Published in final edited form as:

Ear Hear. 2015 ; 36(2): 229–238. doi:10.1097/AUD.0000000000000104.

Synchrony of Maternal Auditory and Visual Cues about Unknown Words to Children with and without Cochlear Implants

Emily Lund¹ and C. Melanie Schuele²

¹Texas Christian University, Department of Communication Sciences and Disorders, Fort Worth, TX, USA

²Vanderbilt University School of Medicine, Department of Hearing and Speech Science, Nashville, TX, USA

Introduction

Vocabulary knowledge is critical to academic achievement. Vocabulary deficits can affect academic, cognitive and professional outcomes (Marchman and Fernald 2008). Despite advances in amplification technology and improvement in overall language proficiency over the past three decades, children with hearing loss continue to exhibit low vocabulary knowledge (Waltzman et al. 2002). Children with cochlear implants generally have smaller lexicons than their same-age peers with normal hearing (for a review, see Ganek et al. 2012). They appear to add words to their lexicons at a slower rate than peers matched for language level (Nott et al. 2009; Ganek et al. 2012) resulting in a widening vocabulary gap between children with cochlear implants and children with normal hearing. Deficits in rapid word learning may contribute to deficits in vocabulary knowledge. Children with cochlear implants learn fewer novel words in rapid word-learning tasks as compared to their peers with normal hearing (Tomblin et al. 2007). To address these vocabulary limitations, professionals must consider possible differences in input provided to children with and without cochlear implants. The purpose of this study was to compare maternal auditory and visual cues about word referents available to children with cochlear implants and children with normal hearing matched for chronological age and matched for vocabulary level.

Rapid Word-Learning Performance in Children with Cochlear Implants

To add a new word to one's lexicon, one must rapidly connect a novel word and its referent (i.e., disambiguation) using cues from the linguistic and nonlinguistic environment (Heibeck and Markman 1987). Typical language learners are able to do this quickly and seamlessly. These rapid word-learning abilities are evident in children as young as 13 months of age (Houston-Price et al. 2005). Typically developing young children can learn a word (i.e., add it to the lexicon) with as few as three exposures to that new word (Woodward et al. 1994).

Address correspondence to Emily Lund, Department of Communication Sciences and Disorders, Texas Christian University TCU Box 297450, Fort Worth, TX 76129. Phone: (817) 257-4450. Fax: (817) 257-5692. e.lund@tcu.edu.

Financial Disclosures/Conflicts of Interest:

This work would not have been possible without the financial support of a Preparation of Leadership Personnel grant (H325K080075; PI: Schuele) from the US Department of Education, and in part by the Vanderbilt CTSA grant TR 000445 from NCRR/NIH. Study data were managed using REDCap electronic data capture tools hosted at Vanderbilt University (1 UL1 RR024975 from NCRR/NIH).

Between the ages of 12 and 36 months, children's rapid word-learning abilities improve, perhaps as a result of cognitive development, experience learning new words, or both (Woodward et al. 1994). Improved word-learning ability may account for some of the "vocabulary explosion" or rapid vocabulary growth observed between one and three years of age (Woodward et al. 1994).

In experimental rapid word-learning tasks, children with cochlear implants as a group perform more poorly than children of the same age with normal hearing. Tomblin, Barker and Hubbs (2007) found that children with cochlear implants ($n = 14$) between the ages of two and five years learned fewer words receptively and expressively in a rapid word-learning task than children with normal hearing ($n = 14$; $d = .99$). Houston and colleagues (2012) found that even children implanted before age two ($n = 25$, age at test ranged from 22 to 40 months) did not learn as many words as children with normal hearing matched for chronological age ($n = 23$; group means not reported). Word-learning performances could be influenced by characteristics of individual children (e.g., listening experience) as well as characteristics of environmental input. However, child-level factors affecting rapid word learning (e.g., age at implantation, speech perception) may be difficult or impossible to change. Because environmental factors are more amenable to manipulation, investigators must explore the role of input on the rapid word-learning performance of children with cochlear implants to inform intervention.

Environmental Input and Word Learning

Adult input to children can support the development of linguistic knowledge. Adults instinctively provide children information through child-directed speech as well as child-directed action in ways that facilitate language learning. Parents tend to provide auditory and visual cues simultaneously. This "multimodal motherese" plays a role in recruiting and directing child attention. The provision of redundant information, as via both auditory and visual channels, clearly focuses the attention of even very young children on salient characteristics of a learning incident (Gogate and Bahrick 1998). Combinations of cues across multiple sensory channels may, in fact, recruit selective attention and facilitate early learning more so than provision of unimodal cues (e.g., only auditory or only visual).

In the "Intersensory Redundancy Hypothesis," Bahrick, Lickliter and Flom (2004) state that intersensory redundancy "promotes detection of salient information, causing the redundant stimulus to become foreground and [other stimuli] background," thus facilitating selective attention (p. 100). If true, multimodal cues should recruit and hold the attention of children better than cues provided in isolation (unimodal cues). As a result, children are more likely to attend to and benefit from multimodal rather than unimodal input (Bahrick and Lickliter 2000; Bahrick et al. 2002).

If children can selectively attend to redundancy present across linguistic patterns, they likely will begin the process of language learning. Gogate and Hollich (2010) proposed that word mapping, or the association of a label with an object, begins with perceiving patterns in redundant relations of sound-object pairings. Children begin learning about basic, consistent sound-referent combinations (e.g., noticing that barking is always associated with dogs) and subsequently begin to pair more arbitrary sound sequences (i.e., words) with objects or

actions. Redundancy in maternal cues about referents may direct a child's attention to important linguistic patterns.

If a reciprocal relation exists between multimodal cue provision and child development, changes in multimodal child-directed communication across time may reflect changes in children's abilities to attend to and learn from those cues. Multimodal motherese may serve the purpose of scaffolding child attention in learning contexts and, consequently, help children learn to attend to relevant characteristics of events without as much support from mothers. Mothers of infants, for example, tend to shake objects during labeling events which, in turn, helps the infant to shift attention from the mother to the relevant object (Matatyaho and Gogate 2008). Infants' abilities to switch gaze from mother to object, in turn, predicts early label-to-referent mapping abilities (Gogate et al. 2006). As children get better at mapping words, they may be able to attend to the task without their mother leading them through the steps (e.g., shaking the object to draw attention).

When adults provide auditory and visual cues to children, those cues can be provided in a number of ways. First, children can receive auditory and visual information that converges to indicate a single referent – a converging cue, such as shaking an object while labeling it or looking at an object while labeling it. Second, children can receive auditory and visual information that diverges to indicate multiple possible referents – a diverging cue, such as talking about one object while holding another or talking about an object and then, later in the interaction, picking up the object. Third, children can receive information via only one sense – an auditory-only cue, such as labeling an object that is out of the room or labeling a still object that is not referenced visually. Converging cues are generally considered more useful for directing infant attention than diverging or auditory-only cues (Gogate et al. 2000).

Multimodal child-directed communication changes as children develop. Gogate, Bahrick and Watson (2000) assessed the timing of mothers' auditory and visual cues during labeling events to children 5–8 months old, 9–17 months old, and 21–30 months old. Mothers were asked to explicitly teach novel nouns and verbs to their children. Gogate and colleagues found that regardless of child age, mothers overwhelmingly provided converging, synchronous cues as compared to other cue types. However, mothers of the 9- to 17-month-old group and the 21- to 30-month-old group provided a higher proportion of diverging cues than mothers of the 5- to 8-month-old group ($d = 1.33$).

Mothers may intuitively match their communication to suit their child's perceptual and consequent lexical development needs (Gogate et al. 2001). At the outset of lexical learning, as children begin to benefit from converging auditory and visual information, mothers provide many overt multimodal cues. As children establish the ability to initiate and sustain joint attention, mothers provide fewer converging (and more diverging) cues (Gogate et al. 2000). It is possible that this shift from converging to diverging cues occurs because the provision of converging cues requires parents to be very directive in interactions with their children (i.e., always visually emphasizing those things they label). As children are better able to take advantage of linguistic knowledge (e.g., use syntax to determine a word

referent), parents can begin to introduce and discuss new concepts with their children without being overtly directive.

Maternal Input to Children with Cochlear Implants

Children with cochlear implants begin learning spoken language at a later age than their normal-hearing peers. Current FDA-labeled indications do not support cochlear implantation under the age of 12 months. Prior to implantation, many children with cochlear implants exhibit age-appropriate nonverbal skills despite a lack of linguistic knowledge (Geers et al. 2003). Parents of a child who looks and acts like a three-year-old (at least non-linguistically) for example, may find it difficult to use language and cues more appropriate for a typically developing, normal-hearing 12-month-old (i.e., potential linguistic level of newly implanted child). If so, maternal input might be influenced more by a child's nonverbal capabilities than his or her linguistic level. Auditory and visual cues, and the manner in which they are provided, may affect the rapid word learning of children with cochlear implants.

However, it is plausible that mothers of children with cochlear implants match their language input to a child's linguistic level, rather than his or her nonverbal capabilities. Mothers of children with cochlear implants tend to provide auditory cues to their children consistent with the widely recognized characteristics of child-directed speech (e.g., high pitch, short utterances, and long pauses; Bergeson et al. 2006; Kondaurova and Bergeson 2011). Mothers of children with Down syndrome provide a rate of utterances per minute consistent with a child's language level rather than his or her chronological age (Zampini et al., 2012). Very few studies, however, have considered the provision of multi-modal cues to children with differing cognitive and linguistic abilities. For example, literature to date does not describe the provision of child-directed actions to children with cochlear implants. To consider characteristics of child-directed actions as possible sources of information to influence rapid word learning, additional investigations of children with hearing loss must be conducted.

Visual cues are important for directing the attention of children with hearing loss. Koester, Karkowski and Traci (1998) compared the tactile, visual, and vocal cues used by deaf and hearing mothers to gain the attention of 9-month-old, pre-verbal infants with varying degrees of hearing loss. Visual strategies were the most successful in re-focusing the attention of hearing and deaf infants. Hearing mothers, however, provided fewer visual cues to children than deaf mothers, regardless of child hearing status. The same pattern of performance in maternal interactions was demonstrated with a group of 18-month-old children with and without hearing loss (Koester et al. 1998). The majority of children with hearing loss are born to parents who have normal hearing (Mitchell and Karchmer 2004). Further investigation of the timing of combined auditory and visual cues available to children with cochlear implants, particularly those born to parents with normal hearing, is warranted.

The current study compared the environmental input to children with and without cochlear implants. Specifically, this study examined maternal auditory and visual cues about word referents available to children with cochlear implants as compared to those available to children with normal hearing matched for chronological age and children with normal

hearing matched for vocabulary level. If mothers can direct their auditory and visual cues to increase the salience of a relevant object in word-learning contexts, they should be able to facilitate their children's language growth. Children in the earliest stages of language learning (i.e., children with fewer than 50 vocabulary words) may benefit most from clear, converging cues that unambiguously direct their attention to the referent of a label. Children in later stages of language learning, on the other hand, may be able to determine word referents using their knowledge of linguistic structure and regularities, with less need for an adult to direct their attention. Thus, identification of differences in input to children with and without cochlear implants represents a first step towards determining if deficits of children with cochlear implants are partially attributable to differences in the word-learning environment.

Three research questions were addressed: (a) Do mothers of children with cochlear implants provide a higher percentage of converging cues to children with cochlear implants than parents of children with normal hearing matched for age level, but not children matched for vocabulary level? (b) Do mothers of children with cochlear implants provide a lower percentage of diverging cues to children with cochlear implants than parents of children with normal hearing matched for age level, but not children matched for vocabulary level? and (c) Do mothers of children with cochlear implants provide a lower percentage of auditory-only cues to children with cochlear implants than parents of children with normal hearing matched for age level, but not children matched for vocabulary level?

Materials and Methods

The study protocol and procedures were approved by the Vanderbilt University Institutional Review Board (IRB).

Participants

Participants included 30 mother-child dyads from three groups: a cochlear implant group ($n = 10$), an age-matched group ($n = 10$), and a vocabulary-matched group ($n = 10$). All participants came from English-speaking families, with families of children with hearing loss committed to developing listening and spoken language skills (not sign language). Maternal education level varied freely across the participant pool and was used as a covariate in analysis. See Table 1 for a summary of group characteristics.

Dyads in the cochlear implant group were recruited from the National Center for Childhood Deafness and Family Communication (NCCD) at Vanderbilt University Medical Center. All dyads included a child with at least one cochlear implant device who had a diagnosis of severe to profound, bilateral hearing loss as measured by auditory brainstem response as well as behavioral audiometry. Each mother reported that her child had no useable access to sound before receiving a cochlear implant. Although pre-implant aided soundfield thresholds were not available for all participants, the expressive vocabulary inclusionary criteria supports the assumption that children in this study did not have sufficient access to sound to begin developing oral linguistic knowledge pre-implantation. Children demonstrated sound field thresholds of at least 30 dB HL for 500 through 4000 Hz wearing a cochlear implant. Children did not have additional diagnoses known to affect cognitive

and/or language development (e.g., Down syndrome) or significant visual impairment. The mean age of children in the cochlear implant group was 23 months ($SD = 9.40$ months, range = 16 to 43 months). Average duration of time using a cochlear implant was 5.5 months ($SD = 3.21$ months, range = 2 to 11 months). All children were currently enrolled in speech-language therapy services. To identify environmental input differences between children with and without cochlear implants within a developmental period when auditory-visual cue combinations matter most, this study focused on very early word learning. Thus, children with cochlear implants were eligible to participate in this study if they had an expressive vocabulary of less than 50 words ($M = 14.50$ words; $SD = 23.24$ words, range = 0 to 49 words) as measured by the MacArthur Bates Communicative Development Inventory - Words and Sentences (CDI; Fenson et al. 2006). Parents also completed the LittleEars Auditory Questionnaire to describe their child's auditory function (Kühn-Inacker et al. 2004). This questionnaire requires parents to answer 35 "yes/no" questions about their child's responses to environmental sounds. See Table 2 for child-specific information.

Dyads in the age-matched and vocabulary-matched groups were recruited via advertisement, research recruitment networks, local area preschools, and local area music programs. Participants in these groups demonstrated normal hearing per parent report. Each child in the age-matched group was within three months of age of a child in the cochlear implant group ($M = 24.10$ months; $SD = 9.49$ months; range = 15 – 43 months). Children in the vocabulary-matched group had an expressive vocabulary of less than 50 words ($M = 10.40$ words; $SD = 9.15$ words; range = 0 – 32 words). Expressive vocabulary was selected as the vocabulary-matching variable over receptive vocabulary because parent report measures of expressive vocabulary correspond more closely to child performance than measures of receptive vocabulary (Ring and Fenson, 2000). Average child age in the vocabulary-matched group was 13.5 months ($SD = 4.01$ months; range = 9 – 18 months). Mothers of children with normal hearing completed the Ages and Stages Questionnaire (ASQ) to confirm their child's status as a typical language learner (Squires and Bricker, 2009). Every participant in the age- and vocabulary-matched groups performed above the referral cutoff in the Communication Skills and Problem Solving sections of the ASQ.

Mothers in all three groups completed the MacArthur Bates Communicative Development Inventory - Words and Sentences (CDI; Fenson et al. 2006). This measure was included for descriptive purposes; it was not included as a variable within this study. See Table 3 for group results.

Procedures

One objective of this study was to observe ecologically valid mother-child interactions. Mealtime routines were selected for data collection because they provide equal opportunity for mother-child interactions across groups of participants. Children with cochlear implants do not always wear their devices during other opportunities for mother-child interactions (e.g., getting dressed, bath time, riding in the car). In addition, families of low socioeconomic status do not always incorporate set-aside play times in their daily routines (Brice-Heath 1996). Thus, mealtime provides opportunity for familiar interaction regardless

of socioeconomic status and in which children with cochlear implants are likely to wear their devices.

Mother-child dyads were video-recorded during two mealtime interactions in participants' home environments on two separate days within a 14-day period. The first author was the observer in all interactions; she did not actively participate in the interactions. Two cameras captured the interaction: one following the mother's face and torso and an additional stationary video camera capturing the face and torso of the child. Children were seated in a highchair or a booster seat throughout the interactions, and mothers were free to move around as necessary. Each mealtime interaction was recorded from the point the mother began feeding the child to the natural end of the meal (usually indicated by the mother asking her child if he/she was finished). Each mother was asked to interact with her child as she typically would during mealtime. Although other people were not routinely present during mealtimes, additional family members (e.g., fathers, siblings) did occasionally enter and exit the interaction. Average mealtime duration was 27.4 minutes (SD = 12.39; range = 11.2 – 48.5 minutes).

The observer provided the same six objects (heretofore called “novel objects”) for the mother to include in each mealtime interaction. These objects were new to the children (as confirmed by the mother prior to beginning the mealtime interaction). The observer named each novel object for the mother, and the name of the item was written on the object (novel names included “blicket,” “dax,” “arge,” “chi,” “runker” and “gow”). The same novel objects were used in each interaction. Mothers were given the following information and instructions before each mealtime interaction: “One of the things I am interested in seeing is how children respond to new objects. I want you to use these things in your mealtime. The names of these things are written on the items. They are called blicket, dax, arge, chi, runker, and gow.” Mothers were not given other instructions regarding the items. Number of exposures to each novel object was not controlled. These novel objects were included to ensure that new words were used in the interaction in the unlikely event that mothers did not discuss other nouns unknown to the child. Inclusion of the novel objects may have prompted mothers to label these objects more than they would label other objects. Follow-up analyses addressed mothers' converging referential cues specific to novel objects to determine if response patterns differed for references to novel objects versus all unknown nouns in the interaction.

Data Preparation

Maternal utterances for each interaction were orthographically transcribed using Systematic Analysis of Language Transcripts conventions (SALT; Miller and Iglesias 2010). For each dyad, one transcript file included both interaction transcripts. All nouns within the transcript, including proper nouns (e.g., dad's name), object names (e.g., spoon) and abstract nouns (e.g., dream) from maternal utterances were identified and coded by the first author. The SALT program then generated an alphabetical listing of all transcript nouns. Within two days of the second interaction, the first author presented the list of nouns to the mother and asked her to identify the nouns she believed her child understood. The authors chose to ask mothers to identify nouns she believed her child understood (child's receptive knowledge)

rather than said (child's expressive knowledge) because mothers' beliefs about understanding were likely to affect their actions. This procedure allowed the research team to consider auditory and visual cues for all unknown nouns presented during the interactions, not only those related to novel (and unusual) objects.

Having identified all unknown nouns (including novel object names) in the mealtime interactions, the first author viewed videos to code referential cues for each unknown noun token (e.g., for converging cue mother points to labeled object; coding manual available upon request). Only those unknown nouns presented in utterances considered child-directed (i.e., not those included in utterances to the examiner or to other people present at any time in the video) were coded.

The authors generated a coding manual for this study based on coding procedures used in similar studies of children with normal hearing (e.g., Gogate et al. 2000). All referential cues for unknown nouns in child-directed utterances were coded as converging, diverging, auditory-only or other, a category that included events that could not be coded due to camera angle. Cue codes were considered mutually exclusive (i.e., a cue could not be coded as both converging and diverging).

In the context of this study, converging cues refer to those cues thought to provide maximal amounts of information to children about word referents. Diverging cues are those that may provide ambiguous information about word referents, and auditory-only cues include those that provide a label with no referent. To identify behaviors consistent with the broad categories of converging, diverging, or auditory-only cues, the authors identified detailed behaviors described in other studies of multimodal child-directed speech (see Table 4). Gogate, Bahrick, and Watson (2000) have identified synchronous cues, or cues provided together temporally (within less than 150 milliseconds) to direct attention to the same object (e.g., shaking an object while labeling it), as the most useful cue for word-referent pairings. In this context, visual cues can include acting on an object (e.g., shaking it), pointing to an object (e.g., both distal and proximal points), showing an object to a child, or purposefully directing eye gaze to an object. Although it is possible that these actions provide differing levels of referent information to children, children with normal hearing use each of these actions regularly to establish word-referent pairings (e.g., Chow, Poulin-Dubois, and Lewis, 2008; Grassman and Tomasello, 2010). Similarly, adults provide cues to infants through follow-in labeling, following the infant's direction of attention, directing adult eye gaze to the objects, and naming those objects at which they are looking. If adult visual cues do not conflict with the provision of a label during follow-in labeling incidents, children also establish reference successfully given follow-in labels (e.g., Baldwin, 1991). Because synchronous and follow-in cues provide unambiguous information about object labels, they were coded as converging cues.

In some cases, adults overtly provide ambiguous referential cues by providing auditory and visual cues that indicate different referents, thus diverging cues (e.g., talking about one object while holding another, talking about one object while looking at another). In these cases, normal hearing infants tend to mis-map words according to the adult's visual (holding) cue rather than his or her label (Grassman and Tomasello, 2010). Adults also

provide auditory and visual cues at different times (more than 400 milliseconds apart; e.g., labeling an object and then shaking it). These kinds of labeling incidents are considered asynchronous and are more difficult for young children to interpret than those cues described above as converging (Gogate et al., 2000). In the context of this study, adults did not provide any visual cues that differed temporally from provision of a word label by 150 to 400 milliseconds.

Adults also provide cues by naming static objects (a unimodal cue) at which they are not looking, and objects that are not present in the room. In these scenarios, a child cannot use multimodal cues to identify the referent of an object. Although discussing objects not present in a room (and thus, likely using more rare words) can be generally useful for a child's vocabulary growth, it is likely not useful for children with very low vocabulary knowledge. At minimum, provision of a label without a referent does not direct a child's attention to the same degree as a converging cue, according to the Intersensory Redundancy Hypothesis (Bahrick, Lickliter and Flom, 2004). Thus, both of these types of cues were coded as "auditory-only." It was also possible for adults to provide visual cues unrelated to a referent (for example, waving a hand or mimicking an action). These cues were not coded as visual referential cues for the purposes of this study. Further descriptions of coding decision-making procedures are available in the coding manual developed for this project (available upon request).

Analysis

Using the SALT program, the frequency of converging, diverging, auditory-only and other cues provided for all unknown nouns (including those nouns referencing novel objects) in child-directed utterances within each transcript was calculated. From the frequency data, the percentage of each type of cue and the percentage of cues provided relative to (a) all unknown nouns and (b) only the novel objects provided by the observer were calculated for each participant dyad. The group means for percentage of three cue types – converging, diverging, and auditory-only – were compared using an analysis of variance. "Other" cues were coded infrequently (an average of less than one time per participant) and thus not compared between groups. Percentage, however, was calculated including "other" cues in the denominator. Group membership (cochlear implant, age-matched or vocabulary-matched) represented the between-subjects independent variable and percentages of auditory-only, converging, and diverging cues represented dependent variables. Within the analyses, maternal education level was applied as a covariate. Main effects between groups were analyzed with follow-up linear contrasts.

Reliability

To establish coding reliability, the first author trained a lab assistant (undergraduate linguistics and psychology major) to code naming events using the coding manual. Data was collected from six non-participant dyads to provide training practice for the reliability coder (data from these dyads were not included in the final study). The author and lab assistant coded two transcripts together and four additional transcripts separately. Following coding of each transcript, reliability was calculated for the identification of nouns and child-directed utterances and for converging, diverging, auditory-only and other codes. The author and lab

assistant discussed patterns of coding discrepancy before proceeding to code other transcripts. Reliability above 90% for each variable was obtained for each of the final two training transcripts, and the lab assistant was determined to be trained in the coding procedures.

The lab assistant then coded a random selection of 33% of the study samples from each group, and point-by-point coding agreement was calculated. She used the uncoded SALT transcript in conjunction with the video recording. Table 5 displays reliability data. Reliability percentages were sufficiently high to indicate that the first author had accurately captured the children's responses. Thus, the first author's scoring was used for analysis.

Results

This study compared percentages of auditory-visual cue types about word referents provided to children with cochlear implants, children with normal hearing matched for vocabulary size, and children with normal hearing matched for chronological age. Mother-child interactions were video-recorded during mealtime. Each dyad participated in two mealtime observations. Maternal utterances were transcribed and coded for (a) all nouns produced, (b) child-directed utterances, (c) nouns unknown receptively to children and (d) auditory and visual cues provided about the referents of these unknown nouns.

Table 6 provides information about the transcripts obtained for each group. This information includes the mean number of total utterances, mean number of child-directed utterances, mean percent of unknown nouns produced in child-directed utterances, mean length of child-directed utterances, and mean number of different words produced by mothers in child-directed utterances. Average number of total utterances and average number of child-directed utterances did not differ significantly between groups. However, mothers of children in the age-matched group used fewer unknown words as a percentage of total nouns produced than the cochlear implant or vocabulary-matched groups ($t(18) = 5.11, p < .01$; $t(18) = 5.38, p < .01$; $d = 2.28$), presumably because age-matched children had higher receptive lexical knowledge. Consistent with data collected by Bergeson and colleagues (2006), mothers of children with cochlear implants had a shorter mean length of utterance than mothers of age-matched children ($t(18) = 3.87, p < .01$; $d = 1.73$) but a mean length of utterance not statistically different than that of mothers of vocabulary-matched children ($t(18) = 1.43, p = .17$). Mothers of children in the cochlear implant group produced a lower number of different words than mothers of age-matched children ($t(18) = 3.13, p < .01$; $d = 1.40$) but not vocabulary-matched children ($t(18) = .40, p = .69$).

The three research questions were addressed with all unknown nouns from the entire transcript of each dyad as the data source. Follow up analyses (next section) were focused on the noun labels for only the novel objects provided to the mothers by the observer. The first research question addressed whether mothers of children with cochlear implants provided a different percentage of converging auditory and visual cues about unknown nouns than mothers of children matched for chronological age or mothers of children matched for vocabulary size. Percentage of converging cues was entered into an analysis of variance with group membership (cochlear implant, age-matched or vocabulary-matched) as

the between-subjects variable. Based on evidence that maternal education is associated with child vocabulary development (e.g., Dollaghan et al. 1999), years of maternal education was entered as a covariate. Years of maternal education positively correlated significantly with percentage of converging cues ($r(28) = .42, p = .02$). The homogeneity of slopes assumptions was not violated as the covariate did not interact significantly with group membership (independent variable). The overall ANCOVA indicated a main effect of group on percentage of converging cues ($F(2, 26) = 8.22, p = .001$). A follow-up linear contrast using adjusted means indicated that mothers of children with cochlear implants provided a lower percentage of converging cues ($M = 68.89$, unadjusted $SD = 13.59$) than mothers of vocabulary-matched children ($M = 83.14$, unadjusted $SD = 11.72$; $F(1, 26) = 5.54, p = 0.03, d = 1.12$). Mothers of children with cochlear implants provided a nonsignificantly different percentage of converging cues compared to mothers of age-matched children ($M = 60.66$, unadjusted $SD = 12.08$; $F(1, 26) = 1.85, p = .19, d = .64$).

The second research question addressed whether mothers of children with cochlear implants provided a different percentage of diverging auditory and visual cues than mothers of children matched for chronological age and mothers of children matched for vocabulary size. An analysis of variance was calculated with percentage of diverging cues as the dependent variable and group membership (cochlear implant, age-matched or vocabulary-matched) as the between-subjects independent variable. Years of maternal education was included as a covariate. Years of maternal education negatively correlated significantly with percentage of diverging cues ($r(28) = -.34, p = .04$). The homogeneity of slopes assumptions was not violated as the covariate did not interact significantly with group membership (independent variable). The ANCOVA yielded a main effect of group ($F(2, 26) = 5.97, p = .003$). Follow-up linear contrasts using adjusted means revealed that mothers of children with cochlear implants provided a higher percentage of diverging cues ($M = 24.55$, unadjusted $SD = 10.90$) than mothers of vocabulary-matched children ($M = 10.44, SD = 11.13$; $F(1, 26) = 8.53, p = 0.007; d = 1.28$), but not significantly different from mothers of age-matched children ($M = 24.57, SD = 15.15$; $F(1, 26) = .00001, p = .99, d = .002$).

The third research question compared percentage of auditory-only cues provided by mothers of children with cochlear implants to those provided by mothers of children with normal hearing matched for age and matched for vocabulary size. Years of maternal education did not correlate significantly with percentage of auditory-only cues ($r(28) = .30, p = .11$). The ANOVA with auditory-only cues as the dependent variable and group membership as a between-subjects variable yielded no main effect of group ($F(2, 26) = 1.81, p = .17$). The overall pattern of results for all cue types is displayed in Figure 1.

Further Analyses

Additional analyses were undertaken to explore other potential patterns of maternal input. The primary research questions for this study compared percentage of cues to control for the number of unknown noun tokens presented by mothers. Using a percentage variable (rather than frequency) ensures that group differences are not solely based on the higher vocabulary knowledge of the age-matched group (i.e., mothers of age-matched children use fewer novel noun tokens because these children understand more words than children in other groups).

This analysis decision is consistent with other studies of multimodal cues presented to children with normal hearing (e.g., Gogate et al. 2000; Matayaho and Gogate 2008). However, it is possible mothers of children with hearing loss and mothers of children with normal hearing (age-matched and vocabulary-matched) present similar frequencies of converging auditory-visual cues. To assess this possibility, an analysis of cues provided in reference to the six novel objects (*dax*, *blicket*, *arge*, *gow*, *chi* and *runker*) was undertaken. Only cues for these objects were analyzed to control for the amount of information (novel object labels) that children did not know. Because converging cues are thought to provide the most information to children, they were the only cues analyzed.

Frequency of converging cues produced in reference to the novel objects were entered into an analysis of variance with group membership (cochlear implant, age-matched or vocabulary-matched) as the between-subjects variable and years of maternal education as a covariate. Years of maternal education correlated significantly with frequency of converging cues ($r(28) = .45, p = .01$). The homogeneity of slopes assumptions was not violated as the covariate did not interact significantly with group membership (independent variable). An overall ANCOVA indicated a main effect of group on number of converging cues ($F(2, 26) = 3.09, p = .045$). Additional linear contrasts using adjusted means indicated that mothers of children with cochlear implants provided a lower frequency of converging cues ($M = 26.90$, unadjusted $SD = 24.19$) than mothers of vocabulary-matched children ($M = 46.70$, unadjusted $SD = 24.05$; $F(1, 26) = 2.86, p = 0.04, d = .82$). Mothers of children with cochlear implants provided a frequency of converging cues that was not significantly different from mothers of age-matched children ($M = 28.10, SD = 34.74$; $F(1, 26) = .08, p = .93, d = .04$). Figure 2 displays this pattern of results.

Discussion

The purpose of this study was to compare types of maternal auditory-visual input about word referents available to children with cochlear implants as compared to children with normal hearing matched for age and children with normal hearing matched for vocabulary size. The results of this investigation demonstrated that mothers provided auditory-visual input to children with cochlear implants in a way that did not significantly differ from the way that mothers provide auditory-visual input to children matched for chronological age. The input to children with cochlear implants, however, was significantly different than that provided to children matched for vocabulary size.

Given that children with cochlear implants demonstrate slower rates of lexical growth than children with normal hearing, the findings of this study may be a first step toward the identification of environmental factors that affect lexical outcomes for this population. The Intersensory Redundancy Hypothesis predicts that the use of converging cues will direct the attention of children, including children with cochlear implants, more so than diverging cues (Bahrick et al., 2004). If mothers can provide auditory and visual cues that increase the salience of relevant word-object pairings in word-learning contexts, they may be able to facilitate the lexical growth of their children. Further, if children with low lexical knowledge (i.e., less than 50 words in their vocabulary) rely on converging auditory-visual cues to learn

words from their environment, access to large numbers of converging cues becomes increasingly important.

Studies of children with normal hearing indicate that converging auditory-visual cues best facilitate learning new words (Gogate et al. 2001). However, as children develop the ability to make use of increasing lexical and syntactic knowledge, they likely rely less on the simultaneous presentation of auditory and visual cues to determine the meanings of unknown words. In other words, children are better able to use other types of cues (e.g., syntactic cues, asynchronous cue presentations) to learn the meanings of words. As normal hearing children develop, parents shift their provision of primarily converging auditory-visual cues to provide increasing numbers of diverging as well as auditory-only cues (Gogate et al. 2000).

Children with cochlear implants present a paradox to parents: they often look and act similar to hearing children of their same chronological age, but they have the lexical knowledge of much younger children (Geers et al. 2003). Consequently, parents may provide auditory-visual cues about word referents consistent with a child's chronological age or according to they may provide cues consistent with a child's vocabulary size. This study indicates that mothers of children with cochlear implants provide percentages of converging and diverging cues that are similar to the percentages of mothers of children matched for chronological age. Mothers of children matched for vocabulary size, on the other hand, provide a higher percentage of converging auditory-visual cues and lower percentage of diverging cues than mothers of children with cochlear implants.

The finding that mothers of children with cochlear implants provide auditory-visual cues ("multimodal motherese") consistent with a child's chronological age and not vocabulary size stands in contrast to findings from studies of unimodal motherese (child-directed speech only). Bergeson and colleagues (2006) found that mothers provided child-directed acoustic cues to children with cochlear implants in the same way as mothers of children matched for language level. The descriptive statistics about maternal child-directed speech in this study corroborated Bergeson's findings. In the current study sample, mothers of children with cochlear implants used shorter utterances than mothers of children matched for chronological age, but their utterance length was similar to mothers of children matched for vocabulary size.

Two factors may have contributed to mothers' provisions of cues to children with cochlear implants. The first is the child's developmental level. Mothers of children with cochlear implants may be more sensitive to their children's overall developmental level than they are to their children's lexical level when providing visual cues to accompany auditory cues. Studies of children with delayed overall development and delayed lexical development (e.g., children with Down syndrome) may provide insight into child-level characteristics that affect maternal provision of visual cues. Iverson and colleagues (2006) found that mothers provided more deictic gestures (i.e., gestures that single out an object from other possible referents) to children with Down syndrome than to typically developing children matched for vocabulary size. This finding supports the hypothesis that mothers may provide visual cues according to a child's overall developmental level.

The second factor that may affect mothers' provisions of visual cues is the responsiveness of the child. Mothers of children with language delays not associated with hearing loss (i.e., language-impaired children) provide less linguistic input to children who are less vocally responsive than to children who are more vocally responsive (Giralometto et al. 1999; Paul and Elwood 1991). It is possible that children with cochlear implants do not solicit visual referential cues from their mothers in the same way that some children with language delays do not solicit linguistic input. Children with normal hearing, on the other hand, may solicit visual cues about word referents when they have a low vocabulary level. Further research should explore the possibility that a child's responsiveness affects the referential cues he or she receives about word referents.

The present study represents an initial and important step toward identification of environmental input differences between children with cochlear implants and children with normal hearing that may affect lexical learning outcomes. This work is essential to identify malleable factors to validate interventions that improve child lexical outcomes. Continued child-level and environment-level research is warranted. At the child-level, the next step is to evaluate the extent to which children with cochlear implants make use of converging and diverging cues during word-learning opportunities. This information will help professionals determine the importance of auditory-visual cue provision to lexical growth in children with cochlear implants. At the level of the environment, next steps may consider (a) the nature of cue provision throughout the day, (b) the nature of cue provision as children age, and (c) the development and implementation of parent training.

This study is among the first to consider visual as well as auditory input provided to children with cochlear implants in the context of a daily routine. The author chose to use a routine, mealtime, that is generally structured similarly across families. A structured measurement scenario may be more representative of the generalized tendency to provide referential cues to children than a less structured scenario, such as free play. Additionally, the authors chose to analyze data from two observations, as opposed to only one. Using data from more than one observation is likely to result in a more stable estimate of mothers' referential behaviors than a single observation (Yoder and Symons 2010). However, analyzing data from only mealtimes represents a potential weakness. If maternal referential cues to children vary based on daily routine context, the results of this study are only representative of information provided to children during mealtimes.

Mealtime, although ideal for the initial stages of this line of inquiry, also may overestimate the number of cues about new word referents available to all children throughout the day. Because mealtime usually involves stationary participants, mothers are able to coordinate the visual cues they provide to their children in a way they may not be able to during other routines (e.g., playing outside). Thus, it is possible that children with cochlear implants receive even fewer converging auditory-visual cues about word referents than suggested by this work. Future studies should examine the provision of auditory and visual cues to children with and without cochlear implants throughout the course of the day.

It is also possible that mothers of children with cochlear implants change their provision of converging versus diverging and auditory-only cues as their children age. The discrepancy

between the language knowledge and developmental level of many children with cochlear implants may change as children use their implant more often, thus affecting the ways in which mothers provide information to their children. Future work should consider the ways in which mothers provide auditory and visual cues about word referents to children with varying amounts of cochlear implant experience.

Another future direction of this study could include parent training. If increasing the number of converging cues presented to children with cochlear implants may improve their vocabulary knowledge, mothers could learn to increase their provision of converging cues during word-learning opportunities. Future studies should evaluate the development and efficacy of parent trainings related to auditory-visual cue provision.

Additional strengths and weaknesses of this study should be considered in the interpretation of these results. The etiologies of children with hearing loss are widely varied. Although sample size for this study was large enough to capture group differences in cue provision, the group of children with cochlear implants was not completely representative of all children with hearing loss. More work should be done to determine if this finding holds for children with varying degrees of auditory experience (e.g., children who use hearing aids). The stringent inclusionary criteria for this study do not allow the author to draw conclusions about the general population of children with hearing loss or children who have used cochlear implants for a longer period of time. For this initial study, it was important to use a narrowly defined subset of children with hearing loss to identify differences in parent input related to tightly controlled child characteristics. However, a limitation of the present study included that the authors did not have access to exact pre-implant aided soundfield thresholds for every participant. It is possible that parents did not understand that their children had some useable access to sound pre-implant. Access to sound may have, in turn, affected participants' responsiveness during communicative interactions. Future works should quantitatively measure residual hearing pre-implantation to control for this limitation.

References

- Bahrick LE, Flom R, Lickliter R. Intersensory redundancy facilitates discrimination of tempo in 3-month-old infants. *Dev Psychol.* 2002; 41:352–363.
- Bahrick LE, Lickliter R. Intersensory redundancy guides attentional selectivity and perceptual learning in infancy. *Dev Psychol.* 2000; 36:190–201. [PubMed: 10749076]
- Bahrick LE, Lickliter R, Flom R. Intersensory redundancy guides the development of selective attention, perception, and cognition in infancy. *Curr Dir Psychol Sci.* 2004; 13:99–102.
- Baldwin D. Infants' contribution to the achievement of joint reference. *Child Dev.* 1991; 62:875–890. [PubMed: 1756664]
- Bergeson TR, Miller RJ, McCune K. Mothers' speech to hearing-impaired infants and children with cochlear implants. *Infancy.* 2006; 10:221–240.
- Brice-Heath, S. *Ways with words: Language, life, and work in communities and classrooms.* New York, NY: Cambridge University Press; 1996.
- Chow V, Poulin-Dobois D, Lewis J. To see or not to see: Infants prefer to follow the gaze of a reliable looker. *Dev Sci.* 2008; 11:761–770. [PubMed: 18801132]
- Dollaghan CA, Campbell TF, Paradise JL, et al. Maternal education and measures of early speech and language. *J Speech Lang Hear Res.* 1999; 42:1432–1443. [PubMed: 10599625]
- Fenson, L.; Marchman, V.; Thal, D., et al. *The MacArthur Bates communicative development inventories: User's guide and technical manual.* 2. Baltimore, MD: Brookes; 2006.

- Ganek H, McConkey-Robbins A, Niparko JK. Language outcomes after cochlear implantation. *Otolaryngol Clin North Am.* 2012; 45:173–185. [PubMed: 22115689]
- Geers AE, Nicholas JG, Sedey AL. Language skills of children with early cochlear implantation. *Ear Hear.* 2003; 24:46S–58S. [PubMed: 12612480]
- Girolametto L, Weitzman E, Wiigs M, et al. The relationship between maternal language measures and language development in toddlers with expressive vocabulary delays. *Am J Speech Lang Pathol.* 1999; 8:364–374.
- Gogate LJ, Bahrick LE. Intersensory redundancy facilitates learning of arbitrary relations between vowel sounds and objects in seven-month-old infants. *J Exp Psychol Gen.* 1998; 69:133–148.
- Gogate LJ, Bahrick LE, Watson JD. A study of multimodal motherese: The role of temporal synchrony between verbal labels and gestures. *Child Dev.* 2000; 71:878–894. [PubMed: 11016554]
- Gogate LJ, Bolzani LH, Betancourt EA. Attention to maternal multimodal naming by 6- to 8-month-old infants and learning of word-object relations. *Infancy.* 2006; 9:259–288.
- Gogate LJ, Hollich G. Invariance detection within an interactive system: A perceptual gateway to language development. *Psychol Rev.* 2010; 117:496–516. [PubMed: 20438235]
- Gogate LJ, Walker-Andrews AS, Bahrick LE. The intersensory origins of word comprehension: An ecological-dynamic systems view. *Dev Sci.* 2001; 4:1–37.
- Grassman S, Tomasello M. Young children follow pointing over words in interpreting acts of reference. *Dev Sci.* 2010; 13:252–263. [PubMed: 20121881]
- Heibeck TH, Markman EM. Word learning in children: An examination of fast mapping. *Child Dev.* 1987; 58:1021–1034. [PubMed: 3608655]
- Houston DM, Stewart J, Moberly A, et al. Word learning in deaf children with cochlear implants: Effects of early auditory experience. *Dev Sci.* 2012; 15:448–461. [PubMed: 22490184]
- Houston-Price C, Plunkett K, Harris P. ‘Word learning wizardry’ at 1;6. *J Child Lang.* 2005; 32:175–189. [PubMed: 15779882]
- Iverson J, Longobardi E, Spampinato K, et al. Gesture and speech in maternal input to children with Down’s syndrome. *Int J Lang Commun Disord.* 2006; 41:235–251. [PubMed: 16702092]
- Koester LS. Face-to-face interactions between hearing mothers and their deaf or hearing infants. *Inf Behav Dev.* 1995; 18:145–153.
- Koester LS, Karkowski AM, Traci MA. How do deaf and hearing mothers regain eye contact when their infants look away? *Am Ann Deaf.* 1998; 143:5–13. [PubMed: 9557327]
- Kondaurova MV, Bergeson TR. The effects of age and infant hearing status on maternal prosodic cues for clause boundaries in speech. *J Speech Lang Hear Res.* 2011; 54:740–754. [PubMed: 20966387]
- Kühn-Inacker, H.; Weichbold, V.; Tsiakpini, L., et al. *LittleEars: Auditory questionnaire.* Innsbruck, Austria: MED-EL; 2004.
- Marchman VA, Fernald A. Speed of word recognition and vocabulary knowledge in infancy predict cognitive and language outcomes in later childhood. *Dev Sci.* 2008; 11:F9–F16. [PubMed: 18466367]
- Matatyaho DJ, Gogate LJ. Type of maternal object motion during synchronous naming predicts preverbal infants’ learning of word-object relations. *Infancy.* 2008; 13:172–184.
- Miller, JF.; Iglesias, A. *Systematic Analysis of Language Transcripts (SALT), Student Version* [Computer software]. Madison: University of Wisconsin—Madison, Waisman Center, Language Analysis Laboratory; 2010.
- Mitchell RE, Karchmer MA. Chasing the mythical ten percent: Parental hearing status of deaf and hard of hearing students in the United States. *Sign Language Studies.* 2004; 4:138–163.
- Nott P, Cowan R, Brown PM, et al. Early language development in children with profound hearing loss fitted with a device at a young age: Part I- the time period taken to acquire first words and first word combinations. *Ear Hear.* 2009; 30:526–540. [PubMed: 19739282]
- Paul R, Elwood TJ. Maternal linguistic input to toddlers with slow expressive language development. *J Speech Hear Res.* 1991; 34:982–988. [PubMed: 1749252]
- Ring ED, Fenson L. The correspondence between parent report and child performance for receptive and expressive vocabulary beyond infancy. *First Lang.* 2000; 20:141–159.

- Squires, J.; Bricker, D. The ages & stages questionnaire. Baltimore, MD: Paul H. Brookes Publishing Co; 2009.
- Tomblin JB, Barker BA, Hubbs S. Developmental constraints on language development in children with cochlear implants. *Int J Audiol*. 2007; 46:512–523. [PubMed: 17828667]
- Tomblin JB, Barker BA, Spencer LJ, et al. The effect of age at cochlear implant initial stimulation on expressive language growth in infants and toddlers. *J Speech Lang Hear Res*. 2005; 48:853–867. [PubMed: 16378478]
- Waltzman SB, Cohen NL, Green J, et al. Long-term effects of cochlear implants in children. *Otolaryngol Head Neck Surg*. 2002; 126:505–511. [PubMed: 12075224]
- Woodward AL, Markman EM, Fitzsimmons CM. Rapid word learning in 13- and 18-month-olds. *Dev Psychol*. 1994; 30:553–566.
- Yoder, P.; Symons, F. *Observational measurement of behavior*. New York, NY: Springer; 2010.
- Zampini L, Fasolo M, D'Odorico L. Characteristics of maternal input to children with Down syndrome: A comparison with vocabulary size and chronological age-matched groups. *First Lang*. 2012; 32:324–342.

Figure 1.
Percentage of Auditory-Visual Cues about Word Referents

Figure 2.
Number of Converging Cues Provided in Reference to Novel Objects

Table 1

Group Characteristics

Group	Child Age in Months Mean (SD)	Years Maternal Education Mean (SD)	Number of Siblings Mean (SD)
Cochlear Implant (n = 10 dyads)	23.00 (9.40) range = 16 – 43	15.95 (2.03) range = 12 – 18	1.20 (1.03) range = 0 – 2
Age-Matched (n = 10 dyads)	24.10 (9.49) range = 15 – 43	17.45 (3.59) range = 13 – 23	1.10 (0.87) range = 0 – 3
Vocabulary-Matched (n = 10 dyads)	13.50 (4.01) range = 9 – 18	18.20 (2.30) range = 15 – 22	0.80 (0.78) range = 0 – 2

Table 2

Characteristics of Individual Child Participants in the Cochlear Implant Group

Participant	Chronological age	Degree of Hearing Loss	Age at Identification	Amount of time with CI	Bilateral implants?	LittleEars Score
1	14 months	Severe to Profound	Birth	2 months	Yes	12
2	15 months	Severe to Profound	Birth	7 months	Yes	25
3	15 months	Severe to Profound	Birth	4 months	No	13
4	18 months	Severe to Profound	Birth	5 months	Yes	23
5	19 months	Profound	Birth	10 months	Yes	30
6	21 months	Severe to Profound	10 months	6 months	Yes	19
7	22 months	Severe to Profound	2 months	11 months	Yes	34
8	29 months	Severe to Profound	Birth	6 months	Yes	25
9	35 months	Profound	29 months	2 months	Yes	2
10	42 months	Severe to Profound	Birth	2 months	No	8

Note. CI = cochlear implant; LittleEars = LittleEars Auditory Questionnaire score out of 35 possible points (Kühn-Inacker et al., 2004).

Table 3

Descriptive Measures (Means and Standard Deviations) by Group

Group	MCDI Receptive Score	MCDI Expressive Score
Cochlear Implant	53.00 (70.41)	13.10 (20.15)
Age-Matched	308.00 (79.67)	175.70 (139.68)
Vocabulary-Matched	91.20 (74.25)	10.40 (9.16)

Note. MCDI = MacArthur Bates Communicative Development Inventory (Fenson et al., 2006).

Table 4

Types of Auditory and Visual Cues Provided to Children about Referents

Cue Code	Specific Behavior	Example
Converging	Moving Synchronous Cues	Shakes one object while labeling, points to or touches object while labeling
	Follow-in Labeling	Labels object child is looking at, directing adult gaze to object
Diverging	Moving Asynchronous	Labels one object then indicates referent after 400+ milliseconds
	Indicating Different Objects	Holds one object while labeling another
Auditory-Only	Still-Object Labeling	Labels an object within the room without indicating visually
	Labeling Objects Not Present	Labels an object not in a child's view

Table 5

Point-by-Point Percent Agreement Calculated Based on 33% of Samples within each Participant Group

	Group		
	Cochlear Implant	Age-Matched	Vocabulary-Matched
Nouns Codes	99.36%	98.99%	98.98%
Child-Directed Utterance Codes	98.35%	96.29%	100.00%
Converging Cue Codes	95.31%	95.07%	99.50%
Diverging Cue Codes	91.89%	97.78%	98.96%
Auditory-Only Cue Codes	91.67%	92.31%	87.11%

Table 6

Group Means and Standard Deviations on Transcript Variables

Group	Mean Number Total Maternal Utterances	Mean Number Child-Directed Utterances	Mean Percent of Unknown Nouns Used by Mothers	Mean MLU of Mothers	Mean NDW of Mothers
Cochlear Implant	387.30 (253.55) range = 60 – 902	297.20 (257.35) range = 60 – 892	65.66 (20.44) range = 32.05 – 92.59	3.27 (.78) range = 1.65 – 4.09	213.80 (98.48) range = 36 – 345
Age-Matched	455.40 (245.98) range = 203 – 581	328.00 (148.69) range = 198 – 578	24.90 (14.76) range = 8.79 – 49.72	4.37 (.44) range = 3.88 – 4.9	355.80 (104.21) range = 188 – 533
Vocabulary-Matched	390.70 (127.02) range = 181 – 742	368.50 (114.27) range = 120 – 600	68.14 (20.69) range = 32.60 – 92.98	3.72 (.61) range = 2.67 – 4.53	228.70 (62.03) range = 157 – 305

Note. MLU = Mean Length of Utterance in words; NDW = Number of Different Words