Variability in Quantity and Quality of Early Linguistic Experience in Children With Cochlear Implants: Evidence from Analysis of Natural Auditory Environments

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Objectives: Understanding how quantity and quality of language input vary across children with cochlear implants (CIs) is important for explaining sources of large individual differences in language outcomes of this at-risk pediatric population. Studies have mostly focused either on intervention-related, device-related, and/or patient-related factors, or relied on data from parental reports and laboratory-based speech corpus to unravel factors explaining individual differences in language outcomes among children with CIs. However, little is known about the extent to which children with CIs differ in quantity and quality of language input they experience in their natural linguistic environments. To address this knowledge gap, the present study analyzed the quantity and quality of language input to early-implanted children (age of implantation <23 mo) during the first year after implantation.

Design: Day-long Language ENvironment Analysis (LENA) recordings, derived from home environments of 14 early-implanted children, were analyzed to estimate numbers of words per day, type-token ratio (TTR), and mean length of utterance in morphemes (MLU_m) in adults' speech. Properties of language input were analyzed across these three dimensions to examine how input in home environments varied across children with CIs in quantity, defined as number of words, and quality, defined as whether speech was child-directed or overheard.

Results: Our per-day estimates demonstrated that children with CIs were highly variable in the number of total words (mean ± SD = 25,134 ± 9,267 words) and high-quality child-directed words (mean ± SD = 10,817 ± 7,187 words) they experienced in a day in their home environments during the first year after implantation. The results also showed that the patterns of variability across children in quantity and quality of language input changes depending on whether the speech was child-directed or overheard. Children also experienced highly different environments in terms of lexical diversity (as measured by TTR) and morphosyntactic complexity (as measured by MLU_m) of language input. The results demonstrated that children with CIs varied substantially in the quantity and quality of language input experienced in their home environments. More importantly, individual children experienced highly variable amounts of high-quality, child-directed speech, which may drive variability in language outcomes across children with CIs.

Conclusions: Analyzing early language input in natural, linguistic environments of children with CIs showed that the quantity and quality of early linguistic input vary substantially across individual children with CIs. This substantial individual variability suggests that the quantity and quality of early linguistic input are potential sources of individual differences in outcomes of children with CIs and warrant further investigation to determine the effects of this variability on outcomes.

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Key words: Cochlear implant, Child-directed speech, Early language input, Variability, Quantity, Quality.

Abbreviations: ADS = Adult-directed Speech; AWC = Adult Word Count; CDS = Child-directed Speech; CI = Cochlear Implant; IQR = Interquartile Range; IRR = Inter-Rater Reliability; LENA = Language ENvironment Analysis; Max = Maximum; Min = Minimum; MLU = Mean Length of Utterance; PLS-AC = The Preschool Language Scale-Auditory Comprehension; PLS-EC = The Preschool Language Scale-Expressive Communication; SD = Standard Deviation; SES = Socioeconomic Status; TTR = Type-Token Ratio.

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INTRODUCTION

Variability in Language Outcomes of Children With CIs

Cochlear implants (CIs) are the most successful prosthetic devices that allow children with severe to profound hearing loss to access sounds and speech in their environments (e.g., Svirsky 2017). Having access to such auditory input permits children with CIs to acquire spoken language (e.g., Cohen et al. 1999; Svirsky et al. 2000). However, there remains enormous unexplained variability among children with CIs in their language outcomes (e.g., Geers et al. 2003; Svirsky et al. 2004; Niparko et al. 2010; Peterson et al. 2010; Ertmer & Goffman 2011; Holt et al. 2012; Tobey et al. 2013). The magnitude of this unexplained variability is notably greater than that of children with typical hearing (Svirsky et al. 2004; Duchesne et al. 2009). Therefore, it is of the utmost importance to further focus on under-studied factors such as children's early language experience, which can potentially contribute to variability in language development. The present study sought to rigorously study language environments of a population of early-implanted children (<23 mo of age) during the first year after their implantation to understand the extent to which children with CIs vary in quantity and quality of language input.

Early linguistic environments have been shown to shape language development in children with typical hearing (e.g., Hart & Risley 1995; Kuhl 2000; Hoff 2003; Weisleder & Fernald 2013; Newman et al. 2016). It is important to note that, the quantity and quality of language inputs vary substantially across language environments of typically-hearing children (e.g., Hart & Risley 1995). Large differences across children in numbers of words heard per day can be compounded over years, giving rise to meaningful differences among children on the order of millions of words by age 3 (Hart & Risley 1995). However, it is important to acknowledge that these word-quantity differences should be interpreted cautiously to avoid negative consequences in areas related to language learning such as policy development and racial bias, as widely discussed in prior studies (e.g., Michaels 2013; Adair et al. 2017; Golinkoff et al. 2019;

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Purpura 2019; Sperry et al. 2019a,b). Despite these valid criticisms, these patterns of word differences across language environments of children with typical hearing have been replicated in several recent studies (Hirsh-Pasek et al. 2015; Romeo et al. 2018; Golinkoff et al. 2019), which translated into individual differences in language outcomes and cognitive skills (Hart & Risley 1995; Hoff 2003; Golinkoff et al. 2019; Wang et al. 2020). Yet there remains a major knowledge gap about the extent to which early linguistic environments vary across children with CIs, recognizing that variability in language outcomes in this at-risk pediatric population likely poses a more significant problem than that of children with typical hearing. In the present study, we rigorously analyzed audio samples recorded from naturalistic auditory environments of children with CIs during the first year after implantation to explore how the quantity and quality of early linguistic environments vary across children with CIs, focusing on the properties of total speech and high-quality, child-directed speech (CDS) experienced by children in their home environments.

Theoretical Frameworks Relevant to the Role of Early Linguistic Environments on Language Development

A child's language system reflects interactions between properties of experienced language input and a neural system with highly plastic structure during early childhood. These are two potential sources of variability that together form a complex dynamic system involved in language development. To motivate studies in the present article, we adopt two complementary theoretical frameworks central to language development. First, variability in outcomes of complex human interactions can be understood within dynamic systems theory (e.g., van Geert & van Dijk 2002; Smith & Thelen 2003). Under this theoretical framework, complex cognitive systems, such as language, develop through interaction between physical and social components of environments (Smith & Thelen 2003; Verspoor et al. 2008). The development of skills for comprehension and production of linguistic units (e.g., phonemes, syllables, and words) is therefore the outcome of active, long-term daily interactions with linguistic input, giving rise to a complex, dynamic language-learning process. As this theory states, examining patterns of variability in language input from children's environments is central to providing better explanations of sources of differences among children in language outcomes (Verspoor et al. 2008; Geers et al. 2011). This is particularly crucial in children with CIs, due to their partial access to fine-grained acoustic cues in speech, as well as the larger variability that has been widely reported in language outcomes of these children compared with their typically-hearing peers (e.g., Svirsky et al. 2004; Duchesne et al. 2009).

Second, the impacts of language environments on language development can be understood relative to frameworks pointing to children's exploiting speech statistical and distributional characteristics to forming linguistic representations (Johnson & Jusczyk 2001; Saffran 2002; Saffran & Kirkham 2018). Children use probabilistic statistical information—such as within-word and across-word transitional probabilities—to assist with vocabulary acquisition and to acquire hierarchical linguistic structures (e.g., Saffran et al. 1996a,b; Saffran et al. 1999; Saffran & Kirkham 2018). From this, it follows that higher exposures to language engender better estimates of statistics of speech and language structures (Hoareau et al. 2019). Considering language learning as a dynamical system and statistical learning process helps explain how variability across children in the quantity and quality of language input may interact with early neural plasticity, leading potentially to differential rate and time-courses of development of linguistic systems with variable proficiency.

Quantity of Ambient Language and its Influences on Language Development

Prior studies have suggested that experiencing a greater quantity of language input during early childhood leads to higher vocabulary growth in children with typical hearing (e.g., Huttenlocher et al. 1991; Hart & Risley 1995; Neville & Bruer 2001; Hoff 2003; Hurtado et al. 2008; Rowe et al. 2012; Weisleder & Fernald 2013; Ramírez-Esparza et al. 2014). While early research pointed to socioeconomic status (SES) as a primary factor in explaining language environment differences (e.g., Hart & Risley 1995), more recent studies have supported that the amount and quality of language input, rather than SES *per se*, is critical (Sperry et al. 2019a). The amount of words that children experience in their linguistic environments is also influenced by their own communication styles (e.g., Gilkerson & Richards 2008; Cates et al. 2012; Ambrose et al. 2014; Warlaumont et al. 2014; Pae et al. 2016). In fact, language development is the outcome of bidirectional interaction between the features of children's intrinsic communicative behaviors and the properties of language environments. Children who engage in more conversational turns and vocalize more frequently not only recruit their language learning apparatus more often, but also increase their chance of receiving more advanced communicative responses from their language environments (e.g., Gilkerson & Richards 2008; Gilkerson et al. 2018).

To investigate the quantity of language input, most prior studies either used parental questionnaires and/or spontaneous speech samples (e.g., Szagun & Stumper 2012; Szagun & Schramm 2016) or relied on the estimates provided by the Language ENvironment Analysis (LENA) recording device (e.g., Gilkerson & Richards 2008; VanDam et al. 2012). However, word count estimates from parental questionnaires, spontaneous speech samples, and LENA may be biased and/or unreliable (e.g., Roberts et al. 1999; Feldman et al. 2000; Lehet et al. 2021). LENA devices are also not designed to specify whether word counts estimate total speech or high-quality, CDS. LENA's limitation in recognition of CDS from other types of speech may explain the null association between children's language proficiency and number of adult words that were reported by VanDam et al. (2012) as they did not exclusively measure high-quality CDS. Therefore, more rigorous, refined approaches are needed to study how the quantity and quality of language input vary among children with CIs.

Quality of Language Input and its Influences on Language Development

Individual differences in language outcomes are also influenced by the quality of language input. Components of language quality such as parents' communication style and the structure of utterances may each influence development of facets of children's language systems (e.g., Hoff 2003, 2006; Weisleder & Fernald 2013). Children learn language in natural auditory environments where multiple adults and other children are often present (Busch et al. 2017). Whether adults' speech was directed to the child—namely, whether it was CDS—or else whether the speech was merely overheard but not addressed to the child in any way, is a major distinction in consideration of the quality of language input (e.g., Fernald 2000; Rowe 2012; Shneidman et al. 2013; Wang et al. 2018a,b). Prior studies demonstrated that the supportive role of the amount of speech input on language learning is mainly driven by the amount of CDS, as compared with overheard speech (e.g., Barnes et al. 1983; Hoff-Ginsberg 1986; Huttenlocher et al. 1991; Hoff 2003, 2006; Shneidman et al. 2013; Weisleder & Fernald 2013; Dilley et al. 2020). While Sperry et al. (2019b) argued that overheard speech is as valuable as CDS for language learning, Golinkoff et al. (2019) pointed to evidence that the amount of high-quality CDS in children's environments was the driving factor, rather than solely the total amount of speech. However, there is still no information about how individual children with CIs differ in terms of amount of high-quality, CDS they experience in their early natural linguistic environments. This is particularly important for children with CIs who heavily rely on high-quality language input for developing a language system due to lack of access to full speech cues (e.g., Ambrose et al. 2015; Svirsky 2017; Oxenham 2018). In the following paragraph, we will further clarify the notion of what is "high quality" in terms of whether speech is directed to the child (i.e., CDS) or was overheard speech.

Acoustic, linguistic, and extra-linguistic qualities of speech are influenced when adult speakers modify their speech from a standard speaking style to a CDS style. Multiple studies have shown that children prefer listening to CDS over ADS, including both typically-hearing children and those with CIs (e.g., Fernald & Kuhl 1987; Wang et al. 2017a,b; Wang et al. 2018a,b), but this preference also facilitates their language learning (Hoff 2003; Weisleder & Fernald 2013). Acoustic-phonetic properties of CDS facilitate speech processing through constraining children's lexical access (Thiessen et al. 2005), enhancing their attention for better syllabication (Karzon 1985), and assisting with word recognition (Singh et al. 2009), although CIs may degrade acoustic properties distinguishing CDS from ADS (Arjmandi et al. 2021). Further, CDS may affect other aspects of language input, such as lexical diversity and morphosyntactic complexity. For example, exposing children to a higher amount of high-quality CDS in a day increases their chances of experiencing both more word types and higher repetitions of words (e.g., Hoff 2006; Newman et al. 2016; Montag et al. 2018). Mothers who speak more to their children provide more examples of semantically relevant utterances, facilitating children's language learning (Hoff-Ginsberg 1994; Hart & Risley 1995; Montag et al. 2018). Morphosyntactic complexity also seems to play a role in language development, although the nature of its effects is currently unresolved. Some studies have found that the simpler model of language input provided by CDS (e.g., shorter MLUs) facilitates syntactic development in children (e.g, Furrow et al. 1979). In contrast, other studies have found positive effects for morphosyntactically complex CDS (i.e., longer utterances) on children's syntactic development (Harkness 1977; Hoff-Ginsberg 1998; Huttenlocher et al. 2002). Taken together, these findings suggest that individual differences in the amount and properties of CDS may contribute to variability across children with CIs in language outcomes. Therefore, there is a pressing need to conduct detailed analyses of language input to understand how properties of CDS vary across children with CIs in their natural linguistic environments.

Present Study

The present study aimed to provide a rigorous and accurate characterization of variability in the quantity and quality of early language input experienced by 14 early-implanted children with CIs in their natural language environments. To study the language environments of children, many researchers have used automatic speech processing tools, such as the LENA (e.g., Xu et al. 2008). However, we have identified highly variable and sometimes large inaccuracies in LENA's automatic word count estimates, especially for CDS (Lehet et al. 2021). Moreover, LENA is not designed to separate the number of child-directed words from total number of words, which was the main focus of the present study. These findings led us to adopt an approach in which we conduct human coding on samples of speech recorded in the homes to characterize the quantity of language input based on estimates of the number of words children heard in a day. Further, we characterized the quality of language input by estimating the number of high-quality, child-directed words in a day. We also characterized properties of total and CDS for their lexical diversity and morphosyntactic complexity. These estimates were used to examine individual differences across children with CIs in the quantity and quality of language input they experienced per day in their language environments. The following specific questions were addressed in this study.

Question 1 • To what extent do children with CIs vary in the numbers of total words and high-quality child-directed words experienced per day in their early linguistic environments during the first year after implantation?

Question 2 • How do the distributions of child-directed words versus overheard words per day vary across children with CIs?

Question 3 • How do early linguistic environments vary across children with CIs in terms of lexical and morphosyntactic information available in total and CDS, as characterized by type-token ratio (TTR) and mean length of utterance (MLU)?

MATERIALS AND METHODS

Participants

Fourteen families with a child (4 boys and 10 girls) with a CI enrolled in this study. Demographic information of participants is presented in Table 1; see also Table S1 in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 for further information. As part of their participation, families agreed to record their home environments using LENA devices for at least one day within the first year following activation of theirs child's CI(s). Recordings were drawn from the first year after implantation (see Appendix I in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 for more details). Children's ages at CI activation ranged from 8.12 mo to 22.57 mo (M_{age} = 14.97 mo, SD_{age} = 4.1 mo). Of these 14 children, 11 children were bilaterally implanted, and three had bimodal devices (a hearing aid in one ear and a CI in the other). Four children had additional comorbid diagnoses. All infants were living in monolingual English language environments. Children's SES was indexed by their parents' education level. Additional demographic and audiological information such as children's SES, preoperative hearing status measures (preimplantation residual hearing), and CI device characteristics are presented in Table S1, Supplemental Digital Content 1, http://links.lww.com/EANDH/A911. This study was approved by the Institutional Review Boards of the Ohio State University and

TABLE 1. Demographic information for 14 children with CIs who participated in this study

Subject ID Code	Subject ID	Gender	Age at CI Activation (mo)	Bilateral/Unilateral	Mean PTA Unaided (dB)	Com. Mode	Degree of HL
BT0001	1	F	22.57	RL	86.25	OC	Profound
BT0004	2	M	17.16	RL	120	TC	Profound
BT0005	3	F	19.77	RL	120	TC	Profound
BT0010	4	F	14.89	RL	120	TC	Profound
BT0032	5	F	19.27	R-HA	92.50	TC	Profound
BT0071	6	F	18.30	RL	119.50	TC	Profound
BT0141	7	M	13.58	RL	113.75	OC	Profound
BT0155	8	M	14.17	HA-L	110	TC	Profound
BT0179	9	F	11.02	R-HA	109.37	OC	Profound
BT0189	10	F	15.25	RL	70.56	TC	Severe
BT0191	11	F	8.13	RL	Unknown	TC	Profound
BT0195	12	M	10.10	RL	120	TC	Profound
BT0210	13	F	12.40	RL	120	TC	Profound
BT0227	14	F	13.03	RL	120	TC	Profound
M (SD)			14.97 (4.1)				

The information in this table includes children's ID, gender, age at CI activation, listening mode, mean unaided PTA, communication mode, and degree of hearing loss. See Table S1 in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 for further details about demographic information.
Gender: F = Female, M = Male.
Bilateral/Unilateral: RL: bilateral implants, HA-L: CI in the left ear and hearing aid in the right ear, R-HA: CI in the right ear and hearing aid in the left ear; PTA is pure-tone average before implantation (across the frequencies of 250, 500, 1000, 2000, and 4000 Hz); Com. Mode is the type of communication program that the child was following in speech-language therapy. OC: oral communication (exclusively spoken); TC: total communication (a combination of spoken language and Signed Exact English); HL: hearing loss

Michigan State University. All participants had given informed consent to participate, and they were fully informed about the purpose of this study.

Acquisition and Selection of Audio Recordings

Recordings were made using a digital audio recorder, the LENA device. LENA is a wearable audio recorder that collects children's daily spoken interactions and provides automated measures of adult word counts and other vocalization measures such as conversational turns (e.g., Gilkerson & Richards 2009; Oetting et al. 2009; Wang et al. 2017a,b). No instruction was given to parents regarding wearing the device or choice of days to wear the device to increase the chance of recording children's language environments in free-living, real-life scenarios. Overall, 32-day long LENA audio recordings were collected and analyzed for the families participating in this study during the first year after implantation. Between one and four recordings were analyzed for each child (average number of recordings = 2.28, SD = 0.91). We analyzed a maximum of four LENA recordings per child in the first year post-implantation. For children with fewer than four recordings, we included the maximum number of recordings available for each child. See Table S1 in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 for further information.

Sampling From Day-long Audio Recordings

In response to LENA's limitations (e.g., Lehet et al. 2021), we developed a comprehensive coding system to analyze early linguistic input. In this study, the basic metric for assessing the quantity of language in children's home environments was to determine per-day estimates of language input. We derived such per-day estimates through analyzing chunks of audio sampled randomly from the entire day-long audio recordings (each up to 16 hr long), a common approach that is necessary to deal with the infeasibility of manually analyzing the entire day-long audio recording (e.g., Hart & Risley 1995; Shneidman et al. 2013; Weisleder & Fernald 2013). From within this set of day-long audio recordings, we randomly sampled intervals constituting 5% of the waking time of the child (adjusting for differences in amounts of waking time across children). To accomplish this sampling in a computationally tractable way, the entire day-long recording was first split into 30-sec intervals as a preliminary to random selection. Next, 30-sec intervals that included any time during which the child was judged to be asleep were removed by hand from the analysis based on contextual cues in the audio such as prolonged heavy breathing, parental discussion of the child sleeping or saying goodnight, and/or other contextually-based cues to naps. From the remaining set, 5% of the 30-sec intervals were randomly selected for the analysis, a proportion that was judged to provide an adequate balance between the amount of time required for human hand-coding of speech and sample representativeness. Finally, the amount of speech (word counts) derived from randomly selected portions of audio recordings was extended to the entire day to estimate the total amount of words experienced by each child per day (e.g., Hart & Risley 1995; Shneidman et al. 2013; Weisleder & Fernald 2013). Overall, a total of 17.7 hr of audio was analyzed by hand by human listeners in 2,118 30-sec length samples. On average, 1.3 hr of audio was analyzed by hand per child with an SD of 0.58 hr. Further information about the sampling procedure is presented in Appendix I in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911.

Analysis of Audio by Human Analysts

Audio samples were labeled by trained human analysts using *Praat* textgrids (Boersma & Weenink 2001) based on annotation conventions described in these sections. These textgrids were time-aligned with their corresponding audio files in *Praat* for coding. The daylong recordings and textgrids were split into 15-minute intervals for coding so that context around each 30-sec interval was available to human analysts to inform their coding decisions.

For each 30-sec audio interval, human analysts first identified whether there was any human-generated sound, either live or recorded. If so, analysts marked the temporal starts and ends of the human-generated sound on the relevant tier in *Praat*

(Boersma & Weenink 2001), breaking contiguous speech into separate utterances as needed. Coding conventions further considered the gender of the talker and whether the sound at the time of LENA recording appeared to have been live or pre-recorded (e.g., television) (see Fig. 1). Human analysts coded only live speech. For stretches judged to contain a human-generated sound, analysts determined whether it was a speech by a "competent talker," defined as a talker over the age of five who articulated words in an intelligible and audible fashion. For portions of audio judged to be speech by a competent talker, analysts determined the following information, all of which was captured in coding conventions in *Praat* textgrid annotations: (a) whether the speech was understandable, in which case they transcribed the words within a contiguous stretch of speech into the relevant *Praat* textgrid interval (including utterance with conventionalized sound-meaning mappings such as *whoosh, moo, choo-choo, woo-hoo, yeah*, etc.), (b) who spoke the speech (whether adult male, adult female, or child); and (c) who the speech was directed to (whether the target child and/or other children or adults). Since our focus was on the language input experienced by the target child, any sounds judged to be from the target child were noted separately and coded in the appropriate tier as a matter of completeness (see Fig. 1 and Tables S2 and S3 in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 for more information about the structure and content of the coding). Table S2 and Appendices II and III in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 provide further information regarding the hierarchical structure and the coding used to analyze information in the present system. Also, see Appendix IV in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 for information about the training protocols and procedure.

Inter-rater Reliability Analysis

An inter-rater reliability (IRR) analysis was conducted to assure acceptable agreement between human analysts in analyzing and coding the LENA audio samples. To conduct the IRR analysis, the 13 human analysts were asked to code 2% of the total 5% of randomly selected audio samples (i.e., ~21.5 min). The audio selected for the IRR analysis had not been previously seen by coders in this study, and analysts coded these files independently of one another. The design of the IRR analysis was a fully-crossed design where all randomly selected audio was coded by all thirteen analysts (Hallgren 2012). Agreement between coders was evaluated based on two analyses of Cohens' Kappa analysis and Fleiss Kappa analysis. Finally, a word-transcription reliability analysis was also conducted to identify how much coders agreed with each other in transcribing the speech of competent talkers at the level of the word. Further information on IRR analysis can be found in Appendix V in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911.

Analysis of Audio Samples Coded by Human Analysts

Following application of the coding system to the 5% of randomly sampled audio stretches, we analyzed the coded speech intervals and their transcriptions in each 30-sec audio sample to capture the following linguistic input measures: (1) total number of words per day, (2) TTR, and (3) mean length of utterance in morpheme (MLU_m). A discussion of how these three measures were calculated is presented in Appendix VI, Supplemental Digital Content 1, http://links.lww.com/EANDH/A911.

We developed a custom *Matlab* toolbox using the *mPraat toolbox* (Bořil & Skarnitzl 2016), where coded *Praat* textgrids were called and analyzed to derive per-day estimates of each of the above linguistic measures. To estimate the number of words heard per day, we assumed that the per-day estimates of language measures calculated in this study can be generalized to the entire first year after implantation as proposed in prior studies (Hart & Risley 1995; Shneidman et al. 2013; Weisleder & Fernald 2013). The results from conducting two linear mixed-effects analyses confirmed the assumption that the estimated number of total words per day and number of child-directed words per day did not change significantly over the four-time intervals of 3, 6, 9, and 12 mo post-implantation (see Appendix VI in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 for

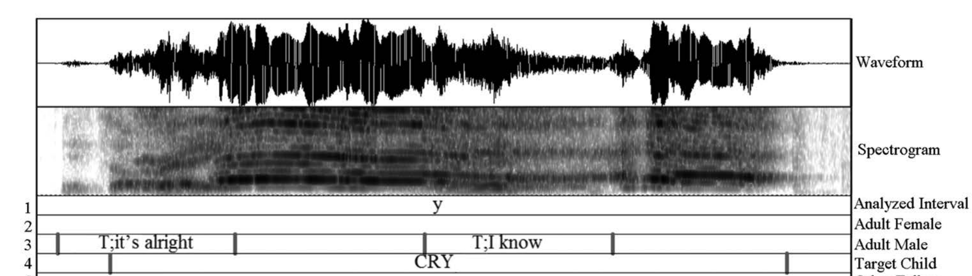

Fig. 1. Annotation scheme used by human analysts to code various sound events of interest in the present study. The illustrated sample interval contains ~3.5 sec of audio within a 30-sec analysis interval drawn from a day-long audio recording of a child in the corpus, and was coded by a human analyst. For this interval, the father of child with CIs was communicating with his child. The two top rows of the display show the waveform and spectrogram, respectively. Coding consisted of *Praat Textgrid* tiers providing for annotation of the following information (top to bottom): (1) the Analyzed Interval tier indicated which 30-sec sampled audio portions had been selected randomly for inclusion in the analysis (given with a "y" label); (2) The Adult Female tier contained speech from competent female talkers (or the primary female for the conversational situation, who was usually the target child's mother but not necessarily always the mother, because our criteria specified that the primary talker was the one who held the floor); (3) The Adult Male tier was the same as Adult Female tier, except it was used to designate speech from male talkers; (4) The Target Child tier was used for the "target child" only and contained speech or speech-like or non-speech vocalization or cries from the target child; (5) The Other Talker tier contained vocal activities from other linguistically competent talkers. See Tables S2 and S3 in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 for further information on the structure and types of codes used in these five tiers. Here, the father's conversation with the target child is coded within two intervals. "T" label at Level 1 of these two coded intervals indicates that the speech was directed to the target child; see Table S3 in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911. The father's speech was transcribed for these two intervals while separated from Level 1 information using a ";".

further details). Therefore, a per-day estimate derived at 6 mo or later was a reasonable basis for estimating how much speech was spoken in the household prior during the first year post-CI. For children with more than one recording, estimates for each day were averaged together across multiple days (i.e., recordings) to derive the final estimate for each child. All these language input measures were also calculated separately for subsets of intelligible speech consisting of either (a) CDS, (b) overheard speech, and/or (c) adult-directed speech. Overheard words included any words not judged to be spoken directly to the target child, including words directed to adults or other children. For number of words, we further estimated cumulative word exposures experienced by each child over multiple years after CI activation based on their per-day word exposure. See Appendix VI in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 for more information.

Measures of Language Outcomes

An exploratory approach was taken in this study to provide an initial test to explore the potential impacts of variables of the language input on standard scores of language outcomes in our small sample of children with CIs. Measures of language outcomes were only available for 13 children at 6 mo post-implantation. One of the children was not available for testing. Language outcomes of the children were measured using the Preschool Language Scale—Fifth Edition (PLS5; Zimmerman et al. 2011), which is a standardized test to assess children's receptive and expressive language skills. Further information can be found in Appendix VII in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911.

RESULTS

Inter-rater Reliability

Good agreement was found for most coding category distinctions; see Table S4 in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 for the results of the IRR analysis. The results show that human coders demonstrated good agreement (0.61–0.80) for most categories that were a focus of this project (Landis & Koch 1977). In addition, pairwise correlations of word count for speech intervals were summed within each sample and calculated for the pairwise correlations between each rater. This analysis revealed high agreement, with $r = 0.95$ (SD = 0.01, range = 0.94–0.97).

Variability Across Children in the Number of Words Experienced

Total Number of Words • We first investigated the extent to which children varied in the total number of words they are estimated to have heard in their language environments. Figure 2A shows the difference among children in estimates of numbers of words experienced per day. On the basis of extrapolations from audio samples, children heard an average of 25,134 words per day, with an SD of 9267 words per day, indicating the large variation of number of words heard per day across children. The first row of Table 2 summarizes the dispersion of estimates of total numbers of words per day experienced across children. Among demographic factors presented in Table S1, Supplemental Digital Content 1, http://links.lww.com/EANDH/A911, only SES predicted the estimated total number of words per day, suggesting that children with CIs who experienced environments with higher-SES parents were exposed to greater numbers of total words per day (Pearson $r(12) = 0.69$, $p = 0.006$). All statistical analyses were carried out using an alpha level of 0.05 (95% confidence interval).

Number of Words Experienced in Child-directed Speech • Figure 2B shows the data for the estimated exposures to the number of child-directed words per day for these fourteen children. On the basis of the extrapolation method, children heard an average of 10,817 child-directed words per day, with an SD of 7,187 words per day across children. This large SD indicates that children varied largely in the quality of language input they experienced in their home environments. The summary measures of variability in the second row of Table 2 (range, SD, and IQR) provide

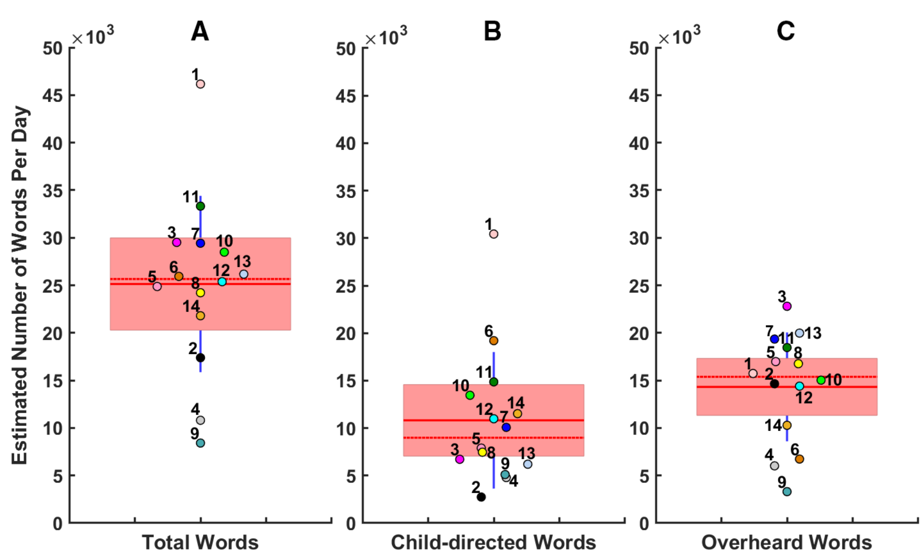

Fig. 2. Estimated (A) total words per day, (B) child-directed words per day, and (C) overhead words per day for each child in their home environments. In each panel, a scatter plot shows the individual children, while the boxplot summarizes the distribution of language experienced in home environments. The data points are laid over a 1.96 SE of the mean (95% confidence interval) in red and 1 SD shown by blue lines. The solid and dotted red lines show the mean and median, respectively, as two measures of central tendency.

TABLE 2. Measures of dispersion (range, SD, interquartile range (IQR)) and central tendency (mean and median) for estimates of number of words per day for each child in his/her linguistic environment

	Measures of Variability						
Measure of Language Input (per day)	Minimum	Maximum	Range	Mean	SD	Median	IQR
Number of words	8,414	46,159	37,745	25,134	9,267	25,656	7,623
Number of child-directed words	2,741	30,431	27,690	10,817	7,187	8,986	7,258
Number of overheard words	3,306	22,797	19,491	14,317	5,724	15,377	8,176

These measures were presented separately for total speech, child-directed speech, and overheard speech.

further information about how dispersed the estimated number of child-directed words were across children. None of the demographic factors in Table S1 in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 predicted the number of child-directed words in children's home environments.

An interesting observation relates to the change in the rank order of children relative to one another in estimates of how many child-directed words they experienced per day versus total words. For example, our method revealed that Child 11 heard more total words than Child 6 (Fig. 2A). However, this order is reversed in terms of exposure to child-directed words, such that Child 6 heard more child-directed words than Child 11 (Fig. 2B), suggesting that exposure to more words does not guarantee exposure to more high-quality CDS words. A similar pattern exists when comparing per-day word estimates between CDS and overheard speech. This data shows that the pattern of variability across children in exposure to number of words changes depending on whether the speech was child-directed or overheard. Although the rank orders of some children were reversed with respect to others, depending on the type of speech (overheard or child-directed), the numbers of total words were strongly positively correlated with numbers of child-directed words (Pearson $r(12) = 0.77$, $p < 0.001$). This suggests that about 59% of the variation in the numbers of child-directed words can be explained by the variation in the number of total words ($R^2_{Adjusted} = 0.59$), leaving around 41% of the variation in child-directed words unexplained.

Finally, Figure 2C shows the distribution of overheard words per day across children, that is, the difference between total words and child-directed words. The third row of Table 2 summarizes measures of variability and central tendency in overheard words across children. There was no significant correlation between the numbers of overheard words and child-directed words. The numbers of overheard words and total words were moderately, positively correlated (Pearson $r(12) = 0.63$, $p = 0.015$), suggesting that around 40% of the variation in the number of overheard words was explained by the total number of words ($R^2_{Adjusted} = 0.40$). The number of overheard words was predicted by children's SES (Pearson $r(12) = 0.69$, $p = 0.006$). This strong correlation suggests that children who had higher SES were exposed to greater numbers of overheard words in a day.

The Proportion of Child-directed Words to Total Words • Figure 3 shows the estimated distribution of child-directed (the areas in blue in the bars) versus overheard words (the areas in orange in the bars) per day for each child. The ratio on the top of each bar is the proportion of child-directed words out of the total number of words per day. This proportion varies greatly among children, ranging from 0.16 to 0.74, with an average value of 0.42 and an SD of 0.17. This plot also

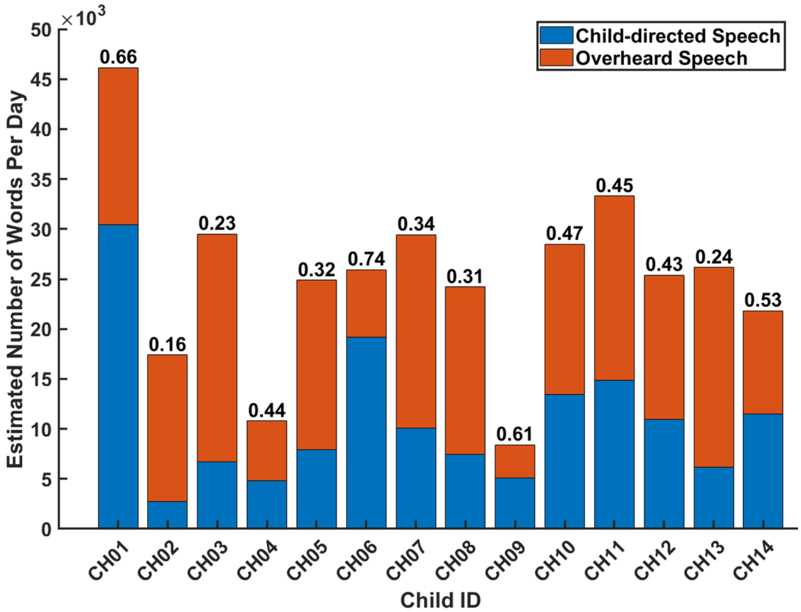

Fig. 3. The distribution of child-directed and overheard words per day in the language environments of each child with a CI. The ratio on the top of each bar is the proportion of child-directed words out of the total number of words (child-directed words plus overheard words) experienced by each child per day.

shows that children who experienced linguistic environments with higher total numbers of words per day did not necessarily hear the most child-directed words per day as high-quality language input. Some children experienced relatively high numbers of total words per day (i.e., higher than the average of total words across children), but less than 50% of the words in home environments were high-quality, child-directed words (Child 3, 7, 10, 11, 12, and 13). On the other hand, some children experienced language environments with a relatively small number of total words (i.e., below average total words across children), even though more than 50% of words in their environments were directed to them (Child 6, 9, and 14). Figure 3 also suggests that differences among children in the quantity and quality of language input depend on the type of speech (i.e., CDS vs. overheard speech). For example, the vast portion of speech in Child 3's environment was overheard speech (see Fig. 3), which changes her distance from other children in terms of the relative quality of this child's linguistic environment. Results of our statistical analyses showed that none of the demographic factors in Table S1 in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 predicted proportions of numbers of child-directed words to total numbers of words per day.

Variability Across Children in the Lexical Richness of Language Input

Figure 4 shows scatterplots of TTR for 14 children with CIs for estimates of total, child-directed, and overheard words. The plot shows a considerable range of variability for TTR obtained from CDS from 0.26 to 0.66, with an SD of 0.1 across children (Table 3). Our investigation of the association between TTR obtained from total speech, CDS, and overheard speech showed that TTR calculated from the total speech was moderately, positively correlated with TTR obtained from CDS (Pearson $r(12) = 0.67$, $p = 0.008$). Conversely, TTR calculated from CDS was not correlated with TTR obtained from overheard speech. The results showed that variation in the TTR of total speech explained 40% of the variation in the TTR obtained from CDS ($R^2_{\text{Adjusted}} = 0.40$). There was a moderate and positive correlation between TTR obtained from total speech and TTR calculated from overheard speech (Pearson $r(12) = 0.65$, $p = 0.01$), suggesting that 37% of the variation in TTR from the overheard speech was explained by the variation in the TTR from total speech ($R^2_{\text{Adjusted}} = 0.37$). None of the demographic factors in Table S1, Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 predicted the TTR derived from the total speech in a day except children's SES, which showed a moderate, negative predictive value (Pearson $r(12) = -0.59$, $p = 0.03$). This significant correlation is mainly driven by the total number of words in the calculation of TTR. The TTR derived from the overheard speech was also significantly correlated with children's SES level (Pearson $r(12) = -0.66$, $p = 0.009$).

Variability Across Children in the Morphosyntactic Complexity of Language Input

Figure 5 shows the scatterplot of MLU_m of adults' speech in the environments of children in this study for total speech, CDS, and overheard speech. Table 4 also presents the dispersion and central tendency of this measure across children for total words, child-directed words, and overheard words. The MLU_m calculated from CDS ranged from 2.8 to 4.5, with an SD of 0.52 (Table 4). This large variability across children in MLU_m of CDS is particularly important because of the impact of high quality, CDS on children's language outcomes. Comparing Figures 2 and 5 reveals an interesting pattern in this data. Language environments that attest a higher total number of words (e.g., Child 1 and 6) do not necessarily provide children with better morphosyntactic information (MLU_m), suggesting that these two measures of language input (number of words and MLU_m) probably characterize speech for two different qualities along largely orthogonal dimensions.

In terms of the association between MLUs derived from total speech, CDS, and overheard speech, we found a strong, positive association between MLU obtained from total speech and that obtained from CDS (Pearson $r(12) = 0.81$, $p < 0.001$), as well as a strong,

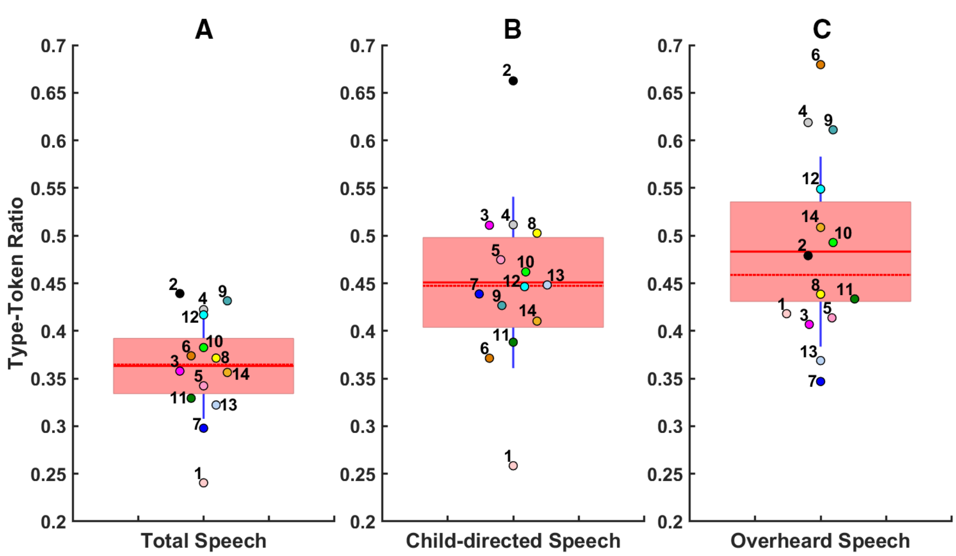

Fig. 4. Type-token ratio (TTR) calculated from (A) total, (B) child-directed, and (C) overheard adult speech in the environment of each child with CIs. The data points are laid over a 1.96 SE of the mean (95% confidence interval) in red and 1 SD shown by blue lines. The solid and dotted red lines show the mean and median, respectively, as two measures of central tendency.

TABLE 3. Measures of dispersion (range, SD, interquartile range [IQR]) and central tendency (mean and median) of type-token ratio, derived across children with CIs

	Measures of Variability						
Measure of Language Input (per day)	Minimum	Maximum	Range	Mean	SD	Median	IQR
Type-token ratio of total speech	0.24	0.44	0.20	0.36	0.05	0.36	0.09
Type-token ratio of child-directed speech	0.26	0.66	0.40	0.45	0.10	0.45	0.09
Type-token ratio of overheard speech	0.35	0.68	0.33	0.48	0.10	0.46	0.13

These measures are presented for total speech, child-directed speech, and overheard speech.

positive correlation between MLUs calculated from total speech and that calculated from overheard speech (Pearson $r(12) = 0.75$, $p = 0.002$). These results suggest that MLUs from total speech explained around 63% of the variation in the MLU obtained from CDS ($R^2_{Adjusted} = 0.63$), as well as about 52% of the variation in MLU obtained from overheard speech ($R^2_{Adjusted} = 0.52$). There was no relationship between MLUs derived from CDS and those obtained from overheard speech. With regard to the predictive value of the demographic factors in Table S1 in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 for the MLU derived from total speech, CDS, and overheard speech, the results from our statistical analyses did not show any significant correlation between MLUs and any of the demographic factors.

The Relationship Between Measures of Language Input and Language Outcomes

Figure S1 in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 shows four plots depicting the relationship between total number of words per day and outcome measures (top plots) and number of child-directed words per day and outcome measures (bottom plots). The analyses suggested that none of these weak correlations were statistically significant for the small sample in the present study. Several simple linear regression analyses were also performed to investigate how well two measures of TTR, and MLU_m predicted PLS-AC and PLS-EC scores at 6 mo post-implantation. Tables S5 and S6 in Supplemental Digital Content 1, http://links.lww.com/EANDH/A911 summarize the results and show that there were no statistically significant correlations between these variables of language input and PLS-AC and PLS-EC. These results were expected due to multiple limitations of the present study that are discussed in the Discussion section.

DISCUSSION

The present study investigated early linguistic environments of 14 prelingually deaf children who received a CI early in childhood (age at activation <23 mo). The primary goal of this investigation was to analyze the day-long audio recordings from children's natural home environments to understand the extent to which individual children vary in the quantity and quality of language input, experienced across a set of lexical and morphosyntactic dimensions. Overall, the results demonstrated large differences across individual children with CIs in the quantity and quality of early language input available in their home environments during the first year following implantation, demonstrating that further investigation into the effects of the quantity and quality of early language input on language outcomes of children with CIs is warranted.

Variability Across Children in the Total Amount of Words Experienced

Our results showed substantial individual variability across children with CIs in the estimated total words experienced per

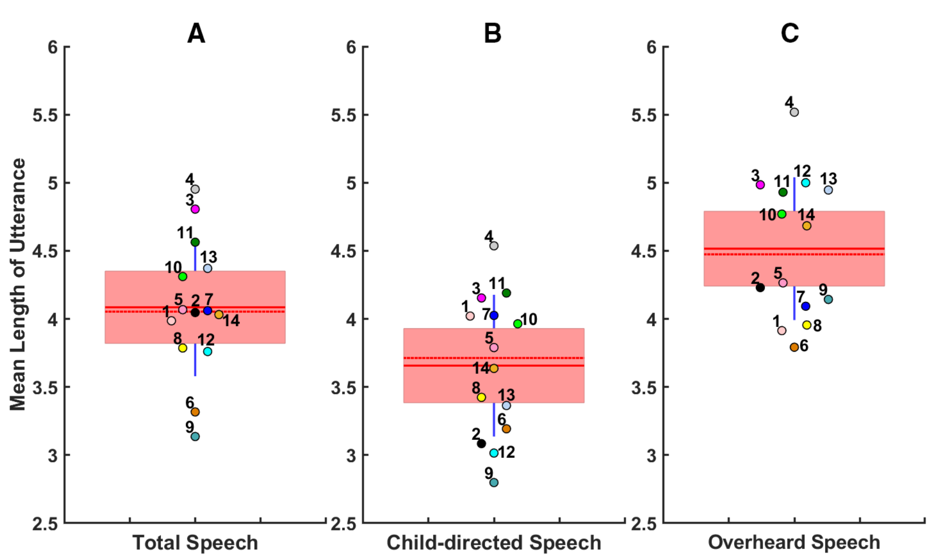

Fig. 5. Mean length of utterance of speech experienced by each child with CIs in her/his linguistic environments derived from (A) total speech, (B) child-directed speech, and (C) overheard speech. The data points are laid over a 1.96 SE of the mean (95% confidence interval) in red and 1 SD shown by blue lines. The solid and dotted red lines show the mean and median, respectively, as two measures of central tendency.

TABLE 4. Measures of dispersion (range, SD, interquartile range [IQR]) and central tendency (mean and median) of mean length of utterance in morpheme (MLUm), derived across children with CIs

Measure of Language Input (per day)	Measures of Variability						
	Minimum	Maximum	Range	Mean	SD	Median	IQR
MLU_m of total speech	3.1	4.9	1.8	4.1	0.51	4.0	0.6
MLU_m of child-directed speech	2.8	4.5	1.7	3.7	0.52	3.7	0.8
MLU_m of overheard speech	3.8	5.5	1.7	4.5	0.52	4.5	0.8

day in their linguistic environments. This large variability is evident from the SD of around 9000 words per day with an interquartile range of around 7000 words per day (25th percentile: ~22,000 words per day; 75th percentile: ~29,000 words per day). Exposure to the relatively larger amount of total words per day in some children (e.g., Child 1 at 46,000 total words per day) compared with other children (e.g., Child 9 at 8000 words per day) suggests that these children might be at risk for experiencing largely variable amounts of language input. Such large individual variability in the number of words heard would affect children's chances to experience extra "nonregulatory" speech, which is argued by Hart and Risley (1995) to be a key source of individual differences in children's language outcomes.

The combination of these distinctions between children with CIs in exposure to very different numbers of total words per day and their highly plastic neural system during early years after implantation can potentially impact their word learning, which is an outcome of active interaction between children's personal characteristics and social components of children's environments under dynamic system framework (Smith & Thelen 2003; Verspoor et al. 2008). Further, children who experience relatively greater amount of words pre-day are more likely to better learn the statistical patterns in speech such as within-word and across-word transitional probabilities and develop more successful word segmentation skills (Saffran et al. 1996; Bulf et al. 2011; Hoareau et al. 2019), that are fundamental to language learning (e.g., Houston et al. 2020).

Variability Across Children in the Amount of High-quality Child-Directed Words

It is not merely individual differences across children in quantities of words heard that account for variability in language outcomes; also, the quality of speech experienced by children matters. One of the major elements of the quality of early linguistic environments is CDS. The role of CDS in intervention for language development is conceivably much higher for children with CIs compared with their peers with typical hearing. This is because these children do not have access to fine-grained spectro-temporal cues in speech and thus may rely more on supportive acoustic, visual, and tactile cues usually associated with CDS. In fact, the exaggerated speaking style with a slower speaking rate and greater pitch fluctuation that is often used by an adult in CDS may enhance acoustic cues that are degraded by CI (e.g., Arjmandi et al. 2021) and reduce listening efforts (e.g., Winn & Teece 2021). Children with CIs in our study differed considerably in amounts of high-quality, CDS they experienced as suggested by the SD of around 7,000 child-directed words across an average of ~10,000 child-directed words per day. Experiencing a higher number of child-directed words per day not only exposes children to a greater number of high-quality words but also increases the chance of hearing more word types with higher repetition (Huttenlocher et al. 1991; Naigles & Hoff-Ginsberg 1998), increasing the chance of learning the statistical patterns in speech (e.g., within-word and across-word transitional probabilities; Hoareau et al. 2019) and better word segmentation (Saffran et al. 1996; Bulf et al. 2011). A rough estimate for accumulation of child-directed words over a 3-year span suggests that children are expected to have experienced on average around 11.8 million child-directed words, with an SD of 7.9 million words (min = 3 million words, max = 33.3 million words; range = 30.3 million words; IQR = 7.9 million words). These results suggest that the per-day variability across children in the amount of child-directed words experienced in a day can be compounded over years, leading potentially to an enormous difference in the quality of language input across children. It should be noted that extrapolation over years is only valid assuming that our per-day estimates were to hold for years after the first year of implantation. Therefore, these results for over years should be cautiously interpreted.

These results extended—for the first time—the prior well-established findings in children with typical hearing to a pediatric CI population, namely, that there is tremendous variability across children in the amount of CDS they experience per day (e.g., Hart & Risley 1995; Hoff 2006; Greenwood et al. 2011; Sperry et al. 2019a). To our knowledge, this is the first study that demonstrates patterns of large individual differences among children with CIs in exposure to total numbers of words and numbers of child-directed words early after cochlear implantation based on data from natural auditory environments, which may conceivably account for a large portion of individual variability between children with CIs in language outcomes. Unlike distal family variables such as parental SES and family size that are less clinically adjustable, proximal family variables such as the amount of high-quality, child-directed words experienced by a child in a day can be clinically modified to maximize the benefit of CIs.

Individual Variability in the Lexical Diversity of Language Input

The degree of word diversity of language input, measured as TTR, has been recognized as a strong predictor of vocabulary growth in children with typical hearing (Huttenlocher et al. 1991; Hart & Risley 1995; Weizman & Snow 2001; Hoff & Naigles 2002; Pan et al. 2005; Rowe 2012; Shneidman et al. 2013). A child who experiences language input with a relatively high TTR will have heard a greater diversity of words, compared with a child experiencing a relatively low TTR, contingent on exposure to the same number of words. The results from the present study suggest that children were different in terms of exposure to more types of words, as reflected by TTR. However, these differences were not purely due to lexical diversity and were also influenced by the number of total words per day. This is because TTR does not reflect merely the diversity of vocabulary in speech input, but is also sensitive to numbers of tokens in the analyzed sample, as observed in our data (e.g., TTR for Child 1) (e.g., Herdan 1960; Montag et al. 2018). This means children who heard fewer words per day in their environments had a higher chance of having a higher TTR, suggestive of hearing more diverse speech. However, the total number of unique word types for these children was not higher; due to exposure to smaller number of words per day, the repetition of words was lower compared with other children. Comparing Figure 4 with Figure 2 highlights the point that the TTR measure for CDS shows more or less the reverse ordering of children compared with the number of child-directed words, indicating the weakness of TTR for appropriate representation of lexical richness of language input. In fact, the TTR measure suggests this child experienced a great deal of repetition in the types of words heard. Future studies with measures that are able to appropriately represent joint variation in numbers of words and word diversity are needed to solve this caveat in using TTR (Montag et al. 2018). Despite this limitation, data from numbers of words and TTR calculated for CDS demonstrate large variability in lexical information of CDS among children. Future studies will further explore whether this variability in lexical information of CDS relates to poor vocabulary growth in some children compared with others.

Individual Variability in the Morphosyntactic Complexity of Language Input

In addition, we examined how children with CIs varied in the morphosyntactic information in language input, which is shown to influence language outcomes both in children with typical hearing (e.g., Harkness 1977; Furrow et al. 1979; Hoff-Ginsberg 1998; Huttenlocher et al. 2002) and those with CIs (Szagun & Stumper 2012; Szagun & Schramm 2016). The results from this analysis showed that MLU_m in speech experienced by 14 children with CIs in a day varied from an MLU_m as short as 2.8 to a long MLU_m of 4.5. Although a few studies showed that shorter MLUs in speech input has a positive impact on syntactic development in children with typical hearing (e.g., Furrow et al. 1979), several others showed the opposite pattern both in typical hearing children (Harkness 1977; Hoff-Ginsberg 1998; Huttenlocher et al. 2002) and in children with CIs (Szagun & Stumper 2012; Szagun & Schramm 2016). This discrepancy across prior findings of the effect of MLU of speech input on children's language outcomes makes the interpretation of the observed variability across children with CIs in MLU_m of language input difficult. Future studies with a higher-constraint design will elaborate on the correlational and causal effects of variation in MLU on language outcomes of children with CIs.

We also explored how well these measures of language input predicted language outcomes at 6 mo following cochlear implantation. We particularly explored the predictive value of the total number of words, number of child-directed words, TTR, and MLU_m for PLS5-AC and PLS5-EC standard scores. None of the results from our simple regression analysis provided any preliminary evidence of the connection between these measures of language input and language outcomes. These null results were anticipated to some extent because prior studies showed that any effect of CDS on language outcomes requires at least about 9 mo from exposure (i.e., time of CI activation) to appear (Szagun & Rüter 2009; Rüter 2011). In contrast, the language outcome scores used for the present study were measured at 6-mo post-implantation and thus were available 3 mo before this minimum time lag for observing the effects of language input. Another reason for these null results could be the limited statistical power in the present study due to the small sample size.

Overall, we have provided evidence that the quality and quantity of early linguistic environments vary substantially across children with CIs. Children with CIs are at high risk for a lack of developing age-appropriate language skills, and language outcomes are shown to be substantially different across children. On the basis of analyzing audio samples recorded from natural linguistic environments of 14 early-implanted children with CIs, this study showed that individual children with CIs are at risk for experiencing extremely variable language input- measured through multiple features of quantity and quality of language input. Results from this study suggest that some children with CIs may be doubly disadvantaged in acquiring spoken language: both due to degradation associated with electronic hearing, as well as due to experiencing relatively poorer linguistic environments (in terms of the amount and quality of language input). This study also provides data relevant to understanding how the effect of language delay, here due to hearing loss, on properties of language input and adults' manner of interacting with children may vary across children with CIs.

Limitations of the Study

The relatively small sample in this study suggests that these results should be cautiously interpreted. Further studies with higher numbers of participants are necessary to assure that these findings are generalizable. Also, our small sample of children was relatively heterogeneous. For instance, some children had mixed combinations of hearing aids and CIs (i.e., bimodal devices), and others had multiple diagnoses. Each of these points of population variation deserves a well-powered investigation. The distribution of daylong audio recordings for each child was also not equal for all children, such that for some children four recordings were available, whereas others had only one recording. Conducting studies with a higher number of recordings during the first years after implantation will reduce the possible effect of noisy data in our small number of recordings on the estimated per-day measures. In addition, the results of this study were based on analyzing 5% of audio that was randomly sampled from each daylong audio recording. Although prior studies demonstrated that estimates based on analyzing several hours of audio fairly represent quality and quantity of linguistic environments of children with typical hearing (e.g., Hart & Risley 1995; Shneidman et al. 2013; Weisleder & Fernald 2013), further studies are required to examine this for children with CIs. Further, since the focus of the present work was on evaluating the properties of spoken language input based on audio recording, it is not possible to examine the amount of early exposure to linguistic structure through the visual modality, which is an important factor for considering in future studies. Considering these limitations, the results should not be taken as the final determination of how the quality and quantity of linguistic environments of children with CIs vary across children, but rather as preliminary findings to guide further exploration of these questions.

Despite these limitations, the present study provides new evidence on how early language environments vary across children with CIs during early childhood based on analyzing their natural home environments. This is the first study to conduct an extensive and fine-grained investigation of the early language experience of children with CIs to assess individual differences in exposure to high-quality language input across lexical and morphosyntactic dimensions, while considering the speaking style of adult talkers in children's environments. Future research with more participants and daylong audio recordings as well as access to language outcomes at higher ages is needed to establish the extent to which variability in the amount and quality of language input in children with CIs predict their language outcomes, and whether any such relationships reflect a causal mechanism.

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Erratum

The Daily Experience of Subjective Tinnitus: Ecological Momentary Assessment Versus End-of-Day Diary: Erratum

In the article that appeared on pages 45-52 of the January/February 2022 issue of Ear and Hearing, "The Daily Experience of Subjective Tinnitus: Ecological Momentary Assessment Versus End-of-Day Diary", there was an error in the second author's affiliation. The citation for Jorge Simoes was listed as University Medical Center Regensburg, Germany.

The correct affiliation for Jorge Simoes is Department of Psychiatry and Psychotherapy, University of Regensburg, Regensburg, Germany.

Reference

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