Mothers' Speech to Hearing-Impaired Infants and Children with Cochlear Implants

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Abstract

The present study investigated the effects of age, hearing loss, and cochlear implantation on mothers’ speech to infants and children. We recorded normal-hearing (NH) mothers speaking to their children as they typically would do at home and speaking to an adult experimenter. Nine infants (10-37 months) were hearing-impaired and had used a cochlear implant (CI) for 3-18 months. Eighteen normal-hearing infants and children were matched either by chronological age (10-37 months) or “hearing experience” (3-18 months) to the CI children. Prosodic characteristics such as fundamental frequency, utterance duration, and pause duration were measured across utterances in the speech samples. The results revealed that mothers use a typical infant-directed speech style when speaking to hearing-impaired children with CIs. The results also suggested that NH mothers speak with more similar vocal styles to NH children and hearing-impaired children with CIs when matched by hearing experience rather than chronological age. Thus, mothers are sensitive to hearing experience and linguistic abilities of their NH children as well as hearing-impaired children with CIs.

Mothers’ Speech to Hearing-Impaired Infants with Cochlear Implants

Several researchers have proposed theoretical accounts to explain mothers’ use of infant-directed (ID) speech. Whether mothers are communicating emotions and modulating their infants’ arousal levels or providing enhanced language models to older infants, it is commonly believed that the infants’ responsiveness reinforces the use of ID speech styles (Burnham, Kitamura, & Vollmer-Conna, 2002; Cooper, 1997; Fernald, 1992; Nakata & Trehub, 2004). Unfortunately, infants with profound deafness may not provide their caregivers with such reinforcement to spoken language, which could significantly affect maternal speech style. The purpose of the present study was to investigate the effects of hearing loss and subsequent cochlear implantation on mothers’ speech to infants and children.

ID speech is typically characterized by higher pitch, increased pitch range, shorter utterances, and longer pauses compared to adult-directed (AD) speech (Bergeson & Trehub, 2002; Fernald, 1991, 1992; Fernald & Simon, 1984; Papoušek, Papoušek, & Bornstein, 1985). Both mothers and fathers change their speaking style when they talk to infants (Fernald et al., 1989). Moreover, ID speech styles are similar across many languages such as English, French, Italian, German, Japanese, Mandarin, Swedish, and Russian (Fernald & Simon, 1984; Grieser & Kuhl, 1988; Jacobson, Boersma, Fields, & Olson, 1983; Kuhl et al., 1997).

Several studies have shown that ID speech successfully modulates infants’ attention and emotional responses. Very young infants will look longer at a visual stimulus in response to ID speech compared to AD speech (Cooper & Aslin, 1994; Cooper & Aslin, 1990; Fernald, 1985; Pegg, Werker, & McLeod, 1992). Moreover, Fernald and Kuhl (1987) demonstrated that pitch, rather than intensity or duration, is the prosodic cue most likely responsible for infants’ interest in ID speech. Infants also produce appropriate affective signals such as smiling in response to female ID speech rather than AD speech (Fernald, 1993; Werker & McLeod, 1989). Finally, the characteristics typical of ID speech may enhance infants' language acquisition (Fernald & Mazzie, 1991; Fernald, Pinto, Swingley, Weinberg, & McRoberts, 1998; Kemler Nelson, Hirsh-Pasek, Jusczyk, & Wright Cassidy, 1989; Liu, Kuhl, & Tsao, 2003; Morgan, Meier, & Newport, 1987; Thiessen, Hill, & Saffran, 2005).

Importantly, caregivers' simulations of ID speech in the absence of their infants are easily differentiated from infant-present speech (Jacobson et al., 1983). That is, the physical presence of the infant is essential to producing the exaggerated characteristics of ID speech. In fact, maternal speech is sensitive to several additional infant factors, such as the child's age. Stern, Spieker, Barnett, and MacKain (1983) recorded mothers speaking to their infants at 4 days, 4 months, 12 months, and 24 months of age. They found that mothers produced the largest pitch ranges, highest pitch levels, and most repetitiveness when talking to their 4-month-old infants, but longest utterance duration and most complex utterances when talking to their 24-month-old infants. A more recent cross-linguistic study of maternal speech directed to 3-, 6-, 9-, and 12-month-old infants revealed a peak in pitch levels at 6 months of age in a non-tonal language (Australian English) and at 9 months of age in a tonal language (Thai; Kitamura, Thanavishuth, Burnham, & Luksaneeyanawin, 2002). Unlike the previous study, they also found that mothers' pitch ranges increase slightly across infant age. Additionally, Kitamura and Burnham (2003) found that the number of utterances and communicative intent in ID speech changes with infant age.

The linguistic skill of the audience also influences mothers' speech. Mothers typically hyperarticulate spoken vowels for young infants (Kuhl et al., 1997), and pronounce vowels and consonants more clearly for children who are beginning to talk compared to pre-verbal and verbal children (Fernald & Mazzie, 1991; Ratner, 1984). Burnham, Kitamura, and Vollmer-Conna (2002) found that mothers used enhanced vowel articulation when speaking to their infants compared to their pets, who do not possess perceived language skills. Thus, the linguistic and cognitive characteristics of infants themselves contribute greatly to caregivers' communication style even though the caregivers may not be consciously aware that they are fine-tuning their performances.

How is communication style affected in mothers with profoundly deaf infants? Deaf mothers' ID sign language parallels hearing mothers' spoken language in several ways. American and Japanese mothers produce signs at a slower rate, exaggerate the movements associated with the signs, and make greater use of repetition compared to AD sign language (Erting, Prezioso, & O'Grandy-Hynes, 1990; Masataka, 1992). Moreover, deaf and hearing infants prefer ID sign language to AD sign language (Masataka, 1996; Masataka, 1998). However, approximately 80% of hearing-impaired children are born to hearing parents, and an additional 10% have at least one hearing parent (Mitchell & Karchmer, 2005). The question then becomes how is ID speech affected in normal-hearing mothers who have profoundly deaf infants?

Because infants' responses to ID speech most likely encourage caregivers' continued use of this vocal register, one might expect that caregivers with hearing-impaired infants would decrease their use of ID speech when they discover their infants are not responding to the auditory information. We know very little about ID speech to infants with hearing loss, primarily because until recently hearing loss was not typically diagnosed until children reached 2-3 years of age (Meadow-Orlans, Spencer, & Koester, 2004). Researchers have shown that when normal-hearing (NH) mothers first learn of their child's hearing loss they tend to increase their use of vocal exaggeration, but over time such vocal exaggeration decreases (Wedell-Monnig & Lumley, 1980). Additionally, NH mothers who have hearing-impaired children tend to be more controlling and less responsive than NH mothers who have NH children (Cheskin, 1981; Goss, 1970; Henggeler & Cooper, 1983). Mothers also tend to repeat utterances rather than expand on them when speaking to hearing-impaired children compared to when speaking to NH children (Cross, Nienhuys, & Kirkman, 1985; Nienhuys, Cross, & Horsborough, 1984). Interestingly, these characteristics in mothers’ speech to hearing-impaired children are more similar to those of the speech directed to NH children of the same linguistic age than to NH children of the same chronological age (Cross et al., 1985; Nienhuys et al., 1984). Finally, NH mothers tend to produce fewer and less complex verbal utterances but more nonverbal attention-getting behaviors in interactions with hearing-impaired infants and children compared to interactions with NH infants and children (Goldin-Meadow & Saltzman, 2000; Koester, Brooks, & Karkowski, 1998; Koester, Karkowski, & Traci, 1998).

It also appears that hearing-impaired infants and children behave differently than NH infants and children when interacting with their NH mothers. Koester (1995) found that 9-month-old infants with hearing loss did not actively elicit their mothers’ attention by means of smiling, greeting, or reaching, in contrast to NH 9-month-olds. Instead, the hearing-impaired infants displayed more self-comforting and repetitious motor behaviors than NH infants. Other studies have found that hearing-impaired children are more passive and less responsive than NH children when interacting with their NH mothers (Henggeler & Cooper, 1983; Wedell-Monnig & Lumley, 1980).

Taken together, these studies suggest that hearing loss does have an effect on infants’ and children’s interactions with their caregivers. However, no research to date has determined the effects of auditory experience and hearing loss on the acoustic characteristics of mothers' speech to hearing-impaired infants and children. One way to answer this question is to investigate mothers' speech to a unique population: infants who were profoundly deaf for a period of their lives and who now have various levels of hearing experience via cochlear implantation. Cochlear implants (CIs) are electronic auditory prostheses that are designed to process speech by stimulating nerve fibers in the cochlea. The FDA has recently broadened CI candidacy criteria to include infants as young as 12 months of age, and several surgeons worldwide have also implanted infants prior to 12 months.

Previous research has shown that early identification of hearing loss and subsequent intervention have a large impact on hearing-impaired infants' language development (Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998), and that the effects of early auditory experience in hearing-impaired infants and children who receive CIs are quite substantial (Bergeson, Pisoni, & Davis, 2003, 2005; Houston, Ying, Pisoni, & Kirk, 2003). Nevertheless, there has been very little research on the nature of the spoken input these infants and children receive on a daily basis from their caregivers. This is an important research problem because language environment and ID speech quality have been shown to have considerable effects on language and cognitive development (Hart & Risley, 1995; Kaplan, Bachorowski, Smoski, & Hudenko, 2002; Liu et al., 2003; Meadow-Orlans & Spencer, 1996; Pressman, Pipp-Siegel, Yoshinaga-Itano, & Deas, 1999; Spencer & Meadow-Orlans, 1996). For example, NH children who hear more parental utterances between the ages of 11 and 18 months are more likely to have much better language skills at ages 3 and 8 years than those children who hear fewer parental utterances during infancy (Hart & Risley, 1995). It is important to note that this study did not control for socio-economic status. Children who hear more diverse maternal input are also more likely to have better vocabulary production growth between the ages of 1 and 3 (Pan, Rowe, Singer, & Snow, 2005). Moreover, Liu and colleagues (2003) found that maternal vowel clarity is positively correlated with 6- to 8-month old and 10- to 12-month old NH infants' speech discrimination abilities. Additionally, Liu et al. found no effects of socio-economic status on mothers' speech or infants' perception skills. NH 4-month-old infants display better learning skills in response to ID speech of nondepressed mothers compared to the much less exaggerated ID speech of depressed mothers (Kaplan et al., 2002). Finally, maternal sensitivity and responsiveness is associated with language gain and representational play in hearing-impaired children (Pressman et al., 1999; Spencer & Meadow-Orlans, 1996).

To our knowledge, there has been only one published study on the early linguistic experience of hearing-impaired children with CIs. In a recent study, Stallings, Kirk, Chin, and Gao (2000) found that parents' familiarity with uncommon words was positively correlated with the vocabulary and language skills of their hearing-impaired children with CIs. However, no research has assessed the acoustic characteristics, such as pitch level, in caregivers' speech to hearing-impaired infants and children with CIs. The purpose of the present study was to determine whether NH mothers of NH infants and children and NH mothers of hearing-impaired infants and children with CIs use similar ID vocal styles. An earlier study suggested that mothers' speech to CI children is influenced by "hearing experience," or duration of implant use, rather than chronological age (Bergeson & McCune, 2004). Thus, a second goal of the current study was to determine whether mothers tailor their vocal style to the chronological age or the hearing experience of their hearing-impaired infants and children with CIs.

Method

Participants

NH mothers of implanted infants and children (n = 9) were recruited from the clinical population at the Indiana University School of Medicine, Department of Otolaryngology – Head and Neck Surgery. All mothers were reimbursed $10 per visit. Table 1 shows demographic data across individual CI children. All CI infants and children experienced profound hearing loss and were implanted before the age of 2 years. Four CI infants were enrolled in programs emphasizing Oral Communication (OC) and five CI infants were enrolled in programs using Total Communication (TC), or simultaneously signed and spoken English. The mean age of the CI children was 25.2 months, the mean age at stimulation was 15.9 months, and the mean duration of CI use (i.e., "hearing experience") was 9.4 months. We used the MacArthur Communicative Developmental Inventories (CDI) to determine the number of words produced by the CI infants and children within 3 months of the time of testing. In normal-hearing populations, the CDI: Words and Gestures form is typically used below the age of 16 months, and the CDI: Words and Sentences form is typically used above the age of 16 months. Hearing experience was significantly correlated with the number of words produced by the CI infants (r = .75, p =.021).

NH mothers of NH infants (n = 18) were recruited from the local community and were reimbursed $10 per visit. Table 2 shows demographic data across individual NH infants. Half of the infants were in the *hearing - age matched* (H-AM) control group. These infants were the same chronological age, within a two-week window, as the CI infants (mean age = 25.2 months). The chronological age of the remaining NH infants in the *hearing - experience matched* (H-EM) control group was the same, within a two-week window, as the "hearing experience" of the CI infants (mean age = 9.3 months). Mothers of NH and CI infants had similar levels of education and musical training.

Procedure

We digitally recorded mothers speaking to their infants or an experimenter in a double-walled copper-shielded sound booth (Industrial Acoustics Company, Inc). In the ID speech condition, we asked mothers to sit with their child on a blanket or a chair, whichever option was most comfortable for them. We also provided the same group of quiet toys for all mother-child dyads. Mothers were instructed to speak to their child as they normally would at home. In the AD speech condition, an experimenter conducted a short interview with each mother. The order of ID and AD performances was counterbalanced across mothers. Mothers' speech was recorded by a hypercardioid microphone (Audio-Technica ES933/H), powered by a phantom power source. The microphone was linked to an amplifier (DSC 240) and a digital/audio tape recorder (Sony DTC-690). We also videotaped the recording sessions using a digital camera (Sony DCR-TRV 120/TRV 320).

Acoustic and linguistic properties known to characterize maternal ID speech were analyzed using Praat speech analysis software (Boersma & Weenink, 1996): average fundamental frequency (F_0; Hz), minimum F_0 (Hz), maximum F_0 (Hz), F_0 range (Hz), F_0 standard deviation (Hz), utterance duration (s), duration of pauses between utterances (s), number of utterances, number of words per utterance, and speaking rate (syllables/s). All properties were measured for each utterance in a two-minute speech sample in both ID and AD conditions and then averaged across utterances. Although utterances in ID speech were typically separated by a significant silent pause (e.g., 300 ms), utterances in AD speech were not. Thus, an utterance was defined in this study as a complete sentence or a complete thought. We also measured the total number of discrete utterances in the two-minute sample. All measures were obtained by three coders and independently verified by an additional coder on 10 of the 27 dyads. These measures were highly correlated (*r* > .9) among the coders.

Results

Figure 1 shows the average F_0 results in NH mothers' speech to infants and an adult for the three hearing conditions. A 2 (speech type: ID vs. AD) x 3 (infant hearing status: CI, H-EM, and H-AM) repeated measures ANOVA revealed a significant main effect of speech type, $F(1, 24) = 292.87$, $p < .0001$, $\eta_p^2 = .92$, and a significant interaction between speech type and infant hearing status, $F(2, 24) = 6.07$, $p = .007$, $\eta_p^2 = .34$. There was no main effect of hearing status. Post-hoc 2-tailed t-tests revealed statistically significant differences in the size of the change in F_0 between ID and AD speech when comparing CI versus H-AM infants, $t(16) = 2.77$, $p = .014$, Cohen's $d = 1.30$, and H-EM versus H-AM infants, $t(16) = 3.56$, $p = .003$, Cohen's $d = 1.68$. However, there was no significant difference in the size of the F_0 change between ID and AD speech when comparing speech to CI and H-EM infants. Thus, pitch was generally higher in mothers' speech to infants than to an adult experimenter, regardless of their infant's hearing status. Additionally, mothers produced similar increases in pitch when talking to CI infants and NH infants matched by hearing experience rather than NH infants matched by chronological age. (See Table 3 for a summary of results for two hypotheses: 1) ID speech to CI infants and children is more similar to ID speech to H-EM controls, and 2) ID speech to CI infants and children is more similar to ID speech to H-AM controls.)

Separate ANOVAs conducted on minimum and maximum F_0 results in NH mothers' speech to infants and an adult experimenter revealed the same main effect of speech type [minimum F_0: $F(1, 24) = 171.46$, $p < .0001$, $\eta_p^2 = .88$; maximum F_0: $F(1, 24) = 82.62$, $p < .0001$, $\eta_p^2 = .78$] and a significant interaction between speech type and infant hearing status only for minimum F_0, $F(2, 24) = 4.44$, $p = .023$, $\eta_p^2 = .27$. Two-tailed t-tests revealed statistically significant differences in the size of the change in minimum F_0 between ID and AD speech when comparing CI versus H-AM infants, $t(16) = 2.29$, $p = .036$, Cohen's $d = 1.08$, and H-EM versus H-AM infants, $t(16) = 2.98$, $p = .009$, Cohen's $d = 1.41$, but not between CI and H-EM infants. Because the interaction between speech type and infant hearing status in maximum F_0 was not significant, post-hoc tests were not performed. Minimum and maximum pitch were generally higher in mothers' speech to infants than to an adult experimenter, regardless of their infant's hearing status. Mothers also produced more similar changes in minimum pitch when talking to CI infants and NH infants matched by hearing experience rather than NH infants matched by chronological age.

The two measures of pitch excursions in mothers' individual utterances were F_0 range (maximum F_0 minus minimum F_0) and F_0 standard deviation. The standard deviation of the mean pitch was calculated for each individual utterance in the 2-minute speech samples and then averaged across utterances. Figure 2 shows the F_0 standard deviation in NH mothers' speech to infants and an adult experimenter for the three hearing conditions. Separate 2 (speech type: ID vs. AD) x 3 (infant hearing status: CI, H-EM, and H-AM) repeated measures ANOVAs conducted on F_0 range and F_0 standard deviation revealed significant main effects of speech type, [F_0 range: $F(1, 24) = 14.47$, $p = .001$, $\eta_p^2 = .38$; F_0 standard deviation: $F(1, 24) = 36.83$, $p < .0001$, $\eta_p^2 = .61$]. There were no main effects of infant hearing status and no interactions between speech type and infant hearing status. Pitch was more variable in mothers' ID than AD speech, regardless of their infant's hearing status.

Figure 3 shows the average utterance durations in NH mothers' speech to NH infants, hearing-impaired infants with CIs, and a NH adult. A 2 (speech type: ID vs. AD) x 3 (infant hearing status: CI, H-EM, and H-AM) repeated measures ANOVA revealed a significant main effect of speech type, $F(1, 24) = 109.10$, $p < .0001$, $\eta_p^2 = .82$. There was no main effect of infant hearing status and no interaction between speech type and infant hearing status. Mothers' utterances were shorter in duration when speaking to their infant than to an adult experimenter, regardless of infant hearing status.

Figure 4 shows the average duration of pauses between utterances in NH mothers' speech to NH infants, hearing-impaired infants with CIs, and a NH adult. A 2 (speech type: ID vs. AD) x 3 (infant hearing status: CI, H-EM, and H-AM) repeated measures ANOVA revealed a significant main effect of speech type, $F(1, 24) = 14.21$, $p = .001$, $\eta_p^2 = .37$, and a significant interaction between speech type and infant hearing status, $F(2, 24) = 4.74$, $p = .018$, $\eta_p^2 = .28$. There was no main effect of infant hearing status. Two-tailed t-tests revealed a marginally significant difference in the size of the change in pause duration between ID and AD speech when comparing CI versus H-AM infants, $t(16) = 1.76$, $p = .098$, Cohen's $d = 0.82$, and a statistically significant difference in the size of the change in pause duration between ID and AD speech when comparing H-EM versus H-AM infants, $t(16) = 2.20$, $p = .043$, Cohen's $d = 1.04$. However, there was no difference in the size of the pause duration change between ID and AD speech when comparing speech to CI and H-EM infants. Mothers' pauses between utterances were longer when directed to infants than adults, and this difference was more pronounced in mothers of the NH chronological age-match infants compared to mothers of NH hearing experience-match infants and hearing-impaired infants with CIs.

A 2 (speech type: ID vs. AD) x 3 (infant hearing status: CI, H-EM, and H-AM) repeated measures ANOVA on the total number of discrete utterances in a two-minute sample revealed a significant main effect of speech type, $F(1, 24) = 109.23$, $p < .0001$, $\eta_p^2 = .82$. There was no main effect of infant hearing status and no interaction between speech type and infant hearing status. A separate ANOVA on the average number of words per utterance revealed a significant main effect of speech type, $F(1, 24) = 137.16$, $p < .0001$, $\eta_p^2 = .85$, and a significant interaction between speech type and infant hearing status, $F(2, 24) = 5.85$, $p = .009$, $\eta_p^2 = .33$. There was no main effect of infant hearing status. The pattern of results were similar to those of utterance duration, depicted in Figure 3. Two-tailed t-tests revealed a statistically significant difference in the size of the change in number of words per utterance between ID and AD speech when comparing CI versus H-AM infants, $t(16) = 3.22$, $p = .005$, Cohen's $d = 1.61$, and when comparing CI and H-EM infants, $t(16) = 2.79$, $p = .013$, Cohen's $d = 1.40$. There was no significant difference when comparing speech to H-EM versus H-AM infants. In sum, mothers produced more discrete utterances but fewer words per utterance when speaking to their infant than to an adult experimenter. Moreover, the difference in words per utterance was most pronounced in mothers' speech to CI infants and children.

Finally, Figure 5 shows the speaking rate of NH mothers' speech to NH infants, hearing-impaired infants with CIs, and a NH adult. A 2 (speech type: ID vs. AD) x 3 (infant hearing status: CI, H-EM, and H-AM) repeated measures ANOVA revealed a significant main effect of speech type, $F(1, 24) = 6.36$, $p = .019$, $\eta_p^2 = .21$, and a marginally significant interaction between speech type and infant hearing status, $F(2, 24) = 3.16$, $p = .061$, $\eta_p^2 = .21$. There was no main effect of infant hearing status. Two-tailed t-tests revealed a statistically significant difference in the size of the change in speaking rate between ID and AD speech when comparing CI versus H-AM infants, $t(16) = 2.43$, $p = .027$, Cohen's $d = 1.15$, and a marginally significant difference in the size of the change in speaking rate between ID and AD speech when comparing H-EM versus H-AM infants, $t(16) = 1.82$, $p = .088$, Cohen's $d = 0.86$. There was no significant difference when comparing speech to CI and H-EM infants. Thus, mothers' speaking rate was slower when directed to infants than adults. Moreover, this difference was most pronounced in mothers' speech to hearing-impaired infants with CIs.

Discussion

As expected from previous literature (Fernald et al., 1989; Grieser & Kuhl, 1988; Kitamura & Burnham, 2003; Kitamura et al., 2002; Stern et al., 1983), the results of the present study revealed that the average, minimum, and maximum F_0 levels were higher in ID speech than AD speech across the three infant groups. Similarly, F_0 range and standard deviation were expanded in ID speech compared to AD speech. Utterances were shorter in duration but inter-utterance pauses were longer in duration in ID speech than AD speech, regardless of infant hearing status. Finally, mothers produced a greater number of discrete utterances in the two-minute sample but produced fewer words within utterances when talking to infants than to adults. Thus, mothers adjusted their speaking style when talking to their 3- to 37-month-old NH infants and hearing-impaired infants with CIs compared to adults.

The results of our analyses also showed that mothers increased their average pitch level more when talking to younger NH infants (3-18 months of age) than to older NH infants (10-37 months of age), as compared to AD speech. Strikingly, the increase in average and minimum pitch from AD to ID speech in mothers' speech to CI infants approximated the pitch increases in speech to hearing experience-matched H-EM infants more closely than the chronological age-matched H-AM infants. Although the interaction between speech type and infant hearing status was not significant for the measures of maximum pitch level and pitch variability, the pattern of results was similar to the average and minimum F_0.

Mothers decreased the duration of their utterances approximately the same amount when talking to infants compared to AD speech, regardless of infant hearing status. Similarly, the increase in number of utterances from AD to ID speech was similar across groups. Although these measures were significantly different in speech directed to infants and adults, they were not affected by infant age or infant hearing status.

The utterance duration decrease from AD to ID speech could be influenced by two factors, number of words per utterance and speaking rate. We found that mothers used fewer words per utterance but a slower speaking rate when addressing infants than adults, suggesting that utterance duration is affected more by the number of words than the speaking rate. Moreover, the size of the differences in these measures was most pronounced in mothers' speech to hearing-impaired infants with CIs. Mothers of CI infants and children used more words per utterance when speaking to another adult than mothers of NH infants and children, whereas the number of words in the ID conditions remained generally the same across hearing level. On the other hand, mothers' speaking rates were similar in all AD speech conditions but decreased when talking to CI infants and children as compared to NH infants and children. Interestingly, a recent study of deaf children who use CIs reported that their speaking rates were slower than NH children (Burkholder & Pisoni, 2003). Moreover, speaking rates were correlated with other language and cognitive skills. These differences may reflect early auditory experiences such as ID speech input at home.

Pause duration in ID and AD speech was influenced by age and hearing status of the infant listener. Mothers produced much longer pauses in ID speech when talking to older than younger NH infants. This pattern of allowing children extra time to respond might reflect a strategy that mothers use in conversations with older children to teach them when it is appropriate to take a conversational turn. Additionally, the size of the change in pause duration was more similar in mothers' speech to CI infants and hearing experience-matched infants than chronological age-matched infants. Perhaps mothers of younger NH infants and CI infants with less hearing experience than the H-AM infants pause for a shorter period of time between utterances because they do not expect the infant to respond back to them.

In summary, although the chronological ages of the NH hearing-age-match infants and CI infants varied quite dramatically, the average difference in several acoustic measures examined in this study between AD and ID speech for these two groups of infants was more similar than the average difference in these acoustic measures between the NH chronological-age-match and CI infants. In fact, in no case was the average difference between ID and AD speech more similar for the H-AM and CI groups than for the H-EM and CI groups. Thus, mothers' speech to infants appears to be controlled by the infants' "hearing experience" rather than chronological age.

Three factors that could affect the characteristics of maternal speech are communication method, age at implantation, and the presence of older siblings. Although our CI sample included a wide range of demographics, our sample size was too small to statistically examine these individual effects. Four of the CI infants were immersed in the Oral Communication (OC) method, and five were immersed in the Total Communication (TC) method. OC emphasizes aural/oral communication, whereas TC uses simultaneously signed and spoken English. Previous studies have demonstrated better speech recognition and intelligibility outcomes for OC than TC children who use CIs (Bergeson et al., 2003, 2005; Cullington, Hodges, Butts, Dolan-Ash, & Balkany, 2000; Kirk, Miyamoto, Ying, Perdew, & Zuganelis, 2002; Kirk, Pisoni, & Miyamoto, 2000; Lachs, Pisoni, & Kirk, 2001). In our small sample, mothers who use only spoken language and mothers who use simultaneously signed and spoken language made similar adjustments in their speech when talking to their hearing-impaired infants with CIs compared to NH adults. However, future studies with a larger sample of CI infants and children who use OC and TC are needed to determine whether communication method does in fact influence maternal speech.

Another factor that has been found to influence speech and language outcomes in children with CIs is age at implantation. Children who are implanted earlier in life consistently demonstrate better speech and language skills than children implanted later in life (Bergeson et al., 2003, 2005; Holt, Svirsky, Neuburger, & Miyamoto, 2004; Kirk et al., 2002; Kirk et al., 2000; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000). The present study demonstrated that duration of auditory experience affects mothers' speech to infants with CIs. Presumably mothers are sensitive to their infants' auditory experience and thus tailor their speech to infants' auditory skill levels. These results further suggest that infants implanted at an earlier age would be exposed to maternal ID speech that more closely resembles the speech style used with their same-age NH peers than infants implanted at a later age, which could subsequently affect the course of CI infants' language development.

Another variable that could have influenced the pattern of results is the existence of siblings. It is possible that mothers speak differently to infants who have older siblings compared to first-born infants. This is particularly important when discussing mothers' speech to implanted infants. Mothers who have had no experience interacting with typically developing infants prior to rearing a hearing-impaired infant with a CI may not know how a child usually responds in certain communicative situations. In the present study, seven of the CI infants (78%) had older siblings, six of the H-AM infants had older siblings (67%), and four of the H-EM infants had older siblings (44%). The two groups with the biggest difference in number of older siblings (CI and H-EM) were the two with the most acoustic similarities in ID and AD speech comparisons. Although it is unlikely that the presence of older siblings played a role in these results, future studies that control for sibling order are needed.

The acoustic characteristics of ID speech that were measured in the present study represent only a small subset of possible features that distinguish ID and AD speech to NH and CI infants. For example, another potentially interesting acoustic parameter that we plan to measure is hyperarticulation of vowels. Previous researchers have argued that mothers hyperarticulate their vowels when speaking to their infants but not adults or pets because of their perceived language development (Burnham et al., 2002; Kuhl et al., 1997). Based on their findings, we might expect amount of hearing experience to influence vowel formant expansion in mothers' speech to infants and children with CIs. It would also be interesting to measure the change across time in mothers' speech to hearing-impaired infants as they gain experience with a CI. We are currently recording mothers speaking to their infants prior to implantation and 3, 6, and 12 months post-implantation.

The results of the present study are both clinically and theoretically significant. ID speech quality has been linked to infants' development of language and other cognitive skills (Kaplan et al., 2002; Liu et al., 2003; Pressman et al., 1999; Spencer & Meadow-Orlans, 1996). Importantly, measures as simple as number and diversity of parental utterances that infants are exposed to predict vocabulary growth and language development several years later (Hart & Risley, 1995; Pan et al., 2005). Additionally, expanded vowel space in mothers' ID speech is related to their infants' speech discrimination abilities (Liu et al., 2003). Recent studies have also shown that very early auditory and audiovisual experiences and activities have significant effects on NH and hearing-impaired children's development of speech perception and language skills (e.g., Bergeson et al., 2003, 2005; Kuhl, Conboy, Padden, Nelson, & Pruitt, 2005; Yoshinaga-Itano et al., 1998). Studies of hearing-impaired children with CIs simply group them into broad dichotomous categories such as Oral Communication (i.e., auditory/verbal communication) versus Total Communication (i.e., simultaneously signed and spoken English) and Early-implanted versus Late-implanted. Although differences in speech and language performance across these groups have been informative and clinically useful, there is still a great deal of variability within these broad categories and it is unclear exactly what types of specific experiences and activities children in each group are receiving. Thus, it is extremely important to investigate other factors that may underlie the observed variability. Further studies of mothers' vocal communication styles while interacting with their hearing-impaired infants and children with CIs should contribute greatly to understanding the large variability in speech and language outcome measures. Our findings could also be used to develop the optimal speech therapy tools to increase speech perception and language performance in hearing-impaired infants and children who receive CIs.

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Table 1

CI Infant Demographic Information

Subject	Chronological age (months)	Hearing experience (months)	Sex	Communication method	Device	Etiology	CDI: Words produced
19	10.3	3.2	F	TC	Med-El C40t	Unknown	8
16	17.5	3.5	M	OC	Nucleus 24	Genetic	47
14	19.8	7.1	M	TC	Nucleus 24	Unknown	56
10	23.0	12.6	M	OC	Nucleus 24	Aud. Neur.	28
12	23.2	6.2	M	TC	Nucleus 24	Unknown	34
03	23.4	12.2	F	OC	Nucleus 24	Unknown	48
20	32.2	16.1	M	TC	Med-El C40t	Meningitis	230*
21	37.0	6.0	F	TC	Nucleus 24	Mondini	60
08	37.1	18.0	F	OC	Nucleus 24	Unknown	160*

Note: All Words Produced scores are from the MacArthur-CDI Words and Gestures test with the exception of those marked with an asterisk, which are from the MacArthur-CDI Words and Sentences test.

Table 2

NH Infant Demographic Information

Subject	Chronological age (months)	Gender	CI infant match
H-AM			
438	10.4	Female	19
281	17.3	Female	16
117	19.8	Female	14
153	22.9	Male	10
165	23.3	Male	12
214	23.6	Female	03
422	32.0	Female	20
242	37.1	Female	21
279	37.3	Female	08
H-EM			
401	2.8	Female	19
366	3.9	Male	16
423	7.2	Female	14
343	12.5	Male	10
408	6.3	Female	12
339	11.5	Female	03
1001	6.0	Male	20
411	16.0	Female	21
198	17.9	Male	08

Table 3

Results for Two Hypotheses across Dependent Measures

	ID speech to CI infants similar to H-EM controls	ID speech to CI infants similar to H-AM controls
Fundamental frequency (F_0)	✔	
Minimum F_0	✔	
Maximum F_0		
F_0 range		
F_0 standard deviation		
Utterance duration		
Pause duration	✔	
Number of utterances		
Words per utterance		
Speaking rate	✔	

Figure Captions

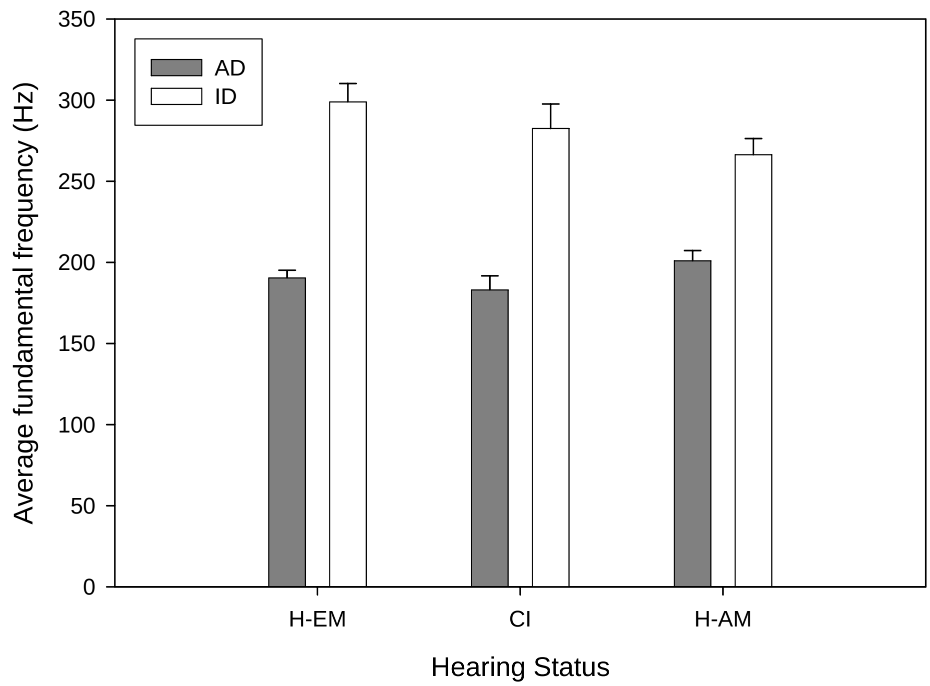
Figure 1. Average F_0 in normal-hearing mothers' speech to hearing-impaired infants with cochlear implants (CI), normal-hearing infants matched by chronological age (H-AM) and hearing experience (H-EM), and a normal-hearing adult experimenter. Error bars represent standard error.

Figure 2. F_0 standard deviation averaged across normal-hearing mothers' speech to hearing-impaired infants with cochlear implants (CI), normal-hearing infants matched by chronological age (H-AM) and hearing experience (H-EM), and a normal-hearing adult experimenter. Error bars represent standard error.

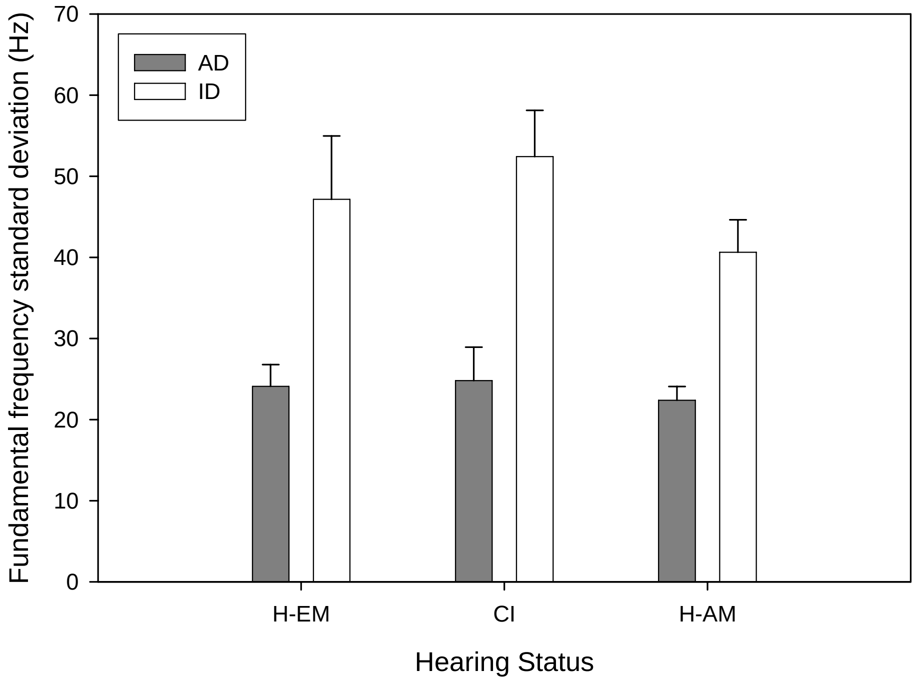
Figure 3. Utterance duration averaged across normal-hearing mothers' speech to hearing-impaired infants with cochlear implants (CI), normal-hearing infants matched by chronological age (H-AM) and hearing experience (H-EM), and a normal-hearing adult experimenter. Error bars represent standard error.

Figure 4. Pause duration averaged across normal-hearing mothers' speech to hearing-impaired infants with cochlear implants (CI), normal-hearing infants matched by chronological age (H-AM) and hearing experience (H-EM), and a normal-hearing adult experimenter. Error bars represent standard error.

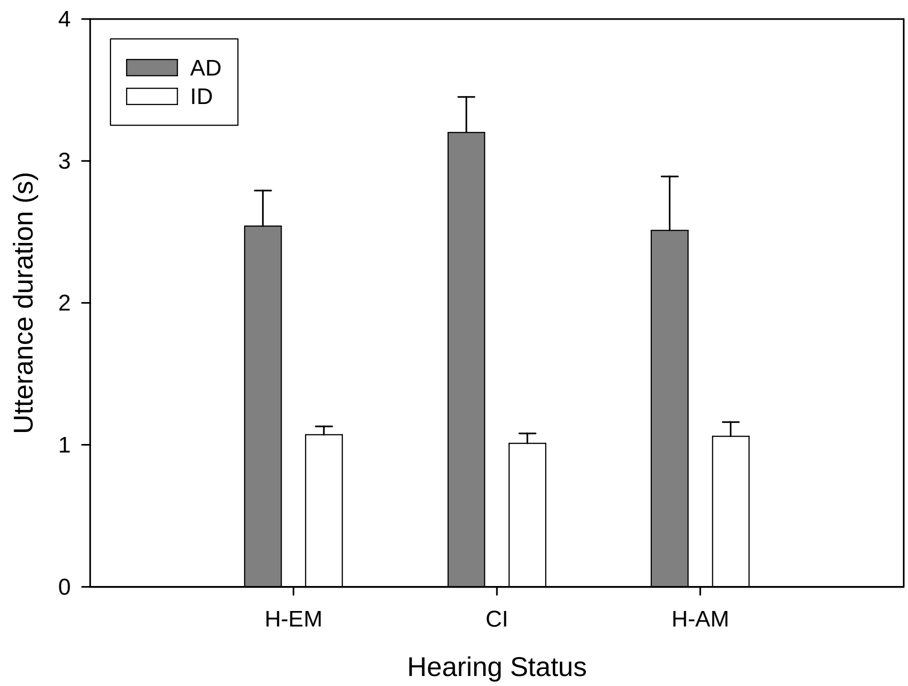
Figure 5. Speaking rate averaged across normal-hearing mothers' speech to hearing-impaired infants with cochlear implants (CI), normal-hearing infants matched by chronological age (H-AM) and hearing experience (H-EM), and a normal-hearing adult experimenter. Error bars represent standard error.

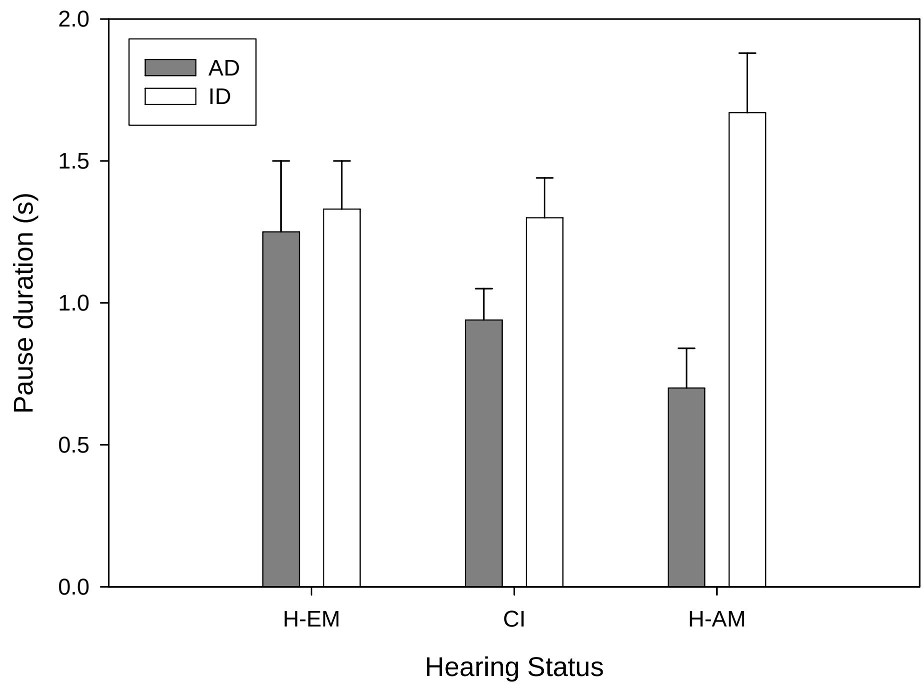


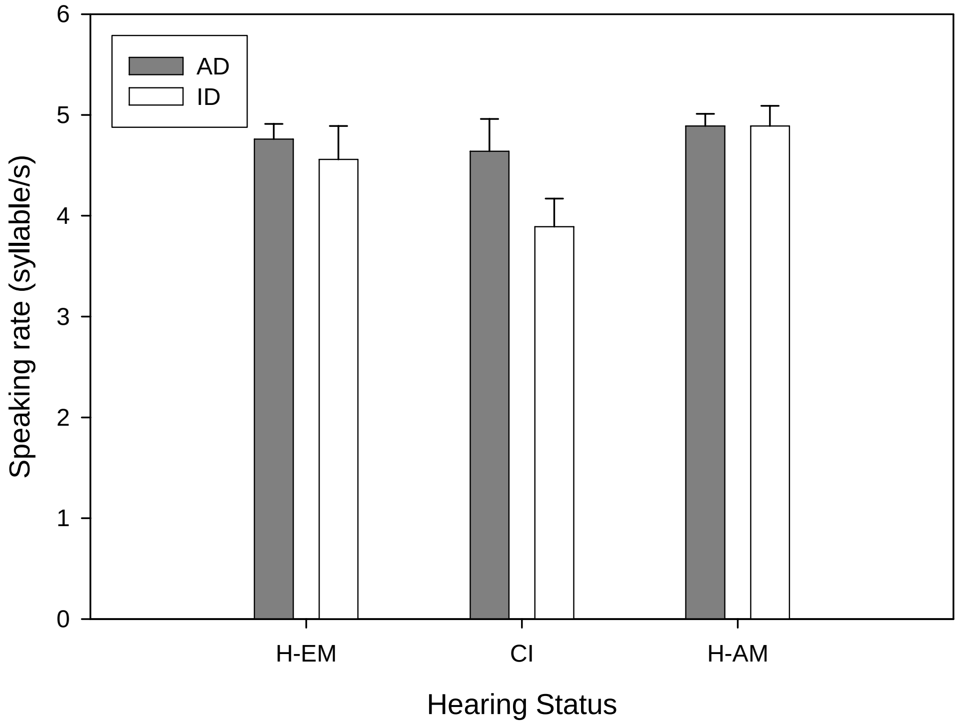
350
300
250
200
150
100
50
0
Average fundamental frequency (Hz)
AD
ID
H-EM
CI
H-AM
Hearing Status



70
60
50
40
30
20
10
0
Fundamental frequency standard deviation (Hz)
AD
ID
H-EM
CI
H-AM
Hearing Status


4
3
2
1
0
Utterance duration (s)
AD
ID
H-EM
CI
H-AM
Hearing Status


2.0
1.5
1.0
0.5
0.0
AD
ID
Pause duration (s)
H-EM
CI
H-AM
Hearing Status


6
5
4
3
2
1
0
AD
ID
Speaking rate (syllable/s)
H-EM
CI
H-AM
Hearing Status