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Age or Experience? The Influence of Age at Implantation and Social and Linguistic Environment on Language Development in Children With Cochlear Implants

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Purpose: The authors investigated the influence of social environmental variables and age at implantation on language development in children with cochlear implants.
Method: Participants were 25 children with cochlear implants and their parents. Age at implantation ranged from 6 months to 42 months (M_{age} = 20.4 months, *SD* = 22.0 months). Linguistic progress was assessed at 12, 18, 24, and 30 months after implantation. At each data point, language measures were based on parental questionnaire and 45-min spontaneous speech samples. Children's language and parents' child-directed language were analyzed.
Results: On all language measures, children displayed considerable vocabulary and grammatical growth over time. Although there was no overall effect of age at implantation, younger and older children had different growth patterns. Children implanted by age 24 months made the most marked progress earlier on, whereas children implanted thereafter did so later on. Higher levels of maternal education were associated with faster linguistic progress; age at implantation was not. Properties of maternal language input, mean length of utterance, and expansions were associated with children's linguistic progress independently of age at implantation.
Conclusions: In children implanted within the sensitive period for language learning, children's home language environment contributes more crucially to their linguistic progress than does age at implantation.

Key Words: language development, children with cochlear implants (CIs), social environment

The acquisition of spoken language in children with cochlear implants (CIs) displays wide variation among individuals, which investigators have documented for different languages (for English, see Niparko et al., 2010; Peterson, Pisoni, Miyamoto, 2010; Stacey, Fortnum, Barton, & Summerfield, 2006; Svirsky, Teoh, & Neuburger, 2004; for French, see Duchesne, Sutton, & Bergeron, 2009; Le Normand, Ouellet, & Cohen, 2003; for German, see Szagun, 2001; for Dutch, see Giezen, 2011; Gillis, Schauwers, & Govaerts, 2002; for Swedish, see Willstedt-Svensson, Löfqvist, Almqvist, & Sahlén, 2004). The extent of variability exceeds that of children with normal hearing (Duchesne et al., 2009; Svirsky et al., 2004; Szagun, 2001). A range of factors has been found to contribute to the observed variability, notably duration of implant use, age at implantation, quality of preimplant hearing, communication mode, and parents' educational status (Connor, Hieber, Arts, & Zwolan, 2000; Geers, Moog, Biedenstein, Brenner, & Hayes, 2009; Geers, Nicholas, & Moog, 2007; Niparko et al., 2010; Peterson et al., 2010; Svirsky et al, 2004; Szagun, 2001; Tomblin, Barker, Spencer, Zhang, & Gantz, 2005). However, the causes of this wide variation remain only partly understood (Geers et al., 2007; Peterson et al., 2010).

The effect of age at implantation on children's language development has been a major focus of research. Two related issues recur in the literature: (a) whether

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the command of language in children with CIs will become equivalent to that of their hearing peers by the age of 4–5 years and (b) whether the likelihood of this happening is greater the earlier that children are implanted within the first 4 years of life. There is evidence that children who receive a CI by 24 months of age make better linguistic progress than do children who are implanted thereafter (Holt & Svirsky, 2008; Nicholas & Geers, 2007; Niparko et al., 2010; Svirsky et al., 2004; Tomblin et al., 2005) and can be expected to catch up with hearing age-mates during the preschool years (Geers et al., 2009; Nicholas & Geers, 2007). However, outcomes differ for different linguistic subsystems. Children seem to do particularly well in tests of vocabulary and less well in tests of productive syntax and morphology (Duchesne et al., 2009; Geers et al., 2009; Niparko et al., 2010). The wide variation remains, and implantation in the second year of life does not ensure that language abilities will be within the normal range several years later (Duchesne et al., 2009). Preliminary results based on nonstandardized language assessments suggest that further improvement may come from implantation in the first year of life (Dettman, Pinder, Briggs, Dowell, & Leigh, 2007; Lesinski-Schiedat, Illg, Heermann, Bertram, & Lenarz, 2004). However, this is not borne out when standardized language measures are used (Giezen, 2011; Holt & Svirsky, 2008; Szagun, 2010). It is noteworthy that whereas age at implantation has been treated as a major influence on the language development of children with CIs, the amount of variance that it actually explains is small (Geers et al., 2007, 2009; Tomblin et al., 2005).

In order to explain why linguistic progress can be expected to be better in children who receive their CI earlier rather than later, researchers have evoked the concept of the *sensitive period* (Holt & Svirsky, 2008; Nicholas & Geers, 2007; Svirsky et al., 2004; Tomblin et al., 2005). According to theories of neurocognitive development, there is a period of heightened sensitivity for language learning in young humans (Johnson & Newport, 1989; Lenneberg, 1967; Mayberry, 2009; Oyama, 1979). The exact end point of this time-limited sensitivity is not known, but its gradual decline from around age 4 is inferred from results of studies on second-language learning and studies on American Sign Language (ASL) learning in children who are deaf who have little functional spoken language (Johnson & Newport, 1989; Mayberry, 2009). Such studies show that proficiency in the new language is best if learning occurs by around 4 years of age (Johnson & Newport, 1989; Mayberry, 2009; Neville & Bavelier, 2002). Results from children with CIs might challenge this view of a sensitive period. They would be indicative of an even earlier decline of heightened sensitivity for language learning, assuming that the mechanism behind the age-at-implantation effect is maturation alone. So far, however, studies in the field of pediatric cochlear implantation have not explained the mechanisms behind the age-at-implantation effect. Viewed from a developmental neurocognitive perspective, the effect may occur as a result of the children's earlier and more extensive experience with spoken language. As pointed out by Tomblin, Barker, and Hubbs (2007), children who are implanted younger, within the sensitive period, engage in linguistic environments more fully earlier on, whereas children who are implanted later have less extensive experience with spoken language and build up different communicative patterns. The role of experience is confirmed by neurophysiological evidence, which shows that the construction of left-hemispheric neural systems for processing grammar between the ages of 20 and 42 months progresses with reliance on experience with language, not chronological age alone (Neville & Bavelier, 2002). This conclusion is drawn from the evidence that children with higher language levels tend to show the neural activation patterns of slightly older children (Neville & Bavelier, 2002). In order to interpret an age-at-implantation effect in the development of language in children with CIs, it is therefore crucial to study the effect of the children's language environment and their experience with language independently of an age-at-implantation effect. This would allow the assessment of to what extent the mechanisms responsible for differential linguistic growth are purely maturational or dependent on experience (see also Tomblin et al., 2007).

Children's experience with language is crucially dependent on their social and home linguistic environment. Environmental effects on language development are known to occur in typical language development (Clark, 2003; Fenson, Marchman, Thal, Dale, Reznick, & Bates, 2007; Hoff, 2003). Higher socioeconomic status, higher levels of maternal education, and rich maternal language input are associated with better linguistic progress in children with typical language development (Clark, 2003; Fenson et al., 2007; Hoff, 2003; Hoff-Ginsberg, 1985). Recently, some of these variables have also been shown to be associated with linguistic progress in children with CIs. For children implanted by age 4—that is, within the period of maximal plasticity for language learning—higher socioeconomic status, higher levels of parental education, and IQ are positively associated with language development in children with CIs (Geers et al., 2007, 2009; Holt & Svirsky, 2008; Niparko et al., 2010). Indeed, parental IQ and parents' educational level explain a considerably larger proportion of the variance in receptive and productive language than does age at implantation (Geers et al., 2009).

In typical language development, the influence of socioeconomic status is mediated via maternal language input to the child and, thus, the child's experience with language (Hoff, 2003). Language that is rich in grammatical structure and vocabulary is associated with better linguistic progress in children (Clark, 2003; Hoff, 2003; Hoff-Ginsberg, 1985). It is likely that quality of linguistic input has a similar or even more decisive effect on language development in children with CIs, as children with atypical language development depend to a greater extent on favorable environmental conditions (Gallaway & Woll, 1994; Snow, 1994). Yet, very few studies have analyzed the communicative and linguistic home environments of children with CIs. In a study based on qualitative interviews, Spencer (2004) found that parents who are highly involved in learning activities at home had children with faster linguistic progress as measured by standardized tests of vocabulary and grammar. Regarding the linguistic environment, a study based on spontaneous speech data of parent–child interaction found that maternal expansions of incomplete or structurally incorrect child utterances were associated with children's subsequent linguistic progress in a very specific way: More expansions of specific grammatical morphemes, such as plurals and articles, were related to children's increased correct use of these morphemes subsequently (Rüter, 2011). This study confirmed the positive role that expansions are known to play in typical language development (Farrar, 1990; Saxton, Backley, & Gallaway, 2005) for children with CIs. Thus, home linguistic environment may crucially influence the language development of children with CIs, and it may, at least partly, account for the observed association between socioeconomic status and the children's linguistic progress.

The objectives of this study were to examine the influence of age at implantation and social environmental factors on the linguistic progress of children who received their CI between 6 months and 3.5 years of age. The first aim was to establish whether there are differences in children's linguistic progress depending on age at implantation. The sample consisted of near equal numbers of children implanted in the first, second, third, or fourth year of life and, thus, may be well suited to answer this question. The second aim was to assess the relative influence of age at implantation and maternal educational level on children's linguistic progress. In order to assess social environmental influences more specifically, the third aim was to explore the contribution of adult language input to the children's language development while controlling for an effect of age at implantation. To this end, we analyzed the influence of two properties of child-directed speech: (a) its structural complexity and (b) expansions of incomplete or erroneous child utterances. Through our analysis, we addressed the influence of the linguistic environment and, thus, of the child's experience with language. An examination of the influence of age at implantation and the child's language environment in the same sample of children may allow an assessment of the extent to which maturational and experience-dependent mechanisms contribute to the children's linguistic progress.

The children in our sample received their CIs within what is generally considered to be the time period of optimal plasticity for language learning. If sensitivity for language learning is greater at younger ages within this period, and if it is experience independent, we would expect an age-at-implantation effect independent of duration of language learning and kind of language input. With respect to social environmental factors, we hypothesized that parental education and the language input factors would be associated with the children's linguistic progress in the sense that higher levels of parental education, structurally rich language input, and more expansions would be associated with faster linguistic progress in children.

Method

Participants

Participants were 25 children who are deaf and who wear CIs, 12 girls and 13 boys. The children received their CIs from 2002 to 2005. They were between 6 and 42 months of age at the time of implantation, with a mean implantation age of 20.4 months (SD = 11.0 months). All of the children were presumed to be deaf from birth. Four children (16%) had bilateral implants. Two devices were used in this sample: Nucleus CI24M (64%) and Advanced Bionics CII (34%). Data on the children's quality of preoperative aided hearing were available for 13 children. Preoperative aided hearing in dB SPL at 1000 Hz ranged between 70 dB SPL and 95 dB SPL. The children had no other diagnosed impairment besides their deafness. All of the children are growing up in monolingual environments with spoken German.

The children and their parents attended the Cochlear Implant Centrum Wilhelm Hirte in Hannover, North Germany (hereafter, "the Cochlear Implant Center") regularly for speech therapy as well as for audiological and technical management of the device. They took part in auditory–verbal programs using interactive methods of hearing, speech, and language education (Bertram & Päd, 1995). They received individualized instruction from speech therapists. The center's employees emphasize parental support, and parents took part in the speech therapy sessions.

In addition, therapy sessions also took place in the children's hometowns. At the Cochlear Implant Center and in the hometown therapy sessions, the extent of speech therapy services was similar for each child. During the first 2–3 years after implantation, the child and his or her parent(s) attended the Cochlear Implant Center for 5 days every 8 weeks, and less frequently thereafter. During the 5-day stay, the child received one

45-min speech therapy session per day. Therapy sessions in the children's hometowns comprised one 45-min session per week. They took place in the child's home or kindergarten.

During the course of the study, the children either were cared for at home or attended kindergarten. By age 3 years, all of the children attended kindergarten for at least 4 hr per day. In Germany, kindergarten is for children ages 3–6 years. Formal schooling does not start before age 6 years. None of the children in the sample had started formal schooling. No sign language was used. The children used their CIs during all of their waking hours except during activities that precluded such use (e.g., swimming).

Design, Data Collection, and Data Transcription

The study was longitudinal. Researchers assessed children's language at four data points: 12 months, 18 months, 24 months, and 30 months after implantation. Language was assessed by measures based on spontaneous speech and on parental questionnaires. For each child, 45-min spontaneous speech samples were collected and audio recorded at the four data points. Data collection took place in a playroom at the Cochlear Implant Center. The situation was free play with a parent. For some of the time, an investigator was present and joined in with the play. The set of toys during the recording sessions was always the same: cars and garage, zoo animals, farm animals, forest animals, Noah's ark with animals and food supplies, ambulance, hospital room with medical equipment, fire station, police car, police motorcycle, and police officers. Each child selected toys to play with. We conducted digital auditory tape (DAT) recording using portable Sony DAT recorders and a high-sensitive Sony microphone.

Five trained transcriptionists transcribed everything spoken by the child and the parent; they used the Child Language Data Exchange System (CHILDES; MacWhinney, 2000) for transcribing and analyzing child speech. The parent was the mother in 87% of the play sessions and the father in 13% of the play sessions. Reliability checks on transcription were calculated for 15% of the transcripts, with percentage agreements between 96% and 100% for different pairs of transcribers.

The parental questionnaire used was a German adaptation of the MacArthur–Bates Communicative Development Inventories (CDI; Fenson et al., 2007; Szagun, Stumper, & Schramm, 2009). Researchers (Thal, DesJardin, & Eisenberg, 2007) have shown that, for American English, this type of parental questionnaire is a valid measure of spoken language abilities for children with CIs. Questionnaires were handed out to the parents by an investigator at the end of a play and recording session. The parents returned the questionnaires by mail.

Language Measures and Coding of Spontaneous Speech

Parental questionnaire. Like the American CDI, the German parental questionnaire measures vocabulary and grammar. However, due to the more highly inflected nature of German, it contains an extended section on morphology, thus rendering three measures of language: vocabulary, inflectional morphology, and sentence complexity (Szagun et al., 2009). The vocabulary checklist contains 600 words. Thus, the maximum score is 600. The inflectional morphology scale measures five grammatical paradigms of German: noun plurals, verb marking for person and tense, verb auxiliaries, gender marking on articles and adjectives, and case marking on articles. Forty-two usage examples of these grammatical structures are presented in the vocabulary checklist, and the parent's task is to check whether the child uses such forms or not. The maximum score is 42. Equivalent to the American CDI (Fenson et al., 2007), the sentence complexity task measures to what extent children are capable of producing short sentences. Thirty-two pairs of short sentences are presented. The parent's task is to indicate whether the child uses the simpler or more complex version. The maximum score is 32. The questionnaire also contains a section on demographic information regarding parents' educational status, children's serious medical problems (if any), and bilingualism. The German questionnaire is a standardized instrument and has been normed for typically developing children between 1;6 (years;months) and 2;6 (Szagun et al., 2009).

Measures based on spontaneous speech. Two language measures based on spontaneous speech were used: *Number of word types,* which is a measure of vocabulary, and *mean length of utterance (MLU) in morphemes* (Brown, 1973), which is a general index of language ability. Coding for MLU for children and parents was performed according to the rules for German morphosyntactic analysis (Szagun, 2001). We used Computerized Language Analysis (CLAN) programs (MacWhinney, 2000) to calculate MLU and frequency of word types.

Parental child-directed speech was further analyzed in terms of expansions of incomplete or erroneous child utterances. An *expansion* is an utterance in which a parent repeats the preceding child utterance and adds the correct grammatical markings. Examples of expansions for English are:

Child: *Louise crying*. Parent: *Louise is crying*.
Child: *Baby's foots*. Parent: *Baby's feet*.

One coder coded the transcripts for expansions. A second coder coded 35% of the transcripts for expansions independently. As a measure of intercoder reliability, we calculated a Cohen's κ of .92, indicating very good agreement between coders.

Measure of parental education. We used maternal educational level as a measure of parental education. This measure is often used in child language studies; in many societies, including Germany, mothers are the people who spend the most time with young children and, thus, their language input is crucial (Clark, 2003; Fenson et al. 2007; Hoff, 2003; Szagun et al., 2009). Maternal educational level is measured on a four-point scale, depending on years of schooling (1 = *9 years*; 2 = *10 years*; 3 = *13 years*; 4 = *university education*).

Results

Differences Between Age-at-Implantation Groups

The first aim of the study was to examine if there are differences in the children's linguistic progress depending on age of implantation. For this analysis, children were grouped into three age-at-implantation groups: (a) children who were implanted in their first year, between the ages of 6 months and 11 months (n = 7); (b) children who were implanted in their second year, between the ages of 12 months and 23 months (n = 9); and (c) children who were implanted in the third or fourth year, between the ages of 24 months and 42 months (n = 9). In this third group, children who were implanted in the third or fourth year were grouped together because there were too few children (n = 3) in the group of 3-year-olds.

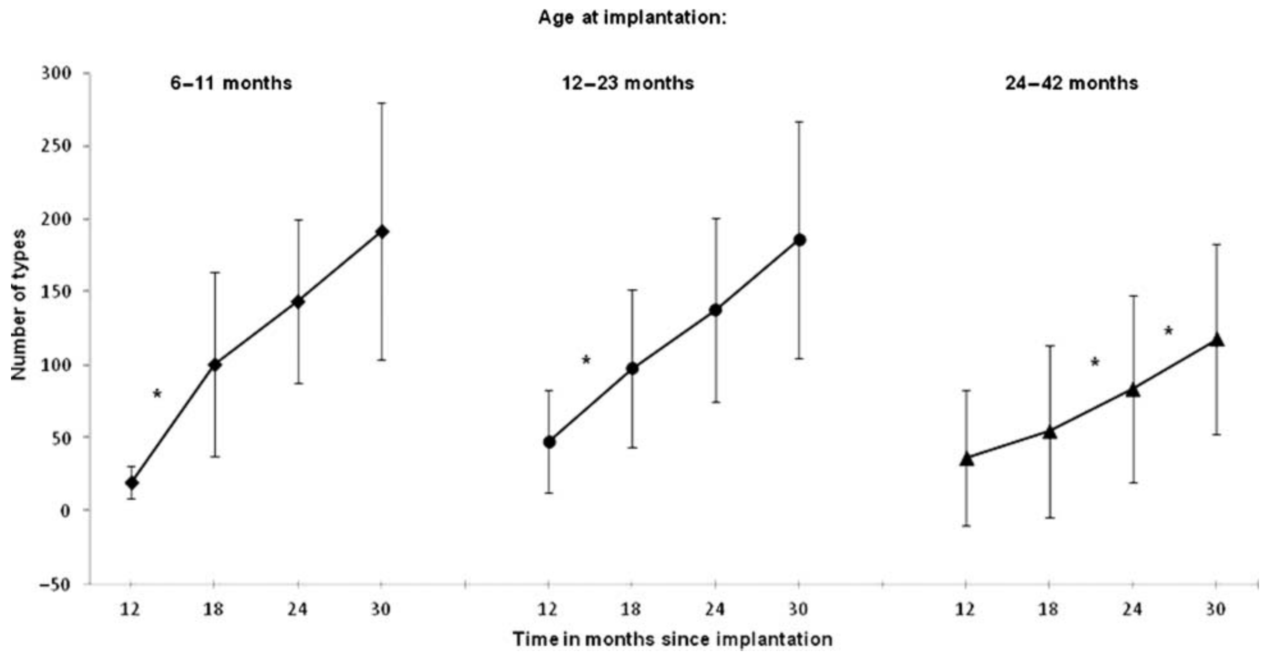
In order to test whether children's linguistic progress was dependent on time since implantation and age at implantation, we conducted two-way analyses of covariance (ANCOVAs) with repeated measures on the factor of time since implantation (4 levels) and the independent factor of age at implantation (3 levels) per language measure. Maternal educational level was entered as a covariate to control for the variance attributable to this variable. Correlations between maternal education and the five language measures were significant at each time point. The correlation coefficients between maternal education and the average of each language measure collapsed over time were as follows: number of word types, r = .56; number of words by questionnaire, r = .55; MLU, r = .60; inflectional morphology, r = 61; sentence complexity, r = 65 (p < .01 per measure). For the analyses based on questionnaire data, the number of participants was reduced to 24 for vocabulary and 22 for inflectional morphology and sentence complexity because not all questionnaires were returned for every data point by all parents.

Measures of vocabulary. Measures of vocabulary are number of word types based on spontaneous speech and number of words as measured by the questionnaire vocabulary list. For number of word types, time since implantation was significant, $F(3, 63) = 8.04$, $p < .001$, $\eta^2_p = .276$. The two-way Time Since Implantation × Age at Implantation interaction was also significant, $F(6, 63) = 2.51$, $p < .05$, $\eta^2_p = .193$. The factor of age at implantation was not significant. For the questionnaire measure of number of words, time since implantation was significant, $F(3, 60) = 22.12$, $p < .001$, $\eta^2_p = .525$, and the two-way Time Since Implantation × Age at Implantation interaction was significant, $F(6, 63) = 4.14$, $p < .01$, $\eta^2_p = .293$. Age at implantation was not significant.

Figures 1 and 2 display the means for number of word types used in spontaneous speech and number of words out of the questionnaire vocabulary list of 600, respectively, per age-at-implantation group and per time point. To give information about the extent of variability, *SD*s are displayed. Figures 1 and 2 show that means increase over time. For both measures, increases were significant between all nonadjacent time points and for some adjacent time points (paired sample t test, $p < .008$, Bonferroni adjustment for six comparisons). Only significant increases between adjacent time points are marked in Figures 1 and 2. Number of word types increased significantly between 12 and 18 months postimplantation for the two younger groups. For the oldest group, number of word types increased significantly from 18 to 24 months and from 24 to 30 months postimplantation. For the questionnaire measure, number of words increased significantly between 12 and 18 months postimplantation in the youngest group. In the middle group, it increased significantly from 12 to 18 months and from 18 to 24 months. On both measures, the vocabulary levels are very similar for the two younger groups, whereas the values for the oldest group are somewhat below. However, no between-group comparisons were significant for either measure (Scheffé test, $p < .016$, Bonferroni adjustment for three comparisons).

Measures of grammar. Measures of grammar are MLU based on spontaneous speech data, inflectional morphology, and sentence complexity as measured by the parental questionnaire. For MLU, time since implantation was significant, $F(3, 63) = 6.39$, $p < .001$, $\eta^2_p = .233$. The two-way Time Since Implantation × Age at Implantation interaction was also significant, $F(6, 63) = 3.91$, $p < .01$, $\eta^2_p = .271$. The factor of age at implantation was not significant. For inflectional morphology, time since implantation was significant, $F(3, 54) = 6.59$ $p < .001$, $\eta^2_p = .268$. The two-way Time Since Implantation × Age at Implantation interaction was also significant, $F(6, 54) = 4.87$, $p < .001$, $\eta^2_p = .351$. Age at implantation was not significant. For sentence complexity, time since implantation was significant, $F(3, 54) = 6.48$, $p < .001$,

Figure 1. Mean number of word types as used in spontaneous speech and *SD* per age-at-implantation group. Significant differences between adjacent groups are marked with asterisks.



$\eta^2_p = .265$, and the two-way Time Since Implantation × Age at Implantation interaction was significant, $F(6, 54) = 3.58$, $p < .01$, $\eta^2_p = .285$. Age at implantation was not significant.

Figures 3, 4, and 5, respectively, show the *M*s and *SD*s for MLU, inflectional morphology, and sentence complexity per age-at-implantation group and time point. For all three measures of grammar, means

Figure 2. Mean number of words as measured by questionnaire (max = 600) and *SD* per age-at-implantation group. Significant differences between adjacent time points are marked with asterisks.

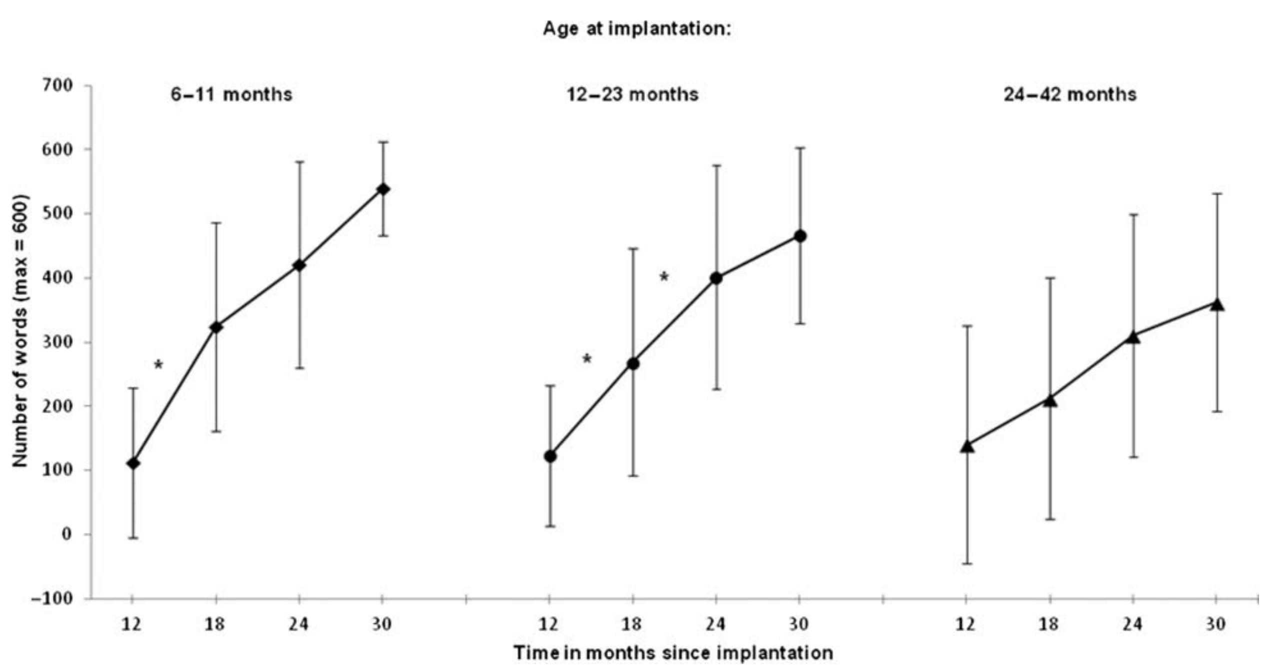
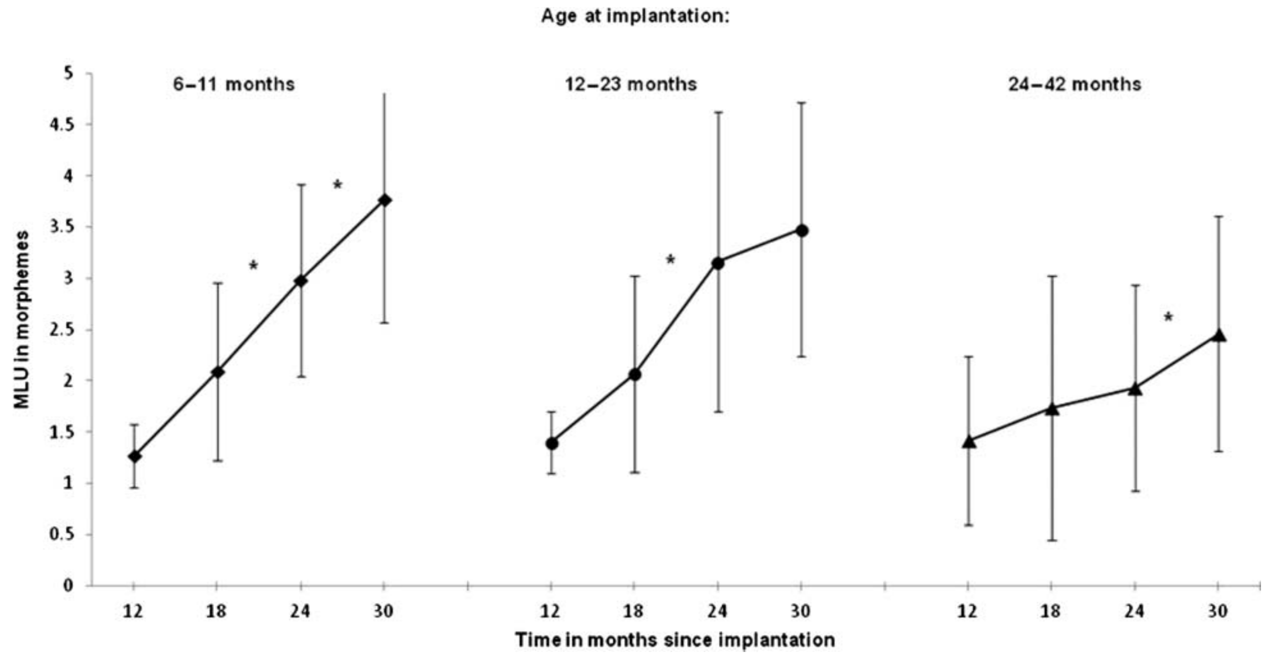


Figure 3. MLU based on spontaneous speech and *SD* per age-at-implantation group. Significant differences between adjacent time points are marked with asterisks.



increased over time—significantly so between all nonadjacent time points and for some adjacent time points (paired sample *t* test, $p < .008$, Bonferroni adjustment for six comparisons). Only significant increases between adjacent time points are marked in Figures 3, 4, and 5. Figure 3 shows that for the youngest group, MLU increased significantly from 18 to 24 months and from 24 to 30 months postimplantation; for the middle group,

Figure 4. Mean inflectional morpheme score based on questionnaire (max = 42) and *SD* per age-at-implantation group. Significant differences between adjacent groups are marked with asterisks.

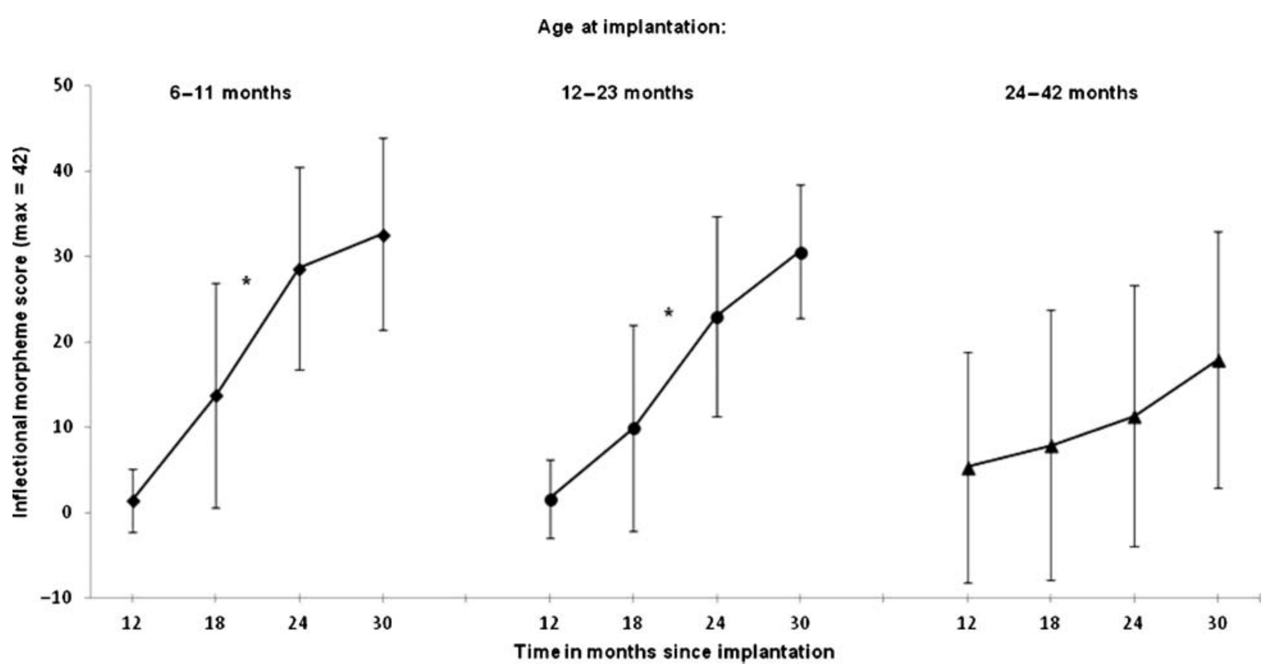
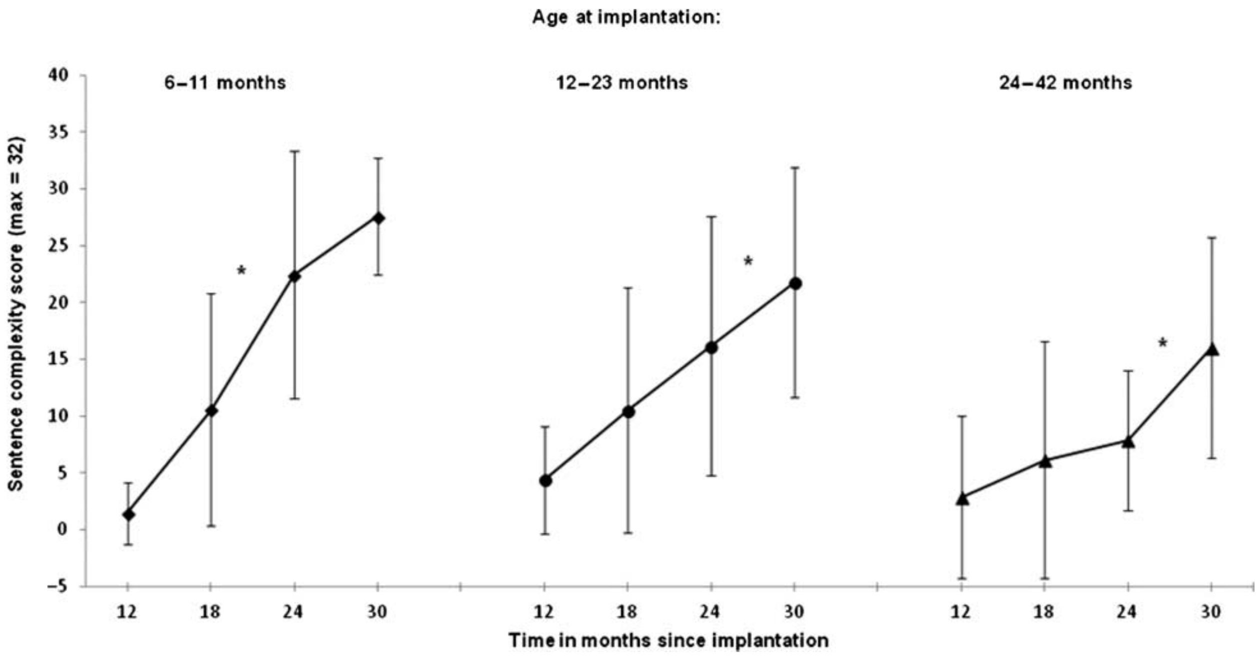


Figure 5. Mean sentence complexity score based on questionnaire (max = 32) and *SD* per age-at-implantation group. Significant differences between adjacent groups are marked with asterisks.



MLU increased significantly from 18 to 24 months postimplantation; and for the oldest group, MLU increased significantly from 24 to 30 months postimplantation. Inflectional morphology increased significantly between 18 and 24 months postimplantation for the two younger groups. Sentence complexity increased significantly between 18 and 24 months postimplantation for the youngest group and between 24 and 30 months postimplantation for the middle and oldest group. Between-groups follow-up tests were not significant for any measure (Scheffé, $p < .016$, Bonferroni adjustment for three comparisons).

Figures 1–5 show that on all language measures, the mean values for the two younger age-at-implantation groups are very similar. They reach higher levels than the oldest group. However, these differences are in no case significant (Scheffé, *ns*). As depicted by the *SD*s, each age-at-implantation group has very large within-group variation. Although the factor of age at implantation is not significant, the significant two-way Age at Implantation × Time Since Implantation interaction indicates that age at implantation affects linguistic growth differently at different time points. This manifests itself in different developmental trajectories. There is an overall tendency for the two younger age groups to make more rapid progress earlier on, whereas for the oldest group, steeper increases occur later on. This pattern is particularly pronounced for vocabulary (see Figures 1 and 2). For grammar, the picture is more mixed. Overall—and viewing all three measures together—the younger groups have steeper increases earlier than do the older groups (see Figures 3, 4, and 5). However, on increases in sentence complexity, the middle and oldest group resemble one another, with the steepest increases occurring between the two last data points for both groups.

Associations Among Maternal Education, Age at Implantation, and Child Linguistic Progress

In accordance with the second aim of the study, we assessed the relative influence of maternal educational level and age at implantation on children's linguistic progress. Although age at implantation is not a significant factor when children are grouped in yearly age groups according to chronological age at implantation, its influence may be detectable if it is treated as a continuous variable. Partial correlations (Pearson) were calculated among maternal educational level, age at implantation, and children's linguistic progress. Maternal educational level was measured on a 4-point scale from 1 to 4, with 1 representing the lowest level and 4 representing the highest level (see Method section). Age at implantation was measured in months. In regard to language measures, we used the values at the final data point—30 months after implantation—because they represent the highest level reached by the children. All five language measures were used. Per language measure, we calculated partial correlations (Pearson) between child language measure and maternal education, partialing out age at implantation, and between child language measure and age at implantation, partialing out maternal education. The correlation coefficients are presented in Table 1. They show that for each language measure, maternal educational level is significantly associated with children's linguistic progress, whereas age at implantation is not. The correlations between maternal education and children's linguistic progress explain between 16% and 28% of the variance. Higher levels of maternal education are associated with better linguistic progress in children with CIs. The correlations between language measures and age at implantation are negative and thus indicate a trend toward an inverse relation between linguistic progress and age at implantation. In the case of inflectional morphology, this trend is marginally significant, $r = .39$, $p = .074$. However, altogether, the trend toward an association between younger age at implantation and better linguistic progress is not significant.

Associations Between Properties of Maternal Child-Directed Speech and Child Linguistic Progress

In accordance with the third aim of our study, we explored the contribution of adult language input to the language development of children with CIs. For these analyses, the data from 24 children and parents were available, as one mother did not want her speech to be analyzed. We analyzed two properties of maternal child-directed speech: (a) maternal MLU and (b) maternal expansions of formally incorrect or incomplete utterances. The child language measure was MLU. We chose MLU because it is the most comprehensive measure of child language and of child-directed adult speech (Brown, 1973; Hoff, 2003; Rollins, Snow, & Willett, 1996). MLU is a measure of grammar, but it correlates highly with measures of vocabulary in child speech and adult child-directed speech (Fenson et al., 2007; Hoff, 2003; Rollins et al., 1996; Szagun et al., 2009). Measures of adult language input were not assumed to be independent of maternal education. Bivariate correlations (Pearson) between maternal education and the language input measures were calculated and are presented in Table 2. At each time point, maternal MLU was significantly associated with maternal education. For maternal expansions, however, the relation was significant only at 18 months postimplantation and was marginally significant at 12 months postimplantation ($p < .067$). More highly educated mothers have higher MLUs in their child-directed speech and, at the initial time points, also use more expansions.

Table 1. Correlations between maternal educational level, age at implantation, and children's language level 30 months after implantation.

Language measure	Maternal educational level[a]	Age at implantation[b]	*n*
Measure of vocabulary			
Number of word types[c]	.40*	−.16	25
Number of words[d]	.45*	−.27	24
Measure of grammar			
MLU[c]	.50**	−.17	25
Inflectional morphology[d]	.52†	−.39	22
Sentence complexity[d]	.53**	−.28	22

Note. MLU = mean length of utterance.

[a]Partialing out age at implantation. [b]Partialing out maternal educational level. [c]Data based on spontaneous speech. [d]Data based on parental questionnaire.

†$p < .02$. *$p < .05$. **$p < .01$, Pearson correlation.

Adult language input has a delayed effect on children's linguistic progress. This is why time-lagged designs are used to study a possible effect. In order to study the effect of maternal MLU and expansions on child MLU, we calculated time-lagged correlations (Pearson). As child language and maternal language are mutually influential (Hoff, 2003; Hoff-Ginsberg, 1994; Richards, 1994), it is necessary to control for the influence of the child's language on the mother's language in order to assess the direction of the effect of the latter on the former. This is done by correlating maternal language at an earlier data point with child language at a later data point, while partialing out the child's language level at the data point when maternal input variables are entered (Hoff, 2003; Richards, 1994). Giving child-directed speech temporal precedence and controlling for the effect of the child's language on it makes a causal interpretation of maternal input more plausible (Hoff, 2003; Richards, 1994). In the present analyses, we also controlled for the effect of age at implantation. Therefore, we calculated correlations, partialing out child MLU and age at implantation. For the time-lagged correlations, maternal MLU/expansions at 12 months and 18 months postimplantation were correlated with child MLU at 24 months and 30 months postimplantation, and maternal MLU/expansions at 18 months postimplantation were correlated with child MLU at 30 months postimplantation (see Table 3). We chose the time intervals of 12 months and 18 months between input measures and child measures because a previous analysis showed that properties of child-directed speech became effective from a time lag of about 9 months (Rüter, 2011; Szagun & Rüter, 2009).

Table 2. Correlations between maternal educational level, maternal MLU, and expansions (n = 24).

Variable	Maternal language measure			
	12 mos. after implantation	18 mos. after implantation	24 mos. after implantation	30 mos. after implantation
MLU				
Maternal educational level	.51**	.63***	.50**	.61***
Expansions				
Maternal educational level	.38	.47[†]	.01	−.30

[†]$p < .02$. **$p < .01$. ***$p < .001$, Pearson correlation.

Table 3 presents the partial correlation coefficients (Pearson) between maternal MLU and child MLU and between maternal expansions and child MLU. In most cases, maternal MLU is significantly associated with subsequent child MLU, except at 30 months postimplantation. Maternal MLU explains between 21% and 44% of the variance in child MLU. Maternal expansions are significantly associated with subsequent child MLU at each data point. The amount of variance in child MLU explained by maternal expansions ranges between 19% and 25%. Specific properties of maternal child-directed speech are, on the whole, significantly associated with subsequent linguistic progress of children with CIs. The higher the mother's MLU and the more expansions she produces, the faster the child's linguistic progress.

Discussion

The results of this study show that children made significant progress in vocabulary and grammar as time since implantation progressed. A comparison of linguistic progress per age-at-implantation group showed that although children who received CIs in the first and second year of life had higher language scores than did children who received CIs thereafter, this difference did not reach statistical significance. However, children in the different age groups displayed different language growth patterns. Overall, children who received CIs in the first and second year of life had the most marked language growth early on, whereas children who received CIs thereafter displayed the most marked language growth somewhat later.

Table 3. Time-lagged partial correlations between maternal MLU, maternal expansions, and child MLU (n = 24).

Input language measure	Child MLU...	
	24 mos. after implantation	30 mos. after implantation
Maternal MLU		
12 months after implantation[a]	.46*	.52**
18 months after implantation[a]		.34
Maternal expansions		
12 months after implantation[a]	.46*	.49[†]
18 months after implantation[a]		.44*

[a]Child MLU at this data point and age at implantation partialed out.

*$p < .05$. **$p < .01$, Pearson correlation. [†]$p < .025$.

Correlational analyses revealed a significant association between maternal educational level and children's linguistic progress. Higher levels of maternal education were associated with faster linguistic progress in children. Age at implantation was not significantly associated with linguistic progress, but there was a nonsignificant trend toward faster linguistic progress with lower implantation ages. A series of time-lagged correlations rendered significant associations between specific properties of maternal language input and children's linguistic growth for most data points, independently of age at implantation. Higher maternal MLU and more expansions of formally incorrect child utterances were associated with more rapid linguistic progress in children subsequently.

Our results show that the children's linguistic progress is extensively influenced by their social—and, more specifically—their home linguistic environment. It is their experience with language rather than their age at implantation that affects their language development most decisively. In this sample of children who were implanted between 6 and 42 months of age, there was, at best, a mild effect of age at implantation. This shows up in the different trajectories of language growth, depending on whether children were implanted in the first or second year of life or thereafter. It could be argued that the more rapid initial progress of the younger children is due to greater sensitivity for language learning earlier in the period of optimal plasticity for language. In this view, maturational processes independent of experience would allow such faster language growth. However, this would not explain why the children who were implanted in the third year of life increased their rate of linguistic progress somewhat later. Another explanation for the different growth patterns is that they reflect the children's experience with communication and language. The older children have already built up communicative patterns that rely less on spoken language, and it may take some time to change from these to the increased use of spoken language, whereas the younger children engage in a spoken language environment almost from the beginning of acquiring words and grammar. This would give them a quicker start into spoken language in the initial period after cochlear implantation because no reorganization of their communicative patterns would be necessary. Given the effect of the linguistic environment established by our correlational analyses, the experiential explanation is preferable.

Our results differ from those that show a significant advantage for language development in children who were implanted by age 24 months (Holt & Svirsky, 2008; Nicholas & Geers, 2007; Svirsky et al., 2004; Tomblin et al., 2005). Upon closer examination, however, the differences may not be very pronounced. Although we did not find an overall significant effect of implantation age, we did find remarkably similar language growth trajectories in children who were implanted by age 24 months; these trajectories differed significantly from those of the children who were implanted thereafter. This finding is in agreement with the observed impact of age, if implantation occurs by age 24 months (Holt & Svirsky, 2008; Nicholas & Geers, 2007; Svirsky et al., 2004; Tomblin et al., 2005). We failed to find an advantage for language development in children who were implanted in the first as opposed to the second year of life. This is in agreement with results by Holt and Svirsky (2008), Giezen (2011), and our own results with a large cross-sectional sample (Szagun, 2010). Finally, when the nonsignificant trend toward an inverse relationship between age at implantation and language growth is viewed in terms of the amount of explained variance, it is not too dissimilar from the results of other studies, where variability explained by age at implantation ranges between 3% and 15% (Geers et al., 2009; Tomblin et al., 2005).

The reason that age at implantation remained statistically nonsignificant as a factor in our sample is likely to be the substantial individual variation within age groups. This is displayed by the large *SD*s in Figures 1–5. Sample characteristics may be responsible for the wide variation in language outcomes irrespective of age at implantation. Our sample is characterized by a wide distribution of educational levels, whereas in many other studies, samples of children with CIs were biased toward higher proportions of participants with high educational levels (Geers et al., 2007, 2009; Stacey et al., 2006). In contrast, in the present sample, maternal educational level represents the education of women between the ages of 20 and 40 years in the population at large (for details, see Szagun, 2010). This age span is usually considered in comparison with population statistics; it is viewed as the life period when many women in Western cultures care for small children (see also Fenson et al., 2007). In socially homogeneous samples, the effect of social background variables may be lowered, and this may heighten the effects of other variables, such as age at implantation (Stacey et al., 2006). Conversely, in a socially heterogeneous sample such as ours, the effect of age at implantation may be lowered because the wide variation in social background variables contributes more substantially to individual variation in language outcomes. It is interesting to note that two other studies of German-speaking children with CIs with very similar demographic sample characteristics (Lesinski-Schiedat et al., 2004; Szagun, 2010) rendered similar results with respect to the age-at-implantation effect: Children who were implanted at younger ages had statistically nonsignificant higher language levels than did those children who were implanted at older ages, and there was very substantial individual variation within age-at-implantation groups. With sample sizes of 89 (Lesinski-Schiedat et al., 2004) and 140 (Szagun, 2010), these studies had large samples (27 and 29, respectively), including a considerable number of children implanted in their first year of life. This discussion highlights the importance of sample characteristics when interpreting effects on the language development of children with CIs.

In the present study, the children's language development followed a pattern in which significant increases in vocabulary preceded significant increases in grammar. This pattern was most pronounced in the two younger age groups. Such a pattern is well documented for typical language development, where increases in vocabulary precede increases in grammar (Fenson et al., 2007; Szagun et al., 2009). Our results show that when children with CIs begin their language development well within the time period of optimal plasticity for language learning, their growth patterns resemble those of typical development in an important aspect.

We assessed vocabulary and grammatical skills by measures based on spontaneous speech and on a parental questionnaire using a CDI that had been adapted into German (Szagun et al., 2009). This instrument is normed for typically developing children between 18 and 30 months of age who are in the early period of language development. Although the children with CIs in our study were older, they were still in the early period of their language development. Thus, the linguistic material presented in the questionnaire may be considered appropriate. The words in the vocabulary list are part of the basic German vocabulary, and the grammatical paradigms are fundamental to the language, such as gender, case, noun plural, and verb inflections.

As the results show, the children did not reach ceiling on any questionnaire measure. This finding underscores the appropriateness of the vocabulary and grammatical items for these older children. In regard to vocabulary, it could be argued that the younger children have steeper initial growth because the CDI vocabulary is more appropriate for their age level. However, this would not explain why the younger children also display faster initial growth when vocabulary is assessed by number of word types in spontaneous speech. In using the CDI, our purpose was to document the course of language development from 1 year postimplantation to 2.5 years postimplantation. According to an earlier study (Szagun, 2001), this is the period in which children who received their CI at a young age undergo the transition from first words to grammar. It is for this developmental period that the CDI is designed (Fenson et al., 2007). It is a useful instrument to assess the course of development within this period, even if language behavior and typical age range are somewhat dissociated. For the American CDI, Thal and colleagues (2007) showed that the CDI can be a valid tool for assessing the language levels of children with CIs during this early developmental period. The advantage of using a CDI-type questionnaire is that its administration does not involve demanding test sessions for the child or time-consuming analyses of spontaneous speech data, yet it provides relatively detailed information on the children's lexical and grammatical development. We also found that many parents welcomed the opportunity to track their child's linguistic progress.

Our results go beyond the influence of such a broad variable as socioeconomic status and show that it is the home linguistic environment, specifically, that influences the language development of children with CIs. One key variable here is maternal MLU. In language acquisition research, maternal MLU is used as a general measure for the quality of maternal language input (Clark, 2003; Hoff, 2003; Hoff-Ginsberg, 1985; Rollins et al., 1996). Higher MLU in child-directed speech indicates language rich in grammatical structure and lexical content (Hoff, 2003; Rollins et al., 1996; Snow, 1977); lower MLU demonstrates the opposite. Our results show that such richness in language input is associated with better linguistic progress in children with CIs. Expansions of formally incomplete or incorrect child utterances—the other property of child-directed speech that is found to be associated with children's linguistic progress here—represent a form of implicit feedback on the grammatical correctness of an utterance. This type of expansion has been described as an automatic response of a native speaker to violations of grammar and occurs spontaneously in natural dialogue (Farrar, 1990; Snow, 1977). Although the influence of the implicit feedback on grammatical correctness provided by expansions may not be surprising, the positive impact of rich language input may well be. In their advice to parents of children with CIs, speech-language pathologists often call for repetitive language input. Such language input is less rich in content and structure. The usefulness of such advice could be called into question on the basis of this study's results.

We view the variables of maternal MLU and expansions as specific ways in which maternal education may exert an influence on child linguistic progress. In the present sample, maternal education correlates significantly with maternal MLU at each data point, whereas there is a mixed picture for maternal expansions. At the two initial data points, maternal education and expansions are associated, with one correlation being significant and one marginally so, but at the later data points, the two variables are not related. This indicates that more highly educated mothers consistently use rich and varied language when they speak to their children, but they may not always use more expansions. A reason for the latter may be that the children's violations of grammar at this elementary stage concern basic inflectional paradigms, such as gender marking on articles and verb and plural inflections (Szagun & Rüter, 2009), which would be noticed by native speakers of German irrespective of their otherwise more or less sophisticated use of the language. Also, all parents may be more aware of grammatical structure because of their child's greater risk of language problems and as a result of attending the child's speech therapy sessions. It might be easier for parents to adjust their response to child errors than to change to the general style rich in grammatical structure and lexical content that is associated with higher parental education (Hoff, 2003). It is less clear why mothers' production of expansions relates to their educational level at the early and not the later data points. It could be that more highly educated mothers intensify their efforts initially but then ease as their children progress well. For the present analyses of associations between maternal input and subsequent child linguistic progress, the initial data points are relevant. At these data points, maternal expansions are related to maternal education, although less strongly than maternal MLU.

The observed relations between maternal education and language input and children's linguistic progress add to the growing evidence on the influence of social environmental factors on the language development of children with CIs. Whereas the influence of parent education and socioeconomic class on the development of children with CIs has been studied more extensively (Geers et al., 2007, 2009; Holt & Svirsky 2008; Niparko et al., 2010), the present results are among the first to examine the influence of the children's home linguistic environment. We feel confident that our results demonstrate an effect of child-directed speech because we observed very strict controls by partialing out not only age at implantation but also the effect of the child's language on the mother's language. It can be argued that removing variance due to child effects from adult input is too strict a control and does not adequately reflect environmental influences relevant to the child's language development (Hoff, 2003). Child and maternal MLU are mutually influential. Children contribute to their own linguistic environment because adults produce language partly contingent on the child's language use (Hoff-Ginsberg, 1994; Richards, 1994; Tomblin et al., 2007). The resulting adult input language is a linguistic environment that has been partly shaped by child effects. By excluding the child's own contribution to his or her language environment, developmentally relevant environmental effects are removed and, thus, the influence of the language environment may be underestimated (Hoff, 2003; Rutter, Pickels, Murray, & Eaves, 2001). Despite these considerations, we chose to err on the side of caution and removed the variance in maternal input that is attributable to child effects. In the context of the language development of children with CIs, the discussion about child effects on language environment is particularly relevant. The longer children remain at low language levels, the more likely this is to affect maternal input in the direction of less rich language input. In this way, the children's experience with language may worsen further.

There were a number of limitations to the present study. We were not able to control for the children's IQ because the conditions and timetables of the hosting institution were not amenable for an additional IQ test administration. Data of the children's routine pediatric developmental checks were available and showed no developmental delays in cognitive behaviors for any of the children. Another limitation may lie in the time period that we covered. It could be argued that we did not find an advantage of earlier implantation because our language data cover the first 2.5 years after implantation only, and age effects may show up later. An argument against this possibility is that the younger children tended to show the most marked progress earlier on and then leveled off, whereas the older children's vocabulary and grammar accelerated at the later data points. This would suggest that the children become more similar over time.

The biggest limitation of this study may be that it examined some isolated variables assumed to influence language development in children with CIs, and its sample size was not sufficient to support multivariate analyses. Many other studies share this problem, and the influence of the variables that we studied must be interpreted within the context of the study design. It would, indeed, be desirable to integrate the many variables that researchers have found to be influential on the language development of children with CIs in a theoretically guided research design in order to assess their relative contributions and their interactions over time.

The present research contributes to the discussion of influences on language acquisition of children with CIs within a framework of developmental theory. In pediatric cochlear implantation research, the role of age at implantation has been prominent. Yet, the mechanism behind age has not been explained. If it is assumed to be maturation of neural systems for processing language independent of experience with language, better language development with earlier implantation within the age span of up to 48 months would imply a decrease in sensitivity of such systems for language learning within the sensitive period for language. Alternatively, an age effect may be attributable to experience with language; children who are implanted at a very young age engage in spoken language environments more fully at an age when the development of grammar typically sets in. Our results come out in favor of the experiential hypothesis. There was no overall significant age-at-implantation effect independent of duration of language learning and quality of language input. However, there was an effect of language environment independent of age at implantation. The implication of this result is that the case for an independent effect of age in terms of a purely maturational mechanism cannot be made. Our results fit well with an epigenetic view of the sensitive period: The construction of a behavioral system and its underlying neural representation is dependent on maturational as well as experiential factors (Michel & Moore, 1995; Neville & Bavelier, 2002; Oyama, 1979).

We believe that clarification of some of the confounds surrounding an effect of age at implantation can inform clinical practice as well as theory. Much emphasis is placed on further improvement of the linguistic skills of children with CIs as a result of earliest implantation. Viewed in isolation, the impact of earliest implantation may lead to unrealistic expectations. Parents may be well advised to view this factor in conjunction with many other influences, some of which relate to the child's social environment—in particular, the child's experience with language.

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