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Age-related changes in prosodic features of maternal speech to prelingually deaf infants with cochlear implants

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Abstract

This study investigated prosodic and structural characteristics of infant-directed speech to hearing-impaired infants as they gain hearing experience with a cochlear implant over a 12-month period of time. Mothers were recorded during a play interaction with their HI infants (N = 27, mean age 18.4 months) at 3, 6, and 12 months post-implantation. Two separate control groups of mothers with age-matched normal-hearing infants (NH-AM) (N = 21, mean age 18.1 months) and hearing experience-matched normal-hearing infants (NH-EM) (N = 24, mean age 3.1 months) were recorded at three testing sessions. Mothers produced less exaggerated pitch characteristics, a larger number of syllables per utterance, and faster speaking rate when interacting with NH-AM as compared to HI infants. Mothers also produced more syllables and demonstrated a trend suggesting faster speaking rate in speech to NH-EM relative to HI infants. Age-related modifications included decreased pitch standard deviation and increased number of syllables in speech to NH-AM infants and increased number of syllables in speech to HI and NH-EM infants across the 12-month period. These results suggest that mothers are sensitive to the hearing status of their infants and modify characteristics of infant-direct speech over time.

Keywords

infant-directed speech; cochlear implants; prosody

INTRODUCTION

The introduction of universal hearing screening programs in the United States allowed for the identification of hearing loss in newborn infants. Clinical interventions consist of fitting infants with assistive devices such as hearing aids or cochlear implants that provide them with access to spoken language (American Speech-Language-Hearing Association, 2003). Previous research has identified several major predictors of speech and language outcomes in infants and children with prelingual hearing loss who received CIs such as age at implantation (Bergeson, Pisoni, & Davis, 2003, 2005; Holt, Svirsky, Neuburger, &

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Miyamoto, 2004; Kirk, Miyamoto, Ying, Perdew, & Zuganelis, 2002; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000) and type of therapeutic intervention (oral communication versus total communication methods) (Bergeson et al., 2003, 2005; Cullington, Hodges, Butts, Dolan-Ash, & Balkany, 2000; Kirk et al., 2002). A growing body of evidence suggests that an important predictor of language skills in normal-hearing infants is the nature of the spoken language input (Hart & Risley, 1995; Hurtado, Marchman, & Fernald, 2008; Liu, Kuhl, & Tsao, 2003). However, very little is known about the features of maternal speech to pre-verbal infants who receive cochlear implants and their developmental functions across time. The present study takes the first step by reporting the prosodic and structural characteristics of maternal infant-directed speech (IDS) to prelingually deaf infants across the first twelve months of cochlear implant use and compares these characteristics to those in maternal speech to normal-hearing infants matched by chronological age and hearing experience.

Speech to normal-hearing infants and children is characterized by a number of salient features across languages and talkers (e.g., men and women). One of its most distinctive features is exaggerated prosody, manifested through higher pitch, greater pitch variability, more repetition, slower tempo, and longer vowels and pauses in comparison to adult-directed speech (ADS) (Bernstein Ratner, 1986; Grieser & Kuhl, 1988; Fernald & Simon, 1984; Fernald, Taeschner, Dunn, Papousek, & de Boysson-Bardies, 1989; Kitamura, Thanavishuth, Burnham, & Luksaneeyanawin, 2002; Papousek, Papousek, & Haekel, 1987; Stern, Spieker, Barnett, & MacKain, 1983). At the segmental level, IDS is also characterized by expanded acoustic vowel space (Burnham, Kitamura, & Vollmer-Conna, 2002; Kuhl et al., 1997; Liu, Tsao & Kuhl, 2009). At the structural level, IDS typically exhibits shorter (Fernald & Mazzie, 1991; Snow, 1977) and structurally simpler utterances (Soderstrom, Blossom, Foygel, & Morgan, 2008, but see Newport, Gleitman, & Gleitman, 1977 for discussion).

Recent studies of IDS to hearing-impaired infants pre- and post-implantation found that exaggeration of prosodic features of IDS occurs in mothers’ speech to infants and children with different hearing status (Bergeson, Miller, &McCune, 2006; Kondaurova & Bergeson, 2011). Bergeson and colleagues (2006) demonstrated that mothers employed higher pitch with more exaggerated pitch range, slower speaking rate, shorter utterance duration, longer pauses, more discrete utterances, and fewer words per utterance in speech directed to hearing-impaired infants who had used a cochlear implant for three to eighteen months than to adults. The results of the study also showed that such prosodic characteristics as pitch level, pause duration and speaking rate were more similar in speech to hearing-impaired and normal-hearing infants matched by hearing experience rather than chronological age, suggesting that the hearing status of the child determines the degree of modifications of these characteristics in IDS of normal-hearing mothers.

Another study (Kondaurova & Bergeson, 2011) examining prosodic cues to clause boundaries (pause duration, preboundary vowel lengthening, and pitch change) in speech to prelingually deaf infants prior to and 6 months post-implantation demonstrated that all cues were exaggerated in speech to hearing-impaired infants at both sessions. The results of the study also demonstrated that mothers tailored preboundary vowel lengthening in speech to hearing-impaired and normal-hearing infants matched by hearing experience rather than chronological age, thus extending the findings in the Bergeson et al. (2006) study to another set of prosodic cues.

The combined results of these studies suggest that mothers modify prosodic characteristics of their speech to prelingually deaf infants and children as well as to infants and children who have been using cochlear implants for several months compared to speech to an adult.

Moreover, mothers adjust some prosodic characteristics to the hearing experience rather than chronological age of their infants. However, it is not yet known how the modification of features of IDS changes across time (Bergeson et al., 2006; Kondaurova & Bergeson, 2011).

Why do mothers exaggerate prosodic characteristics in IDS relative to ADS in such a universal manner even when addressing prelingually deaf infants and children? Research on modification of prosodic features of maternal speech to normal-hearing infants provides some clues to this question. Previous studies suggested that the exaggeration of prosody may modulate infants' attention and arousal level (Fernald & Simon, 1984; Papousek, Bornstein, Nuzzo, Papousek, & Symmes, 1990; Stern et al., 1983), communicate maternal affect, facilitate social interaction (Fernald, 1989; Fernald, 1992; Kitamura & Burnham, 2003) and, finally, support language acquisition (Graf Estes & Hurley, 2012; Fernald & Mazzie, 1991; Gleitman, Gleitman, Landau, & Wanner, 1988; Hirsh-Pasek et al., 1987; Kempler Nelson, Hirsh-Pasek, Jusczyk, & Wright Cassidy, 1989; Liu, et al., 2009; Song, Demuth, & Morgan, 2010; Seidl, 2007; Thiessen, Hill, & Saffran, 2005).

Previous studies on the prosodic characteristics of speech to normal-hearing infants and children also suggest that the degree of exaggeration of these properties in IDS is reduced over time, probably reflecting changes in the functions of IDS over the course of infants' cognitive and linguistic development (Kitamura et al., 2002; Liu, et al., 2009; Stern, et al., 1983). However, the association between the extent of modification of prosodic features in IDS and infant age is not straightforward, especially during the first year of life (Kitamura & Burnham, 2003; Kitamura et al., 2002; Stern et al., 1983). For example, Stern and colleagues (1983) demonstrated that prosodic characteristics of IDS of American English mothers were more exaggerated in speech to 4-month-old infants as compared to newborns or 1- and 2-year-old children. They suggested that the reason for such findings was the particular stage of the child's linguistic development: 4-month-olds respond to greater acoustic exaggeration as compared to newborns in interactions with their mothers. When infants grow older, mothers decrease the degree of modification of prosodic characteristics, presumably, because they can attract attention and convey affect in new and different ways with older infants. Studies of IDS with Australian English and Thai mothers (Kitamura & Burnham, 2003; Kitamura et al., 2002) showed that pitch modifications during infants' first year of life depend on mothers' communicative intent. That is, mothers increased pitch levels in speech to 6- and 12-month-olds to convey positive affect. They also produced more directive utterances with lower pitch and more expanded pitch range to their 9-month-olds, presumably to encourage their infants to attend to speech sounds. In summary, these studies suggest that during the first year of infants' life the modifications of prosodic characteristics in maternal speech to normal-hearing infants are determined by changes in their attentional, affective and linguistic functions (Fernald, 1989; Kitamura & Burnham, 2003; Kitamura et al., 2002; Stern et al., 1983).

Despite the availability of evidence on age-related changes in the prosodic characteristics of speech directed to normal-hearing infants (Kitamura & Burnham, 2003; Kitamura et al., 2002; Liu, et al. 2009; Stern et al., 1983) and the importance of prosody for children's linguistic and cognitive development (Fernald, 1992; Fernald, 1989; Fernald & Mazzie, 1991; Fernald & Simon, 1984; Gleitman, et al., 1988; Hirsh-Pasek et al., 1987; Kempler Nelson, et al., 1989; Thiessen, et al, 2005; Papousek, et al., 1990; Seidl, 2007; Stern et al., 1983) there has been little research examining the modification of these characteristics across time in maternal speech to hearing-impaired infants or children. A recent case study by Lam & Kitamura (2010) demonstrated that a mother decreased her pitch level as her hearing-impaired child wearing hearing aids became older. However, no difference in pitch characteristics was identified when comparing speech to the hearing-impaired child and his normal-hearing twin brother across time (Lam & Kitamura, 2010).

The goal of this study was to evaluate age-related changes in the production of prosodic and structural characteristics (mean pitch level, pitch range and standard deviation, number of syllables per utterance and speaking rate) in mothers' speech to hearing-impaired infants across the first year of cochlear implant use and compare them to the same characteristics in speech to normal-hearing infants matched by chronological age and hearing experience. Based on previous longitudinal research on maternal speech to normal-hearing and hearing-impaired infants (Bergeson, et al., 2006; Kitamura & Burnham, 2003; Kitamura et al., 2002; Kondaurova & Bergeson, 2011; Lam & Kitamura, 2010; Stern et al., 1983) we expected that mothers would decrease mean pitch characteristics over time to both normal-hearing and hearing-impaired infants. However, as no previous research has investigated the modification of prosodic/structural characteristics over time in IDS to hearing-impaired infants with cochlear implants, it was difficult to predict exactly which characteristics would be modified and to what extent. We also expected that the degree of modification of mean pitch level and speaking rate would be more similar in IDS to hearing-impaired infants with cochlear implants and normal-hearing infants matched by hearing experience rather than by chronological age (Bergeson, et al., 2006).

METHOD

Participants

Normal-hearing mothers of infants and children with profound hearing loss who were candidates for cochlear implantation (HI group, n = 27, age range 13 – 27.6 months) 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. The HI group of participants was invited for three visits at 3, 6, and 12 months after cochlear implant stimulation. Table 1 shows the number of mother-infant dyads, the mean age and gender of hearing-impaired infants who completed testing at each session. Thirteen infants in this group were enrolled in education programs using oral communication. Table 2 provides available information on communication method, deafness etiology and the type of cochlear implant device for each infant in the hearing-impaired group.

Normal-hearing mothers of normal-hearing age-matched infants (NH-AM group, n = 21, age range 10.9 – 26.9 months) were recruited from the local community and were reimbursed $10 per visit (see Table 1 for details). They were invited for three sessions: the first session coincided (in infants' age) with the first visit of hearing-impaired infants, the second and third sessions were at approximately 3 and 9 months after the first visit, corresponding to the 6- and 12-month post-CI sessions of the HI group. These infants were the same chronological age as hearing-impaired infants at the time of each visit.

Normal-hearing mothers of normal-hearing experience-matched infants (NH-EM group, n = 24, age range 2.3 – 4.1 months) were recruited from the local community and were reimbursed $10 per visit (see Table 1 for details). They were invited for three sessions: at approximately 3, 6 and 12 months of age. These infants were matched with hearing-impaired infants by approximately the same period of hearing experience at the time of each visit.

On average, mothers in the hearing-impaired infant group were 31.1 years old (*SD* = 5.8), mothers in the normal-hearing age matched infant group were 30.4 years old (SD = 10.1) and mothers in the normal-hearing experience matched infant group were 31.3 years old (SD

= 5.9). In the hearing-impaired infant group eight mothers had high school degrees and nineteen had college degrees (associate, bachelor, master or higher). In the normal-hearing age-matched infant group two mothers had high school degrees and eleven had college degrees, information on eight mothers was unavailable as they participated prior to the lab's routine collection of data on education level and did not respond to attempts to contact them. In the normal-hearing experience-matched infant group eight mothers had high school degrees and sixteen had college degree. This research and the recruitment of human subjects were approved by the Indiana University Institutional Review Board.

Procedure

Recordings—Mothers were digitally recorded speaking to their infants and an adult experimenter in a double-walled, copper-shielded sound booth (Industrial Acoustics Company). In the infant-directed condition (Infant-Directed Speech, IDS) mothers were asked to sit with their child on a blanket on the floor or a chair. Mothers were instructed to speak to their child as they normally would do at home while playing with quiet toys. In the adult-directed condition (Adult-Directed Speech, ADS), an adult experimenter conducted a semi-structured short interview with each mother. Each IDS and ADS session lasted approximately 4–5 minutes. The order of IDS and ADS recordings was counterbalanced across mothers. Mothers' speech was recorded in one of two ways: (a) a hypercardioid microphone (Audio-Technica ES933/H) powered by a phantom power source and linked to an amplifier (DSC 240) and digital audio tape recorder (Sony DTC-690) or (b) an SLX Wireless Microphone System (Shure). This system included an SLX1 Bodypack transmitter with a built-in microphone and a wireless receiver SLX4 which was connected to a Canon 3CCD Digital Video Camcorder GL2, NTSC. The speech samples were recorded directly onto a Mac computer (Apple, Inc. OSX Version 10.4.10) via Hack TV (Version 1.11) software.

In total, there were 253 recordings (IDS condition: HI group = 70 recordings; NH_AM group = 55 recordings; NH_EM group = 56 recordings; ADS condition: HI group = 27 recordings; NH_AM group = 21 recordings; NH_EM group = 24 recordings). We examined 25 utterances taken 60 s after the beginning of the recording from each mother speaking to her infant at three recording sessions and speaking to an adult experimenter at the time of the first visit. For a few cases in which too few utterances were produced, the entire recording was used for the analysis. Table 3 presents the number of utterances produced in each group for both IDS and ADS conditions.

Any utterances interrupted by background noises or by the infant vocalizations (e.g., baby crying, vocalizing, hiccups etc.) were omitted from the analysis. We also excluded mothers' paralinguistic vocalizations bearing non-semantic meaning (e.g., *Umm, Oh* and *Ah*), utterances produced with a creaky voice, in a whispered voice, or too quietly, as well as non-speech behavior (e.g., laughter, kissing, singing).

Syntactic Coding—We completed syntactic coding of utterances in IDS and ADS using the Systematic Analysis of Language Transcripts (SALT), Research V8 software (Miller & Iglesias, 1984). Utterances were segmented following the Communication Units guidelines in which an utterance is defined as "an independent clause and its modifiers" (SALT, Miller & Iglesias, 1984, Appendix E, p. 121) that cannot be further divided without losing its essential meaning. In questionable cases (primarily in ADS), criteria such as pause duration and falling/rising intonation contours were also employed to identify utterance boundaries.

We used the PRAAT 5.0.21 editor (Boersma & Weenink, 2005) to create one text tier along the spectrogram and waveform of each mother's speech sample. The text tier had boundaries that corresponded with each utterance (i.e., the onset and offset of the initial and final consonants/vowels). Consonant/vowel onsets and offsets were identified by eye based on the waveform display; we used the spectrogram to confirm the segmentation decisions. These decisions were based on previously published methodology for acoustic measurements (Hillenbrand, Getty, Clark, & Wheeler, 1995; Ladefoged, 2001). If it was impossible to identify vowel and consonant onsets or offsets at the beginning of the preboundary syllable or the end of the postboundary syllable due to a coarticulation effect in fluent speech (primarily in ADS due to the faster speaking rate), the midpoint region was chosen.

Acoustic Analyses and Measurements

Pitch Characteristics: Average fundamental frequency (F0 mean, Hz), maximum F0 (Hz) minimum F0 (Hz) and standard deviation F0 SD (Hz) were measured for each utterance. Pitch range (F0 range, Hz) was calculated as a difference between maximum and minimum F0 (Hz) of each utterance.

Syllables per Utterance: We measured the number of syllables in each utterance.

Speaking Rate: We divided the number of syllables in each utterance by utterance duration. Utterance Duration (in seconds) was measured from the onset of the initial consonant/vowel in an utterance to the offset of the final consonant/vowel in an utterance

Pitch Conversion to Semitones and Normalization Procedure—We converted pitch range values from absolute Hertz values to ratio pitch values using the semitone scale (12 semitones = one octave, semitones = $12 \log_2(\text{F0 maximum} - \text{F0 minimum})$. The conversion from Hertz to semitones was applied only to F0 range values as previous studies examining IDS and ADS (Fernald & Simon, 1984; Fernald et al., 1989; Grieser & Kuhl, 1988) used semitones for F0 range and Hertz for other measures (mean F0, maximum F0 and minimum F0).

Due to the potential within-speaker variability in speech production (Crystal & House, 1982; Bradlow, Torretta, & Pisoni, 1996; Johnson, Ladefoged, & Lindau, 1993; Kitamura et al., 2002), we normalized F0 mean, F0 range, and F0 SD in the following manner. First, we calculated average F0 mean, F0 range (in semitones) and F0 SD from each mothers' ADS sample. A proportion was then derived by dividing each measure (F0 mean, F0 range, F0 SD) of each IDS utterance of each mother at every session by her average adult levels of these measures. This should result in values greater than 1 for features of IDS that are greater than the features of ADS, and in values less than 1 for features of IDS that are less than the features of ADS.

In addition, because of individual differences in the length of utterances and the number of syllables that are produced during sample collection that could affect Speaking Rate, we ran two one-way ANOVAs with Group (*CI, NH-AM, NH-EM*) as a between-group variable for Utterance Duration and Syllables per Utterance in ADS to examine whether there was a difference between the three groups of mothers that could potentially affect the results of IDS. The analysis demonstrated no significant differences among the three groups (Utterance Duration: $F(2, 69) = 0.47$, $p = 0.62$; Syllables per Utterance: $F(2, 69) = 1.37$, $p = 0.26$), suggesting that mothers in these groups were matched in the length of utterances as well as the number of syllables produced in ADS.

RESULTS

The analysis examined two questions. First, we investigated whether prosodic and structural characteristics differed in speech to (a) HI vs. NH-AM infants and (b) HI vs. NH_EM infants at each visit. Second, we examined whether prosodic and structural characteristics changed over the period of three visits in speech to each HI, NH-AM and NH-EM group.

In order to examine these questions, we applied a mixed-effects regression model (MRM) (Hedeker, & Gibbons, 2006, Vonesh & Chinchilli, 1997). This model employs a general form of regression analysis with both fixed and random effects using the method of restricted maximum likelihood to estimate parameters (Kleinbaum, Kupper, Muller, & Nizam, 1998; Vonesh & Chinchilli, 1997). MRMs are especially useful in longitudinal research as they allow for missing data, i.e., subjects with incomplete data across time are included into analysis. The use of a repeated-measures ANOVA in the current study would result in a substantial list-wise deletion leading to the loss of almost half of the data due to the longitudinal nature of the experiment. The MRM model, however, allowed us to include data from all participants who completed at least two sessions (see Table 1 for the number of participants in each session).

The model dimensions were as follows: (a) Fixed Effects: Intercept, Visit (*First, Second, Third*), Group (*HI, NH-AM, NH-EM*), and Visit x Group interaction, (b) Repeated Effects: Visit (*First, Second, Third*), and (c) Covariance Structure: Compound symmetry. The MRM model calculated estimates of prosodic and structural characteristics based on the input data. Normalized means for pitch characteristics and means for utterance duration, number of syllables per utterance and speaking rate served as input into the MRM model. Table 4 presents both non-normalized and normalized means for pitch characteristics (F0 mean, F0 range, F0 SD) and means for utterance duration, number of syllables per utterance and speaking rate in speech to HI, NH-AM and NH-EM infants and to an adult experimenter.

Comparison of Prosodic and Structural Characteristics at Each Session

To compare the degree of modification of prosodic and structural characteristics of IDS between the HI and NH groups at each visit, we first calculated the estimated values of each prosodic/structural characteristic at each session using the MRM model. Then, we examined the difference (Difference Estimates) between the estimated values of prosodic/structural characteristics in speech to HI and NH-AM and HI and NH_EM groups using a Wald t-test (with Bonferroni correction at α-level = .025)[1]. Cohen's *d* effect size was obtained by dividing the predicted difference by the HI group standard deviation (Cohen, 1988). A value of 0.2 represents small effect size, 0.5 represents a moderate effect size, and 0.7 represents a large effect size. Figure 1 presents the estimated values at the three time points for each prosodic/structural characteristic.

The analysis demonstrated that for F0 mean there was a significant difference between HI and NH-AM groups at both 3-month, $t(102) = 2.63$, $p = .01$, $d = 0.79$ and 12-month, $t(102) = 2.16$, $p = .03$, $d = 0.72$ intervals. Mothers produced higher F0 mean while talking to HI infants at 3 months ($M = 1.60$, $SE = 0.05$) and 12 months ($M = 1.54$, $SE = 0.05$) post CI stimulation as compared to NH-AM infants at both Session 1 ($M = 1.41$, $SE = 0.05$) and Session 3 ($M = 1.37$, $SE = 0.06$).

For F0 range, the results demonstrated a significant difference between HI and NH-AM groups at the 12 month interval, $t(102) = 2.53$, $p = .01$, $d = 0.86$. Mothers produced a more expanded F0 range in speech to HI ($M = 1.37$, $SE = 0.08$) as compared to the NH-AM ($M = 1.05$, $SD = 0.09$) group. For F0 SD there was a strongly significant difference between HI and NH-AM groups at the 12-month interval, $t(102) = 2.96$, $p = .004$, $d = 0.94$. Mothers' speech was characterized by larger F0 standard deviation when addressing HI rather than

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[1] We report only significant and near-significant results (α-level less than or equal to .04) due to space limitations. Detailed analysis is available upon request.

NH-AM infants at the time of the third session (HI: *M* = 2.40, *SD* = 0.18; NH-AM: *M* = 1.6, *SE* = 0.2).

For Number of Syllables per Utterance there was a significant difference between the HI and NH-AM groups at the 12-month interval, *t* (102) = −2.83, *p* = .006, *d* = −0.95, suggesting that mothers in the HI group produced fewer syllables per utterance (*M* = 3.64, *SE* = 0.18) as compared to mothers in the NH-AM group (*M* = 4.44, *SE* = 0.21). The results also demonstrated a significant difference between HI and NH-EM groups at all three testing sessions: Session 1, *t* (102) = −2.93, *p* = .004, *d* = −0.86, Session 2, *t* (102) = − 3.69, *p* < .001, *d* = −1.07 and Session 3, *t* (102) = −2.20, *p* = .03, *d* = −0.75,. Mothers in the HI group produced fewer syllables per utterance at each testing session (3 months post-CI stimulation: *M* = 3.44, *SE* = 0.17; 6 months post-CI stimulation: *M* = 3.87, *SE* = 0.17; 12 months post-CI stimulation: *M* = 3.64, *SE* = 0.18) as compared to mothers in the NH-EM group (Session 1: *M* = 4.16, *SE* = 0.18; Session 2: *M* = 4.78, *SE* = 0.18; Session 3: *M* = 4.27, *SE* = 0.22).

For Speaking Rate, we found significant differences between the HI and NH-AM groups at all three testing sessions: Session 1, *t* (102) = −3.03, *p* = .003*, d* = −0.95, Session 2, *t* (102) = − 2.73, *p* = .008, *d* = −0.86 and Session 3, *t* (102) = −3.23, *p* = .002*, d* = −1.13. These results suggest that the speaking rate of mothers was faster in speech to infants in the NH-AM group (Session 1: *M* = 4.78, *SE* = 0.18; Session 2: *M* = 4.89, *SE* = 0.18; Session 3: *M* = 5.05, *SE* = 0.2) as compared to the HI group (Session 1: *M* = 4.06, *SE* = 0.16; Session 2: *M* = 4.23, *SE* = 0.16; Session 3: *M* = 4.18, *SE* = 0.18). Between the HI and NH-EM groups, we found only a marginally significant difference at the third testing session, *t* (102) = −1.99, *p* = .04, *d* = −0.71 suggesting that mothers' speaking rate was slightly faster in speech to the NH-EM group (*M* = 4.72, *SE* = 0.2) as compared to the HI group (*M* = 4.18, *SE* = 0.18).

In summary, the comparison of ID speech to HI and NH-AM groups demonstrated that pitch characteristics were more exaggerated in speech to HI as compared to NH-AM infants: F0 mean at the time of the first and third sessions, F0 range and F0 SD at the third session. Mothers produced more syllables per utterance in speech to NH-AM than to HI infants at the time of the last session and their speaking rate was faster in speech to NH-AM than to HI infants at the time of all three testing sessions.

The analysis of ID speech to HI as compared to NH-EM infants demonstrated that all pitch characteristics were similar in speech to HI and NH-EM infants. The results also demonstrated that mothers of NH-EM infants produced more syllables per utterance at each testing session than mothers of HI group. There was also a trend suggesting faster speaking rate in speech to NH-EM relative to HI infants at the time of the third testing session.

Age-Related Changes in IDS over Time

In order to evaluate the age-related changes in pitch characteristics, number of syllables and speech rate over time, we compared the estimated values from the MRM model of each prosodic and structural characteristic using F-tests at three testing sessions, separately for each infant group (*HI, NH-AM, NH-EM*). If the F-statistic was significant, suggesting that there was a difference in values of prosodic and structural characteristics between sessions, we proceeded with a Wald t-test (with Bonferroni correction at α-level = .016)[2]. Cohen's *d* effect size was again obtained by dividing the predicted difference between two sessions by the standard deviation at the earlier session.

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[2] We report only significant and near-significant results (α-level less than or equal to .02) due to space limitations. Detailed analysis is available upon request.

HI group—The results demonstrated that there was a significant difference in the number of syllables per utterance among the three testing sessions, $F(2, 102) = 4.88$, $p = .009$. Follow up t-tests demonstrated a significant difference between the first (3 months post-CI stimulation) ($M = 3.44$, $SE = 0.17$) and second (6 months post-CI stimulation) ($M = 3.87$, $SE = 0.16$) sessions, $t(102) = 2.22$, $p = .02$, $d = 0.64$. Mothers increased the number of syllables at the time of the second testing session relative to the first session.

NH-AM group—For F0 SD the results demonstrated that there was a marginally significant difference among the three testing sessions, $F(2, 102) = 2.63$, $p = 0.07$. Follow up t-tests demonstrated a significant difference between the first ($M = 2.02$, $SE = 0.18$) and the third ($M = 1.6$, $SE = 0.2$) sessions, $t(102) = 2.27$, $p = .02$, $d = 0.54$ suggesting that mothers decreased F0 SD in their speech to NH-AM infants at the third session as compared to the first session. For Number of Syllables, the results showed a significant difference among the three sessions, $F(2, 102) = 4.88$, $p = 0.009$. Follow t-tests demonstrated a significant difference, between the second ($M = 3.83$, $SE = 0.19$) and third ($M = 4.44$, $SE = 0.21$) sessions, $t(102) = 2.51$, $p = .01$, $d = 0.85$ as well as between the first (M = 3.74, SE = 0.18) and third sessions, $t(102) = 2.98$, $p = .003$, $d = 1.10$. These results suggest that mothers consistently increased the number of syllables per utterance at the time of both second and third sessions as compared to previous visits.

NH-EM group—The results demonstrated that there was a significant difference in the number of syllables among the three testing sessions, $F(2, 102) = 4.41$, $p = 0.01$. Follow up t-tests demonstrated a significant difference between the first ($M = 4.16$, $SE = 0.18$) and second ($M = 4.78$, $SE = 0.18$) sessions, $t(102) = 2.83$, $p = .02$, $d = 0.67$. These results suggest that mother increased the number of syllables at the time of the second session relative to the first one.

In summary, for both HI and NH-EM groups of infants, the results demonstrated a detectable increase in the number of syllables produced at the time of the second session relative to the first testing sessions. For the NH-AM group, mothers decreased F0 standard deviation and increased the number of syllables produced at each session.

DISCUSSION

The purpose of this study was to compare a number of prosodic and structural characteristics of maternal speech to prelingually deaf infants during the first year after receiving a cochlear implant with those produced in speech to normal-hearing infants matched by chronological age or hearing experience. We also examined age-related changes in the prosodic and structural characteristics of mothers' speech to each infant group over a twelve-month period of time.

The comparison of prosodic and structural characteristics in IDS to HI and NH-AM infants at each testing session demonstrated an expected difference between each group at all or some of the sessions. That is, F0 mean was higher, F0 range was more expanded, pitch variability (as indicated by F0 standard deviation) was larger and speaking rate was slower in speech to HI relative to NH-AM infants. Mothers also produced fewer syllables per utterance in speech to HI relative to NH-AM infants. These results agree with previous cross-sectional findings by Bergeson and colleagues (2006) that showed a more exaggerated pitch level and slower speaking rate in speech to HI infants post-implantation than to HI-AM infants. However, the current study also found a more expanded F0 range and a larger pitch variability and fewer syllables produced in speech to HI relative to NH-AM infants that Bergeson et al. (2006) study did not demonstrate.

The comparison of prosodic and structural characteristics in IDS to HI and NH-EM infants at each testing session demonstrated that all pitch characteristics were similar in speech to HI and NH-EM infants, but mothers produced more syllables in speech to NH-EM group at all testing sessions. The results also demonstrated a trend suggesting a faster speaking rate in speech to NH-EM as compared to HI group at the time of the third session. These results disagree with the results of a previous study (Bergeson et al., 2006) that found no difference in the number of words produced across three hearing conditions or speaking rate between HI and NH-EM groups.

In general, the current study demonstrated that pitch characteristics of maternal speech input, such as mean pitch, pitch range and pitch variability were more similar in speech to HI infants fitted with cochlear implants and NH-EM infants than in speech to HI infants and NH-AM peers over a 12-month course of infant development. These results support and extend the idea that the production of prosodic characteristics in maternal speech is governed by the infants' hearing experience rather than chronological age (Bergeson et al. 2006; Kondaurova & Bergeson, 2011, see also Lam & Kitamura, 2012, 2010 for related findings). We, however, also found that mothers produced more syllables and faster speaking rate (a trend for NH-EM group) while speaking to both groups of NH as compared to HI infants. These results suggest that these characteristics of mothers' input, unlike pitch features, may depend on other factors, for example, mothers' awareness of their infant hearing status that leads to decreased communication (Lederberg & Mobley, 1990; Meadow, 1981; Wedell-Monning, & Lumley, 1980). Previous research identified mothers of HI children as more directive, hostile (frustrated) and over-structuring of their children's play when compared to mothers with NH peers (Brinich, 1980; Lam & Kitamura, 2010; Pipp-Siegal, Blair, Deas, Pressman, & Yoshinaga-Itano, 1998; Schlesinger & Meadow, 1972; Spencer & Gutfreund, 1990; Wedell-Monning & Lumley, 1980) and demonstrated that HI infants exhibit reduced responsiveness (Lam & Kitamura, 2010; Pressman, Pipp-Sieagel, Yoshinaga-Itano, Kunicek, & Emde, 1998). It is possible that these factors could underlie the decreased production of syllables in maternal speech to HI infants in comparison their NH peers as found in our study.

The examination of age-related modifications of prosodic and structural characteristics over the period of twelve months in speech to HI infants with CIs and NH-EM infants demonstrated that mothers produced more syllables in speech to both groups at the time of the second as compared to the first testing session. As suggested by previous research, the initial function of IDS at an early stage of NH infant development (newborns to approximately 3 months) is to gain and maintain infants' attention and to modulate arousal level (Fernald, 1992; Fernald & Simon, 1984; Kitamura & Burnham, 2003; Papousek et al., 1991; Stern at al., 1983). At 6 months mothers initiate more interaction with their infants (Cohn & Tronick, 1987), who become more socially responsive and demonstrate more interest and joy at communication (Malatesta, Grigoryev, Lamb, Albin, & Culver, 1986). Recent studies also found that HI children with better hearing or better aided audibility demonstrate better receptive language skills that may allow them to be more easily engaged in conversations (Hoff-Ginsberg, 1994; VanDam, Ambrose, & Moeller, 2012). It is possible that an increase in the number of syllables produced in IDS at the time of the second session to NH-EM and HI infants in the current study can be accounted for by an increase in infants' responsiveness in both groups.

The current study did not demonstrate any age-related changes in prosodic characteristics of ID speech for HI and NH-EM groups over the 12-month period. The absence of longitudinal changes in prosodic characteristics to NH-EM infants does not agree with findings from previous studies Kitamura & Burnham, 2003; Kitamura et al., 2002; Stern eta l., 1983) and can possibly be explained by large inter-subject variability in mothers' speech. However, the lack of longitudinal changes in prosodic characteristics of speech to HI infants agrees with results from our recent study (Kondaurova & Bergeson, 2011) that examined pitch properties signalling clause boundaries in speech to HI infants prior to and 6 months post cochlear implantation. A previous study by Wedell-Monning & Lumley (1980) suggested that when mothers initially learned about their child's hearing loss, they became more interactive and produced more vocal exaggerations as compared to mothers of hearing children. It is possible that mothers of HI infants in the current study overcompensated for their child's hearing loss by exaggerating prosodic properties that serve both attentional and affective functions (Fernald, 1989) and failed to adjust pitch level to their child's developmental stage. A recent case study also demonstrated that a mother of an older 12.5-month HI child fitted with hearing aids decreased her pitch level while interacting with him over the next 10-month period (Lam & Kitamura, 2010). It is possible that mothers of HI infants fitted with CIs start to modify prosodic characteristics of their speech at a later period of time when infants become older and acquire more hearing experience. Future longitudinal studies with older HI children with CIs are necessary to examine this question.

In speech to NH-AM infants, we observed a decrease in F0 standard deviation between the first and the third session suggesting that mothers' speech became less variable. We also found a constant increase in the number of syllables produced in speech to the chronologically matched NH infants across all three sessions. Overall, these results agree with findings from previous studies suggesting age-related changes in prosodic characteristics and growing complexity of ID speech towards hearing children over time (Cross, 1977; Cross, Nienhuys, & Kirkman, 1985; Liu et al., 2009; Snow, 1972; Stern et al., 1983). The absence of age-related changes in other prosodic characteristics under analysis (F0 mean, F0 range and F0 speaking rate) over the twelve-month period could be accounted for by two factors. First, there was large variability in these characteristics because the infants were matched by chronological age to the HI group (age range 10.9 to 26.9 months). Second, Fernald (1992) suggested that IDS has a more linguistic-oriented role by the end of the first year. Because normal-hearing infants were around one to two years of age at the time of the first session, the rate of change in prosodic characteristics of IDS to this population is possibly slower as compared to speech to younger children when other types of linguistic information (e.g. segmental and lexical) become of primary importance at this stage of child development (Fernald, Perfors, & Marchman, 2006; Fernald, Pinto, Swingley, Weinberg, & McRoberts, 1998; Kuhl et al., 2008; Polka & Werker, 1994; Werker & Tees, 1984).

In summary, our findings provide new insights into the properties of maternal speech to HI infants after receiving a cochlear implant as compared to NH infants matched either by chronological age or hearing experience in a 12-month study. The current study demonstrated that the prosodic and structural characteristics of maternal speech were more similar in speech to HI and NH-EM than to HI and NH-AM infants. These findings extend and support previous research (Bergeson et al., 2006; Kondaurova & Bergeson, 2012) suggesting that mothers' speech style, even across time, is affected by the hearing experience of their infants. Thus, the exaggerated characteristics of maternal speech to HI as compared to NH-AM infants possibly make it easier for a hearing-impaired infant to maintain attention (Fernald & Simon, 1984; Papousek, Papousek, & Symmes, 1991), to respond to affective and emotional cues provided by mothers' speech (Fernald & Kuhl, 1987; Kitamura & Lam, 2009; Kitamura & Burnham, 2003; Kitamura & Burnham, 1998; Trainor, Austin, & Desjardin, 2000), as well as to learn linguistic structure (sound contrasts, words and syntactic organization) of the native language (Kemler Nelson et al., 1989; Kondaurova & Bergeson, 2011; Kuhl et al., 1997; Lam & Kitamura, 2010; Liu, et al., 2003; Seidl, 2007; Seidl & Cristia, 2008). On the other hand, the results of our study also suggested that mothers of HI infants were still sensitive to the hearing status of their infants as they produced fewer syllables across all three testing sessions in comparison to NH-EM group. These results are both theoretically and clinically significant as previous studies demonstrated that the amount of infant and child-directed speech is positively associated with children's later vocabulary growth and language development (Hart & Risley, 1995; Hoff, & Naigles, 2002; Hurtado, et al., 2008; Hutternlocher, Vasilieva, Waterfall, Vevea, & Hedges, 2007; Pan, B.A., Rowe, M.L., Singer, J.D., & Snow, C.E., 2005). Thus, for future research, we need to take into account that a child's hearing loss disrupts the natural reciprocal pattern of communicative interaction in typical mother-infant dyads (e.g., Cross, Nienhuys, & Kirkman, 1985; Henggeler & Cooper, 1983) and examine how factors such as infant responsiveness may influence maternal speech style to HI infants, in order to determine the best clinical interventions that will be useful for speech-language therapists and parents of HI infants.

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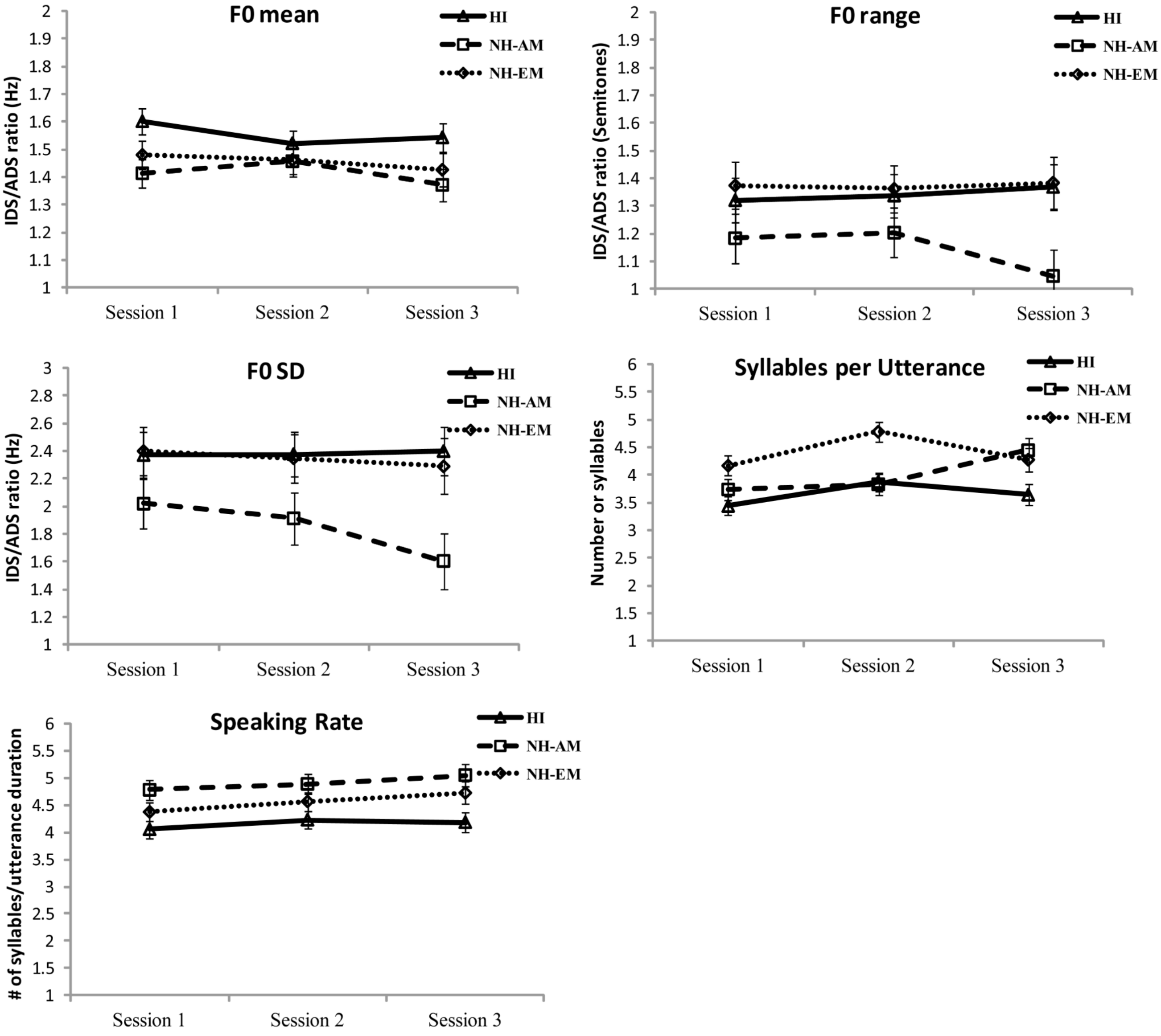

Figure 1.

Estimated values of F0 mean, F0 range, F0 SD, Syllables per Utterance and Speaking Rate in speech to hearing-impaired (HI) and normal-hearing (NH) infants based on a mixed-effects regression model at three time points.

Table 1

Number of mother-infant dyads, mean age and gender for hearing-impaired, normal-hearing age-matched and normal-hearing experience-matched infants at each testing session.

Session	**# of Dyads**	**Age (in months, s.d.)**	**Sex**
		Hearing-Impaired	
3 months post CI stim	25	18.4 (4.3)	M 21, F 4
6 months post CI stim	26	21.6 (4.5)	M 22, F 4
12 months post CI stim	19	27.7 (4.5)	M 16, F 3
		Normal-Hearing Age Matched	
1 session	21	18.1 (4.3)	M 13, F 8
2 session	19	21.6 (4.5)	M 12, F 7
3 session	15	27.1 (4.4)	M 8, F 7
		Normal-Hearing Experience Matched	
1 session	21	3.1 (0.4)	M 13, F 8
2 session	21	6.1 (0.5)	M 13, F 8
3 session	14	12 (0.3)	M 9, F 5

Table 2

Communication method, deafness etiology and the type of cochlear implant device

Participant	Device (L-left ear; R- right ear)	Communication Method	Etiology
2528	Nucleus 24 Contour, R	OC, TC	Unknown
2529	Med El C 40+, R	OC	Brachio-oto-renal Syndrome
2813	Nucleus Freedom--Contour Advance, R	unavailable	Unknown
3098	Nucleus Freedom--Contour Advance, R	unavailable	Unknown
3058	Nucleus Freedom--Contour Advance, L	unavailable	Unknown
3374	unavailable	unavailable	Unknown
4083	Nucleus Freedom--Contour Advance	unavailable	Unknown
2518	Nucleus 24 Contour, R	OC	Connexin 26-DFNB/35delG allele variant/GJB2/DFNB1
2532	Med El C 40+, R	OC	Unknown
2536	HiRes 90K, R	TC	Unknown
2542	Nuclues Freedom-Contour Advance, L	OC	Unknown
2795	Nucleus Freedom--Contour Advance, R	OC	Connexin 26
3029	Advanced Bionics HiRes 90K	unavailable	Unknown
3272	unavailable	unavailable	Unknown
2514	Nucleus 24K, L	OC	Connexin 26-DFNB/35delG homozygote/ossification
2535	Nucleus Freedom--Contour Advance, L	OC	Mild Mondini
2540	Nuclues Freedom--Contour Advance, L	OC	Mondini/genetic
2515	Nucleus 24 Contour, L	OC	Auditory Neuropathy
2543	Nucleus Freedom--Contour Advance, L	OC	Unknown
3259	Nucleus Freedom--Contour Advance	unavailable	Unknown
2523	Nucleus 24 Contour, R	unavailable	unknown
2533	Nucleus 24 Contour, R	OC	Genetic
2534	Nucleus 24 Contour, R	unavailable	unknown
2539	Nucleus 24 Contour, R & L	OC	Meningitis
4325	unavailable	unavailable	unknown
3296	Nucleus 24 Contour, L	unavailable	Genetic
4574	Nucleus System 5, R & L	unavailable	Genetic

Note: OC = Oral Communication, TC = Total Communication

Table 3

Number of utterances produced in infant-directed speech (IDS) at each testing session and in adult-directed speech (ADS) at the time of the first visit

	Number of Utterances					
	Hearing-Impaired		Normal-Hearing Age Matched		Normal-Hearing Experience Matched	
Session	IDS	ADS	IDS	ADS	IDS	ADS
1	625	654	525	499	515	592
2	635		475		525	
3	472		375		350	

Table 4

Prosodic and structural characteristics in infant-directed speech (IDS) and in adult-directed speech (ADS) to (a) hearing-impaired, (b) normal-hearing age-matched and (c) normal-hearing-experience matched infants.

(a)

	Hearing-Impaired			
	Session 1	**Session 2**	**Session 3**	**ADS**
	Non-normalized values			
F0 mean (Hz, s.d.)	300.73 (51.95)	291.01 (45.15)	280.94 (49.61)	187.21 (17.78)
F0 range (semitones, s.d.)	10.05 (2.7)	10.14 (2.43)	9.81 (2.14)	7.84 (1.86)
F0 SD (Hz, s.d.)	55.07 (18.01)	54.78 (17.35)	51.39 (14.99)	23.96 (9.26)
Syllables per utterance (number, s.d.)	3.5 (0.67)	3.87 (0.93)	3.68 (0.92)	9.52 (1.9)
Speaking rate (# of syll. per utterance duration, s.d.)	4.07 (0.79)	4.22 (0.78)	4.23 (0.74)	4.66 (0.48)
	Normalized values (IDS/ADS ratio, s.d.)			
F0 mean	1.61 (0.25)	1.53 (0.25)	1.51 (0.2)	1
F0 range	1.34 (0.4)	1.35 (0.36)	1.31 (0.38)	1
F0 SD	2.43 (0.8)	2.39 (0.9)	2.26 (0.86)	1

(b)

	Normal-Hearing Age-Matched			
	Session 1	**Session 2**	**Session 3**	**ADS**
	Non-normalized values			
F0 mean (Hz, s.d.)	272.84 (45.94)	273.48 (38.56)	267.28 (61.24)	192.14 (20.24)
F0 range (semitones, s.d.)	10.07 (2.8)	9.84 (2.29)	8.49 (2.34)	9.02 (2.61)
F0 SD (Hz, s.d.)	52.90 (16.04)	47.31 (14.61)	42.02 (19.25)	26.74 (8.24)
Syllables per utterance (number, s.d.)	3.74 (0.64)	3.81 (0.73)	4.41 (1.02)	9.09 (2.02)
Speaking rate (# of syll. per utterance duration, s.d.)	4.78 (0.87)	4.88 (0.65)	5.07 (0.94)	4.56 (0.43)
	Normalized values (IDS/ADS ratio, s.d.)			
F0 mean	1.41 (0.24)	1.47 (0.29)	1.37 (0.28)	1
F0 range	1.18 (0.47)	1.20 (0.55)	1.07 (0.41)	1
F0 SD	2.02 (0.76)	1.92 (0.83)	1.66 (0.66)	1

(c)

	Normal-Hearing Experienced-Matched			
	Session 1	**Session 2**	**Session 3**	**ADS**
	Non-normalized values			
F0 mean (Hz, s.d.)	272.15 (47.52)	267.87 (41.24)	259.64 (24.44)	184.21 (25.33)
F0 range (semitones, s.d.)	11.50 (3.06)	11.69 (2.49)	10.78 (2.41)	8.67 (2.36)
F0 SD (Hz, s.d.)	53.33 (18.7)	52.07 (15.59)	48.19 (12.09)	23.59 (8.15)
Syllables per utterance (number, s.d.)	4.13 (0.92)	4.85 (0.87)	4.23 (0.83)	10.06 (2.03)
Speaking rate (# of syll. per utterance duration, s.d.)	4.33 (1.07)	4.58 (0.65)	4.88 (0.71)	4.78 (0.45)
	Normalized values (IDS/ADS ratio, s.d.)			
F0 mean	1.48 (0.2)	1.47 (0.23)	1.38 (0.21)	1

(c)

	Normal-Hearing Experienced-Matched			
	Session 1	**Session 2**	**Session 3**	**ADS**
F0 range	1.38 (0.35)	1.38 (0.41)	1.33 (0.26)	1
F0 SD	2.4 (0.79)	2.37 (0.96)	2.11 (0.77)	1