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Vocal matching in interactions between mothers and their normal-hearing and hearing-impaired twins

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Vocal matching, the ability to imitate properties of speech, was examined in interactions between mothers and their normal-hearing (NH) and hearing-impaired twins who used hearing aids (HAs) or a cochlear implant (CI). Vocalizations of three mother-twin triads were recorded in three sessions over 12 months. In one triad, the twins were 15.8 months old and NH. In another triad, the twins were 11.8 months; one was NH while the other had HAs. In the third triad, twins were 14.8 months; one was NH while the other had a CI. A vocal match was defined as an instance of perceptual similarity between adjacent maternal and infant utterances in relation to pitch contour, utterance duration, rhythm, or vowels and consonants. Reciprocal vocal matching by both partners occurred in 14-62% of vocalizations across triads. At session three, CI and HA infants' and mothers' reciprocal matches increased compared to the two previous sessions and to the NH dyads; reciprocal matches in the NH dyads decreased over time. The results suggest vocal matching is part of linguistic interactions between mothers and their NH and hearing-impaired infants and that early amplification facilitates mothers' and infants' matching.

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1. INTRODUCTION

Speech communication between a caregiver and child is a dynamic interaction in which both members actively influence the other (Ko, Seidl, Cristia, Reimchen, & Soderstrom, 2015). This process, referred to as speech contingency, involves adjustments of an individual's behavior to make them correlated with a partner's prior behavior (Beebe et al., 2010). Evidence from studies with both normal-hearing (NH) and hearing-impaired (HI) pediatric populations suggests that contingency in caregiver-child interactions affects the development of infant language skills (Ambrose, VanDam, & Moeller, 2014; Goldstein, King, & West, 2003; Goldstein & Schwade, 2008; Tamis-LeMonda, Bornstein, & Baumwell, 2001; VanDam, Ambrose, & Moeller, 2012) and cognitive and socio-emotional development (Beebe et al., 2010; Goldstein et al., 2003; Goldstein & Schwade, 2008; Jaffe et al., 2001; Kaplan, Bachorowski, Smoski, & Hudenko, 2002; Koester, Brooks, & Karkowski, 1998; Kuhl, 2007; Oller, Eilers, Steffens, Lynch, & Urbano, 1994).

However, the typical reciprocal pattern of mother-infant interaction in NH-caregiver and HI-infant dyads is disrupted as NH parents adjust to their child's hearing loss (Brinich, 1980; DeMarco, Colle, & Bucciarelli, 2007; Goss, 1970; Henggeler & Cooper, 1983; Lam & Kitamura, 2010; Meadow-Orlans, 1997; Meadow-Orlans & Steinberg, 1993; Pipp-Siegel, Blair, Deas, Pressman, & Yoshinaga-Itano, 1998; Quittner et al., 2010; Spencer & Meadow-Orlans, 1996; Wedell-Monning & Lumley, 1980) . The disruption in the reciprocal pattern of communication in dyads with mismatched hearing status can, consequently, lead to breaks in the bidirectional contingency processes in mother-infant interactions along several communicative dimensions (Gale & Schick 2009; Koester, 1994; Meadow-Orlans, 1997; Prezbindowski, Adamson, & Lederberg, 1998). Thus, understanding contingent processes within NH mother – HI infant dyads may be a crucial next step to narrowing the gap between current and optimal language outcomes in the HI pediatric population as well as suggesting novel interventions.

Vocal imitation is considered to be an important contingent behavior and strategy in child language acquisition (Cicchetti, 1994; Gratier & Devouche, 2011; Hallgen, 2012; Karousou & López-Ornat, 2013; Masur & Olson, 2008; Pelaez, Virues-Ortega, & Gerwirtz, 2011). It is defined as an attempt, intentional or incidental, to match an auditory event to the vocal motor system (Mercado, Mantell, & Pfordresher, 2014). The aim of the current study is to examine the effect of infant hearing loss on the frequency of infant and mother vocal imitations, a property of dyadic contingent behavior that may contribute to the development of infant language skills (Cicchetti, 1994; Karousou & López-Ornat, 2013; Masur & Olson, 2008; Pelaez et al., 2011; Tamis-LeMonda et al., 2001).

Evidence from studies with normal-hearing (NH) infants suggests that babies as young as 2 to 6 months have the capacity for vocal imitation mainly of vocalic but also consonantal sounds (Hallgen, 2012; Kugiumutzakis, 1993; Kuhl & Melitzoff, 1982; Kuhl & Meltzoff, 1996; Papousek & Papousek, 1989). The ability to imitate prosodic contours emerges early in the first year of life (Gratier & Devouche, 2011; Papousek & Papousek, 1989; Van Puyvelde et al., 2010) and word imitation develops before the imitation of sentence contours (Karousou & López-Ornat, 2013). Infant imitative abilities accelerate during the second year of life at the same time that vocabulary acquisition is increasing from production of first words and production of 100 words (Cicchetti, 1994; Karousou & López-Ornat, 2013; Masur, 1993). Developmentally, imitations progress from partial to exact and then expanded imitations which include additional sounds or words (Gazdag & Warren, 2000; Sokolov, 1992). Overall, approximately 30% to 40% of infant vocalizations matched the preceding maternal vocalization at the segmental and/or prosodic level (Gratier & Devouche, 2011; Papousek & Papousek, 1989), with 2-6 imitations in a 7-minute interaction (Kokkinaki & Vitalaki, 2011).

Previous studies demonstrated that infant vocal imitations were essential for infant language development. For example, listening to adult vowel productions elicited infant vocalizations that resembled the adult vowels, suggesting infants attempt to learn phonetic units in a particular language through imitation (Kuhl & Meltzoff, 1996). A number of studies demonstrated that those children who exhibited more imitations in the second year had larger vocabularies, a critical measure of language development and a predictor of early literacy (Bornstein, Tamis-LeMonda, & Haynes, 1999; Masur, 1995; Masur & Eichorst, 2002; Rodgon & Kurdek, 1977; Snow, 1989). In addition, delays in child vocal imitations were associated with problems or delays in language development (Bishop, North, & Donlan, 1996; Sigman & Ungerer, 1984; Stone, Lemanek, Fishel, Fernandez, & Altemeier, 1990).

Vocal imitation is, however, a bidirectional process where not only children, but also their caregivers imitate different acoustic features of their partner's vocalizations. Overall, mothers imitated infants considerably more than infants imitating mothers (Cicchetti, 1994; Hallgen, 2012; Kugiumutzakis, 1993; Pawlby, 1977). Particular forms of infant vocalization also mattered; mothers imitated infant vocalizations of higher articulatory complexity (e.g. consonant-vowel vocalizations) more often than vowel-like vocalizations (Gros-Louis, West, Goldstein, & King, 2006). In addition, infant linguistic development was positively correlated with the frequency of mothers' imitations (Cicchetti, 1994). The frequency of mothers' imitation episodes increased by the middle of the second year of infant age, which coincided with an increase in child lexical acquisition (Cicchetti, 1994). The frequency of maternal imitations was predictive of child linguistic development both in children who were typically developing (Cicchetti, 1994; Masur, Flynn, & Eichorst, 2005; Masur & Olson, 2008; Pelaez et al., 2011; Tamis-LeMonda et al., 2001) and those with language delays (Girolametto, Weitzman, Wiigs, & Pearce, 1999; Meltzoff, 1996). Maternal imitations also served as an effective reinforcer for infant vocal responses in experimental conditions (Haugan & McIntire, 1971; Pelaez et al., 2011).

Most research in dyads with mismatched hearing status have focused on the ability of hearing-impaired (HI) children to imitate the linguistic or phonological structure of experimenter vocalizations using intelligibility measures and sentence or (nonsense) word imitation tasks (Osberger, Robbins, Todd, & Riley, 1994). This research determined that children with normal hearing generally performed better at both prosodic (Carter, Dillon, & Pisoni, 2002; Chin, Bergeson, & Phan, 2012; Nakata, Trehub, & Kanda, 2012) and segmental (Carter et al., 2002; Dillon, Cleary, Pisoni, & Carter, 2004) levels as compared to children with hearing loss.

These findings are not surprising given that comparing productions of HI children to NH peers is problematic. For example, at the prosodic level productions of children who received CIs are characterized by problems with stress, resonance and laryngeal quality, rate and loudness, vowel length, tonal word accent, and pitch and pitch contours, especially rising/interrogative pitch contours (Chin et al., 2012; Lenden & Flipsen, 2007; Lyxell et al., 2009; Nakata et al., 2012; Peng, Tomblin, Spencer, & Hurtig, 2007; Peng, Tomblin, & Turner, 2008). At the segmental level, the phonetic inventory of HI children is reduced in comparison to NH children. The production of consonants in HI children is characterized by multiple errors including substitution of one segment for another, distortions, omission of word-final consonants and errors in place and manner of articulation (Dillon et al., 2004; Kirk, Diefendorf, Riley, & Osberger, 1995; Schauwers, Gillis, & Govaerts, 2005). Common errors in vowel productions of HI children were omissions, tense-lax substitutions, monophthongization of diphthongs, and neutralization, with a higher percentage of errors found on vowels in high rather than central tongue positions (Osberger, Maso, & Sam, 1993; Osberger & McGarr, 1982; Osberger et al., 1994; Schauwers et al., 2005; Smith, 1975). Thus, the accumulated evidence indicates that HI children have problems in imitating linguistic characteristics of caregiver's speech at both the prosodic and segmental levels (Chin et al., 2012; Dillon et al., 2004; Nakata et al., 2012; Peng et al., 2007)

However, very little, if any, research has investigated both mother and infant imitations in NH mother- HI infant dyads during natural interactions despite its importance for infant language development (Bornstein et al., 1999; Masur, 1995; Masur & Eichorst, 2002; Masur et al., 2005; Masur & Olson, 2008; Pelaez et al., 2011; Snow, 1989; Tamis-LeMonda et al., 2001). Previous studies focused predominantly on HI infant imitations in experimental settings using intelligibility tests (Chin et al., 2012; Dillon et al., 2004; Nakata et al., 2012; Peng et al., 2007).

The goal of this twin study was to investigate the frequency of vocal imitation in HI infants and their mothers during natural interactions across the first year of infant assistive device use - CI and hearing aids (HAs) - compared with NH twin peers. The choice of twin dyads will allow the evaluation of the effect of hearing loss on mutual modification of mother-infant vocal behavior while controlling for child-independent (e.g. caregiver socio-economic status (SES) and linguistic background) and child-dependent variables (e.g. child age, stage of development and hearing status) (Hart & Risley, 1995; Kitamura, Thanavishuth, Burnham, & Luksaneeyanawin, 2002; Weisleder & Fernald, 2013). Based on previous studies indicating errors in the linguistic imitations of HI infants (Chin et al., 2012; Dillon et al., 2004; Nakata et al., 2012), we predict that HI infants who use CIs and HAs will produce fewer imitations in comparison to their NH twin peers. It is also possible that the mothers' frequency of imitation will be affected due to disrupted reciprocal patterns of communication in NH caregiver- HI infant dyads (Fagan, Bergeson, & Morris, 2014; Lam & Kitamura, 2010; Meadow-Orlans, 1997; Meadow-Orlans & Steinberg, 1993; Pipp-Siegel et al., 1998; Quittner et al., 2010; Spencer & Meadow-Orlans, 1996; Wedell-Monning & Lumley, 1980).

2. METHOD

Raters

Three independent raters (mean age = 32 years old, *SD* = 10.1, F = 2, M = 1), the first author and two graduate students, rated maternal and child speech samples. Two raters were native American English speakers who grew up in the Midwest and the first author was a native Russian speaker with high proficiency in English as a Second Language. The two graduate students were unaware of infant hearing status and research hypothesis and blind to each others' ratings. All raters had no self-reported history of speech and hearing disability. Raters were not paid.

Perceptual Rating

Mother-Infant Participants. *Mothers*. Three normal-hearing mothers and their twin infants participated in the experiment. The normal-hearing mothers, who had one normal-hearing and one hearing-impaired twin infant who used either a HA (HA-NH) or a CI (CI-NH), were invited to three sessions: 3, 6 and 12 months after infants received their assistive device. The mother with normal-hearing twins (NH1-NH2) was tested at three sessions, with infant age at all three sessions close to the infants' age in HA-NH and CI-NH pairs. All mothers were native English speakers (mid-Western American English dialect) and were reimbursed $10 per visit. The mother of NH1-NH2 twins was 28.8 years old, the mother of NH-HA twins was 36 years old, and the mother of NH-CI twins was 39.2 years old. All mothers were matched by education level (completed more than 12 years of education) and had no family history of hearing problems. The mothers of NH1-NH2 and NH-CI twins identified themselves as Non-Hispanic/Caucasian. The mother of NH-HA twins identified herself as Hispanic-African-American.

***Infants*.** *CI-NH:* The CI-NH family consisted of one male (CI) and one female (NH) dizygotic twin. The CI infant was born with profound hearing loss with unknown etiology (best PTA Right and Left: no response at the limit of the equipment). At age 4 months, he was fitted with bilateral hearing aids but received no benefit. At age 11.94 months he received a Nuclear Freedom unilateral implant in the right ear. The Nuclear Freedom uses the Advanced Combination Encoder processing strategy, and all 22 electrodes were implanted successfully. After receiving his cochlear implant, the CI twin used oral-only communication. Three months post-implantation, the infant's CI-aided hearing was within the normal to mild hearing loss range. The age of CI and NH twins was 14:8, 18:5 and 23:9 months at corresponding three sessions.

HA-NH: The HA-NH family consisted of two male twins (unknown whether monozygotic or dizygotic), one with normal hearing, the other diagnosed at birth with mild hearing loss in both ears (best unaided PTA Right = 40, Left = 30) with unknown etiology. At age 12.3 months the HI twin was fitted with bilateral hearing aids with aided hearing within the normal range. The family used an oral communication mode strategy with the HI infant. The age of HA and NH twins was 11:8, 15.6 and 20.3 months at corresponding three sessions.

NH1-NH2: The NH1-NH2 family consisted of one male and one female dizygotic normal-hearing twin. The age of NH1 and NH2 twins was 15:8, 18:7 and 24:9 months at corresponding three sessions.

None of the infants had cognitive deficits or developmental concerns. This research and the recruitment of human subjects were approved by the university Institutional Review Board.

Recording procedure. The three mothers and their infants were digitally (audio) recorded interacting separately with each of their twin infants for 4-5 minutes as they normally would do at home while playing with quiet toys. In total, for each mother there were 6 recordings, two for each of the 3 sessions with each twin infant. For a detailed description of recording procedures see previous studies (Bergeson, Miller, & McCune, 2006; Kondaurova, Bergeson, & Xu, 2013).

Utterance coding. PRAAT 5.0.21 editor (Boersma & Weenink, 2005) was used to code and segment all mothers and infants' utterances. Data entered included all mothers' and infant utterances, speech-like vocalizations and maternal and infant non-speech vocal behaviors (e.g. laughs and cries). Mother and infant utterance boundaries were determined by silent periods and linguistic units (Brown, 1973).

Rating procedure. ***Rating scales***. Three categories were used to rate the perceptual similarity between adjacent mother-infant (mother is producing a "model", infant is producing a "match", MI match) and infant-mother (infant is producing a "model", mother is producing a "match", IM match) utterances: "exact match" was scored as "7," "partial match" was scored as "4," and "no match" was scored as "1" (scoring criteria described below).

Scoring criteria. (1) It was assumed that if an interlocutor (infant or her mother respectively) were to match an utterance of the other interlocutor (mother or her infant respectively), he or she would do so within two utterances of the prompt utterance due to constraints on memory. The descriptive term "match" was used rather than the interpretive term "imitation," which implies the response of one partner is the result of a preceding utterance. The sequence alone determined whether a MI or IM match was scored.

(2) Raters indicated an "exact" match (7) when all sound features at both the prosodic and segmental levels of the model and corresponding match were similar. The prosodic level included pitch contour (i.e., relative pattern of rises and falls, as opposed to absolute F0 matching), utterance duration and rhythm. An "exact" match in pitch contour required exact auditory and visual resemblance for one of six patterns: level, rise, fall, bell-shape, U-shape, or sinusoidal. An "exact" match in duration was scored when compared utterances were similar in duration (within 10% of the model). An "exact" match in rhythm was scored for those utterances with regularly repeating syllables in which both the number of syllables and the duration of pauses between repeating syllables were the same, and the individual syllables of mother and infant utterances could be reliably identified on the spectrogram.

"Exact" matches for vowels and consonants were scored on the basis of their quantity (the same number of phonemes in the match and the model) and quality (the same height/backness of vowels, the same place and manner of articulation of consonants).

(3) Raters selected a "partial" match when (a) there was some perceptual similarity at either the prosodic or segmental level, or a combination of the two. Due to preliminary nature of data collection and time constraints, more detailed ratings for a "partial" match were not used. At the prosodic level, a "partial" match in pitch contour required partial auditory and visual resemblance for one of the six patterns: level, rise, fall, bell-shape, U-shape, sinusoidal. A "partial" match in duration was scored when compared utterances were approximately similar in duration (within 20% of the model). A "partial" match in rhythm was scored for those utterances with regularly repeating syllables in which either the number of syllables differed and/or the pause duration between repeating syllables were approximately the same (within 20% of the model), and the individual syllables of both utterances could be reliably identified on the spectrogram. A "partial" match in vowels and consonants was scored on the basis of their quantity (unequal numbers of phonemes in the match compared to the model) and quality (similar height/backness of vowels, similar place and manner of articulation of consonants). A "partial" match was also scored when there was an "exact" match along one level (either prosodic or segmental) and a "partial" or no match along the other (prosodic or segmental).

(4) "No match" was scored when there was no perceptual similarity between a model and the potential match on any of the sound features at the prosodic or segmental levels: pitch contour, utterance duration, rhythm, vowels or consonants.

(5) Repetitive matching responses of one partner to an utterance of the other partner were rated as additional matches if they occurred in an uninterrupted sequence (e.g., mother: "ball;" infant "ball;" mother: "ball").

(6) Infant vocalizations (a) produced simultaneously with mothers' utterances; (b) separated from other utterances by more than 3000 ms (Gratier et al., 2015); or (c) produced in sequence one after another (e.g. infant: "ball, ball, ball") were excluded from analysis.

(7) To verify auditory and visual evaluations at the prosodic and segmental levels for "exact," "partial," and "no" matches, raters also used narrow-band acoustic measurements from spectrograms in PRAAT 5.0.21. editor (Boersma & Weenink, 2005).

3. ANALYSIS

The analysis examined two questions. First, to investigate inter-rater reliability (IRR) for vocal match ratings, intra-class correlation coefficients (ICC) were calculated using a two-way random effects model (Hallgen, 2012). The cutoffs for ratings of agreement based on ICC values were as following: IRR is considered to be poor for ICC < .40, fair for values between .40 and .59; good for values between .60 and .74 and excellent for values between .75 and 1.0 (Cicchetti, 1994).

Second, we examined the proportion of MI and IM matches out of all possible turn-taking sequences between a mother and her child where MI and IM utterances were either adjacent (model distance from match = adjacent) or separated by one intervening utterance (model distance from match = the second utterance away from the match). Proportions were used instead of absolute numbers of MI and IM matches for two reasons: a different number of infant vocalizations (*M* = 21.9, *SD* = 11.7) a different recording length (*M* = 311 sec., *SD* = 32.9) in each dyad.

4. RESULTS

The average scores of the three raters are highly reliable as demonstrated by IRR (*M* =.96, *SD* = .02) across the three sessions suggesting high agreement on ratings of vocal matches during mother-infant interaction in all three dyads. Figure 1 presents the proportion of "exact" and "partial" vocal matches summed together in adjacent utterances for all three (CI-NH, HA-NH, NH1-NH2) mother-infant dyads across the three testing sessions.

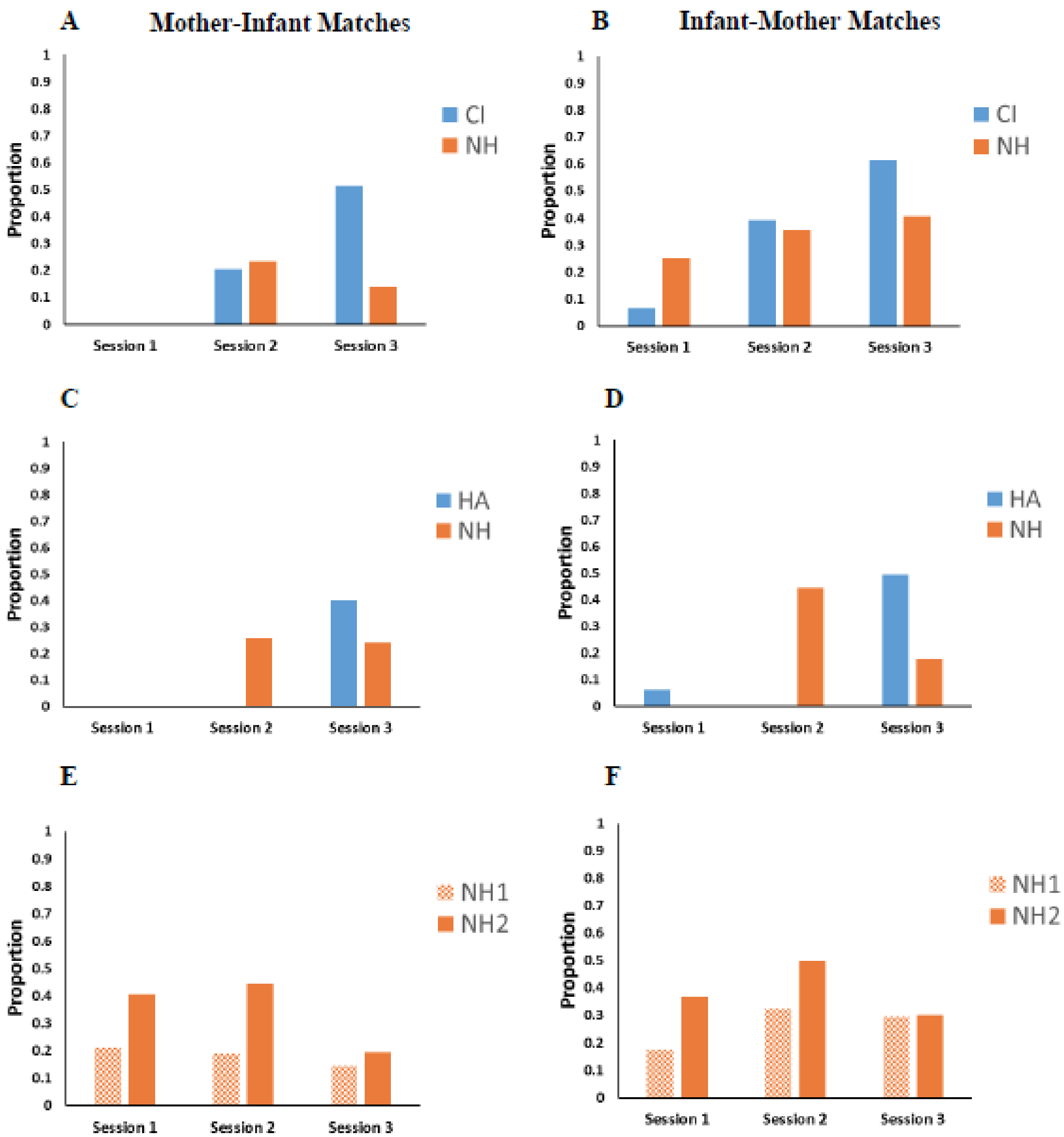

Figure 1. A. CI-NH dyad: Proportion of MI matches. B. CI-NH dyad: Proportion of IM matches. C. HA-NH dyad: Proportion of MI matches. D. HA-NH dyad: Proportion of IM matches. E. HA-NH dyad: Proportion of MI matches. F. HA-NH dyad: Proportion of IM matches.

These proportions are averaged over the three raters. “Exact” and “partial” matches were collapsed into one category because there were more “partial” matches as compared to “exact” matches for all three dyads (CI-NH, HA-NH, NH1-NH2). Only adjacent utterances were analyzed because there were too few matches when the model was the second utterance away from the match. Given evidence that NH child imitative abilities change over time (Cicchetti, 1994; Karousou & López-Ornat, 2013; Masur, 1993; Sokolov, 1992), we examined MI and IM vocal matches at each of the three testing sessions, rather than collapsing them together. Additional detailed data on the proportion of “exact” and “partial” matches in adjacent and non-adjacent utterances over the three testing sessions is provided in Table 4 (a) and (b) correspondingly.

Table 4

(a) Proportion of matches in adjacent utterances

			Exact Matches			Partial Matches		
Dyad	Model	Match	Session 1	Session 2	Session 3	Session 1	Session 2	Session 3
CI	Mother	Infant	0.00	0.00	0.20	0.00	0.21	0.31
	Infant	Mother	0.02	0.01	0.44	0.04	0.38	0.17
NH	Mother	Infant	0.00	0.09	0.01	0.00	0.14	0.13
	Infant	Mother	0.03	0.12	0.19	0.22	0.23	0.22
HA	Mother	Infant	0.00	0.00	0.05	0.00	0.00	0.36
	Infant	Mother	0.02	0.00	0.11	0.04	0.00	0.38
NH	Mother	Infant	0.00	0.12	0.09	0.00	0.13	0.15
	Infant	Mother	0.00	0.25	0.07	0.00	0.20	0.11
NH1	Mother	Infant	0.03	0.03	0.01	0.18	0.16	0.13
	Infant	Mother	0.06	0.16	0.04	0.11	0.17	0.26
NH2	Mother	Infant	0.11	0.09	0.03	0.30	0.36	0.17
	Infant	Mother	0.04	0.16	0.05	0.33	0.34	0.26

(b) Proportion of matches when the model is the second utterances away from the match

			Exact Matches			Partial Matches		
Dyad	Model	Match	Session 1	Session 2	Session 3	Session 1	Session 2	Session 3
CI	Mother	Infant	0.00	0.00	0.08	0.00	0.10	0.22
	Infant	Mother	0.00	0.00	0.25	0.00	0.00	0.00
NH	Mother	Infant	0.00	0.00	0.01	0.00	0.05	0.01
	Infant	Mother	0.00	0.03	0.01	0.00	0.00	0.00
HA	Mother	Infant	0.00	0.00	0.04	0.00	0.00	0.18
	Infant	Mother	0.00	0.00	0.00	0.04	0.04	0.15
NH	Mother	Infant	0.00	0.00	0.04	0.00	0.00	0.05
	Infant	Mother	0.00	0.00	0.00	0.00	0.10	0.03
NH1	Mother	Infant	0.01	0.00	0.00	0.11	0.00	0.00
	Infant	Mother	0.00	0.03	0.00	0.00	0.18	0.00
NH2	Mother	Infant	0.06	0.02	0.00	0.23	0.16	0.02
	Infant	Mother	0.00	0.00	0.01	0.00	0.06	0.08

Note: NH = normal-hearing infant, HA = hearing-impaired infant who used hearing aids, CI = hearing-impaired infant who used a cochlear implant.

Mother-infant matches. In the CI-NH dyad, the proportion of matches produced by the CI infant steadily increased over the three sessions from 0% (Session 1) to 21% (Session 2), and to 51% (Session 3) (Fig. 1A). The proportion of matches produced by the NH infant in the same dyad did not demonstrate the consistent pattern, increasing to 23% at the second session but decreasing slightly to 14% at the third session (Fig. 1A). In the HA-NH dyad, the proportion of matches produced by the HA infant increased from 0% at the first and second sessions, to 40% at the third session (Fig 1C). For the NH twin (HA-NH dyad) the proportion remained stable across the second and third sessions, 26% and 24% respectively (Fig. 1C).

In the NH1-NH2 dyad, the proportion of matches showed a relatively stable pattern for infant NH1 across all three sessions, 21%, 19% and 14% correspondingly (Fig. 1E) and for infant NH2, a steady pattern with decrease at the last session, 40%, 44% and 19% correspondingly (Fig. 1E).

Infant-mother matches. In the CI-NH dyad the proportion of matches produced by the mother imitating her CI infant increased over the three sessions from 7% to 39% and then to 62% (Fig. 1B). The same increase was observed in mothers' speech to her NH infant in the CI-NH dyad over the three sessions from 25% to 36% and, finally, to 41% (Fig. 1B). For the HA-NH dyad, the proportion of matches produced by the mother imitating her HA infant utterances increased at the third (49%), as compared to first (7%), session (Fig. 1D). In the same dyad the proportion of matches produced by the mother imitating her NH infant utterances decreased at the third (18%), as compared to the second (44%) session (Fig. 1D). Lastly, for the NH1-NH2 dyad, the proportion of matches produced by the mother increased from the first (17%) to the second (32%) session and then remained stable (29%) at the third session (Fig. 1F). The proportion of matches produced by mother while imitating infant NH2 did not demonstrate a consistent pattern, increasing at the time of the second (50%) as compared to first session (39%) session and then decreasing slightly (30%). There were more vocal matches produced by the NH2 infant and mother compared to the NH1 infant and the same mother across all three testing sessions. In addition, overall, there were more IM than MI matches for all three dyads (CI-NH, HA-NH, NH1-NH2).

4. DISCUSSION

The purpose of the study was to examine the frequency of vocal imitations in three dyads with twin infants over a period of one year. One of the dyads had NH children while the other two had one NH and one HI child who used an assistive device, either a CI or HAs. Vocal imitation was defined as the proportion of MI and IM vocal matches. The results of the study demonstrated that there were few vocal matches by both partners in CI-NH and HA-NH dyads at the time of the first and/or second testing sessions. However, an increase in the proportion of mother-infant and infant-mother matches in these dyads was identified. There were more matches by both partners at the time of the third as compared to the first and/or second sessions. In the dyad with NH twin infants, a decrease in the proportion of mother-infant and a stable pattern and/or some decrease in the proportion of infant-mother matches was observed. Overall, these results suggest that hearing loss affects the ability of both members of the dyad, mother and her infant, to produce vocal imitations.

Our results are consistent with previous findings suggesting that spontaneous vocal imitation is an important characteristic of contingent behavior in mother-infant dyads with NH infants (Hallgen, 2012; Karousou & López-Ornat, 2013; Masur & Olson, 2008; Pelaez et al., 2011). Yet, our study goes beyond the replication of results of previous research by showing that vocal matching is a part of mother-infant natural interactions with HI infants who have been using a CI or HAs for one year. The methodology employed in the study demonstrated that vocal matching occurred without direct elicitation, during a free play. This methodology was not widely employed before to examine vocal imitations in infants and children with hearing loss.

The majority of both mother-infant and infant-mother vocal matches in all dyads (CI-NH, HA-NH, NH1-NH2) occurred in adjacent utterances. Our results are in agreement with results of previous studies with NH infants suggesting that imitation takes place within mother-infant or infant-mother turn-taking structures and characterized by vocal exchanges between 2 and 10 seconds of a partners' vocalization (Hallgen, 2012; Masur & Olson, 2008; Pelaez et al., 2011). Mothers of both NH and HI infants produced more vocal matches than their infants. The overall direction of vocal matches in dyads with NH and HI infants parallels findings of previous studies indicating that mothers tend to imitate their infants' vocal expressions more than vice versa (Hallgen, 2012; Kokkinaki & Vitalaki, 2011; Kugiumutzakis, 1993; Pawlby, 1977). More "exact' and "partial" mother-infant and infant-mother matches were identified in vocal interactions with both HI and NH twin infants as compared to "exact" matches. Due to the absence of segmental and prosodic analysis that will be completed in future studies, we did not yet determine the developmental stage of infant vocalizations and matches, that is, whether infant matches contained partial repetitions with deletion but no additions or exact repetitions with an additional sound/sounds (Gazdag & Warren, 2000; Sokolov, 1992). Overall, the results of the current study confirm the proposal that infant hearing loss that may affect both mother and infant ability to imitate speech models (Carter et al., 2002; Chin et al., 2012; Dillon et al., 2004; Nakata et al., 2012; Peng et al., 2007).

The results of the current study demonstrated that there was a steady increase in the proportion of mother-infant vocal matches in NH mother- HI infant interactions across three sessions. Previous studies suggest that there is a gradual development of language skills in HI infants after receiving an assistive device. For example, CI children are able to produce consonantal and vowel features correctly reaching

60-70% of consonant targets (Chin & Kaiser, 2000; Geers & Tobey, 1992; Kirk et al., 1995) and 70-80% of vowel (Blamey, Barry, & Jacq, 2001; Geers & Tobey, 1992) targets after 2-3 years of CI use. A significant correlation between gains in hearing ability of children who received HAs and their speech and language outcomes was observed after 3 and 5 years of HAs use (Tomblin, Oleson, Ambrose, Walker, & Moeller, 2014). Consequently, an increase in the production of mother-infant vocal matches by the second year of infant life as found in the current study, might reflect a positive impact of intervention for hearing loss on language development for infants who received assistive devices, CI and HAs (Geers, Nicholas, & Sedey, 2003).

The results of the current study also demonstrated that there was a gradual increase in the proportion of infant-mother vocal matches by the time of the third session in speech to HI infants in both CI-NH and HA-NH dyads. Previous research stresses the reciprocal nature of caregiver-child interaction where caregiver and infant interactive exchanges are viewed as concurrent and bidirectional processes affecting each other (Beebe, Jaffe, & Lachmann, 1992; Beebe et al., 2000; Beebe et al., 2010; Jaffe et al., 2001). Consequently, it is possible that infant hearing loss affects NH mothers' ability to produce vocal matches because of the disruption of the typical reciprocal patterns of mother-infant interaction in NH caregiver – HI infant dyads (Fagan et al., 2014; Goss, 1970; Henggeler & Cooper, 1983; Lam & Kitamura, 2010; Meadow-Orlans, 1997; Meadow-Orlans & Steinberg, 1993; Pipp-Siegel et al., 1998; Quittner et al., 2010; Spencer & Meadow-Orlans, 1996; Wedell-Monning & Lumley, 1980). Vocal imitation is considered to be a part of turn-taking structures in dyadic communicative exchanges (Hallgen, 2012; Papousek & Papousek, 1989; Pawlby, 1977). Recent studies showed there were fewer and shorter turn-taking sequences (Depowski, Abaya, Oghalai, & Bortfeld, 2015; Tait, De Raeve, & Nikolopoulos, 2007) and a greater proportion of speech overlap in dyadic vocal interactions with HI as compared to NH infants (Fagan, Bergeson, & Morris, 2014). Thus, our results agree with evidence from previous studies confirming the effect on infant hearing loss on characteristics of mother-infant vocal interactions (Fagan et al., 2014; Tait et al., 2007). However, they also extend it by suggesting that mothers' increase in the production of vocal matches over time can be driven by the reciprocal nature of mother-infant vocal communication because it coincides with an increase in infant production of vocal matches. Overall, our results suggest that infant hearing loss might affect both HI infants' and NH mothers' ability to produce vocal imitations. Future research with more participants in each group needs to investigate the effect of infant hearing loss and language development on the reciprocal relationship in the production of vocal imitations in dyads with mismatched hearing status.

However, unlike the gradual increase in the proportion of mother-infant and infant-mother vocal matches in CI-NH and HA-NH dyads, no consistent patterns of vocal matching were identified for their NH twins. Thus, a relatively stable decrease was found in mother-infant vocal matches for both NH1 (21%, 19% and 14% respectively) and NH2 (40%, 44% and 19% respectively) infants over the period of three sessions. The proportion of NH1 infant-mother vocal matches increased by second session (17%, 32% and 29% respectively). The proportion of NH2 infant – mother vocal matches increased by the time of the second session and then decreased (37%, 50% and 30% respectively). These findings may reflect individual variability of vocal matching demonstrated by NH infants and their mothers. They, however, agree with previous research on NH infants showing that up to 40 % of vocal matches by either partner in the NH caregiver- NH infant dyad are involved in imitations (Papousek & Papousek, 1989).

Concerning the frequency of vocal matches (by either partner) in the NH1-NH2 dyad, we found that the proportion of vocal matches produced by infants ranged from 14% to 44% and the proportion of vocal matches produces by the mother varied from 17% to 50% depending on the session. It is worth noting that individual differences were also observed in vocal matches between NH twins and their mother. Thus, infant NH2 and her mother produced more vocal matches as compared to infant NH1 and the same mother.

A recent study suggests that parents speak more to infant girls than boys (Johnson, Caskey, Rand, Tucker, & Vohr, 2014). Given the positive relationship between the frequency of maternal imitations and infant linguistic development demonstrated in previous research (Cicchetti, 1994; Haugan & McIntire, 1971; Masur et al., 2005; Masur & Olson, 2008; Pelaez et al., 2011; Tamis-LeMonda et al., 2001), it is plausible to suggest that the individual differences in the frequency of vocal matches in all three CI-NH, HA-NH and NH1-NH2 infant dyads by both partners may also depend on infant gender. However, only in the NH1-NH2 dyad was this explanation supported by differences in infant gender: the higher proportion of vocal matches was produced by the female infant NH2 and her mother as compared to the male infant NH1 and the same mother. In the CI-NH twin pair, the male HI twin infant and his mother produced more imitations at the last session as compared to their female NH twin. In the HA-NH dyad both twins were male, consequently, the difference in the proportion of vocal matches in this dyad can't be accounted for by infant gender.

In summary, our findings provide new insights on the characteristics of vocal matching in dyads with HI and NH infants. Overall, they demonstrate that vocal matching is a regular part of communicative interactions in mother-infant dyads with HI and NH infants during unstructured play. The incidence of vocal matching by both conversation partners increased in dyads with HI infants who received either a CI or HAs, but stayed approximately the same or decreased in interactions with NH infants. These findings suggest that despite infant hearing loss, infants develop an ability to produce vocal imitations over a period of one year after receiving an assistive device. Infant hearing loss was also found to affect their NH mothers' ability to produce vocal matching, suggesting that the reciprocal nature of mother-infant vocal interaction is affected by infant hearing status.

These findings are both theoretically and clinically significant. Previous research suggests that imitation plays an important role in infant socio-cognitive and linguistic development especially in regard to acquisition of new skills and to sharing of experience (Kugiumutzakis, 1993; Nadel & Fontaine, 1989; Pawlby, 1977; Uzgiris, 1981, 1984). Studies demonstrated that those children and their parents who produced more vocal imitations had larger vocabularies, a critical measure of language development and a predictor of early literacy (Bornstein et al., 1999; Cicchetti, 1994; Masur, 1995; Masur & Eichorst, 2002; Masur et al., 2005; Masur & Olson, 2008; Pelaez et al., 2011; Tamis-LeMonda et al., 2001). There is enormous individual variability in language outcomes for children with assistive devices, especially CIs (Miyamoto, Svirsky, & Robbins, 1997; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000) even when taking into account other factors that are known to affect outcomes, such as amount of residual hearing, communication method, and socioeconomic status (Dunn et al., 2014; Geers, Nicholas, & Moog, 2007; Niparko et al., 2010; Peterson, Pisoni, & Miyamoto, 2010). Vocal imitation is an important characteristic of dyadic contingent interaction. Understanding its characteristics and functions serves as an important next step to narrow the gap between current and optimal language outcomes in the HI pediatric populations to contribute to the development of best clinical interventions that will be useful for speech-language therapists and parents of HI infants.

5. CONCLUSION

The results demonstrated that spontaneous vocal matching is a part of reciprocal communicative interactions in mother-infant dyads with both HI and NH infants. Mother-infant and infant-mother vocal matching increased over a period of one year after HI infants received an assistive device, a CI or HAs. These results suggest a positive impact of application of assistive devices, CI and HAs, on the development of language skills in HI infants. An increase in HI infant- NH mother vocal matches suggests that mothers of HI infants were sensitive to hearing status and development of language skills of their infants. The study also confirmed previous findings on the relative incidence of vocal imitation in interactions between mothers and their NH infants. Future research needs to examine whether findings of the current study are supported by data from a larger sample of HI pediatric populations. Vocal imitation at both prosodic and segmental levels of mother-infant communicative interactions needs to be investigated in order to understand its characteristics, function in infant language acquisition and the course of development over time.

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