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Caregivers' vocabulary use for children with cochlear implants and children with normal hearing during the first year of post-activation

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ABSTRACT

This study compared caregivers' use of content words (common nouns, verbs, adjectives) in speech directed to young children with cochlear implants (CIs) and those with normal hearing (NH). Specifically, we examined potential group differences in caregivers' use of content words during the first year following CI activation. We analyzed free play interactions for three groups of 12 caregiver-child dyads: (1) caregivers of children with CIs (*mean* age at activation = 13.77 months, *SD* = 4.31), (2) caregivers of NH children matched by hearing experience to the CI group (NHE), and (3) caregivers of NH children matched by chronological age to the CI group (NCA). Interactions were recorded at 3, 6, and 12 months post-activation (or equivalent). Caregivers' speech was transcribed and coded to measure the number of words (tokens) and unique word forms (types) for each content word class. Linear mixed-effects models showed a marginally significant effect of group on word tokens. A significant difference in word types was found between the CI group and both NH groups. Caregivers of younger NH children used more tokens and types than caregivers of children with CIs. Children with NH experience more word tokens and greater word variety in caregiver speech compared to children with CIs during their first year of robust hearing. This richer input may benefit NH children's language development, while children with CIs may experience different patterns of exposure to a variety of word types, reflecting their current developmental levels. Further research is needed to explore how caregiver speech affects language outcomes in children with CIs.

1. Introduction

Young children acquire various aspects of language, such as vocabulary, grammar, and pragmatics, through interactions and exposure to caregivers' language input (e.g., Anderson et al., 2021; Cartmill et al., 2013; Friedmann & Rusou, 2015; Hart & Risley, 1995; Kalashnikova & Kember, 2020; Rowe, 2012; Rowe & Snow, 2019). Many researchers have investigated the properties of caregivers' language input and its impact on children's language outcomes to better understand the underlying mechanisms of the

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early language acquisition (Genovese et al., 2020; Gilkerson et al., 2017; Hsu et al., 2017; Marchman et al., 2017; Marklund et al., 2015; Outters et al., 2020; Raneri et al., 2020; Spinelli et al., 2017). Research has shown that caregivers adjust their speech for their infants by exaggerating phonological properties, using less complex syntactical structures, and reducing variability in vocabulary (Genovese et al., 2020; Murray et al., 1990; Odijk & Gillis, 2021a; Rowe & Snow, 2019). This is true to some extent for caregivers of children with cochlear implants (CIs). Children with CIs receive degraded auditory signals processed by the cochlear implant device, which impacts their language development. Additionally, since most deaf children do not receive their cochlear implants until at least nine months of age[1] (Food and Drug Administration, 2020), they often lack exposure to spoken language input before attaining robust hearing through implantation. The delayed spoken language exposure can lead to slower vocabulary growth in children with CIs (e.g., Lund, 2015; Niparko et al., 2010; Välimaa et al., 2018; Odijk & Gillis, 2021b). Therefore, knowledge of the properties of caregiver input is important for families of young children with CIs who may face challenges in developing foundational language skills at an early stage (Friedmann & Rusou, 2015; Levine et al., 2016).

In typically developing children, it is well established that caregivers' vocabulary use correlates with children's vocabulary development (Hart, 1991; Huttenlocher et al., 2010; Newman et al., 2016; Quigley & Nixon, 2020; Rowe, 2012). However, only a few studies have examined the specific use of vocabulary (i.e., tokens and types of content words) of caregiver input to children with CIs (e.g., Adi-Bensaid & Greenstein, 2020; Odijk & Gillis, 2021b). This is important because children's early vocabulary development is significantly linked to later language development, executive functions, and academic achievement (Castellanos et al., 2016; Duff et al., 2015; Escobar et al., 2018). Therefore, the current study aimed to investigate the quantity (e.g., number of words, or tokens) and quality (e.g., number of unique word forms, or types) of caregivers' vocabulary use, specifically content words (common nouns, verbs, and adjectives), in caregivers' speech to young children with CIs compared to those with normal hearing (NH).

1.1. Caregivers' vocabulary use and children's vocabulary development

Young children may learn their first words from those that are closely related to their daily routines or from those that their caregivers speak frequently, such as common nouns (e.g., "bottle" and "milk") (Hart, 1991). In many languages, early vocabulary acquisition in children shows noun-dominance, i.e., common nouns are often the main category of words young children acquire during the early phase of vocabulary acquisition (Bates et al., 1994; Gentner, 1982; Nelson et al., 1993; Snedeker et al., 2012). Common nouns are often produced alone (e.g., "Doggy!") or with a few linguistic components (e.g., "Nice doggy!") because of their semantic concreteness, resulting in perceptual saliency (Odijk & Gillis, 2021b). In contrast, other content words such as verbs may require children to understand the relations among agents within sentences, and thus they may require additional linguistic (i.e., syntax) cues for children to acquire (Bedore & Leonard, 1995). These specific properties of word classes may enable young infants to acquire common nouns relatively easily compared with words from other categories.

Additionally, the properties of caregivers' vocabulary use may affect children's early vocabulary acquisition. For instance, caregivers of young children may provide input to their children with particular emphasis on the use of common nouns. Longobardi et al. (2015) reported the stable use of common noun types in Italian-speaking mothers of 14 boys from 16 months to 20 months. In short utterances, such as one- or two-word sentences for young infants, English-speaking mothers frequently place common nouns in sentence-final positions with fewer inflections than verbs (Goldfield, 1993). Bergelson (2020) proposed that a stable proportion of common nouns in the input may benefit young children (i.e., 6–17 months) in learning new words.

The association between caregivers' and children's vocabulary use has been found in several cross-linguistic studies (Choi & Gopnik, 1995; Tardif et al., 2008; Tardif et al., 1997). Tardif et al. (1997) examined words produced by both caregivers and children and found that, across three languages (English, Italian, and Mandarin), children's vocabulary production was consistent with that of their caregivers. For instance, while English-speaking children (mean age = 2 years) produced more common noun types than verb types, Mandarin-speaking children (mean age = 1 year, 10 months) produced more verb tokens and types than common nouns, reflecting the characteristics of their caregivers' language input. Choi and Gopnik (1995) also reported that Korean-speaking caregivers produced more verbs for their young children during their second year of life than American-English-speaking caregivers, and Korean children showed more frequent use of verbs compared to American children.

In contrast, studies on Hebrew child-directed speech have revealed a disparity in vocabulary usage between caregivers and infants. Hebrew-speaking caregivers were found to produce verbs as frequently as nouns, encompassing concrete and abstract nouns, personal names, animal sounds, and onomatopoeic words. Hebrew-speaking children, on the other hand, exhibit a dominance of nouns (Adi-Bensaid et al., 2015; Adi-Bensaid et al., 2017). The authors suggest that this discrepancy may be contributed to language-specific characteristics, particularly the null subject feature in Hebrew. Specifically, in Hebrew, subject noun phrases are optional for first- and second-person references (Vainikka & Levy, 1999), potentially leading to an elevated use of verbs by caregivers and resulting in a discrepancy between caregivers' and children's vocabulary use. Appreciating these specific nuances in caregivers' input is crucial for comprehending children's vocabulary development.

[1] On November 26, 2025, the U.S. Food and Drug Administration (FDA) approved an expanded indication lowering the minimum age for a specific cochlear implant system from 9 to 7 months for infants with profound bilateral sensorineural hearing loss (MED-EL Corporation, 2025; PMA P000025/S134).

1.2. Caregivers' language input to young cochlear implant recipients

Caregivers' language input affects language acquisition in young deaf children who use CIs (Dilley et al., 2020; Holzinger et al., 2020; Majorano et al., 2021; Vanormelingen et al., 2016). Mothers' use of certain facilitative techniques (e.g., recast, or expansion) and mean length of utterances were positively related to language outcomes in young children with CIs (Cruz et al., 2013; DesJardin & Eisenberg, 2007; Szagun & Stumper, 2012). When caregivers used more repetitions of words to their children at 6 months post-activation (i.e., 6 months after the switch-on of the device), the children showed better receptive vocabulary skills at 2 years post-activation (Wang et al., 2020) than when caregivers used fewer repetitions of words. These findings underscore the importance of knowledge of the properties of caregiver input to young children with CIs because it may provide empirical evidence to professionals and families on how to speak to their young children with CIs to support their children's language acquisition.

The framework proposed by Houston (2022) for understanding the mechanism between language input and children's outcomes highlights several variables that moderate the effect of language input quantity on young children with CIs, such as audibility issues, children's attention, coordinated attention, and their understanding of referential meaning. Among these, attention to speech is the central moderator of children's language development. To facilitate children's attention to speech, the framework suggests implementing a strategy in which caregivers coordinate their attention to the child's focus of attention. Moreover, caregivers can keep in mind their child's developmental level, providing appropriate language input that match their cognitive and language abilities. Deaf children may develop non-verbal cognitive and physical skills at a typical level (Monroy et al., 2024; Terhune-Cotter et al., 2021; but see Gremp et al., 2019; Harris et al., 2013; Monroy et al., 2019; Monroy et al., 2022 for findings of nontypical cognitive development); however, even with cochlear implants (CIs), their auditory and language abilities might lag behind those of their peers (Houston et al., 2003; Houston et al., 2012; Lederberg et al., 2013; Meinzen-Derr et al., 2018; Niparko et al., 2010; Tomblin et al., 2015). Therefore, the spoken language input from caregivers of young children with CIs may differ from that of caregivers of children with NH because it is tailored to their children's hearing, attention, cognition, and language levels.

There is evidence that the early vocabulary development of young children with CIs differs from those of children with NH. Whereas the vocabulary growth of children with CIs often lags behind their peers (Lund, 2015; Niparko et al., 2010; Odijk & Gillis, 2021b; Välimaa et al., 2018), the time course to produce first words for children with CIs may be relatively short (i.e., within a few months post-activation; Ertmer & Inniger, 2009; Koşaner et al., 2013). Recent studies have also revealed differences in expressive vocabulary profiles between CI and NH groups when their language abilities were matched Jung et al., 2020; Nott et al., 2009). Both studies showed that the CI group demonstrated an advantage in predicate words (i.e., verbs and adjectives) in spoken vocabulary, regardless of which domain of vocabulary skills (receptive or expressive) was controlled. These discrepancies may be influenced by the fact that the chronological ages of the children with CIs in the two studies were older than their NH controls. Interestingly, when matched by chronological age (2–7 years old), the CI group acquired adjectives comparably to their NH peers (Tribushinina et al., 2013). Furthermore, children with CIs used more adjectives than their NH age peers during the first two years of the study (ages 2–3). This suggests that differences in language development between children with CIs and their peers may be more pronounced during the early post-implantation phase than in later stages.

Research has revealed distinctions in various properties of caregiver input between children with CIs and those with NH (e.g., Kondaurova et al., 2013; Vanormelingen et al., 2016). Caregivers of children with CIs have been observed to tailor their speech patterns, such as mean length of utterances and word choices, to match their children's auditory experience and linguistic proficiency rather than their chronological age (Bergeson et al., 2006; Lund & Schuele, 2015). Moreover, even after adjusting for the children's linguistic abilities, including babbling properties and cumulative vocabulary size, Vanormelingen et al. (2015) discovered that caregivers of young children with CIs exhibited a higher responsiveness to their children's verbalizations compared to caregivers of children with NH.

Regarding lexical properties, Odijk and Gillis (2021b) demonstrated that Dutch-speaking caregivers of young children with CIs, implanted before 24 months of age, used fewer words per utterance compared to those in the NH group (6–24 months of age). These adjustments appeared to reflect the children's developmental milestones in acquiring their first words, which were monitored from one month up to 30 months post-activation. The study compared the mean length of utterance containing content words–such as adjectives, adverbs, nouns, and verbs–used by caregivers between the CI and NH groups. It revealed that caregivers of children with CIs tended to use shorter utterances. This suggests that, even when considering the children's expressive vocabulary skills, caregivers of children with CIs adapted their speech patterns to better align with their children's auditory and linguistic development

Adi-Bensaid and Greenstein (2020) examined Hebrew-speaking caregivers' vocabulary use, focusing on tokens and types of content words, for children with CIs (chronological age ranging from 20 to 48 months; hearing experience ranging from 8 to 32 months) and children with NH (age range of 20–48 months for chronological age matching group; 8–26 months for hearing experience matching group). There were no differences in word token use across groups. However, caregivers of children with CIs used a higher proportion of verbs compared to caregivers of children with NH. Specifically, caregivers in the CI group produced a significantly greater verb-to-noun token ratio than those in the NH group. The increased use of verbs in Hebrew-speaking caregivers' input to children with CIs may suggest distinct patterns in caregivers' vocabulary usage potentially influenced by children's hearing status.

In summary, research indicates that the language input provided by caregivers to children with CIs differs from that given to children with NH. However, our understanding of vocabulary usage among caregivers of young children with CIs compared to children with NH remains limited. Specifically, we are interested in the characteristics of language input offered to children with CIs in their first year of CI use. This focus is due to the distinctive development and communicative competence these children exhibit at the preverbal level, compared to their NH peers matched by hearing experience. To the best of our knowledge, this study represents the first attempt to examine the content word usage of English-speaking caregivers in their language input to young children with CIs and

children with NH during the initial year of CI usage. Identifying the features of caregivers' vocabulary usage during this early CI experience may provide valuable insights into the vocabulary development of young children with CIs.

1.3. Research purpose

The primary purpose of this study was to investigate how caregivers of young children with cochlear implants (CIs) use content words during the first year of CI use, in comparison to two control groups of children with normal hearing (NH): a hearing experience-matched group (NHE) and a chronological age-matched group (NCA). To address this goal, we examined two complementary aspects of caregivers' lexical input: (1) the quantity of content word use, reflected in the number of tokens, and (2) the diversity of content word use, reflected in the number of types. These two aspects together provide a comprehensive view of caregivers' lexical input and allow us to assess whether caregivers of children with CIs differ from caregivers of children with NH in either the overall amount of content-word input or the range of lexical items they provide.

We hypothesized that caregivers of children with CIs would produce fewer content-word tokens and types than caregivers of chronologically age-matched children with NH, given that the linguistic abilities of children with CIs may lag behind those of their hearing peers. We also examined whether content-word use differed between the CI and NHE groups, as previous studies comparing CI users with younger NH children matched for linguistic abilities have produced mixed findings (Lund & Schuele, 2015; Odijk & Gillis, 2021b). Notably, no prior studies have compared groups matched on hearing experience. Thus, we conducted exploratory analyses to compare vocabulary variables (tokens and types) across the three groups.

2. Method

2.1. Participants

This study was conducted retrospectively by examining the database from a large public university in the United States. All procedures and analyses were approved by the Institutional Review Board of the university. Data were collected for the projects to examine the differences in caregiver input properties between caregivers of children with CIs and those with NH. Three groups of children and their caregivers contributed to the data collection: (1) children with CIs and their caregivers; (2) children with NH who were matched to the CI group based on the amount of auditory experience gained following CI activation; and (3) children with NH who were matched their chronological age to the CI group. The groups were matched within $\pm$ 15 days according to the relevant criterion (hearing experience or chronological age). All caregivers spoke American English dialects in the Midwest area of the USA. Using the CI group as a reference, the included data were collected at 3, 6, and 12 months post-activation. We included caregiver-child pairs who contributed data for at least two sessions. Unfortunately, the longitudinal comparison with matching children's language ability between groups was not plausible because of individual variability in language growth.

The final sample consisted of 36 caregiver-child pairs (12 per group), aligning with similar studies in the field. For example, prior research (Adi-Bensaid & Greenstein, 2020; Lund & Schuele, 2015) included a minimum of 10 participants per group, collecting data at a single developmental time point per child. In contrast, our study incorporated data from three time points, providing additional observations. Additionally, Odijk and Gillis (2021b) conducted a study tracking maternal language input in relation to children's first word emergence, which included 10 children with CI and 30 children with NH, demonstrating that similar sample sizes are commonly used in related research.

To further assess sample adequacy to detect group differences, we estimated statistical power by benchmarking our design against the variance components reported in the global mean length of utterance (MLU) model of Odijk and Gillis (2021), which yielded a between-subject variance of 0.12, a residual variance of 0.26, and an intraclass correlation of approximately 0.32. Although their model involved two groups, we believe these variance parameters provide a reasonable empirical benchmark for caregiver-speech data of comparable structure. Given that our design includes three caregiver groups and three repeated observations per participant (α =.05), analytical power approximations based on Cohen's f conventions (Cohen, 1988) and mixed-effects guidance from Brysbaert and

Table 1
Participating children's age, communication modes and caregivers' educational levels.

	CI (n = 12)	NHE (n = 12)	NCA (n = 12)
Mean Chronological Age at 3 Months Post-Activation (*SD*)	16.93 (4.54)	3.04 (0.34)	16.99 (4.57)
Mean Chronological Age at 6 Months Post-Activation (*SD*)	20.25 (4.46)	5.82 (0.41)	20.24 (4.40)
Mean Chronological Age at 12 Months Post-Activation (*SD*)	26.13 (4.70)	12.01 (0.26)	26.12 (4.69)
Communication Modes (*n*)			
Fully Spoken Language	58.33 % (7)	100 % (12)	100 % (12)
Spoken Language with Some Signs	8.33 % (1)	-	-
Spoken Language with Cued Speech	8.33 % (1)	-	-
Total Communication	25.00 % (3)	-	-
Caregivers' Education (*n*)			
High School Completion	25.00 % (3)	8.33 % (1)	8.33 % (1)
Some College	16.67 % (2)	25.00 % (3)	33.33 % (4)
Bachelor's degree	50.00 % (6)	58.33 % (7)	33.33 % (4)
Graduate School	8.33 % (1)	8.33 % (1)	25.00 % (3)

Stevens (2018) indicated that approximately 33 participants per group (99 total) would be required to achieve 0.80 power for a medium group effect (f ≈ 0.25) and about 13 per group (39 total) for a large effect (f ≈ 0.40). As the current design includes 12 caregivers per group (36 total), the achieved power is approximately 0.37 for a medium effect and 0.77 for a large effect, suggesting that the present sample provides adequate sensitivity to detect large and meaningful differences between groups while remaining consistent with prior research in this field. In addition, we report confidence intervals and effect sizes to facilitate the interpretation of our results.

2.1.1. The CI group

The children from the CI group were implanted before 24 months of age. Parental reports of pre-implantation audiological testing indicated that all children had severe-to-profound hearing loss (i.e., hearing threshold > 70 dB HL). All but one reported behavioral audiometry results; one reported 95 dBnHL for the better ear from auditory brainstem response testing using click sounds. Initially, 15 child-mother dyads who contributed data at 3, 6, and 12 months were identified. Children with CIs had bilateral sensorineural hearing loss. According to their parental reports, the children had no other cognitive, behavioral, or physical developmental concerns. However, three children had an additional diagnosis and were excluded from the study. Therefore, 12 pairs of mother-child dyads were included in this study (eight boys and four girls; mean age at activation = 13.77 months, SD = 4.31, range = 8.29 – 22.66). The mean chronological ages at the three data collection intervals are presented in Table 1.

All caregivers used spoken English at home, there was variability in the communication modes used with their children. Three caregivers used total communication[2] to interact with their children. One additional family used some signs, while their primary mode was oral language, and the other family used cued speech. The remaining seven families reported using only spoken language. Although data on early intervention history were not collected, the communication modality might have been influenced by the early intervention approach. However, despite the variance, all families reported pursuing spoken language as their primary communication goal for their children. That is, spoken language input was always prioritized, even when visual support was also used during communication.

2.1.2. Two NH groups

Two groups of children with NH and their caregivers (all female) were included. All children passed newborn hearing screening; no other developmental concerns were reported. The caregivers spoke English at home. The first group included 12 pairs of caregivers and children with NH (seven boys and five girls) who were matched to the hearing experience of the children from the CI group (NHE; range of chronological age at 3 months post-activation session = 2.3 – 3.6 months); therefore, they were much younger than the CI group. Eight of them contributed to data collection fully, and four missed the 6-month session. The second group of children with NH included 12 caregivers and children who were chronologically age-matched peers (NCA; seven boys and five girls) with relatively longer listening experience compared to the CI group (chronological age range = 10.9–25.7 months). All pairs participated in all three data collection sessions.

2.2. Procedures

Interactions between the caregivers and children were audio- and video-recorded. A standardized set of plastic toys was provided to all participants (i.e., a key, a turtle, a ball, a button, a cat, and a dog). The caregivers were instructed to play as they would normally do at home. Each dyad was recorded once at each interval across the 3-, 6-, and 12-month sessions. The mean duration of each recording was 4.99 min (*SD* = 0.78), with variability in the actual duration of the recordings due to the children's condition at testing (range = 1.27 – 7.0 min). Two sessions of videos (6 month-interval for NCA) were not included in the analysis because the session-duration information was not available due to technical issues. The number of utterances included in the analysis varied, ranging from 31 to 238.

All sessions were conducted in a double-walled, copper-shielded sound booth (Industrial Acoustics Company) within a university research laboratory. Video data were captured using a Canon 3CCD digital video camera. During the early phase of data collection, audio was recorded with a hypercardioid microphone (Audio-Technica ES933/H) mounted at a fixed position inside the booth and connected to a phantom power supply, an amplifier (DSC 240), and a digital audio tape recorder (Sony DTC-690). Partway through the longitudinal project, the audio setup was replaced with an SLX Wireless Microphone System (Shure), consisting of an SLX1 bodypack transmitter secured to the child via a vest with an integrated microphone and an SLX4 receiver connected to the video recording system.

2.2.1. Data coding

Caregivers' utterances and behaviors were transcribed following the Systematic Analysis of Language Transcripts (SALT) (Miller & Chapman, 2000). Several coders listened to the audio using headsets and transcribed every utterance and behavior. An utterance was defined as a complete sentence or phrase that can stand on its own. Sentences were also segmented as multiple utterances when there were significant silent pauses (e.g., 1 s) between phrases. The mean numbers of eligible utterances for analyses for each group at different intervals are presented in Table 2. The linear mixed-effect analysis showed that the number of utterances was not significantly

[2] A communication philosophy and approach that uses all available modalities–spoken language, sign systems, gestures, and visual supports–to ensure consistent and accessible communication for individuals with hearing loss.

Table 2
Descriptive analysis of session duration, utterance count, mean length of utterances, and lexical variable count.

Group	Interval	CI	NHE	NCA
Session duration	3 months	4.89 (0.54)	4.90 (0.90)	5.09 (0.60)
Mean (SD)	6 months	5.06 (0.61)	4.90 (0.92)	4.67 (0.88)
	12 months	4.80 (1.25)	5.27 (0.70)	5.21 (0.42)
Number of Utterances	3 months	122.00 (29.90)	113.00 (36.80)	133.00 (48.4)
Mean (SD)	6 months	123.00 (24.30)	81.90 (20.50)	106.00 (29.9)
	12 months	110.00 (42.7)	107.00 (31.00)	131 (26.5)
Mean Length of Utterances	3 months	3.12 (0.70)	3.79 (1.07)	3.41 (0.35)
Mean (SD)	6 months	3.33 (0.84)	4.01 (0.74)	3.65 (0.73)
	12 months	3.08 (0.64)	3.24 (0.80)	3.25 (0.56)
Total Word-Tokens	3 months	95.42 (37.95)	116.75 (55.64)	127.17 (43.35)
Mean (SD)	6 months	99.08 (27.24)	90.00 (32.21)	97.10 (24.50)
	12 months	96.42 (31.43)	112.42 (47.64)	119.67 (40.32)
Noun Tokens *Mean (SD)*	3 months	32.42 (15.17)	36.83 (19.69)	48.58 (21.37)
	6 months	34.75 (14.35)	33.00 (16.31)	36.80 (16.40)
	12 months	34.25 (13.88)	43.00 (16.81)	46.33 (15.59)
Verb Tokens *Mean (SD)*	3 months	53.50 (22.22)	63.92 (30.17)	68.50 (36.99)
	6 months	53.58 (17.78)	48.75 (15.47)	49.90 (15.65)
	12 months	51.33 (18.85)	56.42 (24.38)	59.42 (24.02)
Adjective Tokens	3 months	9.50 (7.27)	16.00 (14.68)	10.08 (5.45)
Mean (SD)	6 months	10.75 (6.00)	8.25 (6.27)	10.40 (5.91)
	12 months	9.83 (4.76)	13.00 (12.19)	13.92 (11.38)
Total Word-Types	3 months	33.25 (10.75)	40.83 (20.09)	46.08 (14.56)
Mean (SD)	6 months	33.33 (8.13)	33.75 (11.04)	41.90 (9.96)
	12 months	34.25 (12.19)	40.33 (16.40)	50.50 (10.10)
Noun Types *Mean (SD)*	3 months	10.17 (4.22)	13.25 (7.52)	16.92 (5.66)
	6 months	10.92 (3.37)	11.38 (5.48)	14.60 (5.50)
	12 months	11.00 (5.31)	12.75 (6.50)	19.83 (4.04)
Verb Types *Mean (SD)*	3 months	17.83 (5.42)	20.25 (9.20)	22.83 (7.33)
	6 months	17.50 (4.44)	17.00 (4.66)	21.30 (5.52)
	12 months	18.58 (5.25)	20.33 (5.38)	22.75 (6.00)
Adjective Types	3 months	5.25 (2.83)	7.33 (5.37)	6.33 (3.94)
Mean (SD)	6 months	4.92 (2.28)	5.38 (3.25)	6.00 (3.53)
	12 months	4.67 (2.84)	7.25 (5.64)	7.92 (4.32)

Note: *SD* = Standard Deviation, CI = children with Cochlear Implant, NHE = Hearing Experience-matched children with normal hearing, and NCA = Chronological Age-matched children with normal hearing.

different across the interval (3-, 6-, or 12-months post-activation) or groups (CI, NHE, or NCA), nor was there a significant interaction effect between interval and group.

To analyze the data, the first author coded three categories of content words: (1) common nouns, (2) verbs, and (3) adjectives. We excluded grammatical words (e.g., adverbs, prepositions, pronouns) and social words, including frozen or formulaic social expressions (e.g., thank you, all gone), animal sounds/onomatopoeic words (e.g., woof, vroom), and proper nouns (Mommy, Daddy, child's name). These words were excluded because they might function differently from their original functions (e.g., the adverb 'up' might function as a verb) in early child language and are sometimes ambiguous to determine their word classes (e.g., animal sounds). Inter-coder reliability was examined for 14 sessions (13.73 %) that were randomly chosen from the samples. The second author independently identified content words and coded their types. The set of coded words was compared with that of the first author for each word item. If one coder identified a word as a content word, but the other did not (e.g., depending on the surrounding contexts, 'go' in 'there you go' was coded as a frozen social expression by one coder whereas it was coded as a verb by another), the item was noted as "disagreement." The total number of utterances that the two coders identified as the same was 1659 out of 1769 (93.78 %). Cohen's kappa value for word type coding was $\kappa = 0.86$ ($z = 49.9$, $p < .001$). According to Viera and Garrett (2005), the κ value between 0.81 and 0.99 is interpreted as "almost perfect agreement."

2.3. Dependent Measures: Word Types and Word Tokens

To understand the quantitative and qualitative properties of caregivers' utterances, we examined the samples using two dependent measures: word types and word tokens. We counted the number of different word types and word tokens for each content word class: (1) common nouns, (2) verbs, and (3) adjectives. To count the number of types, variants of a root form were counted as one type; for instance, productions of 'coming', 'came', and 'to come' during the session would be counted as one word type, 'come' (Huttenlocher et al., 2010). In contrast, for the word token measure, all the occurrences of the inflected cases were counted (i.e., each instance of 'coming', 'came', and 'to come' would be counted as three tokens of the verb form of 'come').

To control the variance in the lexical variables of interest (i.e., word tokens and types), either of sample duration or sample size (i.e., number of utterances) needs to be controlled. We controlled for the effect of the sample size because language input quantity could be a relevant intervention target for caregivers of children with hearing loss (Su & Roberts, 2019). In addition, prior research by

Heilmann et al. (2010) examined the impact of language sample duration on lexical variables, including the number of different words, across a wide age range of children and adolescents (2 years, 8 months to 13 years, 3 months; $n = 231$). Although longer sample durations might be expected to yield higher lexical measures, prior research has demonstrated stability in key lexical and syntactic variables–such as the number of different words (NDW), words per minute (WPM), and mean length of utterance (MLUm)–across varying session durations (1, 3, and 7 min). In their study, trained speech-language pathologists engaged children in conversation following a standardized protocol. While we acknowledge potential differences between children's language samples prompted by adults and caregivers' child-directed speech, this finding suggests that sample duration may not have a robust effect on lexical variables depending on the context. Furthermore, incorporating duration could introduce variability related to caregivers' speaking rate, pausing behavior, or interactional pacing—factors that were not the primary focus of our research questions. Because our aim was to examine caregivers' lexical choice patterns rather than their temporal interaction behaviors, controlling for the total number of utterances was the most appropriate approach. This allowed us to identify subtle patterns in caregivers' vocabulary use during utterance production while mitigating the effects of sample size. Therefore, we controlled for the total number of utterances in our analysis, enabling us to discern subtle patterns in caregivers' vocabulary usage during utterance production while mitigating the effects of sample size.

2.4. Data analyses

Our aim was to investigate how children's hearing status and experiences (CI, NHE, and NCA) influence caregivers' content word usage. The dependent variables included caregivers' total production of word tokens (i.e., number of words) and their production of different content word types (i.e., number of unique words), encompassing common nouns, verbs, and adjectives. We employed linear mixed-effect models due to the repeated data collection from the same individuals. Mixed-effects analyses were performed using the 'lme4' and 'lmerTest' packages in R (R Core Team, 2020).

In the mixed-effect models, we assessed the fixed effects of group (CI, NHE, and NCA), and word classes (common nouns, verbs, and adjectives) with each caregiver-child pair as a random effect (participant variable). We included the number of utterances as a covariate to control for sample size effect. By contrast, we deliberately omitted age as a covariate because our research design aimed to compare the language input properties of the first year of CI experience with those provided to typically developing children. This comparison was made in terms of chronological age and hearing experience, acknowledging the potential differences in their ages. A Fisher's exact test determined that the caregivers' education level was not significantly different across the groups ($p = 0.692$), thus caregiver education was subsequently removed from our analyses. Our data and scripts are available in our OSF depository.

3. Results

3.1. Descriptive analyses

Given the individual variability in session duration and the number of utterances, we tested whether there were significant differences in both session duration and the number of utterances across the groups. When comparing session duration, we did not find any significant differences across groups or intervals. However, when comparing the number of utterances, we found a significant group difference at the six-month interval ($\chi^2 = 32.176$, $df = 2$, $p < .001$) and at the 12-month interval ($\chi^2 = 10.963$, $df = 2$, $p = .004$). At the six-month session, a post-hoc pairwise test, adjusted using the Holm method, revealed that the NHE group produced significantly fewer utterances than the CI group and the NCA group ($ps < .003$). The CI group did not show a difference compared to the NCA group. In addition, at the 12-month session, the NHE group produced significantly fewer utterances than the NCA group ($p = .004$). Table 2 presents the mean session durations, the average number of utterances, and the total number of word tokens, word types, and those of each word class during the 3-, 6-, and 12-month post-activation sessions as a function of the groups.

3.2. Caregivers' use of content word tokens

We conducted a linear mixed-effects model to investigate the impact of group and word classes on the quantity of caregivers' vocabulary usage, while controlling for the number of utterances ((Word Tokens ~ Utterances + Word Classes + Group + (1| Participant)). The CI group was set as the reference, and common nouns were selected as the reference category for word classes. The interval (i.e., the time point at which the data were collected: 3, 6, and 12 months) was initially considered as a covariate. However, it did not improve overall model fit, and its main effect on caregivers' word token use was not significant. We also ran a separate analysis restricted to the CI group to examine any potential effect of post-activation intervals, but no significant effects were observed. Therefore, following the principle of parsimony, the interval variable was excluded from the final model.

Additionally, a model including interaction effects was tested (Word Tokens ~ Utterances + Word Classes * Group + (1|Participant)), but it was not selected because it did not improve model fit ($\chi^2 = 3.761$, $df = 4$, $p = .439$) and did not yield any significant effects. Thus, our final model incorporated the number of total utterances as a covariate, word classes, and group as fixed effects alongside the random effect of participant. The residual variance of the final model indicated a violation of the normal distribution assumption, resulting in application of square-root transformation to the dependent variable.

The estimated variance for Participant was 0.332 ($SD = 0.577$), and the residual variance was 1.123 ($SD = 1.060$). The number of total utterances had a significant main effect, $\chi^2(1) = 103.01$, $p < .001$, indicating that caregivers who produced more utterances also used a greater number of word tokens. For fixed effects, Word Class showed a significant effect on caregivers' word-token use, $\chi^2(2)$

= 849.64, $p < .001$. Caregivers produced significantly fewer adjective tokens than common nouns, whereas verb tokens were used significantly more than common nouns. The main effect of Group was marginally significant, $\chi^2(2) = 4.88$, $p = .087$, driven primarily by differences between the CI and NHE groups (see Table 3). Caregivers of children with normal hearing (NHE) produced more word tokens than caregivers of children with CIs, $b = 0.318$, $SE = 0.278$, $df = 30.36$, $t = 1.14$, $p = .035$, corresponding to a moderate effect size ($d = -0.51$, 95 % CI [-0.99, −0.04]). In contrast, group differences between CI and NCA ($d = -0.26$, 95 % CI [-0.73, 0.21]) and between NCA and NHE ($d = -0.25$, 95 % CI [-0.73, 0.23]) were small and not statistically significant. Fig. 1 illustrates the predicted word-token usage by caregivers of each group as determined by the mixed-effects model.

3.3. Caregivers' use of content word types

To understand whether there was a difference in the use of word types across the groups, we employed a similar mixed effect model to that for token use. The effect of utterance number was controlled by including it as a covariate. The reference group was set as the CI group, and for the analysis of word class, the common noun type was used as the reference. At first, we tested the main effect of the groups and word classes. There was a significant main effect of group ($\chi^2 = 9.102$, $df = 2$, $p = .011$) and word type ($\chi^2 = 627.141$, $df = 2$, $p < .001$). The CI group produced significantly fewer word types than the NCA ($b = 3.767$, $SE = 1.319$, $df = 31.230$, $t = 2.856$, $p = .008$, d = −0.78, 95 % CI [-1.33, −0.22]) and the NHE group ($b = 2.981$, $SE = 1.328$, $df = 32.051$, $t = 2.244$, $p = .032$, d = −0.62, 95 % CI [-1.18, −0.06]). The difference between the NCA and NHE groups was small and not statistically significant (b = 0.78, SE = 1.34, df = 34.15, p = .56, d = 0.16, 95 % CI [-0.40, 0.72]). Regarding Word Class, a greater number of common noun types were produced than adjective types ($b = -7.333$, $SE = 0.550$, $df = 265.829$, t = -13.342, $p < .001$). In contrast, a greater variety of verb types was produced compared to common noun types ($b = 6.422$, $SE = 0.550$, $df = 265.829$, $t = 11.683$, $p < .001$). An additional model including the interval variable was tested. Although the main effects of Group and Word Class remained significant, the interval itself did not significantly predict caregivers' use of word types ($\chi^2(2) = 4.15$, $p = .126$) and did not improve model fit. As with the token analysis, we also conducted a separate analysis for the CI group to examine any potential effect of post-activation intervals, but no significant effects were observed. Accordingly, the interval variable was excluded from the final model.

We then examined the interaction effect between groups and word type, which revealed a significant effect ($\chi^2 = 17.351$, $df = 4$, $p = .002$). We assessed multicollinearity using adjusted generalized variance inflation factors ($GVIF^{1/(2*df)}$) because our model included categorical variables, and all variables showed acceptable levels ($GVIF^{1/(2*df)} < 2.0$). Comparing the models with and without the interaction term, we found a significant improvement in model fit ($\chi^2 = 17.231$, $df = 4$, $p = .002$) when including the interaction. Therefore, our final model incorporated the interaction term. The model (Word Types ~ Utterances + Word Classes * Group + (1| Participant)) demonstrated acceptable residual variation, and quantile-quantile (QQ) plots confirmed adherence to the assumptions of linearity and normality.

The estimated variance for participants was 8.752 ($SD = 2.958$), and the residual variance was 14.672 ($SD = 3.830$). Significant main effects were observed for all fixed effects: number of utterances ($\chi^2 = 58.446$, $df = 1$, $p < .001$), word classes ($\chi^2 = 209.182$, $df = 2$, $p < .001$), and group ($\chi^2 = 16.004$, $df = 2$, $p = .011$). Coefficients and standard errors for the fixed effects of word type are also presented in Table 4. As caregivers produced more utterances, a greater number of different word types were used. Adjectives were produced significantly less than common nouns, while verbs were produced significantly more. Caregivers from both the NCA and NHE groups produced significantly more types in common nouns than those from the CI group. The difference between the number of common noun types and adjective types was greater in the NCA group than in the CI group. Fig. 2 represents the word type usage by caregivers as predicted by the model.

4. Discussion

4.1. Word tokens and type use in caregiver speech across groups

Insights into caregivers' linguistic patterns during interactions with their children are crucial for understanding early vocabulary development (Rowe, 2012). Recent research underscores the influence of children's hearing status on variations in vocabulary usage among caregivers (Adi-Bensaid & Greenstein, 2020; Lund & Schuele, 2015; Odijk & Gillis, 2021b). Our study expands on these findings

Table 3
Coefficient estimates for fixed effects from mixed-effects models predicting caregivers' use of word tokens.

Dependent variables	Parameters	Estimate	SE	*df*	*t*	*p*
Word Tokens$^{\surd}$	(Intercept)	3.140	0.339	121.598	9.257	$< .001^{***}$
	Number of Utterances	0.023	0.002	260.857	10.149	$< .001^{***}$
	Adjectives	-2.914	0.148	265.285	-19.646	$< .001^{***}$
	Verbs	1.309	0.148	265.285	8.826	$< .001^{***}$
	NCA	0.318	0.278	30.356	1.144	.262
	NHE	0.620	0.278	31.551	2.208	.035*

Note: $^{\surd}$ = square root transformation, *SE* = standard error, *df* = degree of freedom, NHE = Hearing Experience-matched children with normal hearing, and NCA = Chronological Age-matched children with normal hearing, ns = not significant. The reference category for words was adjectives. Group comparisons were made with the CI group serving as the reference.
* $p < .05$, ** $p < .01$, *** $p < .001$

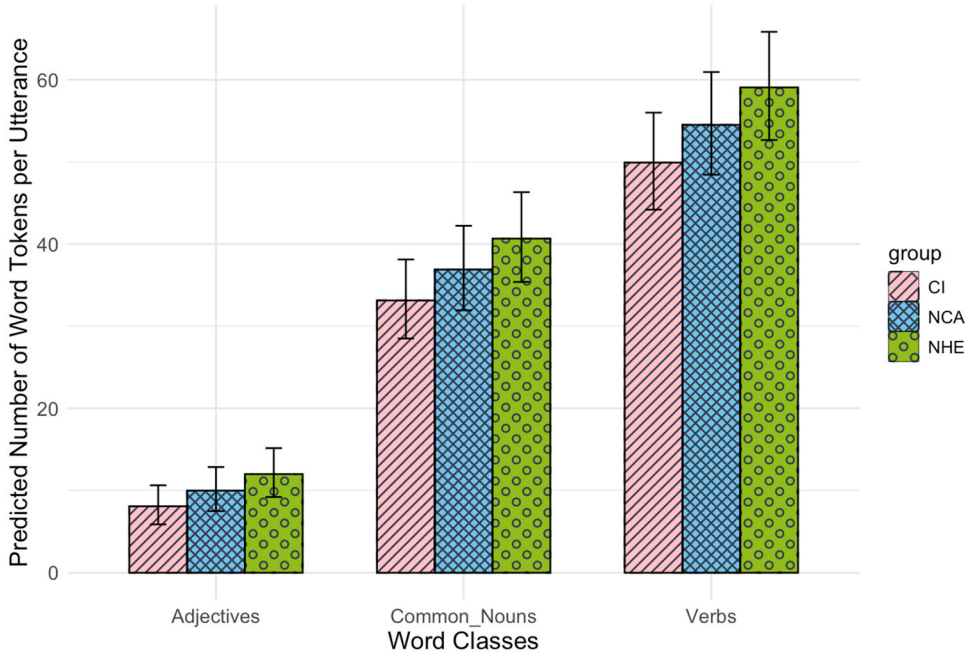

Fig. 1. The effect of groups on the caregivers' word token use.
Note: CI = Cochlear Implants, NHE = Hearing Experience-matched children with normal hearing, and NCA = Chronological Age-matched children with normal hearing. The x-axis represents the word classes, and the y-axis represents the number of word tokens predicted by the model. Due to the non-normal distribution of the residual variance, we square-rooted the dependent variable (word tokens).

Table 4
Coefficient estimates for fixed effects from mixed-effects models predicting caregivers' use of word types.

Dependent variables	Parameters	Estimate	*SE*	*df*	*t*	*p*
Word Types	(Intercept)	3.025	1.464	122.355	2.066	.041*
	Number of Utterances	0.065	0.008	292.158	7.645	< .001**
	NCA	6.069	1.518	54.130	3.999	< .001**
	NHE	3.128	1.531	55.896	2.043	.046**
	Verbs	7.278	0.903	261.881	8.061	< .001**
	Adjectives	-5.750	0.903	261.881	-6.369	< .001**
	NCA * Verbs	-2.190	1.295	261.881	-1.690	.092
	NHE * Verbs	-0.403	1.316	261.881	-0.306	.760
	NCA * Adjectives	-4.721	1.295	261.881	-3.644	< .001**
	NHE * Adjectives	-0.031	1.316	261.881	-0.024	.981

Note: *SE* = standard error, *df* = degree of freedom, NHE = Hearing Experience-matched children with normal hearing, and NCA = Chronological Age-matched children with normal hearing, ns = not significant. The reference category for words was adjectives. The analyses were conducted with the CI group and common nouns as the reference variables.
* $p < .05$, ** $p < .01$, *** $p < .001$

by revealing a higher number of word tokens in caregiver speech to the NHE group compared to the CI group during the first year post-CI activation. However, no significant difference was found between the CI and NCA groups in word token use. Furthermore, English-speaking caregivers of children with CIs used fewer word types compared to both NH groups (NHE and NCA). The current findings of variation in vocabulary use across groups, both in tokens and types of content words (i.e., common nouns, verbs and adjectives), may reflect how caregivers, particularly those of young children with CIs, adapt their input to their children's auditory and linguistic abilities (Genovese et al., 2020; Houston et al., 2003; Murray et al., 1990; Odijk & Gillis, 2021a; Rowe & Snow, 2019).

In comparing the quantity of language use, Adi-Bensaid and Greenstein (2020) found no significant difference in total token usage across the CI, NHE, and NCA groups. The comparison between the CI and NCA groups supports the current findings; however, it does not necessarily imply that the overall input quantity was the same for both groups. For instance, since we only examined content words, it remains unclear whether the NCA group used a greater number of grammatical words. Relatedly, Lund and Schuele (2015) reported that the mean length of utterances (MLU), encompassing all word classes, was shorter for the CI group (age range = 16–43 months; CI experience = 2–11 months) compared to the NCA group (age range = 15–43 months), suggesting that the number of lexical items per utterance was greater in the NCA group than in the CI group. In contrast, the CI group and a vocabulary-matched NH group (age range = 9–18 months) displayed comparable MLU. These findings suggest that caregivers may adapt their language input based

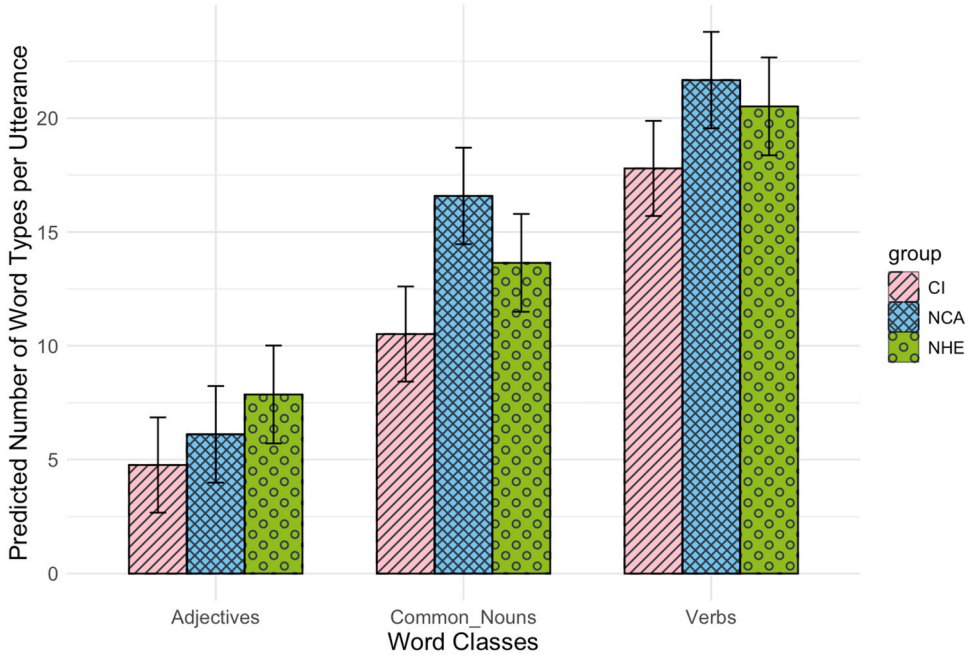

Fig. 2. The effect of groups on the caregivers' word type use.
Note: CI = Cochlear Implants, NHE = Hearing Experience-matched children with normal hearing, and NCA = Chronological Age-matched children with normal hearing. The x-axis represents the word classes, and the y-axis represents the number of different word types predicted by the model.

on their children's language abilities or hearing experiences.

Regarding word types, among Hebrew-speaking children, a greater use of common nouns and adjectives was observed in the CI group compared to the NCA group, but no difference was found between the CI and NHE groups (Adi-Bensaid & Greenstein, 2020). Another study by Lund and Schuele (2015) also demonstrated that the NCA group produced a significantly higher number of different word types than the CI group. However, younger children matched by vocabulary size showed no group differences. The NCA group's longer hearing experience and more advanced verbal abilities likely prompted their caregivers to use a more diverse range of word types.

In contrast, interestingly, our finding indicated that the NHE group used more word tokens and types than the CI group. The children in the NHE group were much younger than those in the CI group, suggesting their cognitive and communication abilities were likely less developed. Thus, the enhanced input quantity in the NHE group was not reflective of the children's language abilities. We controlled for hearing experience, so differences in input are unlikely to be due to variations in hearing experience. The discrepancy between children with CIs and younger children with NH (NHE/vocabulary size matching groups) across the studies may be attributed to differences in the children's ages at the time of data collection. In our study, the NHE group participated during the first year of life, whereas previous studies (Adi-Bensaid & Greenstein, 2020; Lund & Schuele, 2015) might have not sufficiently covered this period, with Hebrew-speaking children aged 8–32 months and English-speaking children aged 9–18 months. In contrast, Odijk and Gillis (2021b) followed the control NH group from 6 months to 24 months, assessing them monthly. The study demonstrated consistently fewer content words per utterance in the CI group compared to the NH group matched by vocabulary size. These findings suggest that caregivers' language input during a child's first year may have distinctive properties, which the CI group may lack.

4.2. Content word use in caregiver input during the first year of cochlear implant use

Caregivers' input during the first year of life exhibits distinct developmental characteristics. Gilkerson et al. (2017) found that caregivers of infants aged 4–5 months used significantly more words than those interacting with infants over 6 months old, suggesting that word quantity is particularly high early in development before stabilizing. Similarly, Odijk and Gillis (2021a, 2021b) reported that caregiver input, measured by MLU, was lowest as children approached their first words–typically between 11 and 16 months for NH children. Thus, the patterns observed in the NHE group in the current study may reflect a period during which caregivers naturally provide enriched linguistic input.

Such enriched early input is crucial for children with NH, who acquire foundational language skills through social and linguistic experiences provided by caregivers (Friedmann & Rusou, 2015; Levine et al., 2016). These skills include statistical learning processes such as speech segmentation, recognizing syntactic patterns, and mapping words to referents. However, our findings show that children with CIs receive relatively restricted content-word input–both in quantity and quality–compared to infants with comparable hearing experience, limiting early opportunities to engage in these learning processes. Because their hearing sensitivity is insufficient

to perceive speech pre-implantation, this discrepancy may place children with CIs at an inherent disadvantage in spoken language development.

Importantly, a growing body of research demonstrates that multimodal cues–such as temporally aligned visual or tactile signals paired with auditory input–play a central role in supporting early language learning (e.g., Frank et al., 2009; Hollich et al., 2005; Jung & Ko, 2025; Nomikou et al., 2017; Seidl et al., 2023). Because reduced input quantity and quality constrain children's ability to detect statistical regularities in the speech signal–including segmentation cues, syntactic patterns, and word–referent mappings–multimodal cues may help infants with CIs by making these regularities more salient and thereby supporting the formation of robust linguistic representations. Caregivers of infants with CIs may incorporate some signs to compensate for limited spoken input, although this possibility was beyond the scope of the current study.

Regarding caregivers' use of each word class, unlike the Hebrew-speaking groups (Adi-Bensaid & Greenstein, 2020), we did not find evidence of enhanced verb token usage in the CI group compared to the NH groups; There was no significant interaction effect in the word token analyses. It remains unclear whether the results reported by Adi-Bensaid and Greenstein (2020) were influenced by the specificity of the Hebrew language, which emphasizes verb usage. Nevertheless, overall, our findings on vocabulary profiles align with previous studies (Adi-Bensaid & Greenstein, 2020; Odijk & Gillis, 2021b), showing that verb tokens were the most frequently used, followed by common nouns and adjectives.

There was a significant interaction effect indicating that caregivers in the NCA group demonstrated a greater difference in their use of common noun types compared to adjective types than caregivers in the CI group. Specifically, while both groups produced fewer adjectives than common nouns, the disparity between these two word classes was more pronounced in the NCA group. This suggests that caregivers in the NCA group provided more common nouns relative to adjectives in their speech compared to caregivers in the CI group. Given the children's mean age of 17 months, they are likely in the phase of actively acquiring their first words, which may have led caregivers in the NCA group to focus more on providing a greater variety of labels in their language input. In contrast, the NHE group appeared to use relatively more varied adjective types than the CI group. Adjectives are a word category that children typically acquire later (Hall et al., 1993; Snedeker et al., 2012), suggesting that the use of various adjective types in the NHE group could represent enriched input, as they did not necessarily reflect the children's immediate language levels. Meanwhile, children with CIs may have missed exposure to a range of word types that exceed their current language levels. It remains unclear what impact exposure to various word classes has on the development of fundamental language skills. Further studies are needed to investigate the role of different word classes in children's language development.

4.3. Study limitations and future directions

First, specifically, the sample size is relatively small, which may limit our ability to detect medium-sized effects, and the data were collected in a laboratory setting, which may not fully reflect naturalistic interactions. Expanding the sample size and incorporating ecologically valid data–collected in real-world environments where caregivers and infants interact naturally–would enhance the generalizability of our findings to the broader population of young infants with CIs. Recent studies have employed daylong recordings to reveal the properties of everyday language inputs (e.g., Marchman et al., 2017). Longer recordings taken in natural environment may allow us to understand extended verbal communication in a variety of contexts at home. However, utilizing daylong recordings also has limitations: it would be challenging and time-consuming to transcribe and code entire recordings. In addition, it is difficult to control for the effects of various contexts. In contrast, the current findings are valuable because they uncovered patterns in the vocabulary use of caregivers from three groups when the same play contexts were given, eliminating the effect of various contexts.

Second, because this was a retrospective study, there were inherent restrictions. For instance, we were able to match groups only on hearing experience and chronological age, although caregivers' input could be affected by children's language ability. However, longitudinal comparisons based on language ability also have challenges such as individual variability in language growth. Matching would be possible at the beginning of the research, but each individual will have different time course for vocabulary development (e.g., Odijk & Gillis, 2021b). In addition, it is critical to determine which domains in a language (e.g., vocabulary, syntax, phonology, or pragmatics) will be matched. Nevertheless, despite these limitations, the current study extends our understanding of vocabulary use by caregivers of young children with CIs.

Finally, future studies should examine the relationships between the properties of caregivers' vocabulary use and children's later-language outcomes. Although we were not able to conduct the analyses because it was beyond the scope of the current study, understanding this relationship will provide important information to implement in family coaching for young children with CIs.

5. Conclusions

The current study indicated that the caregivers differed in the use of vocabulary across the CI and two NH groups. In general, the children in the CI group were exposed to fewer tokens and types of content words than children with NH. Notably, children in the younger age group (NHE) were exposed to a greater number of tokens and types than the CI group. Considering that the NHE group was aged between 3 and 12 months, caregivers may have provided enriched language input to young children who were likely to be in the preverbal stage when the children had normal hearing. Since the first year is critical to build up fundamental skills for language acquisition, the effects found in this study on children's outcomes should be explored further.

CRediT authorship contribution statement

Derek Houston: Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Tonya Bergeson:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Yuanyuan Wang:** Writing – review & editing, Validation, Software, Methodology, Investigation, Data curation, Conceptualization. **Jongmin Jung:** Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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Data availability

Our data and scripts are available in our OSF repository (https://osf.io/dve5x).

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