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Research Article

Lexical Repetition Properties of Caregiver Speech and Language Development in Children With Cochlear Implants

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Purpose: Early language input plays an important role in child language and cognitive development (e.g., Gilkerson et al., 2018; Hart & Risley, 1995). In this study, we examined the effects of child's hearing status on lexical repetition properties of speech produced by their caregivers with normal hearing (NH). In addition, we investigated the relationship between maternal lexical repetition properties and later language skills in English-learning infants with cochlear implants (CIs).
Method: In a free-play session, 17 mothers and their prelingually deaf infants who received CIs before 2 years of age (CI group) were recorded at two post-CI intervals: 3 and 6 months postactivation; 18 hearing experience–matched infants with NH and their mothers and 14 chronological age–matched infants with NH group and their mothers were matched to the CI group. Maternal speech was transcribed from the recordings, and measures of maternal lexical repetition were obtained. Standardized language assessments were administered on children with CIs approximately two years after CI activation.
Results: The findings indicated that measures of lexical repetition were similar among the three groups of mothers, regardless of the hearing status of their infants. In addition, lexical repetition measures were correlated with later language skills in infants with CIs.
Conclusions: Infants with CIs receive the language input that contains similar lexical repetition properties as that in the speech received by their peers with NH, which is likely to play an important role in child speech processing and language development. These findings provide the knowledge for professionals to coach parents to implement specific language intervention strategies to support language development in infants with hearing loss.
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Cochlear implantation allows many deaf children opportunities to learn spoken language. However, challenges remain because children with cochlear implants (CIs) experience a period of spoken language deprivation before receiving implantation; in addition, CIs deliver degraded acoustic signal to their users (Geers et al., 2008; Houston, Beer, et al., 2012; Houston & Bergeson, 2014). While some children with CIs develop age-appropriate speech and spoken language skills, many other children with CIs show considerable delay and variability in their speech and language outcomes (Geers et al., 2011). Much of this variability is not explained by conventional predictors, including demographic, CI device, and medical factors (Geers et al., 2011; Peterson et al., 2010). Poor language skills can lead to later academic underachievement and behavioral problems, causing huge personal, societal, and economic burdens (Mohr et al., 2000). Therefore, identifying early predictors for language development in children with CIs becomes a critical and timely issue. One important factor that might contribute to explaining variability in language skills is children's early linguistic experience, especially the speech provided by their caregivers. The primary purpose of this study was to examine the effect of hearing loss on one aspect of caregiver speech, namely, lexical repetition properties, and their relationship with language development in English-learning children with CIs.

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Maternal Speech and Language Development in Children With Normal Hearing

Early language input plays an important role in child language and cognitive development that is related to later

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personal, academic, and social achievements (e.g., Gilkerson et al., 2018; Hart & Risley, 1995). In the landmark longitudinal study, Hart and Risley (1995) demonstrated that the amount of caregiver speech (also known as *infant-directed speech* or *maternal speech*; we will use these terms interchangeably in this article to refer to the speech that is used when addressing infants) directed to children between 10 and 36 months of age significantly predicted children's vocabulary measured at 3 years of age. This work encouraged much subsequent research examining the properties of caregiver speech to young children and the specific features of caregiver speech that underlie successful language development in children with normal hearing (NH; Greenwood et al. 2011; Place & Hoff, 2016; Romeo et al., 2018; Rowe, 2012; Weisleder & Fernald, 2013).

Research along this line has demonstrated that infant-directed speech has unique acoustic properties, including slower speaking rate, higher pitch, wider pitch range, longer pauses, and expanded vowel space (Burnham et al., 2002; Cristia, 2010; Fernald & Simon, 1984; Papoušek & Hwang, 1991; Wang et al., 2016), as compared to adult-directed speech. In addition, infant-directed speech also differs from adult-directed speech in the domains of morphology, semantics, and syntax, including simpler structures, more repetitions, more concrete references, and shorter utterances, as compared with adult-directed speech (Cooper & Aslin, 1990; Fernald et al., 1989; Hoff-Ginsberg, 1985; Newman et al., 2016; Soderstrom, 2007). Infants are sensitive to these properties and show a preference for infant-directed speech over adult-directed speech (Fernald, 1985, 1989; ManyBabies Consortium, n.d; Wang et al., 2017; Wang, Bergeson, et al., 2018; Werker & McLeod, 1989). This preference could be driven by several factors, including pitch, repetition, and utterance duration, although the specific properties that drive this preference are age dependent (Fernald, 1989; McRoberts et al., 2009; Segal & Newman, 2015).

Previous research has also provided evidence to connect infant-directed speech and language development in infants with NH (Cristia & Seidl, 2014; Drotar & Sturm, 1988; Song et al., 2010; Trainor et al., 2000). For example, infants with NH showed better sound discrimination (Karzon, 1985), word segmentation (Thiessen et al., 2005), word recognition (Singh et al., 2009), and word learning (Ma et al., 2011) under infant-directed speech conditions than under adult-directed speech conditions in laboratory-based learning environments. Longitudinal studies have also demonstrated a link between the quantity and quality of infant-directed speech and speech and language development in children with NH (Greenwood et al., 2011; Romeo et al., 2018; Rowe, 2012; Weisleder & Fernald, 2013). For example, infants who experienced a larger amount of infant-directed speech at home became more efficient in lexical processing and had a larger expressive vocabulary by 24 months of age (Weisleder & Fernald, 2013). Furthermore, vowel space of infant-directed speech significantly predicted consonant perception (Liu et al., 2003) and later receptive and expressive vocabulary (Hartman et al., 2017; Kalashnikova & Burnham, 2018).

Repetition of Maternal Speech and Language Development in Children With NH

In addition to the properties mentioned above, experimental and corpus work began to identify structural properties, namely, repetition, of infant-directed speech that are likely to impact young children's linguistic abilities. Repetitions have been a defining structural feature of infant-directed speech (Hoff-Ginsberg, 1985; Newport et al., 1977; Snow, 1972). Infants seem to be sensitive to the repetitive features of infant-directed speech. For example, McRoberts et al. (2009) found that 6-month-olds preferred listening to infant-directed speech over adult-directed speech, especially when the infant-directed speech contained repeated utterances, relative to novel utterances (although see Segal and Newman, 2015, for different findings). Other work has demonstrated a link between different types of repetitiveness of maternal speech and child word learning and vocabulary development (Horst et al., 2011; Newman et al., 2016; Schwab & Lew-Williams, 2016). For example, Hoff-Ginsberg (1986) showed that maternal self-repetitions were related to the growth of their 2.5-year-old children's verb use. Children also seemed to benefit from contextual repetition. Horst et al. (2011) examined the effects of contextual repetition on children's novel word learning in a storybook reading task. They found that 3-year-olds who heard the same stories repeatedly in succession were more accurate on both recall and retention of the novel name–object associations than the children who heard different stories that contained the same novel–object pairs that occurred for the same number of times. Recently, Newman et al. (2016) examined the relationship between maternal lexical repetition and child language development. Specifically, they recorded mother–infant dyads playing with a set of toys in the lab when the children were 7 months of age and assessed children's vocabulary scores at 2 years of age. They found that the type–token ratio of maternal speech input significantly negatively predicted spoken vocabulary, as children's vocabulary sizes were larger if their mothers' speech contained more repetition.

While the overall frequency of repetition in the input seems to be important for child language learning, structured repetition, specifically contingent repetitions of the same structure or item over brief time windows, might be more beneficial for language learning (Brodsky & Waterfall, 2007; Goldstein et al., 2010). Both theoretical and empirical evidences provide support to this view. According to Goldstein et al.'s (2010) theoretical framework Align Candidates, Compare, Evaluate Statistical/Social Significance, infants learn by integrating prominent statistical regularities over a restricted time window. Empirical evidence also suggests that structured repetition could have an impact on child language development. For example, in a longitudinal study, Waterfall (2006) recorded parent–child interactions in their homes for 90 min every 4 months when the children were 14–30 months of age. They found that parents' partial repetitions of phrases were correlated with children's production of these structures. Moreover, in a recent experimental work, Schwab and Lew-Williams (2016) assigned 30-month-old children to two word-learning conditions: a structured condition and an unstructured condition. In the structured condition, the children were presented with blocks of three adjacent utterances referring to the same object (e.g., "*Do you know what a fep is?/ Wow, this fep looks neat./ Can you find the fep there?"*). In the unstructured condition, children listened to identical utterances presenting the same novel object pictures, but no two adjacent utterances referred to the same object (e.g., *"Do you know what a fep is?/ Wow, this coro looks neat./ Can you find the dax there*?"). They found that children in the structured condition learned novel labels, whereas children in the unstructured condition did not show evidence of learning. Taken together, these findings suggest that structured lexical repetitions, especially the lexical repetitions that occur across successive utterances, are associated with language development in children with NH.

Language Development in Children With CIs

Due to limited linguistic experience, as well as the degraded nature of speech transmitted by CIs to the auditory nerve, many children with CIs lag behind their peers with NH in a range of perceptual and language skills (Conway et al., 2011; Geers et al., 2011; Holt et al., 2012; Houston & Bergeson, 2014). For example, children with CIs showed reduced attention to speech (Houston & Bergeson, 2014; Wang, Shafto, et al., 2018) and poorer phoneme discrimination and perception of speech in noise (Caldwell & Nittrouer, 2013; Eisenberg, 2007; Houston et al., 2003). Moreover, they showed poorer language skills, including expressive and receptive language (Fitzpatrick et al., 2011), phonological awareness (Ambrose et al., 2012), vocabulary (Lund, 2016), and verbal intelligence (Geers & Nicholas, 2013), among many others. For example, in a recent meta-analysis including 1,158 children, Lund (2016) found that children with CIs had lower receptive and expressive vocabulary as compared to their peers with NH.

Maternal Speech and Language Development in Children With CIs

Because language development depends heavily on early linguistic experience, speech directed to children likely influences their language development. Previous research has demonstrated that properties of maternal speech relate to language skills in children with CIs (Cruz et al., 2013; DesJardin et al., 2014; DesJardin & Eisenberg, 2007; Markman et al., 2011; Szagun & Schramm, 2016). For example, mothers' mean length of utterance and facilitative language techniques (recast and open-ended questions) were positively correlated with concurrent language skills in their 2- to 7-year-old children with CIs (DesJardin & Eisenberg, 2007). Moreover, current early intervention programs have recognized the importance of involving and empowering families to support their children with hearing loss (Moeller et al., 2013). One important aspect of family support and involvement is to teach families appropriate communication techniques to enhance their children's language learning (McWilliam & Scott, 2001). Therefore, examining properties of caregiver speech, including lexical level repetitions, that relate to language development in children with CIs has important clinical implication as it would identify efficacious targets for early intervention to improve language outcomes.

To our knowledge, the very limited research on maternal speech to infants with CIs has focused primarily on the acoustic properties. This body of research has shown that infant-directed speech directed to infants with CIs has a higher pitch, an expanded pitch range, shorter utterances, longer pauses, and a larger vowel dispersion, compared to adult-directed speech (Bergeson et al., 2006; Wieland et al., 2015). These findings, in general, suggest that caregivers of infants with CIs provide linguistic input that contains similar acoustic properties as the speech directed to infants with NH. Similar to infants with NH, infants with CIs are sensitive to the properties of infant-directed speech and show a perceptual preference for infant-directed speech over adult-directed speech, at least at some points during the development (Robertson et al., 2013; Wang et al., 2017; Wang, Bergeson, et al., 2018). For example, Wang et al. (2017) presented infant-directed speech and adult-directed speech stimuli to infants with CIs who had 12 months of hearing experience. They found that infants with CIs, similar to infants with NH, preferred listening to infant-directed speech over adult-directed speech. They further found that the degree of preference for infant-directed speech over adult-directed speech was associated with later language outcomes.

Research on the repetition properties of maternal speech to children with CIs, however, is very limited. For example, Bergeson (2011) investigated utterance repetition in maternal speech from 13 mothers of infants with CIs at pre-activation and at 3, 6, and 12 months postactivation compared to those of children with NH. They found that mothers of children with NH showed decreased utterance repetition across time; mothers' use of utterance repetition increased from pre-activation to 3 months postactivation and then decreased over time for children with CIs. This study provides the first analysis of utterance repetition properties of maternal speech to infants with hearing loss. However, there has been no research examining the structured lexical repetition properties of maternal speech to children with CIs and the potential relationships between these properties and language development.

Conceivably, although more lexical repetitions across successive utterances in the input may generally be important for learning, they may be particularly useful for language learning in children with CIs, for the following reasons. First, from an auditory perceptual perspective, the acoustic signal that infants with CIs receive is greatly impoverished and degraded (Zeng, 2004); they hear speech signals that are much poorer than the speech received by infants with NH. Therefore, lexical repetitions across successive utterances may allow infants with CIs more opportunities to identify and segment lexical items that they would otherwise miss. Second, from a cognitive perspective, infants with CIs show reduced attention to speech skills relative to children with NH (Wang, Shafto, et al., 2018). Given the significant correlation between attention to speech and language development in children with CIs (Wang, Shafto, et al., 2018), it is possible that lexical repetition in the input may facilitate language development in children with CIs by enhancing their attention to speech. Indeed, there is evidence that the preference for infant-directed speech was driven by the repetitive feature of the stimuli for 6-month-old infants with NH (McRoberts et al., 2009; Wieland et al., 2015).

Purpose of This Study

The first aim of this study was to explore the effects of hearing loss on structured lexical repetition properties, namely, the repetition of the same lexical item across successive utterances, of maternal speech to infants with CIs. Based on previous findings on the maternal speech to infants with CIs and infants with NH, we predicted that mothers of infants with CIs would produce these properties similar to the mothers of infants with NH. The second aim was to examine whether variations in maternal repetition properties related to language development in infants with CIs. To address this question, we collected measures of language outcomes at approximately two years postactivation. Based on the findings from previous research showing associations between lexical repetition and word learning and vocabulary (Newman et al., 2016; Schwab & Lew-Williams, 2016), we hypothesized that lexical repetition in maternal speech would be correlated with language skills in infants with CIs.

Method

Participants

A total of 49 mother–infant dyads participated in the study. They came from English-speaking families in a midwestern town in the United States. To be included, participants had to use English as the primary language for over 80% of the time. We included 17 prelingually deaf infants (four girls, 13 boys; CI group) who received CIs between 8.31 and 21.48 months of age (M = 13.90 months, SD = 3.38 months). They were recruited from a CI program in a university's medical center in a midwestern town. Additional demographic and audiological information for infants with CIs is shown in Table 1. The infants with CIs and their mothers were invited for multiple visits to our lab, including 3, 6, 9, 12, and 18 months postactivation. Only children who participated in both 3- and 6-month intervals were included, because there were not enough data from other intervals for the current analyses due to attrition. We also included another two groups of mother–infant dyads: an older group and a younger group. The older group consisted of 14 dyads of mothers and chronological age–matched infants with NH (NH-CAM group; six girls, eight boys); the younger group included 18 dyads of mothers and their hearing experience–matched infants with NH (NH-HEM group; seven girls, 11 boys). All the infants with NH passed the newborn hearing screening, and all had NH at the time of testing by parental report. The detailed age information of the three groups of infants is presented in Table 2. The infants with NH were born full term with typical development and no known history of language or hearing impairment. This study received approval from the university's institutional review board. Experimenters provided caregivers with informed consent prior to the experiment. All mothers were compensated with $10 for their time per visit.

Procedure

Mothers and their infants were videotaped in the lab for approximately 5 min of semistructured free playing in an sound-treated booth by Industrial Acoustics Company, Inc.. Mothers were asked to sit with their infants either on a chair or on the floor and were informed that they were being video- and audio-recorded. They were provided with several quiet toys (e.g., *turtle, kitten, dog, key, ball, button*) and asked to play with their children as they normally would at home. The mothers were not explicitly instructed to play with the toys with the infants. Each session was videotaped using a digital camera (Sony DCR-TRV 120/TRV 320). In order to obtain high-quality speech, we also used a hypercardioid microphone (Audio-Technica ES933/H) to record mothers' speech. The microphone was linked to an amplifier (DSC 240) and a digital tape recorder (Sony DTC-690).

Coding

Mothers' speech was transcribed using the conventions of Systematic Analysis of Language Transcripts (Miller & Chapman, 2000). The coders listened to the audio recordings and transcribed every utterance using prosodic and syntactic cues from the recordings to segment the utterances. In addition, the words that were repeated across utterances were annotated as target words. All open-class words (i.e., adjectives, verbs, nouns) can be a target. To be qualified as target words, the words had to occur across successive utterances. Nonlinguistic noises such as laughter, sneezing, and coughing were excluded from the analyses. A more detailed coding protocol is provided in Supplemental Material S1. Five measures were computed to characterize each mother's lexical repetition for each session, including the total number of target words produced during the entire session (Total Repetition), the number of unique target words produced (Novel Context Repetition), the average number of repetition of target words (Average Repetition), the maximum frequency of target words repeated (Max Repetition), and the number of target words that were repeated three times or more (Repetition $\geq$ 3). An additional coder coded the target words from 20% of the sessions (20 audios). The resulting agreement was 91.7%

Table 1. Demographic information for mothers and their infants with cochlear implants (CIs).

ID	Etiology	Race	Maternal education	Maternal age	Gender	Age at CI	Mean PTA	Com mode
2514 CI	Genetic	Caucasian	12	21	M	12.77	117	TC
2518 CI	Genetic	Caucasian	16	31	M	11.88	109	OC
2525 CI	Unknown	Caucasian	—	—	M	16.11	120	OC
2529 CI	Genetic	More than one race	18	38	M	16.47	114	OC
2533 CI	Unknown	Caucasian	16	33	F	8.31	120	TC
2534 CI	Genetic	Caucasian	16	28	M	10.4	107	OC
2535 CI	Genetic	Caucasian	13	33	F	16.7	114	OC
2536 CI	Unknown	Caucasian	16	36	M	21.48	99	OC
2540 CI	Unknown	Caucasian	16	27	F	13.16	120	TC
2542 CI	Unknown	Caucasian	12	34	M	12.76	88	OC
2813 CI	Unknown	Caucasian	12	39	M	11.94	120	OC
3098 CI	Unknown	Caucasian	15	27	M	10.26	119	OC
3259 CI	Unknown	African American	14	32	F	15.97	120	TC
3374 CI	Unknown	Caucasian	18	29	M	13.7	109	TC
4083 CI	Unknown	African American	15	39	M	17.3	120	TC
4574 CI	Genetic	Caucasian	25	39	M	10.17	115	OC
4577 CI	Unknown	Caucasian	—	—	M	16.87	87	OC
M (*SD*)			15.6 (3.27)	32.4 (5.34)		13.90 (3.38)	112 (11)	

Note. Maternal education and maternal age are in years. Em dashes indicate information not available. PTA = mean unaided pure-tone average before implantation in dB HL (amount of residual hearing pre-implantation); Com mode = the type of communication program the infant was following in speech language therapy; M = male; TC = total communication: a combination of spoken language and a manual communication mode; OC = oral communication: exclusively spoken; F = female.

across all the coded files. See the Appendix for an example of annotation and how these measures were calculated.

Language Skills

To assess language skills in children with CIs, certified speech-language pathologists administered the Peabody Picture Vocabulary Test[1] (PPVT–III and Fourth Edition; Dunn, 1997; Dunn & Dunn, 2007) and the Preschool Language Scale–Fourth Edition (PLS-4; Zimmerman et al., 2002) Auditory Comprehension (AC) and Expressive Communication (EC) scores approximately twenty-four months after activation. These tests were well-established standardized tests assessing different aspects of language abilities, such as receptive vocabulary and receptive and expressive language. These tests have been widely used in previous research to assess language skills for children with CIs (Fitzpatrick et al., 2007; Houston, Stewart, et al., 2012).

Results

Lexical Repetition Properties of Maternal Speech

The means and standard deviations of measures of maternal lexical repetition are reported in Table 2, separated by interval (3 months, 6 months) and hearing status (CI, NH-HEM, and NH-CAM). The average duration of the sessions was approximately 5 min across intervals and hearing status ($M = 5.0$, $SD = 0.75$, range: 1.9–6.8). Because the duration of each session was different, we normalized the five repetition measures by dividing each measure by the duration of the session. To determine the effects of hearing loss on maternal lexical repetition properties, we ran five repeated-measures analyses of variance (ANOVAs), with interval (3 months, 6 months) as the within-subject variable and hearing status (CI, NH-HEM, NH-CAM) as the between-subjects variable for each of the five measures: Total Repetition, Novel Context Repetition, Average Repetition, Max Repetition, and Repetition ≥ 3. In addition, in order to corroborate our parametric analyses, we conducted nonparametric Kruskal–Wallis H tests to compare group differences for each interval, and Wilcoxon signed-ranks test to compare each repetition measure between the 3- and 6-month intervals for each group.

For the measures of Total Repetition, Average Repetition, Max Repetition, and Repetition ≥ 3, repeated-measures ANOVAs did not show any significant interactions or main effects, Fs < .963, ps > .389, $\eta^2 < .040$. Kruskal–Wallis H tests showed that no statistically significant differences between the three groups were found for either the 3-month interval or the 6-month interval, $\chi^2(2) < 3.93$, $p > .140$. Wilcoxon signed-ranks tests revealed that none of the four measures was different between the two intervals for any of the three groups, zs < 1.16, ps > .245. For the measure of Novel Context Repetition, similarly, no significant interaction or main effects were found, Fs < 1.84, $p > .170$, $\eta^2 < .074$. Kruskal–Wallis H tests did not show significant differences among the three groups for either the 3-month interval, $\chi^2(2) = 5.64$, $p = .060$, or the 6-month interval, $\chi^2(2) = 0.806$, $p = .668$. Wilcoxon signed-ranks tests showed that Novel Context Repetition was similar between the 3- and 6-month intervals for the CI group, $z = 0.67$, $p = .501$,

[1]PPVT-III was administered during an early period of data collection, whereas PPVT-4 was administered during a later period when it became available. Throughout this article, we will refer to PPVT-III and PPVT-4 as PPVT.

Table 2. Child age (mean and *SD*) and measures (mean and *SD*) of maternal repetition, separated by hearing status (CI, NH-HEM, NH-CAM) and interval (3 months, 6 months).

Measures	Interval					
	3 months			6 months		
Hearing status	CI	NH-HEM	NH-CAM	CI	NH-HEM	NH-CAM
Hearing age	2.98 (0.52)	3.08 (0.44)	17.05 (3.58)	6.32 (0.76)	6.15 (0.55)	20.43 (3.49)
Chronological age	16.88 (3.49)	3.08 (0.44)	17.05 (3.58)	20.22 (3.37)	6.15 (0.55)	20.43 (3.49)
Session duration	5.11 (1.04)	4.68 (0.81)	5.05 (0.59)	5.02 (0.69)	4.79 (0.73)	5.24 (0.38)
Total words produced	65.5 (20.9)	68.9 (21.4)	81.6 (21.4)	64.8 (23.3)	69.7 (21.2)	79.6 (18.7)
Total utterance produced	22.54 (6.51)	20.64 (5.56)	27.52 (4.61)	21.71 (5.91)	22.26 (9.04)	27.44 (4.34)
Total Repetition	3.78 (2.99)	3.21 (1.85)	4.56 (1.72)	3.93 (2.91)	3.80 (2.62)	3.88 (1.94)
Novel Context Repetition	1.24 (0.94)	1.01 (0.47)	1.61 (0.65)	1.08 (0.73)	1.18 (0.72)	1.28 (0.63)
Average Repetition	0.58 (0.27)	.69 (0.25)	0.58 (0.11)	0.66 (0.30)	0.64 (0.28)	0.59 (0.19)
Max Repetition	0.94 (0.53)	1.08 (0.63)	0.99 (0.36)	1.09 (0.66)	0.95 (0.51)	0.97 (0.37)
Repetition ≥ 3	0.69 (0.55)	0.57 (0.39)	0.83 (0.44)	0.67 (0.47)	0.62 (0.52)	0.60 (0.36)

Note. Total words produced, Total utterance produced, and all the five repetition measures reported were normalized by session duration. Hearing age = duration of child hearing experience in months; Session duration = the duration of the session in minutes; CI = infants with cochlear implants; NH-HEM = hearing experience–matched peers with normal hearing; NH-CAM = chronological age–matched peers with normal hearing.

and the NH-HEM group, $z = 1.11$, $p = .267$; however, the two intervals for the NH-CAM group reached the threshold, $z = 1.98$, $p = .048$, because maternal speech at the 6-month interval exhibited a slightly larger number of Novel Context Repetition as compared to the 3-month interval. The normalized repetition measures separated by hearing status and interval are presented in Figures 1a–1e. In summary, these findings suggest the measures of maternal lexical repetition under examination, in general, were very similar among the three groups, regardless of the child hearing status or child age.

Maternal Repetition and Language Outcomes in Children With CIs

The means, ranges, and standard deviations of each language outcome standardized score for children with CIs are reported in Table 3. To determine the relationship between lexical repetition properties of maternal speech and language outcomes in infants with CIs, we ran a series of Pearson bivariate correlational analyses between the five repetition properties from the two intervals (3 and 6 months) and measures of language, PPVT standardized score, and PLS-4 standardized scores. These exploratory analyses yielded the relationship between lexical repetition properties of maternal speech and language outcomes in children with CIs. Correlational coefficients are shown in Table 4.

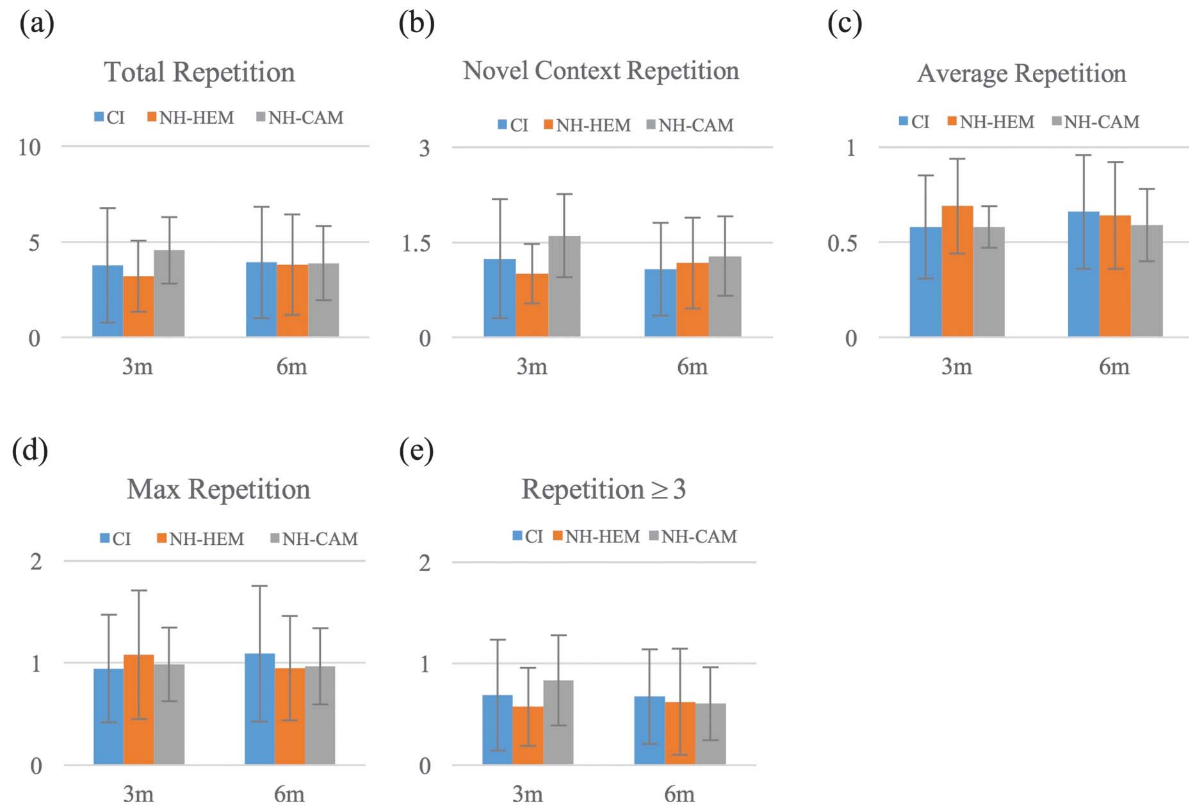
At the 3-month interval, none of the correlations between the five lexical repetition measures and language scores was statistically significant, rs < .583, ps > .170. At the 6-month interval, Total Repetition was significantly correlated with PPVT, $r = .551$, $p = .033$; Novel Context Repetition was significantly correlated with PPVT, $r = .569$, $p = .027$; and Average Repetition was significantly correlated with PLS-AC, $r = .581$, $p = .037$, and trended toward the same direction with PPVT, $r = .508$, $p = .053$, and PLS EC, $r = .543$, $p = .055$. Max Repetition was significantly correlated with PPVT, $r = .618$, $p = .014$, PLS-4 AC, $r = .723$, $p = .005$, and PLS-4 EC, $r = .685$, $p = .010$; Repetition ≥ 3 was significantly correlated with PPVT, $r = .579$, $p = .019$. All the other correlational coefficients were not significant. Most of these correlations remained significant or marginally significant even after controlling for amount of residual hearing (see Table 4 for correlation coefficients).

To examine the role of maternal lexical repetition, we ran Pearson bivariate correlations between maternal education and measures of lexical repetition properties taken at the 6-month interval for children with CIs. The analyses showed that maternal education was significantly correlated with Average Repetition, $r = .546$, $p = .035$, and Max Repetition, $r = .683$, $p = .005$. To examine the effect of communication mode on maternal lexical repetition properties during the 6-month interval, we ran multiple ANOVAs with communication mode (total communication vs. oral communication) as the independent variable and measures of maternal lexical repetition as the dependent variable. The results did not show any significant main effect of communication mode, Fs < 0.636, ps > .438. In general, these findings suggest that mothers who received higher education used a larger number of lexical repetitions in their speech.

Discussion

Maternal speech input provides one of the most important sources of information for infants to acquire spoken language (e.g., Gilkerson et al., 2018; Hart & Risley, 1995). Previous studies have demonstrated a link between measures of lexical repetition and language skills in children with NH (Newman et al., 2016; Schwab & Lew-Williams, 2016). Given that properties of maternal speech may be affected by child hearing status, we investigated the effect of hearing loss on lexical repetition properties of maternal

Figure 1. Measures of maternal lexical repetition to the three groups of children: children with cochlear implant (CIs), their hearing experience–matched peers with normal hearing, and chronological age–matched peers with normal hearing, separated by interval: 3 months (3m) and 6 months (6m) postactivation. (a) Total Repetition, (b) Novel Context Repetition, (c) Average Repetition, (d) Max Repetition, and (e) Repetition ≥ 3. Error bars indicate standard deviations.



speech and their relationship with language outcomes in infants with CIs.

Effects of Hearing Loss on Lexical Repetition Properties of Maternal Speech

The first aim of this study was to examine the effects of hearing loss on maternal lexical repetition properties, specifically the repetition of target words that occurred across successive utterances. Mothers of infants with CIs were matched to mothers of infants with NH who had the same chronological age or hearing experience. No significant differences were found for the measures of maternal lexical repetition among the three groups of infants differing in hearing status. These findings are novel as this is the first study to explore the lexical repetition properties of maternal speech to infants with hearing loss.

Table 3. Means and standard deviations of language outcome standardized scores taken at approximately twenty-four months after cochlear implantation for children with cochlear implants.

Measures	***M***	***SD***
PPVT	81.6	20.98
PLS AC	73.44	21.02
PLS EC	79	20.98

Note. PPVT = Peabody Picture Vocabulary Test; PLS AC = Preschool Language Scale–Fourth Edition Auditory Comprehension score; PLS EC = Preschool Language Scale–Fourth Edition Expressive Communication score.

Previous research comparing acoustic and prosodic properties of caregiver speech to infants with CIs and their peers with NH yielded different findings (Bergeson et al., 2006; Kondaurova et al., 2013; Wieland et al., 2015). For example, Bergeson et al. (2006) demonstrated that mothers adjusted the prosodic properties to the hearing experience, rather than the chronological age of their infants. For example, the increase in average and minimum pitch from adult-directed speech to infant-directed speech in mothers' speech to CI infants was more similar to that in the speech to the control groups with matched hearing experience and distinct from control infants with matched chronological age. By contrast, Wieland et al. (2015) showed that the vowel space area and vowel space dispersion properties in the speech directed to infants with CIs were similar to those in the speech directed to their peers with NH matched by both chronological age and hearing experience. Our findings are consistent with Wieland et al.'s as we

Table 4. Bivariate and particial correlations between maternal lexical repetition measures (Total Repetition, Novel Context Repetition, Average Repetition, Max Repetition, and Repetition ≥ 3) and language outcome measures (Peabody Picture Vocabulary Test [PPVT] and Preschool Language Scale–Fourth Edition [PLS-4]) taken at approximately twenty-four months after cochlear implantation for children with cochlear implants.

	Bivariate correlation			Partial correlation (controlling for PTA)		
Language measures (*N*)	**PPVT 15**	**PLS-4 AC 13**	**PLS-4 EC 13**	**PPVT 15**	**PLS-4 AC 13**	**PLS-4 EC 13**
3 months						
Total Repetition	–.161	–.252	–.415	–.156	–.273	–.413
Novel Repetition	–.117	–.251	-.437	–.114	–.269	–.435
Average Repetition	–.162	–.262	–.389	–.224	–.249	–.445
Max Repetition	–.182	–.268	–.440	–.211	–.259	–.452
Repetition ≥ 3	–.225	–.264	–.410	–.215	–.296	–.411
6 months						
Total Repetition	.551*	.464	.454	.594***	.534***	.599***
Novel Repetition	.569*	.400	.387	.561***	.476	.509***
Average Repetition	.508**	.581*	.543***	.618*	.642*	.706*
Max Repetition	.618*	.723**	.685**	.741**	.751**	.785**
Repetition ≥ 3	.579*	.503***	.427	.749**	.692*	.738**

Note. *p* values were not corrected for multiple correlation due to the exploratory nature of the study and the complementary nature of the repetition properties. PTA = mean unaided pure-tone average before implantation in dB HL; AC = Auditory Comprehension score; PLS-4 EC = Expressive Communication score.

$^{*}p < .05$. $^{**}p < .01$. ***$.05 < p < .01$ (two-tailed).

found that measures of lexical repetition were similar among the CI group, the NH-HEM group, and the NH-CAM group.

These differences might be due to the nature of the properties under examination. It is possible that lexical repetition properties of maternal speech, different from pitch properties but similar to vowel space properties, are relatively stable during the first couple of years. Our data support this hypothesis as we did not find a significant effect of interval (3 months, 6 months) for most measures of lexical repetition. An alternative explanation is that mothers adjust lexical repetition properties to their infants' hearing experience, rather than the chronological age. However, the change of maternal lexical repetition properties may show a nonlinear (U-shaped) pattern, such that, although these properties are very similar between 3 and 6 months (hearing age of the CI and the NH-HEM groups) and 17–20 months (the age of our NH-CAM group), there might be an intermediate stage when the maternal lexical repetition properties are different. This is possible as previous work has shown that infants' preference for infant-directed speech demonstrated a U-shaped developmental pattern. For example, while Japanese-learning infants who were between 7 and 10 months of age did not show a preference for infant-directed speech, younger and older infants did show a strong preference (Hayashi et al., 2001). Future studies are encouraged to examine lexical repetition properties of maternal speech at multiple time points during early development to tease apart these possibilities.

Mechanisms Underlying Lexical Repetition and Language Development in Children With CIs

The second aim of this study was to examine the relationship between lexical repetition properties of maternal speech and later language outcomes in infants with CIs. We hypothesized that lexical repetition properties of maternal speech would contribute to explaining variability in language skills in infants with CIs. In support of this hypothesis, we showed that measures of lexical repetition at 6 months, in general, were positively correlated with child language skills measured 2 years postactivation. These results support and extend previous research in several ways. First of all, the findings that maternal lexical repetition correlated with language skills support the Align Candidates, Compare, Evaluate Statistical/Social Significance theoretical framework that prominent statistical regularities over a restricted time window might help infants learn. Second, these findings are also consistent with previous empirical evidence that structured lexical repetition could have an impact on child language development (Schwab & Lew-Williams, 2016; Waterfall, 2006). Finally, findings from this research provide additional evidence to support that some variability in language outcomes in children with CIs may be explained by differences in the maternal speech input. For example, DesJardin and Eisenberg (2007) showed that mothers' mean length of utterance and facilitative language techniques were positively correlated with concurrent language skills in their children with CIs. Below, we discuss the possible mechanisms, which may not be mutually exclusive, by which maternal lexical repetition facilitates language development.

First, lexical repetitions across successive utterances in the input provide infants more immediate opportunities to process these lexical items, which may allow for the more efficient processing of novel information in the utterances. This is especially important for children with CIs, because due to the degraded nature of speech input, they may need more repetition to encode words and build lexical representations.

This explanation is in line with a body of literature showing that early lexical processing speed is associated with later language development (Marchman et al., 2015; Marchman & Fernald, 2008; Weisleder & Fernald, 2013). For example, speech processing efficiency at the latter half of the second year predicted receptive vocabulary at 3 years in preterm infants (Marchman et al., 2015) and expressive vocabulary at 2 years in infants from families with low socioeconomic status (Weisleder & Fernald, 2013).

Second, another possible mechanism is that this relationship is driven by attention. Specifically, infants may have paid more attention to the speech that contained more repetition. Indeed, there is evidence that both adults and infants are biased toward input that contains regularity (McRoberts et al., 2009; Zhao et al., 2013). For example, 6- but not 3-month-old infants' preference for infant-directed speech was driven by the repetitive feature of the stimuli (McRoberts et al., 2009). Note that the hearing age that they found an effect of repetition on infant-directed speech preference was consistent with the age that we showed an association between lexical repetition and language outcomes. Therefore, infants with 6 months of hearing experience may have paid more attention to the speech that contains repetitive information, which facilitates their speech perception, memory, and language learning. This explanation is in line with previous findings that attention to speech predicts later language development in both children with NH (Vouloumanos & Curtin, 2014) and children with CIs (Wang et al., 2017; Wang, Shafto, et al., 2018).

Third, the association between lexical repetition and language outcomes could also be driven by discourse continuity. Repetition of the same objects or labels across successive utterances reflects a consistency of discourse content across time, which young children are sensitive to and benefit from (Akhtar et al., 1996; Horowitz & Frank, 2015; Kidd et al., 2011). Frank et al. (2013) demonstrated that maternal speech for young infants contained referential continuity in the discourse. In addition, their analysis suggested that infants use this discourse cue to judge the current reference. Presumably, infants' knowledge of discourse structure is primitive, but repetitions of the same objects or labels across successive utterances could construct concrete discourse continuity, which young infants may benefit from. Horowitz and Frank (2015) examined children's sensitivity to discourse structure and found that children can use discourse position information to resolve reference ambiguity. It has also been shown that discourse continuity benefits children's word learning and vocabulary development (Frank et al., 2013; Schwab & Lew-Williams, 2016; Sullivan & Barner, 2016). For instance, children as young as 2 years old can successfully learn new words by relating them to the context of discourse and the intention of a speaker (Sullivan & Barner, 2016).

Implications and Future Directions

Given the significant associations between maternal lexical repetition and language outcomes in infants with CIs, providing optimal linguistic input, including using the same words repeatedly across successive utterances, might be an important component of effective early intervention for children with hearing loss. It should be noted that no significant differences for the measures of maternal lexical repetition among the three groups of infants differing in hearing status do not necessarily suggest that children with hearing loss may not benefit from additional lexical repetitions in the input. Our results support this notion as we show that children with CIs who heard more repetitions had better PLS and PPVT scores 2 years later. Therefore, due to the limited linguistic experience, as well as the degraded nature of speech input, lexical repetitions may be a particularly effective means of teaching new words to young children with CIs. Indeed, previous research has indicated that repetitions of target words or morphemes facilitate learning in young children with hearing loss (Encinas & Plante, 2016; Lund, 2016). Recent pilot intervention studies have provided preliminary support for the effect of a parent-implemented intervention on language skills for children with hearing loss (Lund, 2018; Roberts, 2019). For example, Lund (2018) included six mother–child dyads in a short-term intervention study. Mothers were taught to use transparent labeling and linguistic mapping strategies in a 4-week intervention program. At the end of the intervention program, results showed a relation between parent training and the use of transparent labeling and linguistic mapping. Moreover, four out of six children showed increased vocabulary growth rate from the baseline. Our findings that maternal education was correlated with lexical repetition provided additional evidence to support the importance of providing parents education about the role of caregiver speech input in child language development to maximize parent-implemented intervention for children with hearing loss.

Despite the contributions of this study, we acknowledge several limitations of the current study that warrant future investigation. First, because the nature of this study was observational and correlational, it is not possible to draw a firm conclusion about the direction or the causality of the relationship. Therefore, future studies with careful experimental manipulation are encouraged to elucidate the direction of this relationship. Second, we only examined maternal lexical repetition at two intervals, 3 months and 6 months postactivation, and followed children's language outcomes at 2 years postactivation. Future work should explore this more fully by examining maternal lexical repetition at later points during the development and a longer term predictive value of lexical repetition for language development. Findings from this line of work would guide caregivers and intervention professionals to optimize children's language input and maximize children's linguistic and educational potentials. It is also worthy of mention that, in the wild, infants hear speech in rich multimodal contexts, and their experience with language is above and beyond receiving speech input alone. Therefore, examining multimodal experience at home and child language development would provide important information for the mechanisms underlying child language development. Finally, we acknowledge the limitations associated with the small sample size, the small sample of speech gathered from mothers, and the fact that measures of language skills were not collected from children with NH.

Conclusions

The findings from this study demonstrated that maternal speech directed to children with CIs contained similar lexical repetition properties as that directed to their peers with NH. These findings suggest that infants with CIs receive similar lexical repetition properties from their mothers as compared to their peers with NH. In addition, we showed that measures of repetition properties of maternal speech predicted language development in children with CIs. These findings contribute to our understanding of the specific properties of maternal speech that are associated with child language development. Our findings also provide the knowledge to develop evidence-based early intervention for professionals to coach parents to implement specific language intervention strategies to support language development in children with hearing loss.

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Appendix

An Example of Transcription and Annotation in SALT (M = mother)

– M Is that a fish [TAR1:1]?
– M What a cute fish that is [TAR1:2]!
– M Fish [TAR1:3]!
– M Would you like to hold the fish [TAR1:4]?
– M Let/'s put the dog in here [TAR2:1]
– M Where did the dog go [TAR2:2]?
– M There/'s the dog [TAR2:3].
– M Where/'s the dog [TAR2:4]?
– M Can you get the dog [TAR2:5]?
– M A fish [TAR3:1]!
– M What a cute fish! [TAR3:2]!
– M Look, that/'s a Fish [TAR3:3]!
– M The dog!

We coded how many different target words were used and how many times they were used as [TAR(target #):(target repetition #)]. In the example, since "fish" was the first target repetition and was repeated four times, it was coded as [TAR1:1], [TAR1:2], [TAR1:3], and [TAR1:4], respectively.

We extracted five measures of lexical repetition, namely, Total Repetition, Novel Context Repetition, Average Repetition, Max Repetition, and Repetition ≥ 3, from each session. Below are the definitions of these measures and how they were calculated based on the example above.

Measure	Definition	Results
Total Repetition	Total number of target words coded	12 (4 *fish*, 5 *dog*, and 3 *fish*)
Novel Context Repetition	Number of unique target words coded	3 (*fish, dog*, and *fish*)
Average Repetition	The average number of repetition of target words, calculated by dividing Total Repetition by Novel Context Repetition	4 (12 Total Repetitions/3 Novel Context Repetitions)
Max Repetition	Maximum number of occurrence of target words	5 (*Dog* occurred 5 times)
Repetition ≥ 3	Number of target words that are repeated three times or more	3 (all the three target words, namely, *fish, dog,* and *fish* were repeated at least three times)