995; Huttenlocher et al., 1991). These studies and others spurred additional work as well as technologies to further explore the contributions of language quantity on language outcomes. The development of the language environment analysis (LENA) system, in particular, has facilitated researchers' ability to obtain in-home measures of the quantity of language input in children's environments. LENA's software estimates the number of words spoken near a child, the number of conversational turns between the child and an adult, and the number of child vocalizations.

Studies using LENA, which have been conducted primarily in the United States with predominantly English-speaking families, have produced mixed results, with only some showing correlations between amount of language input and language outcomes (Wang et al., 2020). Nevertheless, in a meta-analysis of 17 studies that obtained LENA recordings of language input, across studies, there was a small (r = .21) but statistically reliable correlation between the estimated number of words spoken by adults near the child and children's language abilities (Wang et al., 2020). This small effect may be because LENA does not differentiate words addressed to children from overheard speech, which does not affect children's vocabulary development (Weisleder & Fernald, 2013). Also, the accuracy of word count can vary considerably across recordings. For example, American English female adult speech collected from primarily non-Hispanic White, socioeconomically diverse homes are more likely than a male adult speech from the same homes to be misclassified as child speech, and speech directed to children is more likely than speech directed to adults to be misclassified as child speech (Lehet et al., 2020). Nevertheless, the LENA system has greatly facilitated obtaining estimates of in-home language input.

Despite the acceleration of this work in typically hearing children, few studies have considered the effects of the quantity of language input on language development in young children (<3 years old) who are deaf and hard of hearing, a population at risk for less optimal language outcomes. Results have been inconclusive, with several U.S. studies reporting no significant association between quantity of language input and language outcomes (Ambrose et al., 2014, 2015; VanDam et al., 2012), and with only one showing an association between the amount of language input and language outcomes in children who are deaf or hard of hearing (Dilley et al., 2020). The latter study obtained language samples in a laboratory rather than in the home.

We might expect that the role of language input would be even stronger for children at risk of adverse language outcomes than it is for typically hearing children (Nittrouer et al., 2019). But for several reasons, the association between quantity of input and language outcomes may be more complex for children who are deaf or hard of hearing, especially those with severe to profound hearing loss who use cochlear implants. In the next section, I discuss moderating factors that might complicate the association between quantity of language input and language outcomes in children with cochlear implants.

But first, let us consider the role of sign language in the acquisition of spoken language. The effect of learning sign language on the development of spoken language is a topic of ongoing debate and research. Some studies suggest that learning sign language or sign support systems can interfere with the development of spoken language (Geers et al., 2017), while others have found that learning sign language can help support the development of spoken language (Davidson et al., 2014). Discrepancies of results may be due, in part, to the nature of the sign language input to children. Sign language input from caregivers with less sign language competency may not help, whereas a rich sign language model may help the development of early linguistic skills that can carry over to the acquisition of spoken language. Surprisingly little research has addressed this topic in detail. Many of the same factors I discuss next may also apply to the acquisition of sign language, but additional work is needed to determine that. More work is also needed to determine the role of learning sign language as a moderating factor for spoken language acquisition. For these reasons, the remainder of the discussion focuses on spoken language.

POSSIBLE MODERATING FACTORS

I organize moderating factors into a conceptual framework (see Figure 1), according to which **t**otal language directed to children with cochlear implants (left side) and children with typical hearing (right side) is filtered by what is **a**ccessible, **a**ttended to, and **c**oordinated (TAAC). What is accessible, attended to, and coordinated varies more for children with cochlear implants than for typically hearing children (represented by more variability in bin sizes). This is because the moderating factors that affect children (e.g., auditory thresholds, attention to speech) vary more for children with cochlear implants (represented by thicker arrows from the factor nodes to the funnel filters between bins). The larger

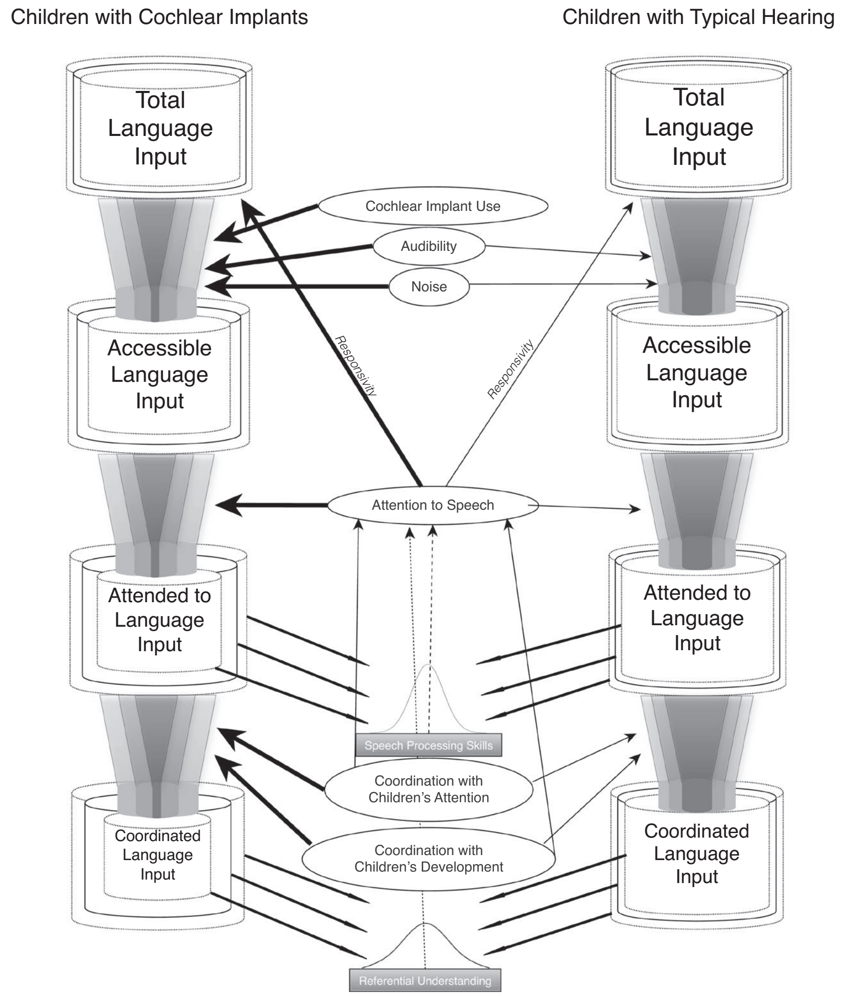

FIGURE 1 The TAAC conceptual framework. Variability in different types of language input (**t**otal, **a**ccessible, **a**ttended to, **c**oordinated, TAAC) is represented by the variability of bin sizes. Moderating factors are represented by ovals (nodes) and the thickness of arrows from nodes to funnel filters represents variability on those moderating factors (i.e., greater for children with cochlear implants than for children with typical hearing). Variability in filter size represents the impact of moderator variability on the variability of what gets filtered from one bin to the next. Variability in child language outcomes (speech processing skills and referential understanding) is represented with distribution curves

variability of moderating factors leads to larger variability in how much input is filtered from one bin to the next (represented by larger variability in filter sizes). The larger variability in attended to coordinated language input complicates the association between total language input and language outcomes in children with cochlear implants relative to children with typical hearing.

Accessibility of language input

For language input to affect language development, it has to at the very least be audible. Children with cochlear implants have access to sound, but only when the external components of the implants are worn. The number of hours per day that children wear their implants varied considerably among socioeconomically diverse families in Italy (Majorano et al., 2021). Moreover, although cochlear implants provide access to sound when they are worn, the resulting auditory thresholds are still higher and more variable than what they are for children with typical hearing (Peixoto et al., 2013). Thus, not all language input that gets picked up by a LENA or other recording device as language input is necessarily audible for children with cochlear implants, even when the devices are worn.

Another factor affecting accessibility is whether audible speech is distinguishable from other sounds in the environment. Across socioeconomic status, children who are deaf and hard of hearing have more difficulty processing speech in noise than children with typical hearing (Caldwell & Nittrouer, 2013). Thus, noise in the environment, as well as how often children wear their cochlear implants, may result in much more variability in access to language input than what may be found in children with typical hearing. This larger variability is represented in Figure 1, with thicker arrows and larger variability in filter sizes leading to larger variability of accessible language input bin sizes for children with cochlear implants than for children with typical hearing.

Variability in accessibility may affect language outcomes. In a study that used data logging from cochlear implants, the amount of speech in quiet processed by children's implants correlated with their language outcomes, but the amount of speech in noise did not (Majorano et al., 2021), suggesting that speech in noise was inaccessible and did not contribute to language development. Also, noise in the home correlates with reduced conversational turns in children with cochlear implants (Wang et al., 2021) and children with hearing aids (Ambrose et al., 2014). One possible reason for this effect is that noise may affect audibility and thus what children can attend and respond to, which in turn may reduce how much caregivers speak to children and the number of conversational turns (see Figure 1: the *responsivity* arrows from attention to speech to total language input). Taken together, these findings and others suggest that it may be important to consider issues of accessibility when assessing the quantity of language input to children with cochlear implants.

Attention to speech

Typically hearing children in the United States demonstrate preferential attention to human speech over similarly complex nonspeech auditory signals within the first days of life (Vouloumanos & Werker, 2007), and this attentional bias to speech contributes to language development (Vouloumanos & Curtin, 2014), although the extent to which this pattern is consistent across diverse populations is unknown. Attention to speech seems to be less robust in young children with cochlear implants. In studies using looking time measures of attention to speech versus silence, deaf infants with cochlear implants, on average, did not demonstrate the degree of attention to speech that their typically hearing peers did (Houston et al., 2003; Wang et al., 2017, 2018). Those who did demonstrate attention to speech more in line with their typically hearing peers recognized words more successfully at later ages (Wang et al., 2018), suggesting an association between attention to speech and speech processing skills. Greater attention to speech may lead to better speech processing skills (see Figure 1: arrows from attended to language input bin to distribution curve for speech processing skills), or better speech processing skills may increase children's interest in speech (see Figure 1: arrow from speech processing skills to attention to speech), or the two may be mutually reinforcing.

Attention to speech depends more on the acoustic properties of speech associated with infant-directed speech in children with cochlear implants than in children with typical hearing (Wang et al., 2017). Further work is needed to determine which acoustic properties are important for attention to speech in children with these implants. For now, one study provides some insight: In this work, vowel dispersion of infant-directed speech was associated more strongly with language outcomes in children with cochlear implants than were the prosodic properties, suggesting that the vowel dispersion characteristic of infant-directed speech might influence attention to speech more than prosodic characteristics (Dilley et al., 2020). This possibility is consistent with findings that in children with cochlear implants, access to differences in fundamental frequency between infant-directed speech and adult-directed speech is reduced (Arjmandi et al., 2021).

Attention to speech is also likely to be influenced by children's ability to comprehend its meaning (see Figure 1: arrow from referential understanding distribution), and also by the degree to which input from caregivers is coordinated with what the child is attending to and coordinated or appropriate to the child's development (see Figure 1: arrows from coordination nodes to attention to speech node). In the TAAC conceptual framework, attention to speech is central. It is influenced by several factors and, in turn, influences both learning and the input to be learned (see Masek et al., 2021, for another model on the role of attention and parents' contingent behavior in language development).

Coordination of speech input with children's attention and development

Although attention to speech alone may facilitate the development of speech processing skills, referential understanding of language requires that children connect speech with what they experience. Language input that is coordinated with what children are visually attending to or playing with helps them relate what they are hearing with the world they are experiencing, which facilitates word learning in the U.S. children (Yu & Smith, 2012). That describes one coordination factor—*coordination with attention*. Another coordination factor is *coordination with development,* which describes the extent to which language input is coordinated with the language and cognitive skills of the child. As I discuss in the next section, both these coordination factors may be more variable for children with cochlear implants than for children with typical hearing, thus serving as stronger moderators for the association between language input and language outcomes.

Coordination with attention

A primary function of language input is to help children learn words. Many children with cochlear implants have difficulty learning to associate novel words with their referents compared with typically hearing peers because of several factors (Houston et al., 2003, 2005, 2012). For example, novel-word learning skills are influenced by early auditory experience—the age the cochlear device is implanted and preimplantation hearing. Word learning skills may develop, in part, by having ample opportunities during interactions to learn words. Across several cultures, caregivers provide opportunities for word learning when they are generally sensitive to the attention needs of the child (Tamis-LeMonda et al., 2014), and specifically when they label objects in coordination with children's attention to those objects (Yu & Smith, 2012).

Recently, researchers have investigated the synchrony of caregivers' labeling of objects and young children's attention to objects during free-play interactions. Parents of deaf and hard-of-hearing children, including those with cochlear implants, were less likely to label toys in synchrony with their children's attention to those objects than were parents of children with typical hearing (Chen et al., 2019a). Difficulty coordinating attention between caregiver and child may reduce the benefits of language input to referential learning. Other differences in caregiver-child interactions suggest the value of taking a deeper dive into the nature of these interactions when children have hearing loss and how the quantity of language input may affect those interactions. For example, sustained attention to objects is less influenced by caregivers' talk about objects in deaf and hard-of-hearing children than in typically hearing peers (Chen et al., 2019b), and deaf and hard-of-hearing children tend to use caregivers' eye gazes to achieve coordinated attention with their caregivers more than children with typical hearing do (Chen et al., 2020), at least among primarily non-Hispanic White families in the United States.

Another difference in how parents interact with children with cochlear implants is in the quality of language they use, which can play a role in its coordination with children's attention. Many directive utterances are aimed at shifting attention away from what the child is attending to (e.g., "Look at this one."). In U.S. children from socioeconomically diverse families with mild to severe hearing loss, less use of directives to children at 18 months was associated with more optimal language outcomes at 3 years (Ambrose et al., 2015), and researchers identified a similar pattern in preschool-age children with cochlear implants from somewhat more ethnically diverse families (Cruz et al., 2013). Although neither study specified how many of the directives parents used were aimed at shifting attention, parents of children with cochlear implants might have more difficulty coordinating their language with their children's attention and may use language that is more likely to shift their children's attention away from what they were attending to; both of these might result in more variability in how much of the input is coordinated with their children's attention.

Coordination with development

Caregivers modify their language as children develop. Providing language that is age-appropriate is related to more optimal language outcomes than providing language that is less age-appropriate (Dave et al., 2018). Typically developing children's language skills are tightly coupled with their chronological age. However, language skills in children with cochlear implants are likely to lag behind their cognitive development, presenting a potential challenge for parents in coordinating their language input with children's developmental needs. One example of this potential discordance is in the prosodic properties of caregiver input. Across socioeconomic status, parents of children with cochlear implants use prosodic patterns characteristic of "parentese" that is used when speaking to children with the same hearing age rather than reflecting the child's chronological age (Bergeson et al., 2006). Coordinating some characteristics of language input, such as exaggerated vowel dispersion (Dilley et al., 2020), with children's hearing age could help extract meaning from language.

Another way language can be coordinated with children's development involves its repetitiveness. Language to younger children tends to be simpler and more repetitive than language to older children. In an investigation of the role of mothers' repetition of lexical items in their children's language outcomes, higher degrees of lexical repetition during free-play interactions three to six months after cochlear implantation were associated with children's more optimal performance on language measures two years after implantation, suggesting that in socioeconomically diverse samples, hearing words many times during conversations facilitates vocabulary acquisition (Wang et al., 2020). This may be an example of caregivers coordinating a lexical property of language input (word repetition) with children's delayed language development. Language input that is coordinated with what the child is attending to and the child's development contributes to children's ability to connect the speech they hear to what they are experiencing (see Figure 1: arrows from the coordinated language input bin to the distribution of referential understanding). It is also likely to contribute to how much attention children pay to the input.

IMPLICATIONS FOR EARLY INTERVENTION

The TAAC conceptual framework has characteristics that are relevant for early intervention practices in children with cochlear implants. The centrality of attention to speech suggests that focusing on it may be key to enhancing speech processing, which contributes to spoken language development (Weisleder & Fernald, 2013). The TAAC framework assumes that what may help develop attention to speech is providing input that is coordinated with children's attention and developmental needs, which is supported by research on the importance of parent sensitivity for language development

(Tamis-LeMonda et al., 2014). Although most providers of early intervention appreciate the role of parents in their children's language development, many feel it is their responsibility and the responsibility of other professionals to instill spoken language in children, and many do not coach parents on how to facilitate their child's language development in their role as the primary source of language input. Early intervention strategies for children with cochlear implants should enhance parents' knowledge and self-efficacy (Davenport et al., 2021) so parents can provide accessible and coordinated language input tailored to each family's home environment (Holt et al., 2020).

Cultural diversity among families should also be acknowledged given its role in shaping the linguistic environment (Masek et al., 2021), as well as the goals and priorities parents have for their children. Providers can learn from parents about family dynamics, incorporate these into goals that are set together, and work together to accomplish them. Providers should always recognize that most early language development, even for children who struggle with it, happens in the home (Tamis-LeMonda et al., 2019).

Likewise, developmental scientists can learn from providers about their experiences with families and the factors that contribute to the diversity of language input. Developmental scientists can further advance understanding of the association between language input and language outcomes by considering the full diversity of children's needs, contexts, and cultures, as well as the moderating factors reviewed here. To accomplish this, researchers must conduct studies in locations that have greater ethnic and racial diversity than where most prior studies have been conducted. Taking such a whole-child and whole-family approach with a diverse representation of families will help inform provider-guided, parent-implemented language interventions (Roberts, 2018) for all children who use cochlear implants as well as for other children.

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