A comparison of maternal and child language in normally hearing and children with cochlear implants.

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Abstract

The present study looked at the amount of input and output in two groups of children and their normally hearing mothers: congenitally hearing-impaired children with a cochlear implant (CI) and normally hearing children (NH). The aim of the study was threefold: (a) to investigate the input provided by the two groups of mothers, (b) to investigate the output of the two groups of children, and (c) to investigate the influence of the mothers' input on children's output and on their expressive vocabulary sizes. Mothers are less influenced by their children's hearing status than children are: CI children are more talkative and slower speakers. Mothers influenced their children on most measures, but the most striking finding is that not mothers' talkativeness as such, but the number of maternal turns out to be the best predictor of children's expressive vocabulary size.

Keywords

Cochlear implantation, child-directed speech, talkativeness, speech rate, language development

1. Introduction

1.1 Background: Hearing-impaired children with a cochlear implant

The incidence of children born with a hearing-impairment is 3 out of every 1,000 births. Of these children 25-30% have a profound hearing loss (>90 dB) and 20-25% a severe hearing loss (71-90dB) (Verhaert, Willems, Van Kerschaver, & Desloovere, 2008). Hearing-impaired children with a cochlear deficit, or sensorineural hearing loss, are candidates for cochlear implantation (henceforth: CI). Such an implant bypasses the damaged cochlea and stimulates the auditory nerve directly so that auditory experience is enhanced. It is clear that not every hearing-impaired newborn is a cochlear implant candidate: only children with a severe-to-profound hearing loss are considered for an intervention, testing should have revealed a problem in the cochlea and an intact hearing nerve, fitted acoustic hearing aids should not have resulted in sufficient auditory progress, etc. (De Raeve & van Hardeveld, 2012; Gifford, 2011). Over the last three decades cochlear implantation has become a common practice in most western countries, though there still remain marked differences. For instance, in the USA only 7,049 of the 12,816 children between 12 months and 6 years who were candidates for cochlear implantation actually received a device (Bradham & Jones, 2008). In contrast, in Flanders, the northern, Dutch-speaking part of Belgium, 93% of the severe-to-profound hearing-impaired preschool children were implanted (De Raeve & Wouters, 2013). A recent study shows that approximately 80% of the cochlear implanted children – without other disabilities – enter mainstream primary school instead of specialised schools "for the deaf" (Verhaert et al., 2008). Hence, examples such as these show that cochlear implantation has opened unprecedented opportunities for severe-to-profound hearing-impaired individuals.

What is the effect of a CI for severe-to-profound hearing impaired children? First of all their audition ameliorates significantly from severe-to-profound (a hearing loss of 70dB or more) to a mild hearing loss, i.e., nowadays typically in the area between 20 and 40dB. Practically speaking this implies that the implant enables detection of virtually all speech sounds and provides a hearing sensitivity and functionality which is superior to that obtained with conventional acoustic hearing aids. In other words, CI children "hear" but their hearing is still impaired: even though the implant takes over the function of the cochlea and restores the child's hearing, normal hearing is not completely restored (Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000).

As to spoken language acquisition and development, there is a broad consensus that congenitally severe-to-profound hearing impaired children – the population investigated in the present study – gain enormously from the CI device (Niparko et al., 2010). There is also a consensus that implantation as early as possible in life, preferably in the first two years of life, leads to superior results for measures of expressive language and language comprehension (Geers & Nicholas, 2013; Niparko et al., 2010; Schorr, Roth, & Fox, 2008). For instance, children implanted before their second birthday need only a few months of auditory experience to start babbling (Molemans, 2011; Schauwers, Gillis, Daemers, De Beukelaar, & Govaerts, 2004). This achievement is in sharp contrast with hearing-impaired children who did not receive a CI: their babbling onset is notoriously late (Koopmans-van Beinum, Clement, & van den Dikkenberg-Pot, 2001; Oller & Eilers, 1988). However, CI children's entrance into the canonical babbling stage is still delayed as compared to normally hearing children (Colletti et al., 2005; Molemans, 2011), and since late babbling onset is considered to be a marker of possible delayed or abnormal language development (Oller, Eilers, Neal, & Cobo-Lewis, 1998), the question turns up if CI children's language development is eventually delayed or even abnormal. Hence a central research question that has motivated a growing body of research is: does CI children's language eventually become age appropriate?

Do CI children eventually catch up with their normally hearing peers, or will the initial delay caused by their hearing deficit remain? Research results are not straightforward in this respect: some researchers found that children implanted in the second year of life have caught up for spoken language levels with their NH peers before they enter kindergarten (Nicholas & Geers, 2007). Others found that even after three or more years of device use, there is still considerable delay in language comprehension, in phonological and morphological skills, as well in narrative development (Boons et al., 2013; Caselli, Rinaldi, Varuzza, Giuliani, & Burdo, 2012; Duchesne, Sutton, & Bergeron, 2009; Niparko et al., 2010). But virtually all researchers report large individual variation between children. For instance, Boons et al. (2013) compared language outcomes in a group of 70 school-aged (5 to 13-year-olds) CI users with at least three years of device experience, and found that approximately half of them achieved age adequate language levels, implying that half of them have not achieved age appropriate language skills yet. In a study involving 27 children with 23 to 71 months of device experience, Duchesne et al. (2009) concluded that individual patterns revealed language profiles from normal language levels in all domains to general language delay, and they add that "receiving a CI between the age of 1 and 2 years does not ensure that language abilities will be within normal limits after up to 6 years of experience with the implant" (p. 465).

An explanation for the large individual variability in language outcomes has been sought in many directions, including variation in children's age at implantation and/or length of device use, evolving CI technology, preoperative hearing level and speech performance, etc. (for a review see i.a. Boons et al., 2012; Cosetti & Waltzman, 2012). A factor that has not received ample attention yet, with a few notable exceptions to be discussed later, is CI children's language environment. Here we will focus on the input CI children receive. CI children have a rather "special" status because they are no longer severe-to-profound hearing-impaired, given the fact they have received a cochlear implant, which restores (at least in part) their auditory abilities. Yet, they cannot be considered as normally hearing because a cochlear implant does not restore the full potential of a healthy cochlea (Svirsky et al., 2000). Hence, it remains an open question whether they receive the amount of input that is typical for normally hearing children. Moreover even if that were the case, it remains an open question if CI children themselves are less talkative than their normally hearing peers, which may be reflected in their allegedly poorer linguistic abilities. The latter aspect will be studied by examining the influence of CI children's input on their expressive vocabulary size.

1.2 Maternal input and its relationship to children's language development

Maternal characteristics as well as traits of the children have been found to exert a major influence on various aspects of maternal talkativeness, i.e. how much a mother[1] speaks to her child. For instance, maternal socio-economic status (SES) has a strong impact on the talkativeness of mothers in interaction with their children, and hence on the amount of direct input that they provide. Mothers of lower socio-economic background talk significantly less with their children (Hart & Risley, 1995; Rowe, 2008). Also, mothers of hearing impaired children (henceforth: HI children) are significantly less vocally talkative in comparison with mothers of NH children (Clement, 2004; Clement, den Os, & Koopmans-van Beinum, 1994). Are CI children considered to be hearing-impaired by their caretakers or are they treated as "normally hearing"? Hence, if the former were the case, then CI children are expected to get firmly reduced amounts of input as compared to normally hearing children. But if the latter were the case, then it is expected that the amount of input CI children receive is comparable to that of their normally hearing peers. Moreover, as indicated before, the cohort of CI children in this study are severe-to-profound hearing-impaired at birth, and they received a CI in the first two years of their life. This may result in a different amount of input: because CI children have "restored" hearing, it is possible that their mothers want to make up for their "lost time" by providing a surplus amount of input compared to normally hearing peers. A first aim of this paper is to answer the following question: do mothers of CI children provide their children with more, less or an equal amount of input than mothers of NH children?

The issue of the amount of input children receive is a basic though very important one: several studies have established clear relations between the input mothers provide to their typically developing children and the language outcomes of the children (Hart & Risley, 1995; Hoff & Naigles, 2002; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991; Tamis-

[1] We use mother as a generic term for mothers, fathers and other primary caregivers.

LeMonda, Bornstein, Baumwell, & Damast, 1996; Weisleder & Fernald, 2013). More speech directed to young language learning children has been shown to result in children's larger vocabularies (Hart & Risley, 1995) and faster vocabulary growth over time (Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991). Also the number of different words used by the parents predicts children's vocabulary production (Pan, Rowe, Singer, & Snow, 2005). Here we will investigate mothers' input to NH and CI children, and scrutinise the relationships between maternal input and children's own output. Is there a relationship between mothers' input and (CI) children's output? Does the amount of input predict CI children's lexical development as it the case for NH children? By answering these two research questions, the current study clearly contributes to the existing research about (CI) children's language development.

1.3 Methodological issues

1.3.1 Mothers' speech or amount of input

The amount of input has a tremendous impact on children's language development. However, several studies define "amount of input" in different ways. In the following paragraphs we will discuss the different measures used to describe amount of input, each highlighting a different aspect of the language provided to young children. The following section discusses the five measures we investigated.

First, amount of speech can be expressed as the total duration of speech addressed to a child (Pearson, Fernandez, Lewedeg, & Oller, 1997; Quigley & McNally, 2014). This measure provides a first, rough estimate of the amount of input provided to the child. But evidently it overlooks the interactional nature of spontaneous conversations which are characterised by frequent turn-taking (Sacks, Schegloff, & Jefferson, 1974; Snow, 1977).

Hence a second measure to quantify the amount of input is to count the number of conversational turns. The number of conversational turns has been shown to be correlated with children's (receptive) linguistic abilities (VanDam, Ambrose, & Moeller, 2012; Zimmerman et al., 2009). Both VanDam et al. (2012) and Zimmerman et al. (2009) used the LENA system ("Language ENvironment Analysis") to analyse the number of turns. In the present study, mothers' number of turns will also be analysed.

A third measure of amount of speech is the number of utterances addressed to the language learning child (Hoff & Naigles, 2002). Using this criterion, the amount of linguistic material provided to the child is taken into account. This is a widely used measure which can be expressed in several ways: the total number of words (or tokens) directed to the child (Hoff & Naigles, 2002; Huttenlocher et al., 1991; Rowe, 2008), the number of word (tokens) per time unit (Henning, Striano, & Lieven, 2005), or the total number of verbal utterances per time unit (Hoff & Naigles, 2002; Pancsofar & Vernon-Feagans, 2006). In the current study, the amount of speech will be operationalised as the total number of utterances per hour in both NH and CI mothers.

Counting the number of utterances or turns provides a rough estimate of the amount of input. That estimate becomes sharper when the length of the utterances is taken into account. A mother may produce a lot of short utterances, whereas another mother may have fewer but longer utterances (in duration), resulting in an equal amount of input for the child. When also utterance duration is analysed, we have a more detailed image of mothers' input. Therefore, in addition to the total duration of speech, the number of utterances, and the number of turns, a fourth measure of amount of input is utterance duration. Short utterances are typical of Motherese, the language register mothers adopt and which is shown to facilitate their children's language acquisition and development (Newport, Gleitman, & Gleitman, 1977). Mothers' utterance durations are shorter when interacting with their children than when talking to adults (Bergeson, Miller, & McCune, 2006). When comparing the utterance durations of mothers of CI and NH children, no main effect of hearing status was found (Bergeson et al., 2006). Mothers thus do not significantly differ in the length of their utterances to CI or NH children. However, that study only analysed mothers and children in laboratory settings, whereas the current study investigates maternal input and children's output in spontaneous interactions.

Utterance durations are an indication of the amount of time that mothers address their children, but that figure does not capture the amount of linguistic material the utterances contain. Slow speakers can package less linguistic material in an utterance than faster speakers, and hence speech rate is an additional index. Speech rate gives information about the pace with which someone speaks and can be expressed in several ways: syllables per second (Bergeson et al., 2006; Verhoeven, De Pauw, & Kloots, 2004); syllables per minute (Guitar & Marchinkoski, 2001; Kelly, 1994); or words per minute (Bernstein Ratner, 1992) and is hence the fifth measure under investigation. Some mothers may have longer utterances with fewer syllables, indicating a slower speech rate whereas others may have more syllables in a shorter utterance, suggesting a faster speech rate. Recent research has shown that mothers speak slower to their children than to adults (Bergeson et al., 2006). Moreover, this difference is more pronounced in the speech rate of mothers of CI children than of mothers of NH children (Bergeson et al., 2006). This suggests that mothers of CI children speak slower to their children which was confirmed in a later study (Kondaurova, Bergeson, & Xu, 2013). In the latter, mothers of CI children had a significant slower speech rate than mothers of NH children. So even though Bergeson et al. (2006) did not find a main effect of hearing status on mothers' speech rate, a later study did find a significant difference (Kondaurova et al., 2013).

Yet, these studies only analysed a couple of minutes of mothers' speech in laboratory settings. Therefore we will analyse mothers' speech rate in a large group of mothers and for a longer period.

Up till now no research has systematically analysed the number of utterances or turns by mothers of CI and NH children in spontaneous interactions longitudinally. In this contribution we will analyse the following measures of amount of speech addressed to CI and NH children: the total duration of speech, the number of utterances per hour, the number of turns per hour, the length of the utterances and the speech rate. Mothers/children can differ in talkativeness (as measured by the number of utterances, the total duration of speech and the number of turns), but also in the amount of linguistic material they package. Therefore we analysed also the mean duration of the utterance and the number of syllables in these utterances. Of course, the length of the utterance is variable according to the number of syllables used. To give a more detailed picture, we also looked at utterances of one up to eight syllables. However, this is not detailed enough because some mothers/children might be slower speaker than others, and hence package less material in an utterance of the same duration. Therefore we also analysed how fast they speak by measuring both their speech rate as the number of syllables per second and syllable duration. However, we are not only interested in measuring the amount of input, but also in children's output: are there differences in the amount of output between NH and CI children? And, crucially we are interested in the relationship between the amount of input these children receive and their lexical development.

1.3.2 Children's speech or amount of output

Studies disagree on whether or not CI children's speech develops within age-appropriate ranges after implantation. To our knowledge, no study has ever analysed CI children's quantity of speech shortly after implantation. Furthermore, whereas the literature is rather clear about the fact that mothers of HI children use less speech in interactions with their children (Clement, 2004; Lederberg & Everhart, 1998), there is no consensus about the talkativeness of HI and NH children. When comparing NH and HI children in prelexical age ranges, i.e. before they produce conventional words, conflicting results have been found. Some studies claim that HI children produce significantly more utterances than NH children (Clement, 2004; Clement et al., 1994; van den Dikkenberg- Pot, Koopmans-van Beinum, & Clement, 1998) whereas others have revealed that HI and NH children are equally talkative (Iyer & Oller, 2008; Moeller et al., 2007). Yet, the status of CI children compared to HI children is different, because CI children have (at least in part) restored hearing. The following research question pops up: is the amount of speech (or talkativeness) of CI children comparable to that of NH children? Whether or not CI children are more, less or equally talkative as NH children shortly after implantation has not been investigated so far. Therefore, to be able to analyse whether or not mothers' input has an impact on children's output, the same measures concerning talkativeness are analysed for the two groups of children: the number of utterances per hour, the total duration of speech, and the number of turns per hour. In this way, a more complete image of children's quantity of speech is provided.

A difference between NH and HI children has been found concerning children's utterance durations: HI children produce significantly longer utterances than their NH peers (Clement et al., 1994; but see Clement, 2004). Other studies also found a difference in the duration of the HI and NH children's vocalisations, but could not statistically confirm this (Clement, 2004; Ryalls & Larouche, 1992). A statistical difference was found for older CI children: nine-year-old CI children's sentence durations[2] were significantly longer than those of NH children (Burkholder & Pisoni, 2003). Hearing status thus seems to affect children's utterance duration. Because for this measure a rather clear difference between NH and HI children has been found, longer utterance durations would suggest that CI children have characteristics of hearing-impaired children. Whether or not this is the case will be investigated in this paper.

Longer mean durations of utterances may stem from the fact that children with a hearing impairment talk more slowly, i.e. they take more time to produce a syllable than NH children. In other words, it is possible that the speech rate of HI children is slower. Research by Burkholder and Pisoni (2003)[3] has revealed that nine-year-old CI children indeed speak significantly slower than NH children in experimental settings. Whether or not this difference can already be found in younger children has not yet been investigated. Therefore, next to the different measures of children's talkativeness (total duration of speech, number of utterances, and number of turns), we also analysed the child's utterance duration, speech rate and syllable duration. In this way, we are able to extent the literature by providing longitudinal results of two groups of children and their mothers.

In conclusion, the current study focuses on both maternal input and children's output in two groups: NH children and their mothers and CI children and their mothers. The relationship between the input and output will also be investigated. The study adds to the existing body of literature whether or not there are differences in the mothers' and children's quantitative aspects of speech. This study will analyse the environmental characteristics of CI and NH children, and whether or not young implanted children benefit from the early implantation and hence catch up with their NH peers in terms of quantity. The major strength

[2] Burkholder & Pisoni (2003) analysed sentences durations of sentences with three, five and seven syllables.
[3] Burkholder & Pisoni (2003) have analysed articulation rate (= number of articulations in a certain amount of time).

of the current study is that it is among the first to analyse both mothers and children's speech longitudinally with naturalistic data.

2. Method

2.1. Participants

The CCLC (CLiPS Child Language Corpus) contains data from 30 normally hearing and 10 congenitally deaf children with a cochlear implant. This corpus includes video- and linked audio-recordings of spontaneous interactions of the children with their parents, other family members such as a sibling and the researcher. These recordings were made at the children's home on a monthly basis. The NH children were videotaped between the ages of 6 and 24 months. The CI children were followed from the moment they received their cochlear implant up to 30 months post activation.

Participants for this analysis were 9 CI children and 25 randomly selected NH children because the data points of 1 CI child were too sparse to be included in the statistical analyses. Detailed information about the CI children is provided in Table 1.

@ Insert Table 1

As Table 1 shows, all CI children were implanted at an age younger than 20 months. Only one child had already received her second implant, i.e. S1 received her first implant at 5 and her second at 16 months of age. The cause of deafness was in 7 of the cases genetic of which five were mutations in the connexin-26 gene. In the two other cases the cause of deafness is unknown. As Table 1 shows, the causes of deafness were not confirmed for S4 and S5.

All children were born in the Flemish part of Belgium and were acquiring Dutch. All parents were normally hearing and were monolingual Dutch-speaking. Participants' SES was controlled for. All children were considered to be of mid-to-high SES based on the mothers' educational level and the current job position. All NH children were normally developing: they had no cognitive or other patent health problems. Kind & Gezin (the Flemish infant welfare centre) checked children's hearing within 3 weeks after birth with an otoacoustic emissions test.

2.2. Procedure

The video-recordings of 25 NH and 9 CI children were studied. Data of NH children were analysed on 7 moments with timespans of three months in between, starting when the children were 6 months old for the NH children. For the CI children data were available starting one month post implantation, i.e., the month their device was activated. The video-recordings lasted on average 1'03"58 hours for the NH children (median = 1'02"30 hours; range = '38"26 hours – 1'54"26 hours) and 1'01"59 hours for the CI children (median = 1'01"36 hours; range = '32"36 hours – 1'22"22 hours). A total of 285,108 utterances were analysed.

The CLAN software (MacWhinney, 2015) was used to determine the exact starting and end point of each utterance (expressed in milliseconds, cumulatively). We also identified who was speaking: the child (main tier *CHI) or the mother (main tier *ADU). Every person directing speech to the child was labelled as *ADU. After having determined all utterances' starting and end points, the number of syllables in each utterance was counted. A syllable was considered as such when it contained at least a vowel. For instance, an utterance such as /ata/ contains two syllables whereas an utterance such as /prt/ does not contain any. Vegetative sounds such as a coughs, burps, cries and laughs were excluded. Adult utterances were coded in the same way. For instance, when a parent said "*ja da's goed*" (*yes, that's good)*, the number of syllables is three.

Unintelligible material was included when it was possible to count the number of syllables. Pauses were excluded, but false starts were coded as one utterance. Other sounds such as laughter, coughing and sneezing were all excluded.

Utterances and turns should not be confounded. Zimmerman et al. (2009: 344) defined conversational turns as "the number of times the speaker changes within a single conversation". Thus a single turn may consist of several utterances (Sacks et al., 1974). Therefore, a python script was written to count the number of turns for both mothers and children automatically. An utterance was considered to belong to the same turn when it followed the previous utterance within 2 seconds. If the interval was longer, it was considered as a new turn. This interval was arbitrarily chosen. The number of turns was normalised for time: the number of turns per hour was computed for each mother and for each child.

Children's expressive vocabulary sizes were counted cumulatively using the CLAN software (MacWhinney, 2015) on the transcriptions. Children's cumulative vocabulary was measured as the cumulative number of word types over time. The identification of words in the transcriptions was based on the criteria proposed by Vihman & McCune (1994), see Molemans (2011), Van Severen (2012), and van den Berg (2012) for a methodological discussion and validation of the identification of words in the transcripts also used in the current study. In brief, several criteria had to be met for a child's vocal production to be considered as a word: (1) mothers identify it as a particular word, (2) the word occurs in a particular context, and (3) the phonological shape is comparable to the target word. Several phonological instance of one word were however coded as one word, as for instance, the word "auto" (car) pronounced as /□uto/, /toto/ or /to/. CLAN's *freq* command was used for the cumulative vocabulary counts. Consequently, inflected variants of one word (e.g., different inflected forms of a particular noun or verb) were counted as separate word types. Word types were counted cumulatively, i.e., if a child produced a specific word type in the first recoding session, this word type was considered to be part of the child's cumulative vocabulary. For instance, when a child had a vocabulary of 5 words in the first session and produced two new words in the second session, the cumulative vocabulary was seven in the second session. This is a widely used measure for estimating vocabulary growth in young children (Huttenlocher et al., 1991; Pan et al., 2005; Rowe, Raudenbush, & Goldin-Meadow, 2012).

2.3. Reliability

Two researchers independently coded 20 % of the data. They each received the same instructions for coding the data and went through the same training phase under the supervision of the first author of the present paper. They marked start and end points of the utterance and counted the syllables in each utterance. Utterances were identified based on the conventions proposed in the CLAN manual and hence based on (1) the syntax of the utterance (for instance "and" was used to combine to sentences into one utterance), (2) the length of the pause, and (3) the intonation contour (MacWhinney, 2015). The two researchers received the same instructions and, even though the definition of an utterance was not specified in detail, agreement between coders was very high: 0.91 for total duration of speech (Spearman's Rho, $p<0.001$), 0.94 for number of utterances (Spearman's Rho, $p<0.001$), and 0.99 for number of syllables (Spearman's Rho, $p<0.001$).

2.4. Statistical Analyses

For the current analyses we used Multilevel Modeling (MLM). Advantages of MLM are that (1) it circumvents the assumption of sphericity; (2) it is able to handle missing data; and (3) variance at different levels is possible (Baayen, Davidson, & Bates, 2008; Hox, 2008; Quené & van den Bergh, 2004). MLM is a statistical tool that consists of a random and a fixed part. In the random part the complexity of the data structure can be taken into account. Our dataset exhibits three levels: individual utterances at the lowest level, nested in observation sessions at consecutive ages, which are nested in individual children/mothers, at the highest level. Our models contain, at the level of children/mothers both random intercepts and random slopes for the linear effect of Age. As such we acknowledge the fact that we assume that children/mothers differ from each other at the level of the intercept and that the effect of age (or put differently the growth parameter) differs between children/mothers. Variance between mothers/children, ages and the residual variance is provided in the tables that can be found in the Appendix. To improve the interpretation of these variance estimates it is advised to transform them to standard deviations by taking the square root of the variance estimate. From the standard deviation the range of the 95% confidence interval can be calculated: 95% of the observations fall within 1.96 standard deviations of the mean (intercept). For instance, for the number of utterances of the mothers (Table1 in the Appendix), the variance between the mothers is 22928.01. The standard deviation is the square root of 22928.01, which equals 151.42. The 95% confidence interval is thus between 419 (lower limit: 716-1.96*151.42= 419) and 1,013 (upper limit: 716+1.96*151.42= 1,013). This indicates that, at the age of 12 months, 95% of the mothers uses between 419 and 1,013 utterances per hour. There is no standard error of the variance reported because (1) R does not generate one; and (2) several authors have suggested that it does not make sense to test levels of significance on variances (Long, 2012; Pinheiro & Bates, 2000).

In the fixed part of the model the fixed effects or independent variables are added. Mothers' and children's outcomes are estimated at the age of the intercept, which is set at 12 months for the maternal and child' variables because only starting from this age enough data for both groups are available. However, the intercept is set at 21 months for the analyses concerning cumulative vocabulary, because by that age children were uttering enough words to provide reliable results. The fixed effects are among others age, age squared (which is only kept in the model when it improves the model significantly), hearing status, and possible interactions between two effects, for instance age and hearing status.

For all analyses we used the R software and the lme4 package (R Core Team, 2013). The cut-off level of significance for these analyses is set at $p=0.05$. We discuss the best fitting model or the model including the explanatory factors under investigation such as hearing status or maternal influence.

3. Results

3.1. Amount of input

The amount of input was measured in several ways: the total duration of speech, the number of utterances per hour, the number of turns per hour, the mean utterance duration and the speech rate. The corresponding models can be found in the Appendix (Table 1).

3.1.1. Total duration of speech, number of utterances and number of turns

Our results reveal no significant differences in talkativeness between mothers of NH and CI children. Looking at the total duration of speech, mothers of NH children and mothers of CI children talk equally much to their children ($p>0.05$). Also the number of utterances per hour does not differ significantly ($p>0.05$). Figure 1 shows that the development of the number of utterances and the total duration of speech is not linear. Even though there seem to be differences between the two groups, our analyses revealed no statistical differences. Mothers' total duration of utterances and their number of utterances per hour thus increase over time, but hit a ceiling at a particular point, after which the increase is less steep, hence a quadratic effect of age.

@ Insert Figure 1

The number of turns increases over time as is indicated by a significant effect of age ($p<0.01$). Mothers of CI and NH children also have a comparable amount of turns per hour, at the age of 12 months (the intercept) ($p>0.05$). However, a significant interaction between hearing status and age indicates that with age, the number of turns per hour of the mothers of NH children grows faster than the number of turns of mothers of CI children ($p<0.05$). This is graphically represented in Figure 2.

@ Insert Figure 2

Taken together, mothers of CI and NH children take up an equivalent amount of input: they do not differ concerning the total duration of speech and the number of utterances. But the amount of turns of mothers of NH children increases more sharply over time. This suggests that mothers of NH children have fewer utterances per turn over time than mothers of CI children. In general, mothers of CI and NH children thus hardly differ in the amount of input they provide.

3.1.2. Utterance duration

As to the utterance durations, mothers of NH children produce significantly longer utterance durations (in milliseconds) than mothers of CI children ($p<0.01$). This can be explained by the fact that mothers of NH children have also significantly more syllables per utterance than mothers of CI children ($p<0.001$). For both mean utterance duration and number of syllables the development is linear as indicated by a positive significant effect of age (for mean utterance duration, $p<0.05$; for number of syllables, $p<0.01$): over time the utterances become longer. For number of syllables, an interaction between age and hearing status adds that mothers of NH children have a more rapid increase of the number of syllables per utterance over time compared to mothers of CI children ($p<0.01$).

Nevertheless, when the number of syllables per utterance is controlled for, no differences in the durations between mothers of CI and NH children are revealed ($p>0.05$). Utterances containing more syllables have longer durations ($p<0.001$). Interestingly, an interaction between hearing status (NH versus CI) and number of syllables was found ($p<0.001$), meaning that mothers of NH children produce longer utterances with a shorter duration.

3.1.3. Speech rate

The interaction between hearing status and number of syllables may indicate that there is a difference in speech rate. Speech rate was measured in two different ways, i.e. by examining the number of syllables per second (#syllables/s) and by measuring the mean syllable duration. For neither measure, a significant impact of children's hearing status on mothers' speech rate was found (number of syllables per second, $p>0.05$; syllable duration, $p>0.05$). The speech rate of mothers of CI or NH children is thus not influenced by their children's hearing status at the age of 12 months (the intercept). Even though there was no main effect of hearing status, an interaction between hearing status and age was found for speech rate ($p<0.001$) and syllable duration ($p<0.001$). Speech rate and syllable duration develop differently over time for the two groups of mothers. Mothers of NH children speed up faster over time: they have more syllables/second and shorter syllable durations compared to mothers of CI children.

In conclusion, children's hearing status has no influence on their mothers' talkativeness, not when looking at the total duration of speech nor when analysing number of utterances or turns. However, over time, mothers of NH children produce significantly more turns than mothers of CI children. Children's hearing status also has a significant impact on maternal speech rate: over time, mothers of NH children speak faster compared to mothers of CI children.

In the following section, we will analyse whether or not these differences are reflected in the amount of output of their children. Furthermore we will analyse the influence of maternal input on their children's expressive vocabulary.

3.2. Amount of output

For the results of the children, we discuss two main aspects: the effect of hearing status and maternal input on children's output. The models that are discussed in the following sections can be found in the Appendix (Table 2).

3.2.1. Hearing status

Total duration of speech, number of utterances and number of turns

CI children talk significantly more than NH children: they have a higher total duration of speech ($p<0.05$) and produce more utterances per hour ($p<0.05$). Children's utterances and total durations first decrease over time after which they increase again, hence a quadratic effect of age, as shown in Figure 3.

Even though that main effect of hearing status indicates the CI children are more talkative, over time NH children are catching up, i.e. they are becoming more talkative. This is shown by an interaction between hearing status and age for both the total duration of speech ($p<0.01$) and the number of utterances ($p<0.01$). As shown in Figure 3, it appears that initially CI children produce more utterances, but that NH children gradually become more talkative and seem to have caught up by 20 months of age. The same is found for the total duration of speech: at first CI children have longer total durations, but gradually NH children catch up around 18 months and have longer total durations. This is shown in the right part of Figure 3.

@ Insert Figure 3

CI children have more utterances per hour, but there is no significant effect of hearing status when analysing the number of turns per hour ($p>0.05$). The number of turns develops linearly as indicated by a positive effect of age ($p=0.01$). This means that over time, all children produce more turns. Because CI children have more utterances per hour than NH children but an equal amount of turns, this suggests that they have more utterances per turn.

In conclusion, CI children are more talkative both when looking at the number of utterances and the total duration of speech, but NH children are catching up rapidly. NH children produce fewer utterances than CI, but an equal amount of turns, suggesting that CI children have more utterances per turn.

Utterance duration

Is there a difference in utterance duration between CI and NH children? Multilevel modelling shows that indeed CI children have longer mean utterance durations than NH children ($p<0.01$). This effect is maintained when the number of syllables is controlled for, i.e. when only utterances of an equal number of syllables are compared. Utterances durations for CI children were significantly longer ($p<0.001$) for utterances of 1 up to 8 syllables. In other words, CI children need more time to produce utterances of 1 up to 8 syllables than their NH peers.

However, over time the utterance durations of CI children approach those of NH children, whilst still remaining significantly longer. This is shown by an interaction effect between age and hearing status for utterance duration ($p<0.01$) and for utterance durations of productions from 1 to 8 syllables ($p<0.001$). So, even though CI children start as slower speakers, they tend to catch up when they are getting older.

In the "controlled" utterances, i.e. the utterances with 1 up to 8 syllables, an extra syllable costs more time ($p<0.001$). This means that utterance durations are longer (in duration) when they contain more syllables. An interaction between age and number of syllables ($p<0.001$) indicates that with getting older, producing an extra syllable costs less time for both CI and NH children.

In sum, CI children have longer utterance durations even when the number of syllables is controlled for. Nevertheless, an interaction between age and hearing status indicates that as they get older, their utterances become shorter and they are slowly catching up with their NH peers. But, these findings seem to suggest that there might be a difference in the children's speech rate.

Speech rate

Are CI children slower speakers than their normally hearing peers? Our analyses reveal for both syllable duration ($p<0.001$) and number of syllables per second ($p<0.001$) a main effect of hearing status: CI children speak significantly slower than their NH peers.

Even though the main effect of hearing status indicates that CI children are slower speakers, over time CI children seem to approach the speech rate of NH children. A significant interaction between hearing status and age for syllable duration ($p<0.001$) and for number of syllables per second ($p<0.001$) was found. CI children are gradually catching up and become faster speakers.

In conclusion: hearing status seems to affect children's talkativeness, utterance duration and speech rate, but not their number of turns. CI children speak more in terms of total duration of speech and number of utterances, and have longer utterance durations and are slower speakers. Over time, the two groups seem to approach one another.

In the following paragraphs the influence of the maternal input will be discussed: is the maternal input predictive for the children's output? Is there an effect of maternal input on their children's expressive vocabulary size?

3.2.2. Effects of maternal input

In the following paragraphs we first discuss how the maternal outcomes predict the language outcomes of the children (at the same moment). We analysed this for all measures: number of utterances per hour, number of turns per hour, total duration of speech, mean utterance duration, utterance durations of 1-8 syllables, speech rate measured as number of syllables per second and syllable duration. In the Appendix this is indicated as "maternal influence" (Table 2 in the Appendix). Second, we examine whether measures of mothers' talkativeness (total duration of speech, number of utterances per hour and number of turns per hour) predict children's lexical development (cumulative vocabulary; Table 3 in the Appendix). We performed these analyses because the literature (see infra) shows clear relationships between maternal input and children's expressive language development.

Effects of maternal input on children's output

There was a positive effect of the number of maternal utterances on the number of children's utterances ($p<0.01$). The talkativeness of the mothers predicts the talkativeness of their children. However, this is also true in the opposite direction: the number of child utterances predicts the number of maternal utterances ($p<0.001$).

Moreover, the number of maternal turns predicts the number of children's turns ($p<0.001$). Again, this effect is found in the opposite way as well ($p<0.001$). Furthermore, this predictive effect becomes stronger over time as indicated by an interaction between age and maternal number of turns ($p<0.001$) and between age and number of utterances ($p=0.01$). Thus, the number of maternal utterances as well as the number of maternal turns predict the number of child utterances and child turns. When an interaction between maternal utterances or turns and hearing status was added, our model did not improve significantly. This means that the effect of maternal utterances and turns is the same for CI and NH children.

When analysing whether the total duration of maternal speech predicts the total duration of the children, no significant effect was found ($p>0.05$). So, concerning children's talkativeness the number of maternal utterances and the number of maternal turns are predictive for children's talkativeness, whereas the total duration of speech is not predictive at all.

Does the mothers' mean utterance duration predict the mean utterance duration of their children? The answer is yes and no: maternal utterance duration does not predict children's mean utterance duration ($p>0.05$). However, for NH children, their mothers do have a positive effect on their mean utterance duration ($p<0.05$) as indicated by an interaction between hearing status and maternal influence. So, for CI children their mothers' mean durations are not predictive whereas they are for the NH children.

When only utterances of 1 up to 8 syllables were analysed, the effect of maternal input reached significance ($p<0.01$), indicating that mothers indeed predict their children's durations for these controlled utterances. So, the durations of mother's utterances of 1 up to 8 syllables predict their children's utterance durations. The interaction between hearing status and maternal influence was not significant and did not improve our model. The maternal influence was thus the same for the two groups of children.

The fact that mothers' durations predict those of their children might suggest that we will also find a predictive effect of mothers' speech rate on children's speech rate. Both for number of syllables per second ($p<0.001$) and syllable duration ($p<0.001$), mothers predicted their children's speech rates. However, this maternal influence was not the same for the two groups of children as indicated by an interaction between maternal influence and hearing status (for syllable duration, $p<0.01$; for #syllables/s, $p<0.001$). The speech rate of mothers of NH children was far less predictive than the speech rate of CI mothers and their children. Mothers' speech rate thus predicts their children's speech rate mainly in the CI group. Furthermore, an interaction with age indicates that the predictive 'power' of maternal syllable duration increases over time ($p=0.001$). This is also confirmed for number of syllables per second ($p<0.001$). So, mothers of CI children influence their children more concerning the speed with which they speak. This is probably due to the fact that NH children already start with a higher speech rate, which makes the influence of their mothers less intrusive.

Effects of maternal input on children's expressive vocabulary size

We were not only interested in the effects of mothers' input on the children's output, but also on the lexical development of the children. Therefore, we examined whether the number of maternal turns, the number of maternal utterances, and the total duration of maternal speech had an influence on children's expressive cumulative vocabulary (Table 3 in the Appendix).

Cumulative vocabulary is measured as the number of different word types over time. For these analyses, the intercept was set at 21 months.

Our results revealed that only the number of maternal turns was predictive for children's lexical output ($p<0.01$). This effect becomes even stronger over time as is indicated by an interaction between number of maternal turns and age ($p=0.01$). Hearing status was also added as a factor but did not reveal any differences in vocabulary outcomes between the CI and NH children ($p>0.05$). When an interaction between number of maternal turns and hearing status was added to analyse whether the effect was different for the two groups, this did not improve our model significantly. Therefore this effect is not shown in Table 3. In general, the number of maternal turns is thus equally predictive for both groups of children.

Even though the number of turns was predictive for children's lexical development, the number of utterances was not ($p>0.05$). The number of maternal utterances did not predict children's vocabulary sizes. Again, there was no difference between CI and NH children ($p>0.05$). An interaction between maternal utterances and hearing status was not significant and did not improve our model.

As a final step we also analysed whether the maternal total duration of speech was predictive for the children's lexical development. Our analyses reveal that there was a negative impact on children's language growth ($p<0.01$). Children thus do not benefit of long total durations of speech. Hearing status did not influence children's lexical growth ($p>0.05$). However, an interaction between hearing status and maternal total duration of speech shows that this negative impact is less intrusive for NH children ($p<0.001$). It thus seems that for CI children in particular their mothers' total durations of speech have a negative impact on their cumulative vocabulary. Nevertheless, an interaction between age and total duration of speech ($p<0.05$) shows that this negative impact decreases over time. This indicates that the negative impact of total duration of speech thus seems to diminish over time and to be less intrusive for NH children.

4. Discussion

The current research addressed three main questions: (1) is the input cochlear implanted children get comparable to that of mothers of normally hearing children?, (2) do children who receive a cochlear implant early in life catch up with their normally hearing peers concerning talkativeness and speech rate?, and (3) is there a relationship between mothers' input and children's output?

The current study shows that mothers provide their CI children an equal amount of input (operationalised in terms of speaking time, number of turns and number of utterances) in comparison to mothers of NH children. This finding contrasts with studies that investigated the speech provided by mothers of hearing-impaired children (without CI) during spontaneous interactions (Clement, 2004; Clement et al., 1994; Lederberg & Everhart, 1998), but confirms the more recent study of VanDam et al. (2012). The input that mothers of CI children provide is thus *grosso modo* comparable to the input provided by mothers of NH children. Mothers of CI children consider their children as normally hearing, and not as hearing-impaired. Yet it may come as a surprise that mothers of CI children do not provide their children with a larger amount of input. Mothers of hearing-impaired children with a CI may be more sensitive to the fact that their children are indeed still hearing-impaired and may thus be expected to provide even more input. Moreover, since their children's hearing was only (partly) restored after a relatively long period of sound deprivation, they could have been trying to make up for the "lost time" by addressing even more speech to their children. But this does not seem to be the case: the amount of speech is statistically not significantly different in the two groups. A possible explanation for this finding is that the two groups are compared relative to their chronological age. A recent study that compared the responsiveness of mothers of NH children to that of mothers of CI children came to slightly different findings (Vanormelingen, De Maeyer, & Gillis, 2015). Instead of looking at the sheer amount of speech addressed to the children, this study looked at mothers' responsiveness to children's verbal efforts. The same CI and NH children were compared based on their "linguistic age" instead of their chronological age, i.c., not the children's age was the basis of comparison, but their cumulative vocabulary. Thus the children had approximately the same number of words in their vocabulary, but the CI children were all slightly older than the NH children. It was found that mothers of CI children responded more frequently to their children's utterances than mothers of NH children. This suggests that mothers of CI children provide more contingent responses to their children and that by responding more frequently to their children's utterances, they provide more feedback (and input) to their children.

Even though the input seems to be more or less the same in the two groups, the development of the speech rate of mothers of CI children is less steep: whereas mothers of NH children speak faster over time, this increase is less pronounced in the speech rate of the mothers of CI children. It thus seems that this characteristic of Motherese, i.e. speaking more slowly to children, is influenced by their children's hearing status. This suggests that, even though there are no major (statistically significant) differences in the input of mothers of CI and NH children, mothers of CI children are aware of the fact that their children have a "special" status, and consequently speak somewhat slower. This is in line with the findings of Kondaurova et al. (2013) who revealed that mothers speak slower to their CI children. In sum, to answer the first research question: the characteristics of mothers of CI children's input are consonant with the characteristics of mothers of NH children's input. Mothers of CI children do not behave as mothers of HI children in spontaneous interactions with their children, but even exaggerate some characteristics of Motherese.

The input of mothers of CI children is comparable to the input of mothers of NH children, but what about the children? Is the amount of output that CI children produce comparable to that of HI children or is their speech more like that of NH children? In other words: is the speech of CI children "abnormal" in some way? Our results demonstrate that CI children are more talkative than NH children at the beginning of the period studied. This is in line with previous studies claiming that HI children are more talkative than NH children (Clement, 2004; Clement et al., 1994; van den Dikkenberg- Pot et al., 1998). Yet, over time the values of the CI and NH children approach one another: by approximately 18 months of age CI and NH children are equally talkative (see Figure 3). At first sight, the speech of the CI children thus seems somewhat "abnormal" and reflecting the speech characteristics of HI children, but approaching the NH children over time. This could be explained by the fact that, at the age of the intercept (12 months), the two groups of children are in a different linguistic stage, i.e. the language of the CI children is at this age not yet as advanced as that of the NH children. NH children start to produce conventional words around their first birthday (Coplan, 1995; Fagan, 2009; Hart & Risley, 1999). When we look at the word onset in our data set, the median age is 13 months (range=10-17 months, SD =1.74 months) for the NH children and 19 months for the CI children (range=15-24, SD=3.39). Interestingly, it is around 19 months of age that CI and NH children have more or less an equal amount of utterances and total durations of speech. The values of the CI and NH children thus approach one another at this age point, which suggests that CI children are gradually catching up with their NH peers and are reflecting gradually the speech characteristics of NH children, and resemble less HI children.

However, stating that the CI children are speaking like NH children on all measures would be too far reaching. Analysing the results for speech rate, a main effect of hearing status was found: CI children are significantly slower speakers than their NH peers. But even though there is a significant difference between the NH and CI children, our research also reveals that the values of the CI and NH children approach one another over time (as is statistically confirmed by an interaction between age and status). CI children are not yet completely in line with their NH age-mates in the age bracket studied, but they are approaching them very quickly. These results thus show that early intervention and implantation of profoundly hearing-impaired children is beneficial for their language development. In sum, to answer the second question "is the speech of CI children's more like that of NH or HI children?" our results clearly show that their speech is more comparable to that of NH children, but not yet entirely at the same level. These outcomes are thus promising for the CI children's later language development.

The final question we addressed was whether there was a relationship between the mothers' input and the children's output. Mothers predicted their children's outcomes for the following measures: the number of utterances, the number of turns, controlled utterances durations, speech rate and syllable duration. The fact that mothers' measures predict their children's utterances and turns and not their total durations of speech is intriguing. This suggests that in early dyadic interactions smooth turn-taking is at stake, and it seems to reflect the children's more limited linguistic resources, and, hence, discrepant total durations of speech. Moreover, the number of turns, which can be considered as a more qualitative aspect of the input, is the only significant predictor of CI and NH children's expressive vocabulary sizes. Whereas the number of utterances had no significant influence on children's vocabulary development and the impact of the total duration of speech was even negative, the number of maternal turns predicted children's expressive vocabulary sizes (measured as cumulative vocabulary) significantly. The negative effect of the total duration of speech means that the more (measured as duration) a mother spoke to her child, the fewer words he or she acquired. This negative influence was especially apparent for the CI children, which suggests that CI children have more difficulties with processing a lot of input than NH children. For instance, it has been found that CI children have slower verbal processing speeds than NH children (Aubuchon, Pisoni, & Kronenberger, 2015). This "slowness" could explain why CI children have more difficulties in acquiring new words from larger speech streams. The fact that the number of maternal utterances had no impact on children's vocabulary growth suggests that children benefit far more from actual interactions and not solely from amount of input (measured as number of utterances and total duration of speech), which confirms earlier findings (VanDam et al., 2012; Zimmerman et al., 2009). More specifically our data show that when mothers take more conversational turns, children have more words at the age of 21 months. This finding can be interpreted as follows: more turns means more opportunities for the mother to hand over new words or new information on the one hand and more opportunities for the child to hear and hence acquire new words on the other hand. This confirms earlier research showing that conversational interactions support the process of language acquisition (Clark, 2010). In sum, mothers who take more turns provide their children with more opportunities for language learning and consequently the children acquire new words at a faster rate.

The answer to the third question, viz. whether there is a relationship between mothers' input and children's output, is positive: our results showed several effects of mothers' input on children's output measures, such as number of utterances. Furthermore, only the number of maternal turns seems to be beneficial for both CI and NH children's expressive vocabulary development.

Conclusion

This study demonstrated that children’s hearing status has more influence on children’s own language development than on their mothers’ speech. The amount of input mothers provide their children with is the same across both groups. This indicates that the characteristics of mothers of CI children’s speech are more comparable to those of mothers of NH children, rather than to those of mothers of HI children. CI children are much more talkative and speak slower then their NH peers. However, over time the values of the CI and NH children approach one another, suggesting that the CI children are gradually becoming more like their NH peers. The relationship between mothers’ input and children’s output is also illustrated in this study: mothers’ values predicted children’s number of utterances, number of turns, utterance durations of productions with 1 up to 8 syllables, and speech rates. Children’s vocabulary sizes are only positively predicted by the number of turns of their mothers.

Children need a large amount of input to acquire their maternal language, which is even more important for children with hearing difficulties. Several studies have found that the socio-economic status in which families live, has a large impact on the children’s language development (Hart & Risley, 1995; Rowe, 2008), therefore future research should examine the input that CI children in a lowSES population receive.

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Résumé

La présente étude examine le langage produit par deux groupes d'enfants et leurs mères : nous comparons la quantité d'input et d'output chez des enfants congénitalement malentendants porteurs d'un implant cochléaire (IC) et chez des enfants normo-entendants (NH). L'objectif de l'étude est triple : (a) analyser l'input chez les deux groupes de mères, (b) analyser l'output chez les deux groupes d'enfants, et (c) analyser l'influence de l'input maternel sur l'output et sur le développement du vocabulaire expressif des enfants. Les mères sont moins influencées par l'état auditif de leurs enfants que les enfants ne le sont eux-mêmes : les enfants porteurs d'un IC parlent plus et plus lentement que les normo-entendants. L'influence des mères sur les enfants apparaît dans la plupart des mesures, mais le résultat le plus marquant est que ce n'est pas la volubilité des mères en tant que telle, mais le nombre de tours de parole qui est le meilleur prédicteur du développement du vocabulaire des enfants.

Tables

Table 1 Individual child characteristics of the CI group.

Subject	**Etiology**	**Residual hearing loss (in dB)**	**Age Hearing Aids (HA) (y;mm.dd)**	**Residual hearing loss with HA (dB)**	**Age Implantation CI**	**Age activation CI**	**Uni- or bilateral**	**Residual Hearing loss with CI (dB)**
S1	genetic	117	0;4.0	107	0;5.5	0;6.4	Bilateral (1;4)	43
S2	connexin-26	120	0;1.4	120	0;6.21	0;7.20	Unilateral	30
S3	connexin-26	120	0;1.21	107	0;8.23	0;9.20	Unilateral	43
S4	connexin-31[4]	103	0;5.8	63	0;8.21	0;9.21	Unilateral	32
S5	CMV infection[1]	115	0;1.18	113	0;10.0	0;11.20	Unilateral	33
S6	connexin-26	120	0;9.3	120	1;1.15	1;2.27	Unilateral	47
S7	connexin-26	93	0;4.24	47	1;4.27	1;5.27	Unilateral	35
S8	connexin-26	113	0;10.0	117	1;6.5	1;7.9	Unilateral	42
S9	unkown	112	0;2;0	58	1;7.14	1;9.4	Unilateral	52

Appendix – Statistical Models[5]

Table 1 Parameter estimates for the mothers

	Total duration of speech		**Number of utterances**		**Number of turns**		**Mean duration of utterance**		**Mean number of syllables per utterance**	
Effect	**Estimates**	**(se)**	**Estimates**	**(se)**	**Estimates**	**(se)**	**Estimates**	**(se)**	**Estimates**	**(se)**
Fixed Parameters										
Intercept	664.72***	90.47	713.69***	58.12	350.16***	30.54	884.5***	60.079	1.2***	0.06
Age	25.99***	3.24	21.61***	3.52	9.24**	2.43	3.6*	1.845	0.008**	0.003
Age squared	-0.56*	0.23	-0.47*	0.24						
Hearing [NH]	49.96	102.78	-83.69	63.71	-18.98	33.81	213.82**	69.061	0.25***	0.07
Age*Hearing[NH]					7.02*	3.003			0.01**	0.003
Random Parameters										
$S^2_{Mother\_intercept}$	63883.81		22928.01		3765.05		36482.31		0.0298	
$S^2_{Mother\_age}$	68.56		85.88		23.55		43.21		0.00006	
$Cor_{Mother\_intercept\_age}$	-0.14		-0.31		-0.03		-0.17		-0.21	
$S^2_{Age\_intercept}$	107.15		585.43		375.34		2833.53		0.004	
$S^2_{residual}$	26856.20		20721.95		6090.76		321241.85			

[5] p≤0.05*
p≤0.01**
p≤0.001***

Table 1 continued

	Duration of utterances with 1-8 syllables		**Speech rate (#syl/s)**		**Syllable duration**	
Effect	**Estimates**	**(se)**	**Estimates**	**(se)**	**Estimates**	**(se)**
Fixed Parameters						
Intercept	371.74***	50.5	3.77***	0.16	286.33***	10.89
Age	-1.12	2.97	-0.02*	0.01	1.86*	0.79
Age squared	-0.30*	0.13	0.002***	0.0005	-0.13***	0.03
Hearing [NH]	77.29	55.68	-0.16	0.18	10.81	12.27
Age*Hearing[NH]			0.05***	0.01	-3.08***	0.64
Number of Syllables	175.65***	0.90				
Hearing[NH]*Number of Syllables	-6.21***	1.05				
Random Parameters						
$S^2_{Mother\_intercept}$	22098.90		0.211		941.329	
$S^2_{Mother\_age}$	45.18		0.0005		1.857	
$Cor_{Mother\_intercept\_age}$	-0.29		-0.05		-0.18	
$S^2_{Age\_intercept}$	2689.37		0.0350		116.816	
$S^2_{residual}$	147076.84		2.094		11539.290	

Table 2 Parameter estimates for the children

	Total duration of speech		Number of utterances		Number of turns		Mean duration of utterance		Duration of utterances with 1-8 syllables	
Effect	**Estimates**	**(se)**	**Estimates**	**(se)**	**Estimates**	**(se)**	**Estimates**	**(se)**	**Estimates**	**(se)**
Fixed Parameters										
Intercept	403***	45.52	442.60***	44.57	238.40***	15.60	1196.72***	127.95	848.64***	114.20
Age	-15.47*	6.23	-12.44*	5.69	2.47*	0.942	-47.58***	12.60	-65.53***	10.57
Age squared	1.33***	0.24	0.84**	0.23			1.79***	0.43	2.001***	0.34
Hearing [NH]	-105.7*	50.84	-105.5*	50.58	16.03	16.89	-514.58**	140.83	-781.79**	128.18
Maternal influence	0.005	0.04	0.18**	0.06	0.702***	0.045	-0.02	0.21	0.45**	0.14
Age*Hearing [NH]	19.36**	5.71	17.67**	5.16			35.55**	9.99	48.23***	9.05
Maternal influence * Hearing[NH]							0.57*	0.26		
Age*Maternal influence			0.02*	0.007	0.02***	0.004				
Number of Syllables									385.04***	4.242
Hearing[NH]*#Syllables									10.48**	3.76
Age*#Syllables									-3.75***	0.23
Random Parameters										
$S^2_{Child\_intercept}$	4826.21		5302.03		988.069		122337.0		98019.6	
$S^2_{Child\_age}$	66.92		34.76		5.603		589.4		460.08	
$Cor_{Child\_intercept\_age}$	0.01		0.02		-0.05		-0.78		-0.87	
$S^2_{Age\_intercept}$	0		0		0		35539.2		20677.5	
$S^2_{residual}$	18826.84		16703.07		3067.391		387604.3		225803.5	

Table 2 Continued

	Speech rate (#syl/s)		Syllable duration	
Effect	**Estimates**	**(se)**	**Estimates**	**(se)**
Fixed Parameters				
Intercept	0.84***	0.22	635.37***	24.65
Age	0.16***	0.03	-19.02***	3.60
Age squared	-0.009***	0.001	0.91***	0.13
Hearing [NH]	1.97***	0.21	-129.7***	27.14
Maternal influence	2.91***	0.24	2.97***	0.45
Age*Hearing [NH]	-0.17***	0.02	14.97***	3.21
Maternal influence * Hearing[NH]	-2.67***	0.27	-1.62**	0.54
Age*Maternal influence	0.05***	0.006	0.13***	0.02
Number of Syllables				
Hearing[NH]*#Syllables				
Age*#Syllables				
Random Parameters				
$S^2_{Child\_intercept}$	0.18		2891.12	
$S^2_{Child\_age}$	0.003		49.14	
$Cor_{Child\_intercept\_age}$	0.11		-0.37	
$S^2_{Age\_intercept}$	0.28		1943.33	
$S^2_{residual}$	1.13		41418.94	

Table 3 Parameter estimates for maternal effects on child vocabulary

	Number of turns		**Number of utterances**		**Total duration of speech**	
Effect	**Estimates**	**(se)**	**Estimates**	**(se)**	**Estimates**	**(se)**
Fixed Parameters						
Intercept	131.01***	22.06	101.58***	22.58	98.60***	21.13
Age	23.87***	3.40	29.17***	3.05	26.4***	3.02
Maternal influence	0.1**	0.03	-0.007	0.02	-0.06**	0.02
Hearing [NH]	0.34	11.69	17.67	13.07	19.04	12.69
Maternal influence*Hearing[NH]					0.09***	0.02
Age*Maternal influence	0.01*	0.005			0.005*	0.002
Random Parameters						
$S^2_{Child\_intercept}$	6023.6		4298.7		4031.1	
$S^2_{Child\_age}$	167.7		126.5		117.6	
$Cor_{Child\_intercept\_age}$	1		1		1	
$S^2_{Age\_intercept}$	3290.2		3639.4		2898.7	
$S^2_{residual}$	364.9		322.9		294.8	

Figures

Figure 1 Number of maternal utterances per hour (left) and total duration (right) (predicted values)

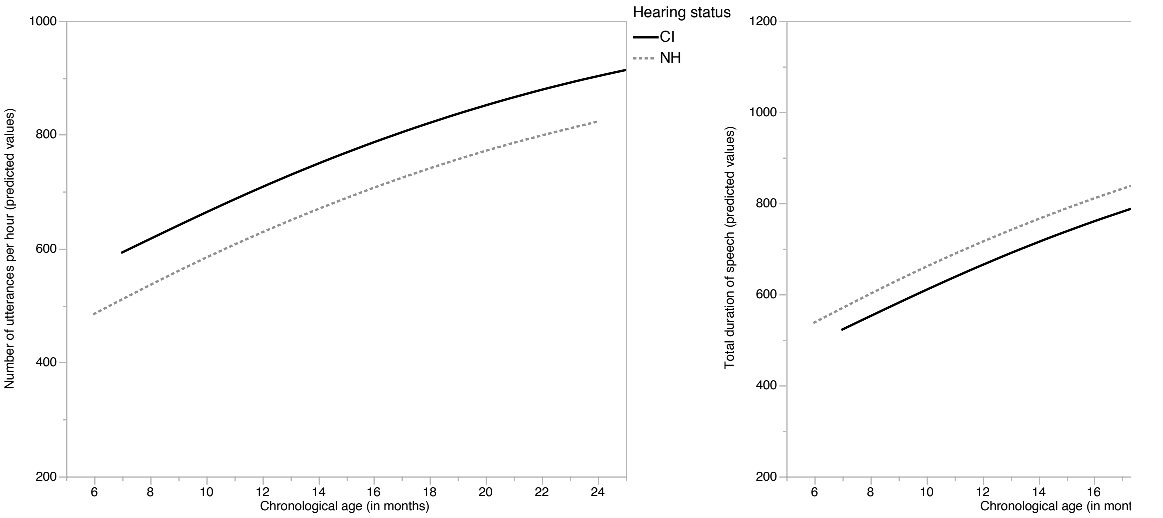

Figure 2 Number of maternal turns per hour (predicted values)

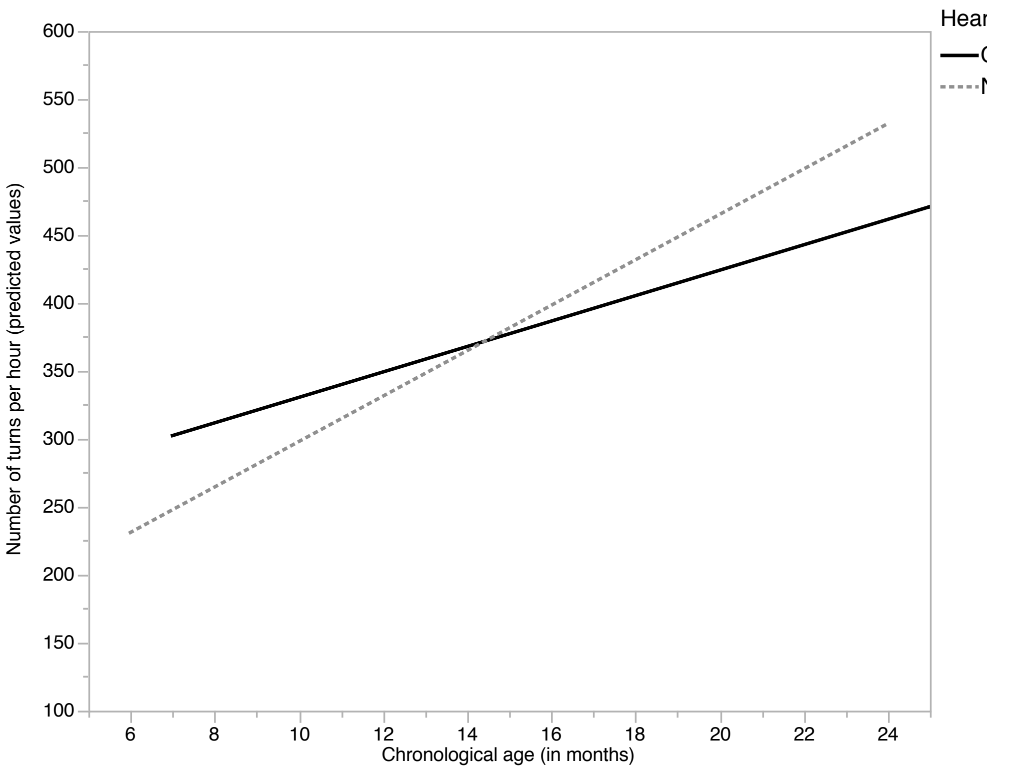

Figure 3 Number of child utterances per hour (left) and total duration of speech (right) (predicted values)

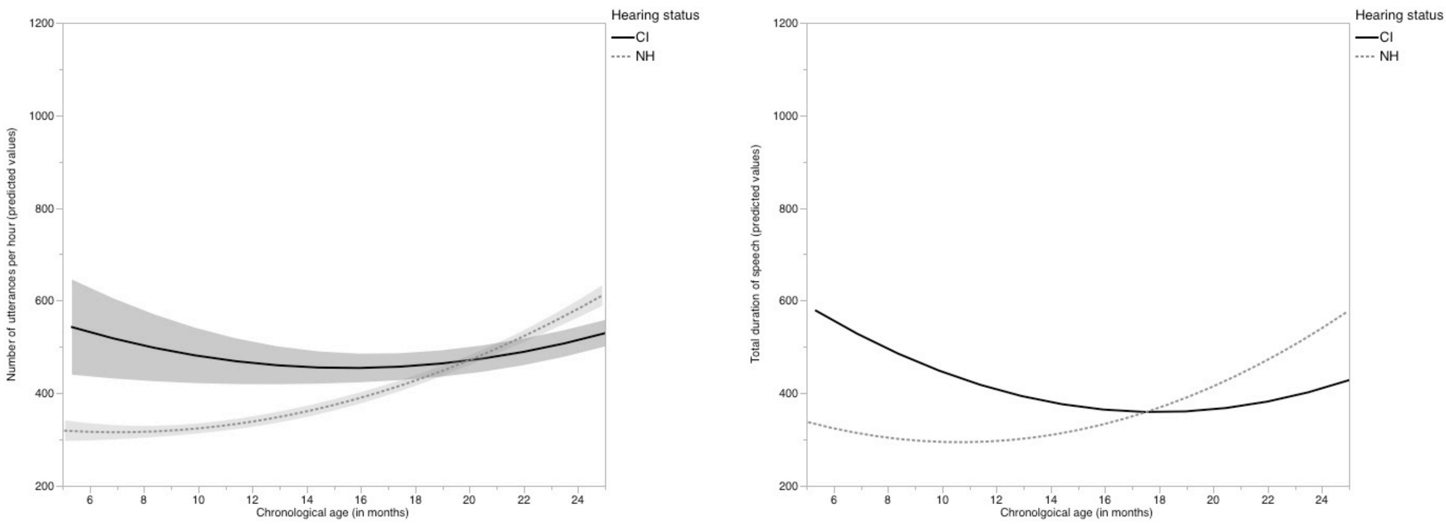

Figure 4 Number of child turns per hour (predicted values)