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Synchrony, Complexity and Directiveness in Mothers' Interactions with Infants Pre- and Post-Cochlear Implantation

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Abstract

This study investigated effects of profound hearing loss on mother-infant interactions before and after cochlear implantation with a focus on maternal synchrony, complexity, and directiveness. Participants included two groups of mother-infant dyads: 9 dyads of mothers and infants with normal hearing; and 9 dyads of hearing mothers and infants with profound hearing loss. Dyads were observed at two time points: Time 1, scheduled to occur before cochlear implantation for infants with profound hearing loss (mean age = 13.6 months); and Time 2 (mean age = 23.3 months), scheduled to occur approximately six months after cochlear implantation. Hearing infants were age-matched to infants with hearing loss at both time points. Dependent variables included the proportion of maternal utterances that overlapped infant vocalizations, maternal mean length of utterance, infant word use, and combined maternal directives and prohibitions. Results showed mothers' utterances overlapped the vocalizations of infants with hearing loss more often before cochlear implantation than after, mothers used less complex utterances with infants with cochlear implants compared to hearing peers (Time 2), and mothers of infants with profound hearing loss used frequent directives and prohibitions both before and after cochlear implantation. Together, mothers and infants adapted relatively quickly to infants' access to cochlear implants, showing improved interactional synchrony, increased infant word use, and levels of maternal language complexity compatible with infants' word use, all within seven months of cochlear implant activation.

Keywords

infant; hearing loss; cochlear implant; dyadic interaction; mother-infant interaction

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1. Introduction

Synchronous, or temporally coordinated, events are ubiquitous in early mother-infant interactions. Early interactions are characterized, for example, by synchrony in coordinated gaze, affect, arousal, turn-taking, and vocalization (see Feldman, 2007). Temporally coordinated early interactions are instrumental in advancing infant language and cognitive development (Bates, 1976; Bigelow & Walden, 2009; Bornstein & Tamis-LeMonda, 1997; Bornstein, Tamis-LeMonda, & Haynes, 1999; Jaffe, Beebe, Feldstein, Crown, & Jasnow, 2001; Snow, 1972). For example, the timing of infant word use was predicted by mothers' contingent responses to infant vocalizations (Tamis-LeMonda, Bornstein, & Baumwell, 2001) and mothers' responsiveness to infants at 13 months was more predictive of 20-month vocabulary than was mothers' actual vocabulary use (Bornstein et al., 1999). Synchronous interactions, however, are vulnerable both to transient disruptions in interpersonal timing and chronic conditions affecting one or both members of the dyad, such as maternal depression, premature birth, and insecure attachment (Bigelow & Walden, 2009; Feldman, 2007; Goldstein, Schwade, & Bornstein, 2009; Isabella, Belsky, & von Eye, 1989).

Despite the significant potential impact of profound hearing loss on temporally coordinated mother-infant interactions, specifically auditory-verbal interactions, to our knowledge, no research has examined measures of vocal synchrony in dyads of hearing[1] mothers and infants with profound hearing loss or patterns of change in synchrony following cochlear implantation. Instead, studies of hearing loss have typically focused on maternal behaviors, such as maternal language complexity (i.e., mean length of utterance), affect, prosody, and use of directives (Bergeson, Miller, & McCune, 2006; Cross, Johnson-Morris, & Nienhuys, 1980; Goldin-Meadow & Saltzman, 2000; Kondaurova, Bergeson, & Xu, 2013). However, few have examined these maternal variables pre and post-cochlear implantation. Therefore, the purpose of this research was to investigate mother-infant synchrony, maternal complexity and maternal directives—influential variables in early language development in hearing infants—in relation to hearing loss and cochlear implantation. Examining these measures is vital for understanding both the effects of hearing loss on mother-infant interactions before cochlear implantation and dyadic adaptability following cochlear implantation.

1.1. Synchrony in Hearing Dyads

In studies of hearing dyads, mothers responded contingently to most infant signal types, including vocalizations, smiles, looks, cries, and play behaviors (Bornstein, Tamis-LeMonda, Hahn, & Haynes, 2008; Van Egeren, Barratt, & Roach, 2001). Synchronous responses to infants' signals (i.e., verbal, and behavioral) were important not only for language and social-emotional development, but also for infants' growing awareness of their ability to causally affect the behavior of others (Bates, 1976; Bigelow & Walden, 2009; Baumwell, Tamis-LeMonda, & Bornstein, 1997; Bornstein et al., 1999; Ensor & Hughes, 2008; Jaffe et al. 2001; Tamis-LeMonda et al., 2001; Goldstein et al., 2009; Henning and Striano, 2011; Isabella et al., 1989; Traci & Koester, 2003). Mothers typically were more

[1]For ease of readability, we refer to mothers and infants with normal hearing as *hearing*.

responsive to infant signals than infants were to maternal signals; however, both partners in mutually satisfying interactions engaged in responsive, temporally synchronized behavior (Henning & Striano; 2011; Ensor & Hughes, 2008; Van Egeren et al., 2001). For example, nearly all responses of mothers and 4-month-old infants were closely timed, occurring within 3-seconds of the others' signal. Although infants did not equal mothers in vocalization frequency, the majority of response behaviors of mothers and infants were vocalizations (Van Egeren et al., 2001) and instances of overlap were infrequent (Rutter & Durkin, 1987). Moreover, mothers who vocalized contingently (i.e., within 3s) tended to have infants who also vocalized contingently (Van Egeren et al., 2001). Thus, patterns of vocal synchrony are relatively well established in hearing dyads early in the first year.

1.2. Experimental Manipulation of Synchrony in Hearing Dyads

In speaking to infants, mothers typically used shorter utterances with more exaggerated pitch and longer pauses than in speech to adults (Fernald, 1985). However, these well-documented characteristics of infant-directed speech were sensitive to feedback from infants themselves (Smith & Trainor, 2008). For example, in research investigating effects of infant feedback, mothers linked to infants by videocamera believed infants heard their voice, when in fact infants could not (Smith & Trainor, 2008). As mothers spoke, a hidden experimenter elicted a response from infants by selectively displaying positive affect whenever the mothers' pitch either rose above or fell below a predetermined level. Mothers' subsequent shift toward the experimentally targeted pitch reflected their attention to infant affect, evidence that mothers were keenly sensitive to and quickly influenced by infant feedback.

Experimental manipulation has shown infants, too, are sensitive to contingent feedback (Bigelow & Walden, 2009; Goldstein et al., 2009; Henning & Striano, 2011). Henning and Striano (2011) studied mothers and 3- and 6-month-old infants interacting over monitors on which images were transmitted to the other either live or 3-seconds delayed. Under both timing conditions, mothers and infants were generally responsive to behaviors of the other. For example, mothers' smiles closely followed infant smiles, and infant smiles closely followed mothers' smiles. However, whereas the three-second delay did not significantly impact maternal behavior, infants smiled less often in the delayed compared to the live feedback condition. Therefore, relatively small disturbances in the timing of feedback had a direct effect on infant satisfaction, revealing infants' early sensitivity to interactional synchrony. Together these studies of mothers and infants highlight the dynamic, synchronous, and mutually regulated nature of early interactions in hearing dyads.

1.3. Maternal Complexity: Hearing Dyads and Mixed-Hearing Dyads

In dyadic studies of hearing loss, *mixed-hearing* dyads are often contrasted with *matched-hearing* dyads. Matched-hearing dyads include either mothers and infants with normal hearing (Hh), or mothers and infants who are Deaf (i.e., profound hearing loss; Dd). Mixed-hearing dyads include hearing mothers and infants with hearing loss (Hd) or, less frequently, mothers with hearing loss and infants with normal hearing (Dh). Mothers' speech to infants in Hd dyads (i.e., mixed-hearing dyads) was typically less complex than speech to hearing infants (i.e., Hh dyads). Reduced maternal complexity, or mean length of utterance (MLU) in Hd dyads, was found across infant ages (Cross et al., 1980) and cultures (Goldin-Meadow

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& Saltzman, 2000). In fact, mothers' speech to infants with hearing loss was sometimes less complex than speech to even younger hearing infants (Cross et al., 1980). Cross et al. attributed reduced maternal MLU to Hd infants' limited comprehension and unreliable conversational responsiveness—a view consistent with evidence from Hh dyads showing maternal complexity increased with infant age, language and conversational competence (Cross & Morris, 1980). However, additional research is needed to assess potential changes in Hd maternal complexity following Hd infants' access to cochlear implants.

1.4. Maternal Directiveness: Hearing dyads and Mixed-Hearing Dyads

Maternal directiveness has been described as the tendency to prompt, prevent, or prohibit given behaviors, elicit responses, and control conversational turns and topics (Henggeler, Watson, & Cooper, 1984; Nelson, 1973; Spencer & Gutfreund, 1990b; Taylor, Donovan, Miles, & Leavitt, 2009). Maternal directives and prohibitions have received particular attention given consistent evidence of their negative impact on language development in hearing children (Nelson, 1973; Taylor et al., 2009). Thus, past evidence that both verbal imperatives and non-verbal control behaviors (e.g., removing toys) were observed more often in Hd dyads than in Hh dyads was noteworthy (Cross et al., 1980; Henggeler et al., 1984; Lederberg & Everhart, 2000; Spencer & Gutfreund, 1990b). Mothers may have used controls in attempts to manage auditory and visual attention (Cross et al., 1980; Henggeler et al., 1984; Meadow-Orlans & Steinberg, 1993), despite evidence that Hd infants were less likely than hearing infants to hear or see directive cues (Meadow-Orlans, 1997).

More recently, comparatively high levels of parental control and directiveness have also been associated with low vocabulary scores in children with cochlear implants (Holt, Beer, Kronenberger, Pisoni, & Lalonde, 2012); whereas, contrasting measures of positive regard and respect for children's autonomy were associated with less marked language deficits (Quittner et al., 2013). Given consistent evidence of vocabulary delay in children with cochlear implants (Fagan & Pisoni, 2010; Holt et al., 2012; Thal, DesJardin, & Eisenberg, 2007), maternal directiveness is an important area for additional investigation both pre- and post-implantation.

This study extends research on dyadic interaction in Hd dyads by investigating synchrony, complexity and directiveness, variables in mother-infant interaction closely tied with language development, by comparing hearing dyads with Hd dyads before and after cochlear implantation. Investigating dyadic interaction in relation to cochlear implantation will directly address not only effects of hearing status on early mother-infant interactions, but also dyadic resilience and adaptability to changes in auditory awareness associated with cochlear implantation.

2. Method

2.1. Participants

Two groups of mother-infant dyads participated in the study: 9 dyads of hearing mothers and hearing infants (Hh dyads), and 9 dyads of hearing mothers and infants with profound, bilateral sensorineural hearing loss (Hd dyads). Hd dyads were recruited from a clinical population of families whose infants received unilateral cochlear implants before 24 months of age. Infants in Hh dyads, recruited from the local community, were matched by chronological age to infants in Hd dyads.

Infants with profound hearing loss (3 girls, 6 boys) were identified at birth (*n* = 6), or within 6 months of birth (*n* = 3), and had no known developmental diagnoses other than hearing loss. One Hd infant was premature, born at 32 weeks gestation; adjusted age was used in analyses for that infant. All other infants were full-term. Hearing infants (5 girls, 4 boys) had passed a newborn hearing screening and had no known developmental concerns. All participants were from monolingual English-speaking families. One Hh infant was biracial; all others were Caucasian. Approximately one-third of the mothers in each group (*n* = 7 of 18 total) were college graduates; the rest for whom data were available were high school graduates, with the exception of one mother in the Hd group who did not complete her senior year. Maternal education data were unavailable for 4 mothers.

All dyads were observed at two time points (Time 1 and Time 2), separated on average by 9.7 months (*SD* = 2.3, range = 5.7 to 13.4 months). Time 1 was scheduled before infants in Hd dyads received cochlear implants, and Time 2 occurred after cochlear implantation. Mean infant age at Time 1 was 13.6 months (*SD* = 5.3); mean age at Time 2 was 23.3 months (*SD* = 5.1). Table 1 shows mean and individual ages for each group. Hd infants' mean age at cochlear implant activation (approximately 4 weeks after implantation) was 16.6 months (*SD* = 4.9). Mean duration of cochlear implant use at Time 2 was 6.8 months (*SD* = 0.85).

Infants in Hd dyads had undergone trial use of hearing aids, required by pre-implant protocols. All Hd infants were enrolled in early intervention services (Time 1 and Time 2) using an oral approach to speech and language development, typically receiving services once or twice a week. Two families introduced some signed communication before cochlear implantation; none reported using sign language after cochlear implantation. Time 1 sign language information was missing for one dyad.

2.2. Procedure

Mothers interacted with infants, sitting on a blanket or chair in a double-walled copper-shielded sound booth. A standard set of quiet toys was provided for use in all interactions including several small animals (e.g., giraffe, dog, bear, fish), a ball, stacking rings, and nesting cups. Mothers were instructed to speak to their child as they normally would at home.

Mother-infant interactions were digitally recorded in one of two ways: (a) a hypercardioid microphone (Audio-Technica ES933/H) linked to an amplifier (DSC 240) and digital audio tape recorder (Sony DTC-690) or (b) a SLX Wireless Microphone System (Shure) connected to a Canon 3CCD Digital Video Camcorder GL2, NTSC. Interactions were recorded directly onto a Mac computer (Apple, Inc. OSX Version 10.4.10) via Hack TV (Version 1.11) software. Mean duration of recordings was 4.8 minutes (*SD* = 1.2). Due to variation in length of recorded sessions, raw frequency counts for behaviors described below were converted to rate per minute (e.g., utterances per minute) or proportions. Length of sessions did not differ significantly by group (Hh, Hd), $t(34) = 1.45$, $p = .15$.

Recorded interactions were transcribed and entered into Systematic Analysis of Language Transcripts (SALT; Miller & Iglesias, 1984) Windows Research Software. Data entered included all mothers' utterances, infants' words, speech-like vocalizations (i.e., infant vocalizations containing one or more vowels and/or consonants), maternal and infant non-speech vocal behaviors (e.g., laughs, cries, and tongue clicks), and codes indicating overlapping utterances. Mother and infant utterance boundaries were determined by silent periods and linguistic units (e.g., Brown, 1973). Decisions regarding infant word use were determined by contextual cues, phonetic similarity to presumed targets, and parental response (Vihman & McCune, 1994). Due to infants' emerging use of words and small MLU (M = 0.53, SD = .63), numbers of infant words per minute were used as a measure of language use. SALT software was used to calculate numbers of infant vocalizations and maternal utterances per sample, maternal mean length of utterance (in morphemes), infant words per minute, and number of overlapping maternal utterances (i.e., mother vocalizing at the same time as infant)[2].

Measures of maternal directiveness, defined as combined numbers of maternal verbal directives and prohibitions, were separately computed from the transcripts. Verbal directives were imperative commands directing or commanding infant behavior (e.g., *come here; let go; put it in the box; say, please*). Prohibitions, containing *no*, *not*, or their contracted forms, warned infants to cease or avoid various behaviors (e.g., don't touch; no bite; no no). Thus, prohibitions and directives were similar in directing infant behavior; however, directives commanded infants to perform certain behaviors, whereas prohibitions told them what they must *not* do.

All recorded interactions were independently transcribed by two trained coders. Any discrepancies between coders in number of utterances, overlap, word use, or classification type (e.g., prohibitions and directives) were resolved by mutual agreement. Intraclass correlation coefficients for number of utterances, overlapping utterances, and infant word use were .94, .99, and .90, respectively. There were no disagreements regarding number of utterances classified as prohibitions and directives.

3. Results

Analyses focused on mother-infant vocal synchrony, maternal complexity and maternal directives. Dependent variables relevant to the analyses included maternal utterance rate, proportion of maternal utterances that overlapped infant vocalizations, maternal complexity (MLU), and number of combined maternal directives and prohibitions, as well as infant vocalization rate and rate of word use (i.e., words per minute), relevant to analyses of vocal synchrony and maternal complexity, respectively. Table 2 shows mean measures for each variable at both time points. Preliminary analyses indicated none of the measures differed significantly by infant gender; therefore, gender was not included in further analyses.

[2]At times, mothers spoke first and infants followed; at other times infants vocalized first and mothers spoke over infants' vocalizations. However, we focused on proportions of mothers' utterances that contained overlaps of infant vocalizations because mothers vocalized more frequently than infants did and because mothers are more likely to control turn taking in early interactions than infants are (Rutter & Durkin, 1987; Snow, 1977).

3.1. Synchrony

3.1.1. Maternal Utterance Rate—A 2 (Group) × 2 (Time) repeated-measures Analysis of Variance (ANOVA) for number of mothers' utterances per minute revealed no significant main effects or interactions. Thus, the frequency of mothers' speech to infants was stable over time and mothers of Hd infants spoke to their infants as often as mothers of Hh infants did.

3.1.2. Infant Vocalization Rate—A 2 × 2 repeated-measures ANOVA for number of infant vocalizations per minute indicated the Group × Time interaction was not significant. However, main effects of Time, $F(1, 16) = 4.81$, $p < .05$, $\eta^2 = .23$, and Group, $F(1, 16) = 4.91$, $p < .05$, $\eta^2 = .24$, were significant. Thus, Hh infants vocalized significantly more frequently than Hd infants did, and both groups vocalized significantly more often at Time 2 than at Time 1 (Table 2).

3.1.3. Mother-Infant Vocal Synchrony—A 2 × 2 repeated-measures ANOVA for proportions of maternal utterances that overlapped infant vocalizations indicated the Group × Time interaction was not significant, $F(1, 15) = 1.12$, $p = .31$. The main effect of Time was also not significant; however, the main effect of Group was significant, $F(1, 15) = 7.04$, $p < .05$, $\eta^2 = .31$. Thus, despite similar Hh and Hd maternal utterance rates, mothers in Hd dyads overlapped a greater proportion of infant vocalizations than mothers in Hh dyads did. By comparison, dyssynchrony in Hh dyads was relatively infrequent (Table 2). Hd dyads showed a trend toward decreasing dysynchrony after cochlear implantation, $t(7) = 2.12$, $p = .07$, with levels equivalent to that of Hh dyads at Time 2, $t(16) = 2.07$, $p = .06$.

It is important to note that because infants vocalized at similar rates at Time 1 (as did Hh and Hd mothers), differences in synchrony in mother-infant interactions did not occur in relation to infant vocalization rate. Moreover, in hearing dyads, relatively low levels of dyssynchrony were observed at Time 2 despite Hh infants' significantly increased vocalization rate.

3.2. Maternal Complexity

A 2 × 2 repeated-measures ANOVA of maternal MLU indicated a significant Group × Time interaction, $F(1, 16) = 9.62$, $p < .01$, $\eta^2 = .38$. Follow-up independent-samples *t*-tests revealed MLU in both groups (Hh, Hd) was similar at Time 1, $t(16) = .23$, $p = .81$; however, at Time 2, mothers in Hh dyads used significantly more complex utterances than mothers of Hd infants did, $t(16) = 2.42$, $p < .05$, $d = 1.16$. Thus, whereas mothers' language complexity in speech to hearing infants increased over time (paired-samples $t(8) = 3.55$, $p < .01$, $d = .70$), maternal complexity in Hd dyads remained stable and did not increase, $t(8) = 1.63$, $p = .14$. In fact, Hd maternal complexity at Time 2 did not differ significantly from Hh mothers' speech to younger hearing infants (Time 1), $t(16) = 1.11$, $p = .28$.

A 2 × 2 repeated-measures ANOVA of infants' rate of word use also indicated a significant Group × Time interaction, $F(1, 16) = 15.84$, $p < .01$, $\eta^2 = .49$. Note that none of the Hd infants and fewer than half of Hh infants (44%) produced any words during Time 1 interactions and that Hd and Hh infants' rate of word use did not differ significantly, $t(16) =$

1.89, $p = .09$. However, at Time 2, when more than half of infants in each group used words, Hh infant word use was significantly greater than Hd infants' rate of word use, $t(16) = 4.09$, $p < .01$, $d = 1.94$. Moreover, infants' rate of word use at Time 2 was significantly correlated with maternal MLU, $r = .59$, $p < .05$, 2-tailed. Therefore, Hd mothers, whose Time 2 utterances were less complex than Hh mothers', may have adjusted their language complexity in accordance with infants' word use, as maternal MLU was not significantly correlated with infant age, $r = .36$, $p = .14$, 2-tailed.

3.3. Maternal Directiveness

A 2 × 2 repeated-measures ANOVA of maternal prohibitions and directives revealed only a significant main effect of Group, $F(1, 16) = 9.42$, $p < .01$, $\eta^2 = .37$. The Group effect indicated maternal directives and prohibitions were relatively infrequent in hearing dyads; however, at both time points, mothers in Hd dyads used prohibitions and directives significantly more frequently than mothers in hearing dyads did (Table 2).

4. Discussion

We compared Hh and Hd dyads on measures of vocal synchrony, maternal complexity, and maternal directiveness at two time points scheduled to occur before and after cochlear implantation for Hd infants (i.e., Time 1, and Time 2). At Time 1, mothers' speech to infants with profound hearing loss was similar in many respects to mothers' speech to age-matched hearing infants. Mothers spoke as frequently to their infants with hearing loss as mothers of hearing infants did, and they used sentences of similar length and complexity. However, Hd mothers were notably different from mothers in Hh dyads at Time 1 in two principal ways: they used more prohibitions and directives, and their interactions with infants were significantly more dyssynchronous—mothers' utterances overlapped infant vocalizations more than twice as often as in hearing dyads (i.e., 0.44 vs. 0.21, respectively; Table 2).

At Time 2, mothers continued to speak as frequently to Hd infants as to Hh infants. Despite similarities in maternal utterance rate, however, dyssynchrony in Hd dyads was less frequent after cochlear implantation, with Hd interactions becoming as synchronous as Hh interactions at Time 2. At the same time, mothers' MLU in speech to infants with cochlear implants—similar in Hd and Hh dyads at Time 1—was significantly less complex than speech to age-matched hearing infants at Time 2. That is, unlike Hh dyads, maternal MLU in Hd dyads did not increase with overall infant age or cochlear implantation. Instead, Hd mothers' MLU (and that of Hh mothers') may have been regulated by infant rate of word use at Time 2, as both measures (infant word use, and maternal MLU) were significantly correlated.

Maternal prohibitions and directives also differed significantly at Time 2, remaining higher in Hd dyads than in Hh dyads. Thus, neither directiveness nor maternal MLU changed significantly in Hd dyads after cochlear implantation compared to before cochlear implantation.

The results of this study are consistent with a study of synchronous turn-taking in hearing dyads alone (Rutter & Durkin, 1987) in showing instances of overlap were relatively infrequent in hearing dyads. Rutter and Durkin (1987) found fewer than twenty percent of Hh maternal utterances overlapped 12- to 24-month-old infants' utterances, roughly similar to proportions of overlap found in Hh dyads in this study (Table 2). Thus, in the present study, vocal dyssynchrony before cochlear implantation was remarkably frequent, suggesting hearing loss significantly affected turn-taking predicatability and vocal timing, skills well-established in hearing dyads in the first year.

Stability in maternal utterance rate in Hh and Hd dyads was consistent with results from other studies showing mothers produced similar numbers of utterances to hearing infants and infants with hearing loss (Henggeler et al., 1984; Spencer & Gutfreund, 1990a), but differed from studies showing Hd mothers produced more (Spencer & Gutfreund, 1990b) or fewer (Goldin-Meadow & Saltzman, 2000) utterances than Hh mothers did. Differences between the latter two studies and ours may be attributable to differences in the number (n = 3, Spencer & Gutfreund, 1990a) and age (4-year-olds, Goldin-Meadow & Saltzman, 2000) of Hd participants. Mothers, however, vocalized reliably more often than infants in this study and others (Anderson, Vietze, & Dokecki, 1977; Van Egeren et al., 2001; Wedell-Monnig & Lumley, 1980).

At Time 2, mothers' speech to infants with cochlear implants was significantly less complex than speech to age-matched hearing peers. Similarly, with respect to age and hearing status, Cross et al. (1980) and Goldin-Meadow and Saltzman (2000) found mothers speech to 2-and 4-year-old children with hearing loss was significantly less complex than speech to age-matched hearing children. Nevertheless, in the present study, mothers' speech to Hd infants, before cochlear implantation, was not less complex than speech to age-matched hearing infants. This apparently inconsistent pattern of maternal complexity in Hd dyads may indicate Hd (and Hh) mothers responded to infants' relative lack of word use at Time 1. Further, at Time 2, when Hh infants' rate of word use was significantly greater than that of Hd infants, Hh mothers' speech was significantly more complex than Hd mothers' speech (see also Cross et al., 1980; Cross & Morris, 1980; Goldin-Meadow & Saltzman, 2000). Thus, maternal MLU did not increase solely with infant age or cochlear implantation (i.e., Hd dyads), but rather with infants' rate of word use.

Together, stable (rather than increased) maternal MLU and improved mother-infant synchrony in Hd dyads' at Time 2 support the idea that mothers were attuned and responsive to infants' rather limited word use in interactions that took place relatively soon after cochlear implantation and that interactions were more predictable for both partners. For their own part, after cochlear implantation, Hd infants may assume a role in timing their vocalizations to alternate with those of their mothers, sharing responsibility for vocal turns as Hh infants do (Anderson et al., 1977; Rutter & Durkin, 1987). Infants' new and developing auditory ability to perceive and recognize sounds after cochlear implantation (Sharma, Dorman, & Spahr, 2002), in combination with their emerging use of single words, potentially contributed to mothers' awareness of and adaptation to infants' new language and auditory abilities. Before cochlear implantation, hearing loss alone did not elicit adjustments in mothers' speech to relatively young (M = 13.7 months) infants, as Hd and Hh mothers' utterances were similar in frequency and complexity at Time 1, when infants did not differ with regard to mean age or word use. However, following cochlear implantation, infants' emerging word use and improved auditory awareness potentially influenced maternal complexity similar to the way in which linguistic behaviors associated with infant age and vocabulary development influenced maternal responsiveness in hearing dyads (e.g., Bornstein et al., 1999). Nevertheless, any relevant feedback, or lack of feedback, from Hd infants indicating poor auditory awareness before cochlear implantation (e.g., limited comprehension, conversational responsiveness, or awareness of auditory cues; Cross et al., 1980; Meadow-Orlans, 1997) did not result in decreased maternal complexity compared to Hh maternal complexity. Therefore, it may be the case that the new *presence*, rather than the absence of auditory awareness, as well as infants' growing use of linguistic cues, signaled mothers to adapt to post-cochlear-implant infants by using comparatively simple utterances themselves. Research investigating comparative effects of infant age, auditory attention, and verbal responsiveness on maternal language complexity is an important area for future investigation in infants with hearing loss as well as infants with other developmental concerns.

Frequent maternal use of prohibitions and directives at both time points was consistent with evidence from other studies showing mothers used more prohibitions with Hd infants (without cochlear implants) than with Hh infants (Cross et al., 1980; Henggeler et al., 1984; Lederberg & Everhart, 2000; Spencer & Gutfreund, 1990b). Notably, maternal directives and prohibitions did not decline significantly with cochlear implantation in this study; however, mean duration of implant use in our study was relatively brief (i.e., 6.8 months). Therefore, additional studies are needed to investigate associations between maternal directiveness and duration of implant use. Directiveness is an important area for research given evidence not only that relatively high levels of control and directiveness were associated with low receptive vocabulary scores in children with cochlear implants (Holt et al., 2012), but also that maternal sensitivity—a measure of positive verbal response to infant-initiated verbal and exploratory behavior—predicted gains in vocabulary comprehension in Hh dyads, especially for infants with low initial receptive vocabulary scores (Baumwell et al., 1997).

In earlier research, however, maternal sensitivity, affect, and overall mother-infant enjoyment in Hd dyads received relatively low ratings that did not improve over time (Meadow-Orlans, 1997; Meadow-Orlans & Steinberg, 1993; Spencer & Gutfreund, 1990b). However, the source of dissatisfaction in association with hearing loss was not clearly discussed. Results from our study may shed light on the early behavioral dynamics that contribute to the formation and potential maintenance of the patterns found in previous studies. Specifically, early dyssynchrony and maternal use of prohibitions and directives may be both symptomatic of unpredictable, stressful, or unsatisfying interactions for mothers and infants (e.g., Henning & Striano, 2011; Smith & Trainor, 2008; Van Egren et al., 2001) and formative in establishing patterns shown to persist over time (Meadow-Orlans, 1997). Fewer instances of dyssynchronous, or poorly coordinated and unpredictable interactions at Time 2, together with mothers' use of less complex language to Hd infants compared to Hh infants, potentially signaled a shift toward more predictable and possibly more satisfying and mutually responsive interactions following cochlear implantation. However, despite persistent dissatisfaction in dyads in which infants did not receive cochlear implants (Meadow-Orlans, 1997), little other research has examined interactions with Hd infants who did. Therefore, additional research is needed to address long-term dyadic satisfaction following cochlear implantation.

Advocates of early intervention have argued for increased focus on empowering and collaborating with families to enhance parenting skills and modify interactions to increase contingent responsiveness (Feldman, 2007; Moeller, 2000; Spencer & Gutfreund, 1990b; Traci & Koester, 2003; Quittner et al., 2013). The potential to achieve these goals is evident in studies showing increased maternal responsiveness and sensitivity following even relatively brief participation in intervention programs (Greenberg, Calderon, & Kusche, 1984; Meadow-Orlans & Steinberg, 1993; Wendland-Carro, Piccinini, Millar, 1999). Pressman, Pipp-Siegel, Yoshinaga-Itano, Kubicek, & Emde (2000) suggested intervention directed toward increasing maternal sensitivity and support could supplement traditional speech and language treatment programs, an important idea given evidence that such intervention can benefit infant vocabulary development and positively affect maternal stress and response to behavioral cues (Meadow-Orlans & Steinberg, 1993; Pressman et al., 2000; Traci & Koester, 2003). The potential long-term benefits of such intervention may be overlooked when early cochlear implantation is anticipated.

Limitations of the present study include the relatively small number of participants and measurement times, longitudinally. Larger studies would be beneficial; however, the population of infants with profound hearing loss who receive cochlear implants is relatively small. Additional limitations include within-group variation in infant age (at Times 1 and 2) and variation in length of recording sessions.

In summary, both mothers and infants adapted relatively quickly to infants' new auditory access after cochlear implantation, demonstrating improving mother-infant verbal synchrony, emerging word use, and maternal language complexity compatible with infants' word use within seven months of cochlear implant activation. Nevertheless, the 23-month-old Hd infants with cochlear implants were less than half as verbal as age-matched hearing infants (see Fagan, 2014) and used words significantly less frequently than hearing peers. These results highlight important advantages and limitations of early cochlear implantation, as well as relevant goals for parent education and intervention, including mother-infant synchrony, responsiveness, and reduced use of maternal directives and prohibitions before and after cochlear implantation. Directions for future research include investigating dyadic satisfaction after cochlear implantation and measuring change in maternal directiveness in association with duration of cochlear implant use.

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Highlights

- We studied mother-infant dyads before and after infant cochlear implantation (CI).
- Mothers overlapped infant vocalizations more often before than after CI.
- Infant word use emerged soon after cochlear implantation.
- Mothers' language complexity was correlated with infants' rate of word use.
- Mothers of CI infants used frequent directives and prohibitions before and after CI.

Table 1

Gender, Age, Age at Cochlear Implant Activation, and Duration of Implant Use (in months) by Group and Time

Hearing Infants			Infants with Profound Hearing Loss				
Gender	**Age Time 1**	**Age Time 2**	**Gender**	**Age Time 1**	**Age Time 2**	**Age at Activation**	**Duration Use**
M	6.3	15.9	F	6.0	15.8	8.3	7.6
M	9.8	23.2	M	9.7	23.2	16.5	6.8
F	10.3	16.0	F	10.7	16.4	10.7	5.4
F	11.7	23.0	M	11.6	23.1	17.1	6.0
M	12.3	22.9	F	12.3	23.0	16.7	6.3
M	12.3	24.1	M	13.2	23.8	16.1	7.7
F	15.5	23.0	M	15.5	23.1	16.8	6.3
F	19.8	29.5	M	19.7	29.5	22.7	6.9
F	24.2	31.6	M	24.2	32.2	24.2	8.0
Mean *(SD)*	13.6 *(5.4)*	23.2 *(5.2)*		13.7 *(5.4)*	23.3 *(5.2)*	16.5 *(4.9)*	6.7 *(.85)*

Table 2

Mean measures (SD) of mother and infant vocal behavior

	Time 1		Time 2	
Measure	**Pre-CI**	**Hearing**	**Post-CI**	**Hearing**
Maternal utterances/minute	26.26 (6.4)	25.59 (7.8)	24.96 (6.7)	24.93 (6.3)
Maternal MLU-morphemes	2.65 (.60)	2.59 (.37)	**2.39** (.38)	**2.89** (.47)
Infant vocalizations/minute	3.07 (2.5)	4.65 (4.2)	4.37 (4.0)	8.85 (4.5)
Infant words/minute	0.00 (.00)	0.77 (1.2)	**0.35** (.53)	**7.80** (5.4)
Proportion maternal overlap	0.44 (.23)	0.21 (.20)	0.30 (.16)	0.16 (.08)
Proportion maternal directives	**0.17** (.11)	**0.06** (.04)	**0.20** (.12)	**0.07** (.03)

Note. Pre-CI = Infants with profound hearing loss before cochlear implantation; Hearing = Age-matched hearing infants; Post-CI = Infants with Profound hearing loss after cochlear implantation; MLU = mean length of utterance-morphemes.

Significant between group differences at Time 1 or Time 2 are shown in boldface, $p < .05$.