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The Effect of Hearing Loss on Novel Word Learning in Infant- and Adult-Directed Speech

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Abstract

Objectives—Relatively little is known about how young children with hearing impairment (HI) learn novel words in infant- and adult- directed speech. Infant-directed speech (IDS) supports word learning in typically developing infants relative to adult-directed speech (ADS). This study examined how children with normal hearing (NH) and children with HI learn novel words in IDS and ADS. It was predicted that IDS would support novel word learning in both groups of children. In addition, children with HI were expected to be less proficient word learners as compared to their NH peers.

Design—A looking-while-listening paradigm was used to measure novel word learning in 16 children with sensorineural HI (age range 23.2–42.1 months) who wore either bilateral hearing aids (n = 10) or bilateral cochlear implants (n = 6) and 16 children with NH (age range 23.1–42.1 months) who were matched for gender, chronological age, and maternal education level. Two measures of word learning were assessed (accuracy and reaction time). Each child participated in two experiments approximately one week apart, one in IDS and one in ADS.

Results—Both groups successfully learned the novel words in both speech type conditions, as evidenced by children looking at the correct picture significantly above chance. As a group, children with NH outperformed children with HI in the novel word learning task, however there were no significant differences between performance on IDS vs ADS. More fine-grained time course analyses revealed that children with HI, and particularly children who use hearing aids, had more difficulty learning novel words in ADS, compared to children with NH.

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Conclusions—The pattern of results observed in the children with HI suggests that they may need extended support from clinicians and caregivers, through the use of IDS, during novel word learning. Future research should continue to focus on understanding the factors (e.g., device type and use, age of intervention, audibility, acoustic characteristics of input, etc.) that may influence word learning in children with HI in both IDS and ADS.

INTRODUCTION

Infants with normal hearing (NH) sensitivity begin their auditory development before birth, and experience language learning primarily through the auditory modality. By age of 4 to 5, children with NH have developed vocabularies with approximately 3000–5000 words (Nation & Waring 1997). However, the vocabulary of children with congenital hearing impairment (HI) of the same chronological age is often estimated to be significantly lower (Mayne et al. 2000; Blamey et al. 2001; Yoshinaga-Itano et al. 2010). Children with hearing loss often have drastically different early experiences with auditory input than typically developing infants. Their ability to hear soft sounds may be delayed, depending on when they are identified and fit with hearing devices. Additionally, the quality of their hearing is largely dependent on factors associated with hearing loss and the device (cochlear implant or hearing aids) that is processing the sound for them. Given that early experience with speech and language has been shown to have a significant impact on word learning and predicts later vocabulary development in typically developing children (Marchman & Fernald 2008; Fernald & Marchman 2012), it is imperative to understand how these divergent early auditory experiences affect word learning in children with hearing loss.

Despite continued strides toward earlier identification and intervention for children with HI, the current generation of children with HI still lags behind their normal hearing peers on a number of outcome measures including word learning (Lederberg et al. 2000; Stelmachowicz et al. 2004). Several studies have examined novel word learning abilities in older children with hearing loss. These studies have shown that reduced access to hearing affects children's ability to learn the phonological features of new words (Stelmachowicz et al. 2004; Pittman 2008), and reduces their ability to learn from incidental presentation of words compared to NH children (Davidson et al. 2014). Converging evidence from school-aged children with hearing loss (aged 4–9 years) suggests that better novel word learning performance is associated with larger vocabulary size (Gilbertson & Kamhi 1995; Lederberg et al. 2000), better complex working memory (Hansson et al. 2004), and greater audibility (Gilbertson & Kamhi 1995; Stelmachowicz et al. 2004; Pittman et al 2005; Lederberg & Spencer 2009; Houston et al. 2012; Davidson et al. 2014; Bagatto et al. 2016). Studies of novel word learning in younger infants with hearing loss are relatively rare and are needed to determine what factors support word learning in infants with HI.

Acoustic cues, particularly those found in infant-directed speech (IDS), can to be used to bootstrap word learning in young, typically developing children. IDS is a unique speech style that has been shown to facilitate many aspects of early language learning (Thiessen et al. 2005; Ma et al. 2011; Graf Estes & Hurley 2013). When compared to adult-directed speech (ADS), IDS includes greater variation in the mean fundamental frequency (F0) and the frequency range, longer duration and hyper-articulation of vowels (though see Cristià &

Seidl 2014 and McMurray et al. 2013 for differing views on hyperarticulation of vowels), slower tempo, and higher amplitude (Stern et al. 1983; Fernald & Simon 1984; Cooper & Aslin 1990; McRoberts & Best 1997). IDS is generally thought to serve important social, attention, and language related functions (Cooper & Aslin 1990). The lively exaggerated tempo of IDS has been shown to capture and maintain the infant's attention to speech (Fernald & Simon 1984; Papousek et al. 1991). In laboratory studies, using preferential looking times or visual habituation paradigms, young infants look longer at visual stimuli when listening to IDS over ADS, suggesting a preference for IDS (Fernald 1985; Werker & McLeod 1989; Cooper & Aslin 1990; Pegg et al. 1992; Robertson et al. 2013). As infants get older, IDS also functions to support linguistic development, including speech discrimination (Liu et al. 2003), syntax acquisition (Kemler Nelson et al. 1989), word segmentation (Thiessen et al. 2005), word recognition (Singh et al. 2009), and word learning (Ma et al. 2011; Graf Estes & Hurley 2013). Finally, listening preferences for IDS over ADS appear to decrease by the end of the second year (Robertson et al. 2013), but see Hayashi et al. (2001) and Newman and Hussain (2006) for evidence to the contrary. Consistent with this shift in perceptual preferences across development, caregivers begin to decrease their use of highly exaggerated pitch contours as their infants' linguistic competencies increase (Amano et al. 2006). Interestingly, mothers of young children with HI have been shown to fine-tune their speaking style according to their child's hearing experience rather than their chronological age (Bergeson et al. 2006; Kondaurova et al. 2013). In addition, Bergeson et al. (2006) found that the hearing experience of children with HI was significantly correlated with their productive vocabulary. These studies suggest that parents of children with HI are also sensitive to their child's language competencies, and adjust their speech accordingly. Thus, the availability of and reliance on specific speech cues appears to shift across development.

Recent studies have highlighted the important role that IDS may play in early word learning at different ages (e.g., Ma et al. 2011; Graf Estes & Hurley 2013). For example, Graf Estes and Hurley (2013) investigated the role IDS plays in word learning by 17-month-olds. Across three experiments they found that 17-month-olds are better able to map novel words to objects if the words are produced in IDS rather than ADS, and that the variability in the prosody associated with IDS may be particularly important for early word learning. In a second study, Ma and colleagues (Ma et al. 2011), compared word learning in IDS to word learning in ADS in 21-month-old infants and found evidence that word learning is not necessarily driven by the age of the infant; rather, it is mediated by language abilities. Following the training phrase in which two novel labels and objects were repeatedly paired, only infants who had heard the labels presented in IDS during training, but not those who heard the labels presented in ADS, showed evidence of having learned the label-object pairs as evidenced by an increase in looking at the labeled object as compared to the distractor object. However, a comparison of the infants' performance with their productive vocabulary revealed that infants with a higher vocabulary performed better than the infants with a low vocabulary. In fact, infants with higher vocabularies showed learning in the second block of the test trials in the ADS condition. In a separate group of 27-month-olds, infants were able to learn the novel words produced in ADS, regardless of their vocabulary size. The authors suggested that IDS facilitates word learning, especially for infants with smaller vocabularies.

Given the importance of IDS in early language acquisition, and current trends in early identification and intervention, researchers are beginning to explore the effect of hearing loss on infant preferences for IDS. For example, Segal and Kishon-Rabin (2011) found that infants (aged 14–33 months) with profound hearing loss who use cochlear implants (CI) preferred listening to IDS over both white noise and time reversed speech. In a separate study, Kishon-Rabin et al. (2010) demonstrated that infants who use CIs can differentiate exemplars of IDS in their native language (Hebrew) from exemplars of IDS in a non-native language (English). Although both of the studies by Kishon-Rabin and colleagues (Kishon-Rabin et al. 2010; Segal & Kishon-Rabin 2011) established that CIs provide infants with profound hearing loss access to IDS, their studies did not address whether these infants show perceptual preferences for IDS relative to ADS. In a recent study Robertson, et al., (2013) examined listening preference for IDS over ADS in a group of infants with HI (8.9 to 32.2 months) whose hearing age ranged from 5.1 to 11.5 months. Their performance was compared to two control groups with NH, one group with a similar mean listening age (5.3 to 9.3 months) and one group with a similar mean chronological age (16.3 to 25.3 months). The results showed that infants with hearing loss were able to detect differences between IDS and ADS and that they demonstrated a preference for IDS over ADS, like their NH peers who were matched for listening experience. Taken together, these studies suggest that infants with HI show a preference for IDS over ADS, like their normal hearing peers. It remains unclear whether a preference for IDS also facilitates early word learning in children with HI.

There are only a few published studies that have examined how hearing loss affects word learning in younger children. In one recent study, Houston et al. (2012) examined the effect of early auditory experience (early CI versus late CI, and NH children matched for chronological age) on novel object-label associations. Using methods similar to Ma and colleagues (2011), Houston and colleagues found that children who were implanted earlier performed better on the word learning task, as evidenced by above chance looking to the labeled object, than those who were implanted later, who showed no evidence of learning. In contrast, the NH age-matched controls demonstrated learning of the label-object associations. The early implanted group performed similarly to their age-matched NH peers, whereas the late CI group's performance diverged significantly from that of their age-matched peers. The authors suggest that early auditory experience plays a significant role in word learning abilities for children with early onset hearing impairment. Since the study by Houston and colleagues (2012) used only IDS, it remains unclear whether children with hearing loss are also able to learn novel words presented in ADS.

The present study used the looking-while-listening (LWL) procedure (Fernald, et al. 2008) to investigate how experience with IDS and ADS impacts novel word learning in children with HI relative to children with NH matched for chronological age. Children participated in two experiments, one designed to test novel word learning in IDS and the other designed to test novel word learning in ADS. We predicted that both NH and HI groups would show facilitated novel word learning in the IDS relative to the ADS condition, as evidenced by increased accuracy in the IDS condition. Further, we predicted that children with NH matched for chronological age would show increased accuracy and faster reaction time compared to children with HI.

MATERIALS AND METHODS

Participants

Sixteen children (11 Female) with sensorineural hearing loss (mean chronological age = 31.2 months, range 23.2–42.1) who wore either bilateral hearing aids (n=10) or bilateral cochlear implants (n = 6) were recruited from the University of Tennessee's Child Hearing Services Clinic, and surrounding area. Table 1 shows the mean age, gender, the hearing age (defined as the amount of time amplification had been used from the initial hearing aid/ cochlear implant fitting until day of test), the type of devices worn by the children, and Speech Intelligibility Score (SII). Although the researchers recognized that some children's SII scores were below the optimal SII speech audibility target values (Bagatto et al. 2016), they did not want to make changes to the fittings made by the child's audiologist. Children with HI had a mean gestational age of 37.5 weeks (range = 27.0–41.3 weeks, see Table 1) and had the following characteristics: 1) bilateral, congenital, sensorineural hearing loss diagnosed with an auditory brainstem response test, 2) use of bilateral hearing aids and/or cochlear implants for at least 5 months, 3) no indication of auditory neuropathy spectrum disorder (defined as otoacoustic emissions present in combination with hearing loss greater than 40 dB HL and/or cochlear microphonic component recorded in combination with no obvious auditory brainstem response), and 4) for children with hearing aids, an aided SII score of > 20.

Communication mode for all the children was primarily aural/oral and all children participated in a therapy program 1 to 3 hours a week that emphasized an aural/oral approach. Four of the children were also exposed to sign language in another therapy program 2 times weekly. It was unclear how much sign language was used throughout the day with these children. Data from two additional children with HI were excluded from the analysis because of inattention (1) and fussiness (1).

Normal hearing children (NH group, n = 16) were matched with the HI group for gender, maternal education level, and chronological age (mean = 31.2 months, SD = 6.1; range 23.1–42.1; Table 1). When possible, participants were also matched on gestational age. Participants H5 and H10 were born premature (at 27 and 35.3 weeks, respectively) and unfortunately, there were no NH gestational age matches available at the time this study was conducted. Participant H2 was also born premature at 28.1 weeks gestation, however their NH twin served as their matched control. All other participants were matched within ± 2 weeks of their gestational age. The mean gestational age for children with NH was 38.7 weeks (range = 28.1–41.1 weeks). We chose not to match for hearing age as 7 of the 16 children with HI had hearing ages that were below the age of 14 months. It is difficult to demonstrate novel word learning in the laboratory using the looking-while-listening method in such young children. Children with NH had fewer than four prior ear infections, had no history of hearing or vision impairments, passed a hearing screening using distortion product otoacoustic emissions [DPOAEs] on the day testing, and scored > 20th percentile on the MCDI vocabulary measure (Fenson et al. 2006). Six children with NH were excluded from the analysis due to inattention (5) and experimenter error (1).

All of the children in both groups were monolingual learners of English and were free of severe motor, cognitive or visual delays or impairments according to parental report. Socioeconomic status (SES) was determined by the educational level of the mother (Yoshinaga-Itano et al. 1998; Bornstein et al. 2003; Sininger et al. 2010). The mothers' mean educational level for the HI group and the NH group was 14.8 years (SD = 2.3) and 15.25 years (SD = 1.5), respectively (see Table 1). This study received approval from the University of Tennessee Health Science Center's Institutional Review Board.

Procedure

Speech Stimuli—Four novel words (dax, /dæks/; nila, / nɪlə/; blick, / blɪk/; and modi, / moʊdi/) were used in the current experiment. The novel words were composed of phonotactically legal sound sequences and were balanced for the phonotactic probability of phoneme occurrence in English (Vitevitch & Luce 2004). The novel words were used in pairs (dax-nila and blick-modi), one pair in each experiment. Although young word learners are typically successful at distinguishing known words with similar phonetic content (Swingley & Aslin 2002; Swingley 2005), previous research suggest that phonological encoding of similar sounding novel words may be difficult for early word learners (Pater et al. 2004; Yoshida et al. 2009). Therefore, to encourage word learning, the novel word pairs were dissimilar in number of syllables and had no repetition of phonemes. Four familiar words (baby, doggie, shoe, and ball) were also included during the test phase, but were not included in the analyses.

All speech stimuli were recorded by the same female speaker in IDS and ADS at a sampling rate of 44.1 KHz. The speaker was a trained speech-language pathologist and mother of a 12-month-old infant. She was asked to imagine that she was talking to her infant (for IDS) or to an adult (for ADS). The training phase consisted of short phrases (Look at the [target]! It's a [target]! [Target]!), paired with presentations of a novel object. To preserve the natural quality of speech during the training phase, target words were produced in the context of the carrier phrase, and thus, on each training trial children heard three different exemplars of each target word. The test trials consisted of a short question followed by a repetition of the target word (Where's the [target]? [Target]!). In order to eliminate potential effects of variability associated with the carrier phrase, within each speech type the same carrier phrase was spliced into every test trial. The spliced stimuli allowed the authors to maintain precise timing for the presentation of the target word onsets while preserving very natural sounding speech. To ensure that the IDS and ADS phrases and novel words differed on the relevant dimension [i.e., IDS has a higher fundamental frequency (F0), a wider frequency range, and is typically longer in duration than ADS (Garnica 1977; Jacobson et al. 1983; Fernald 1993)], an acoustic analysis was done on all of the training phrases and on the novel target words used in training and test trials, using Pratt software (Boersma & Weenink 1996, see Table 2). The pitch analyses revealed greater overall variability in F0 range and higher mean average F0 in the IDS than in the ADS phrases and novel words, consistent with values presented in previous research (Fernald 1989; Thiessen et al. 2005; Ma et al. 2011). The duration of the novel words and phrases in IDS were longer than in ADS. In order to equalize the duration of the training and test trials across speech type conditions, longer pauses were inserted between phrases in the ADS condition. The resulting training and test trials were each 6.5 seconds long. In addition to the test trials, filler trials were used during testing to help maintain interest (e.g. 'Good job! Here's another picture!'). The stimuli were adjusted in Adobe Audition® to have the same root-mean-square power (−20 dB) and were presented at 65 dB SPL (A-weighted scale). Calibration of the sound field was checked periodically with a sound level meter (Larson Davis System 824).

Ten naïve adults participated in a perceptual judgment task where they were asked to classify the sentences used in the experiment and indicate if each sentence sounded as though it was being spoken to young child or to an adult. The IDS and ADS sentences were randomly presented. Adult successfully classified the sentences as IDS and ADS with 99.5% accuracy, with one adult judging one sentence as ADS instead of IDS.

Visual Stimuli—Visual stimuli consisted of digitized photographs of colorful objects (see Table, Supplemental Digital Content 1). All images were matched in size (11.5 in. × 8 in.) and brightness. Filler trials consisted of more complex and colorful pictures than the experimental novel word and familiar word trials. During the training phase the objects, presented in isolation, moved across the screen in various patterns while the object was being labeled. The motion of the objects was not tied to the timing of the speech stimuli. During the test phase, two stationary objects (in yoked pairs) appeared on the left and right sides of the screen, 14 in. apart (Fig. 1). Each object served as the target and distractor object on an equal number of trials.

Apparatus

The procedure was conducted in a semi-darkened sound-attenuated double-walled booth. Images were presented on a 43″ LCD/LED monitor (Samsung 450) located 37 inches from the child's face. The auditory stimuli were presented at 65 dB SPL through a loudspeaker placed below the monitor. A hidden video camera placed below the monitor, captured the child's looking behavior at a rate of 30 frames per second. Trials were later coded for eye gaze position frame-by-frame to determine whether children were looking at the target object, the distractor object, or elsewhere during the trial. The coders were blind to which object was the target versus the distractor while coding the test phase. To assess coder reliability, 25% of the data were coded by a second trained coder. The proportion of frames on which coders agreed was 98.5% and the mean proportion of shifts on which two coders agreed within one frame was 94.6%.

Each child participated in two experiments approximately one week apart, one in IDS and one in ADS, counterbalanced across participants. Two novel label-object pairs (dax-nila or blick-modi) were used in each experiment and counterbalanced across participants, such that children heard different novel words at each testing session. The child was seated on the caregiver's lap facing the monitor. The caregiver wore headphones and listened to music during the experiment to reduce the potential for bias. The experimenter, located outside the booth, controlled the experiment. There were 2 pseudo-random training orders. Within each order there were 12 trials in which the novel labels and objects were paired (6 trials per novel word). The testing phase consisted of 16 novel word trials (8 trials per novel word), 16 familiar word trials, and 4 filler trials. Figure 1 shows an overview schematic of the experimental protocol. Familiar word trials were included to help children understand the referential nature of the task, to help maintain attention throughout the procedure, and to collect measures of speech processing efficiency. Data from familiar word trials are not reported here. On each test trial, the carrier phrase began 1 sec after the onset of the object presentation, with the target word beginning 2.5 seconds into the trial (Fig. 2). Including a delay between object presentation and target label onset helps ensure that children have adequate time to look at both objects before label onset. There were 2 pseudo-randomized testing orders; no word was presented twice in succession; the target object was presented on the left and right sides an equal number of times; the target object did not appear on the same side more than 3 trials in a row; novel and familiar word trials alternated; and filler trials occurred after every 8 test trials. The entire experiment lasted 5–6 minutes.

Measuring Novel Word Learning

Two measures of novel word learning were obtained: accuracy and reaction time (RT; Fernald et al. 2008). Accuracy represents how reliably children looked at the correct picture, which was calculated as the mean time spent looking at the target picture as a proportion of the total time spent on either the target or the distractor picture (i.e., proportion correct = [looking time to target]/[total looking time to target + distractor]), within the time window of 367–2000 ms following target onset. This time window increases the likelihood that the accuracy measure reflects a response made by the child in response to hearing the target word. Eye movements to the target object initiated within the first 366 ms following word onset, or after 2000 ms, are unlikely to have been initiated in response to hearing the label (Fernald et al. 2008). Given that there are only two objects presented at any given time, performance is measured relative to a chance accuracy value of .5. Children who learned the object labels were expected to perform at above chance accuracy (>0.5), as indicated by proportionately more looking to the target picture than to the distractor picture following label onset across the analysis window. If children performed at chance accuracy, as indicated by equal looking to the target and distractor pictures, this would suggest that they had not learned the object labels. Trials in which the participant appeared inattentive or there was interference (e.g. parent talking or child’s eyes not visible) were excluded.

Reaction time (RT) represents the latency to orient to the target from the distractor following target word onset. Because the RT measure can only be calculated when the child is looking at the distractor picture at target word onset, target-initial trials and away-initial trials (trials when the child is looking at neither picture at target onset) are not used in the RT analysis. Additionally, any shifts to the target made outside the 367–2000 ms time window did not contribute to RT calculation. Thus, often times the data used for the RT measure includes fewer than half the total number of trials.

Vocabulary Measure

Parents completed the appropriate version of the McArthur-Bates Communicative Development Inventories (MCDI) (Words and Gestures for children up to 17 months; Words and Sentences for 18 months and older; Fenson et al. 2006). The vocabulary measure used in the analysis was the number of words the child “understands and says” (i.e. productive vocabulary). The MCDI Words and Sentences is designed for 16- to 30-month-olds but has been used with older developmentally delayed children (i.e. Lew-Williams & Fernald 2007). Although six children in each group were older than 30 months, none of them performed at ceiling on the MCDI.

RESULTS

A preliminary analysis was conducted to ensure that there were no object biases within each pair of novel objects. An object bias was defined as a preference for one particular object over its matched pair if, before target word onset, it was looked at more than 75% of the time across all trials (Graf Estes et al. 2011). No object biases were found and thus all subsequent analyses were collapsed across object.

Accuracy

As a reminder, accuracy measures were computed on each trial, for each participant, as the mean proportion of time looking to the target divided by the mean proportion of time looking to the target or to the distractor [i.e. (looking time to target) / (total looking time to target + distractor)] within the time window of 367–2000 ms following target label onset. One child with HI failed to contribute sufficient data (i.e., > 2 trials) to the IDS condition. A second child with HI did not contribute sufficient data to the ADS condition. All of the children with NH provided sufficient data in both Speech Type conditions to be included in the Accuracy analysis. On average, children in the HI group contributed 9 trials (range 4–16) to the accuracy measures. The children with NH contributed an average of 10 trials (range 4–15) to the accuracy measures. Accuracy was significantly higher than chance level (0.5) for each group in each condition, indicating that both groups learned the word-object associations for the novel words (Fig. 3); children with HI: [IDS mean = 62.4%, SD = 16.4%), ($t(14) = 2.93$, $p = 0.011$) and in ADS mean = 56.8%, SD = 7.4%, ($t(14) = 3.55$, $p = 0.003$)], children with NH: [IDS mean = 66.2%, SD = 15.7%, ($t(15) = 4.15$, $p = 0.001$) and in ADS mean = 68.6%, SD = 12.9%, ($t(15) = 5.78$, $p = 0.000$)].

To test for between group effects of Hearing Status (HI vs NH) and within group effects of Speech Type (IDS vs ADS) on accuracy of novel word recognition a mixed model analysis using a restricted maximum likelihood estimation method was implemented. This method accounts for the unbalanced data as not all of the children with HI contributed accuracy data to both the IDS and ADS conditions. The main effect of Hearing Status was significant [$F(1,50.26) = 5.108$, $p = 0.028$], suggesting that the children with NH had better overall performance (67.4%) than did the children with HI (59.6%). There were no main effects of Speech Type [$F < 1$, $p > 0.05$] and no Hearing Status by Speech Type interaction [$F(1,50.26) = 1.33$, $p = 0.255$].

Reaction Time

Measures of RT included only trials in which the child was looking at the distractor picture at the onset of the target word. In addition, each participant needed to contribute 2 trials to be included in the analysis. Only a subset of the children contributed RT data (HI group IDS n = 12 and ADS n = 11; the NH group IDS n = 9 and ADS n = 11), and even fewer contributed RT data to both IDS and ADS conditions (8 children with HI and 5 children with

NH). As a group, children with HI and NH, who were included in the analysis, contributed an average of 3 trials (range 2–6) and 4 trials (range 2–7), respectively, to the RT measures. To account for the unbalanced data a mixed model analysis using a restricted maximum likelihood estimation method was used to test for between group effects of Hearing Status (HI vs NH) and within group effects of Speech Type (IDS vs ADS) on RT during novel word recognition. The results of this analysis showed no significant main effects of Hearing Status [$F(1,37.56) = 3.05$, $p = 0.09$] or Speech Type [$F < 1$, $p > 0.05$] and no Hearing Status by Speech Type interaction [$F < 1$, $p > 0.05$].

Time-Course Analysis

The omnibus analyses on accuracy and reaction time provide a partial and potentially overly broad examination of the data. For example, to determine accuracy we have calculated a proportion of looking to the target by averaging where each individual child is looking at every time point between 367 ms and 2000 ms following label onset, for each trial. While this method can reveal average accuracy it does not speak to how long it took the children to look at the target, their peak accuracy, and whether or how children may be responding differently based on where their eye gaze was at target onset. The child's task is very different if they are already looking at the target - in which case the correct response is to inhibit moving their eyes – than if they are looking at the distracter at label onset, in which case the correct response is to shift their gaze to the target. Thus, we opted to include the more fine-grained analysis in order to explore the data and potential differences in performance that are masked through averaging of individual time points.

The profile plot tracks children's accuracy over time, averaged across all participants for all valid trials. On this type of plot, the extent to which accuracy is above 50% indicates that the children are looking at the target picture more than the distractor picture overall as the target word unfolds (Fernald et al. 2008). Figure 4 shows the profile plots for both speech types and for children in both groups. Children with NH quickly exceed 50% accuracy in both ADS and IDS. However, as seen in Figure 4, they appear to spend proportionately more time looking at the target object following word onset in ADS as compared to IDS. In contrast, the profile plots for the children with HI show that accuracy overall was lower relative to that of the children with NH in both speech type conditions. Additionally, the data for the children with HI shows that accuracy in the ADS condition increased only a very little above 50% over the entire trial period suggesting that they were looking at the target only slightly more than the distractor in ADS. Finally, the profile plot for the children with HI shows that they spent proportionately more time looking at the target object in IDS relative to ADS over the same time window.

Additionally, the data can be examined by dividing trials according to where the child is looking at the onset of the target word. An onset-contingent (OC) plot (e.g. Figs. 5–7) provides a visual overview of the child's gaze shifting behaviors based on where the child is looking by chance at target label onset. The OC plot separates target-initial trials (the child is looking at the target at label onset) from distractor-initial trials (child is looking at the distractor at label onset). If the child is looking at the distractor initially (distractor-initial), the correct response is to shift away from the distractor to the target word picture. If, however, the child is already looking at the target at the onset of the trial (target-initial), the correct response is to maintain fixation to the target picture, in other words not shift away. If the child is initially looking at the target at onset and shifts away, this is an incorrect response. Therefore, the OC plot shows correct shifts from distractor to target, and incorrect shifts from target to distractor. Specifically, on the y-axis the graph shows the mean proportion of trials in which children are looking at a picture that is different from where they started at the onset of the target word. The wider the split between the two curves, the larger the difference in the children's behavior in response to the two trial types, indicating successful word learning.

Figure 5 shows an OC plot for the children with NH in the IDS and ADS conditions. Children showed significantly more shifts from distractor-initial trials than from target-initial trials in both ADS and IDS, indicating that they were able to identify the target word and match it with the correct referent. On further examination, the split between the curves is larger in ADS compared to IDS, suggesting the children may have learned the labels somewhat better in ADS.

Figure 6 shows the time course analysis for children with HI in both the IDS and ADS conditions. The split between the distractor-initial and target-initial curves in IDS indicates that children with HI were able to identify the target word and match it with the correct referent. In contrast, the OC plots for the ADS condition reveal a very narrow split between target-initial and distractor-initial trials, indicating the children were less reliable at shifting to the correct target or maintaining their gaze on the target in ADS. This overall gaze pattern suggests that the children with HI were better at matching the target label to the object in IDS compared to ADS.

To better understand the performance of the children with HI across both speech types, the role that device type (CI vs HA) might play during novel word learning was explored. Thus, the OC plots for children with CIs (n = 6) versus those with HAs (n = 10) were examined next. Figures 7A and B shows OC plots for the CI and HA groups in response to novel words in IDS. Global examination of the OC plots indicates that both groups show a similar and substantial split between the distractor-initial and target-initial trials, suggesting that both groups learned in the IDS condition.

Figures 7C and D shows the OC plots for the CI and HA groups when listening to novel words in ADS. For the CI children, global analysis of the OC plot shows overlap between the distractor-initial and target-initial trials for the first 1200 ms, with an appropriate split occurring only in the later part of the analyses window. This pattern of looking behavior suggests that the ADS words may have been processed more slowly by the CI group relative to their performance on words in IDS, and relative to the performance of the children with NH. Analysis of the OC plots for the children with HAs (Fig. 7D) shows that there is essentially no split between the distractor-initial and target-initial trials. This gaze pattern suggests that children with hearing aids did not learn to associate the novel object-label pairs in ADS.

Correlations Between Vocabulary Size, Age, and Measures of Novel Word Learning

Correlations between MCDI productive vocabulary raw scores, age, and measures of novel word learning were explored for each group of children. Although the participants were matched for chronological age, the children with NH had significantly higher vocabulary scores (mean = 555.3, SD = 101.6) than the children with HI (mean = 301.5, SD = 250.7), $t(30) = -3.75$, $p = 0.001$. Ten of the 16 children in the HI group scored less than half of their matched peers vocabulary score.

Children with Normal Hearing

Surprisingly, there were no significant correlations between chronological age and vocabulary size for the children with NH [$r(16) = 0.350$, $p = 0.184$], perhaps due to the small sample size. Vocabulary size and accuracy were significantly correlated [$r(16) = 0.562$, $p = 0.024$] in ADS, but not IDS, suggesting that children with a larger vocabulary were better at learning the novel words in ADS. Vocabulary size was not correlated with RT in either Speech Type condition. Age was significantly correlated with accuracy [$r(16) = 0.506$, $p = 0.045$] and RT [$r(11) = -0.642$, $p = 0.033$] in ADS but not in IDS, suggesting that older children with NH were better able to learn the novel words in ADS and were faster at responding to the label when it was presented in ADS.

Children with Hearing Impairment

Pearson correlations between chronological age and vocabulary size were significant for children with HI [$r(16) = 0.599$, $p = 0.014$]. Further exploration revealed no significant correlations between vocabulary size and hearing age. Vocabulary scores were significantly correlated with accuracy [$r(16) = 0.497$, $p = 0.050$] in IDS but not ADS [$r(15) = -0.053$, $p = 0.850$]. When controlling for the effect of chronological age on this relationship, vocabulary size and accuracy were no longer correlated [$r(15) = 0.272$, $p = 0.327$], suggesting that chronological age was the primary mediating factor. Additionally, vocabulary scores were significantly and negatively correlated with RT in IDS even after controlling for the confounding effects of age [$r(11) = -0.776$, $p = 0.005$]. These correlations suggest that children with larger vocabularies had faster reaction times when processing novel words in IDS than did children with smaller vocabularies. Although there were no significant correlations between vocabulary scores and RT in ADS [$r(11) = 0.336$, $p = 0.313$], it should be noted that 5 children (4 using HAs) did not contribute sufficient RT data in ADS. Thus, the lack of correlation may be due to the low sample size for that condition.

DISCUSSION

Perceptual cues, such as those available in IDS, have been shown to facilitate novel word learning in toddlers with normal hearing. For example, 17- to 21-month-olds are better able to map novel words to objects if the words are produced in IDS rather than ADS (Ma et al. 2011; Graf Estes & Hurley 2013). By 27 months of age toddlers show novel word learning in ADS (Ma et al. 2011). However, relatively little is known about how children with HI use perceptual cues to support novel word learning. One recent study by Houston et al. (2012) demonstrated that children with HI can learn novel label-object associations in IDS, however, they did not test learning in ADS. Because previous research (Robertson, et al.

2013) found a perceptual preference for IDS versus ADS in infants and toddlers with HI (mean age = 19.1 months, range = 8–32 months), the current study asked whether speech type (IDS and ADS) affects novel word learning in children with HI and NH. Importantly, this work extends research by Ma et al. (2011) and Graf Estes and Hurley (2013), by testing older children in a word learning task in both IDS and ADS, and to the authors' knowledge, provides the first exploration of the relative roles of speech type during novel word learning for children with hearing loss.

As a whole, in the present study, children with normal hearing (mean age of 31.4 months, range 23.1 to 42.1 months) learned the novel object-label associations in both the IDS and ADS conditions. Further, mean accuracy and reaction time measures were not statistically different across speech type conditions. These results suggest that, by this age, children with NH may no longer derive significant benefits from IDS relative to ADS. These findings are consistent with data from the authors' previous work exploring perceptual preferences for IDS versus ADS in younger and older toddlers with NH (Robertson, et al. 2013). In that study, infants (mean age = 7.8 months, range 5–9 months) showed a significant listening preference for IDS over ADS, whereas, toddlers (mean age = 18.6 months, range = 15–25) did not, suggesting that as infants get older their preference for IDS relative to ADS begins to diminish. The profile plots (Fig. 4), reveal a somewhat more nuanced view of the data and suggest that children with NH in this age range show proportionately more looking to the target objects in ADS as compared to IDS. Thus, during this developmental time period, children with NH may be starting to find ADS more useful during novel word learning. Although our data cannot speak directly to the link between age and the relative benefits of IDS versus ADS, we do suggest that this shift away from a preference for IDS in NH children may be driven by a confluence of factors. First, as children get older they may amass a sufficiently large vocabulary to no longer need the added perceptual cues available in IDS when learning new words. Second, because caregivers tailor their speech to the language abilities of their children, NH children's exposure to IDS may be diminishing by this age period. Unfortunately, we do not have the maternal input data for our participants. Further research is needed to confirm the link between novel word learning and maternal input.

Ultimately, the goal for all children is to transition to acquiring language skills from ADS over the course of development. It is believed that IDS initially increases infant attention to speech (Werker & McLeod 1989) and subsequently allows infants to detect words in the speech stream during infancy (Thiessen et al. 2005). This early ability to segment the speech stream prepares infants for the later task of word learning (Graf Estes et al. 2007; Hay et al. 2011). Additionally, it has been suggested that the hyperarticulation that generally accompanies IDS (although see Cristià & Seidl, 2014; McMurray et al. 2013 for a different perspective on the role of hyperarticulation in IDS) may allow infants to develop stronger phonological representations, and that this may, in turn, free attentional resources to allow for improved object-label mapping (Werker & Curtin, 1995). Finally, different characteristics inherent to IDS (e.g., such as repetition, intonation, longer pauses, and sentence/referential context etc.,) dynamically contribute to novel word learning in IDS (Graf Estes & Hurley 2013; Ma et al. 2011). To better understand what drives differences in word learning in IDS versus ADS, Graf Estes and Hurley (2013) explored whether toddlers could learn words if the cues inherent within the context of sentence presentation were removed. Unlike, Ma and colleagues (2011), who presented IDS and ADS passages with embedded target words, Graf Estes and Hurley (2013) presented the IDS and ADS target words in isolation (i.e., no sentence or passage context was provided). They found that the prosodic variations included in the IDS object-labels were sufficient to promote word learning in 17-month-olds. As a whole, infants in the ADS condition failed to learn the novel object label pairs. Importantly, because they used the Switch paradigm (Stager & Werker 1997), they were also able to obtain a between subjects measure of attention to IDS versus ADS during the habituation phase of the experiment, and found no differences in time or trials to habituation between speech type conditions. Based on their results, Graf Estes and Hurley proposed that up through17 months, infants may “tune out” the auditory signal when hearing labels that lack sufficient variation (i.e., ADS). They further suggest that although IDS may not influence the duration of attention in infants, the variability inherent in IDS may instead affect the quality of attention to the speech signal. Finally, although not statistically significant, Graf-Estes and Hurley observed that some of the 17-month-olds were on the cusp of learning in ADS. Although children with NH in the current study learned in both IDS and ADS, they showed evidence of slightly better learning in ADS. Thus, the children with NH studied here (ages 23–42 months), appear to be beginning their transition to employing more adult-like learning strategies and may no longer be relying on the variability inherent in IDS when forming new object-label associations.

The children with HI were also able to learn the novel object-label associations at above chance levels in both ADS and IDS, albeit at reduced levels compared to the children with NH. To our knowledge, this is the first study to demonstrate that young children with hearing loss can learn object-label associations in both speech types. Given our small sample size it is not surprising that gross measures of accuracy at the group level did not show a difference in learning across Speech Type conditions or a Speech Type by Hearing Status interaction. The averaging of individual time points across the analysis window may have masked important differences in performance. Time course analyses, however, did reveal some intriguing patterns of looking behavior that may help provide additional insight into the word processing behaviors of children with HI. Specifically, looking behaviors over the analysis window (367–2000 msec), as shown on the profile and OC plots, reveal that the children with hearing loss tend to look at the target on a higher proportion of trials in IDS relative to ADS. This pattern is opposite of what we found with the age matched children with NH, and is consistent with our predictions that word learning would be facilitated by IDS relative to ADS in children with HI. Additionally, the profile plots (Fig. 4) for the children with HI show accuracy performance that is only slightly above chance in the ADS condition, indicating that the children are looking at the target only slightly more than at the distractor. Analysis of the OC plots (Fig. 6) revealed that in IDS condition children shifted their gaze appropriately on distractor-initial trials, and maintained gaze on target-initial trials in response to hearing the target word. However, in ADS, the children with HI, as a group, were as likely to shift from target to distractor as they were from distractor to target (the split between the distractor-initial and target-initial trials was narrow) following label onset. This pattern of results suggests that children with HI with a mean chronological age of 31 months, may not learn as well in ADS as in IDS, and highlights the benefits of looking at eye gaze behaviors over the time course of trials, in conjunction with looking at gross measures of accuracy.

Why was the performance of children with HI reduced compared to that of the NH matched controls in both IDS and ADS? First, the age matching for the children with NH was a chronological match and not a hearing experience match. This resulted in a hearing age difference between the two groups of approximately 14 months. It is not surprising that 14 months of additional hearing experience would put the NH children at a word learning advantage relative to the HI group. We may have seen more comparable performance from the two groups had we been able to match their hearing age. However, this was not feasible because it is difficult to demonstrate novel word learning in the laboratory in such young children, especially when using a looking-while-listening procedure. A related factor that may account for differences in performance across the two participant groups is the significant between-group differences in vocabulary size. In the current study 10 out of 16 children with HI had a productive vocabulary size that was less than half of their age matched NH peers, with half of the HI group having vocabulary scores that were considerably lower than what would be expected for children of the same age. The other half of the children with HI had age appropriate productive vocabulary based on the MCDI measure. Thus, children with HI with larger vocabularies may have performed better on our task. Future research with a larger sample size will be needed to verify possible links between hearing age, vocabulary size, and novel word learning in children with HI.

Interestingly, the hearing age of the children with HI in the present study is more comparable to the chronological age (17.5 months) of children with NH tested by Graf Estes & Hurley (2013). In that study, although some children were on the cusp of learning in ADS, as a group they did not show learning. It may be the case that the children with HI in the present study did not have sufficient language or hearing experience to facilitate learning in ADS. Importantly the results of the present study suggest that until more is known about when children begin to transition to learning in ADS, clinicians and caregivers should continue using IDS based on the child’s language competencies instead of their hearing or chronological age. Bergeson et al. (2006) found that mothers of 3- to 18-month-old children who had used CIs, tended to adjust their speech type to the hearing experience of their children rather than to the chronological age of the child. Thus, future studies should continue to explore the hearing age, chronological age, and language proficiency at which children with HI begin to learn words reliably in ADS. Other factors are also likely to be influencing differences in performance across groups. As stated previously, it has been suggested that characteristics of IDS heighten attention to the speech signal (Thiessen et al. 2005), and may ultimately influence the strength of the phonological representations formed by children, subsequently allowing resources to be used to strengthen mapping of labels to objects (Zangl & Mills 2007). However, children with congenital HI have a very different experience with speech input than children with NH, as they have drastically reduced access to auditory input, particularly during their first year of life, which is a crucial period for language learning. For example, the average age of intervention for the children in this study was 11.4 months of age (range 1–31 months), with approximately only half of the children receiving intervention below 12 months of age. Thus, over the first year of life, these children were deprived of listening experiences for several months. According to Werker and

Hensch (2015), the perceptual experiences gained in the first year of life set the stage for future language outcomes, and suggest that early delays can result in cascading effects on later language development. Thus, delayed access to the speech signal may in fact interfere with the processes necessary to develop age-appropriate word learning skills.

One additional factor that affects children with hearing loss who use amplification devices relates to the stability of the input they receive on a daily basis. Recent studies show that hearing aid (HA) use is highly variable in infants and toddlers (Marnane & Ching 2015; Muñoz et al., 2014, 2015; Walker et al. 2015). For example, it has been shown that children between 6 months and 2 years of age use their HAs for an average of 4.36 hours per day; whereas, pre-school children between the ages of 2 and 4 years wear their hearing aids on average 7.5 hours per day (Walker et al. 2015). While there is no comparison regarding wear time in the literature between children younger than 3 years who use HAs and children who wear CIs, recent unpublished data on CI use in young children also show variable use (Tournis, Reference Note 1). Tournis (Reference Note 1) reports that children between the ages of 0–3 years log only about 7 hours of CI use per day, similar to the 2 to 4 year olds who use HAs. Additionally, Marnane and Ching (2015) compared device use at 3 years of age for HA and CI users, and found that CI users reported using their devices more often than HA users. Thus, it seems that between the ages of 0–3, the most crucial language learning period in development, both children with HAs and CIs have reduced use of their device, with children with HAs using their device the least during this period. One factor that may affect variable device use is that infants and toddlers often do not want to wear their devices, and spend much time during the day pulling them out, forcing parents to be vigilant throughout the day, and leaving children spending a portion of the day without optimal input. A second issue that affects children with hearing loss is related to the audibility of the speech signal across the frequency spectrum of speech. Regardless of device type, audibility of the entire speech signal is not completely restored to the child with either device type. In children with severe-to-profound sensorineural hearing loss (Stelmachowciz et al. 2004), restoring high frequency amplification to an audible range is often not possible, but CIs seem to accomplish this better than HAs (Davidson et al. 2014). In addition, several children in this study who wore hearing aids had audibility that was less than what would be recommended clinically, evidenced by their low SII scores (Bagatto et al. 2016, see Table 1). This could have contributed to the wide variability in the performance between the hearing aid group and the CI group, and may have contributed to the differences observed between the NH and HI children. Thus, the combination of audibility issues and an unstable input throughout the day may affect how well children with HI are able to learn novel words.

Because our group of children with HI was not homogeneous in terms of device use, we wanted to explore whether any differences in processing of novel words in IDS and ADS was affected by the type of device used, HA (n = 10) or CI (n = 6). Global analysis of the OC plots (Fig. 7A, B) in the IDS condition for children wearing CIs and HAs, shows a significant split between distractor and target-initial trials. This split suggests that children using both types of device are showing learning in IDS. However, global analysis of the OC plots (Fig. 7C, D) for the children with CIs and HAs for ADS suggest that children with HAs process ADS differently from children with CIs, and both process ADS differently from children with NH. Specifically, children with CIs do not show a split between distractor and target-initial trials until approximately 1200 ms post onset of the target word, suggesting that they are slower to process newly learned words compared to children with NH. Further, global analysis of the OC plots shows that the characteristic split between target- and distractor-initial trials seen in children with NH, is not evident in children who use HAs. Specifically, children who use HAs do not consistently shift to (or inhibit shifting from) the target picture following target word onset in the ADS condition. This pattern of results suggests that children with hearing aids may not have adequately learned the ADS label-objects associations or may have difficulty accessing their newly acquired knowledge in the context of the experimental paradigm. It may be the case that poor performance on this task could be attributed to the low SII scores evidenced by some hearing aid users. Thus, this data should be interpreted with caution, as it may not be representative of all children using amplification. However, if poor audibility results in poor word learning, this highlights the need for clinicians to be vigilant in monitoring SII scores to maximize audibility stability.

Although these findings are preliminary and are based on small sample sizes, the differences in novel word learning in children who use HAs versus CIs need to be investigated further. If these differences are evident in larger groups of children, then clinicians may need to change their strategies for supporting vocabulary growth based on device type, as children with hearing aids may need extended support in IDS for optimal vocabulary learning. This work highlights the importance of ensuring that future research continues to assess word learning in children with hearing loss in both IDS and ADS. Further, the importance of specifically including children with HAs cannot be overemphasized, as this group of children tends to be understudied relative to those wearing CIs.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

Amano S, Nakatani T, Kondo T. Fundamental frequency of infants' and parents' utterances in longitudinal recordings. J Acoust Soc Am. 2006; 119(3):1636–1647. [PubMed: 16583908]

ANSI. ANSI S3.5-1997, American National Standard Methods for Calculation of the Speech Intelligibility Index. American National Standards Institute; New York: 1997.

Bagatto M, Moodie S, Brown C, et al. Prescribing and Verifying Hearing Aids Applying the American Academy of Audiology Pediatric Amplification Guideline: Protocols and Outcomes from the Ontario Infant Hearing Program. Journal of the American Academy of Audiology. 2016; 27(3):188–203. [PubMed: 26967361]

Bergeson TR, Miller RJ, McCune K. Mothers' speech to hearing-impaired infants and children with cochlear implants. Infancy. 2006; 10(3):221–240.

Blamey PJ, Sarant JZ, Paatsch LE, et al. Relationships among speech perception, production, language, hearing loss, and age in children with impaired hearing. J Speech Lang Hear Res. 2001; 44:264–285. [PubMed: 11324650]

Boersma, P., Weenink, D. Pratt: A system for doing phonetics by computer [Computer program]. Amsterdam, the Netherlands: University of Amsterdam, Institute of Phonetic Sciences; 1996. (Rep. No. 132)

Bornstein, M., Hahn, C., Suwalsky, J., et al. Socioeconomic status, parenting, and child development: The Hollingshead Four-Factor Index of Social Status and the Socioeconomic Index of Occupations. In: Bornstein, MH., Bradley, RH., editors. Socioeconomic status, parenting, and child development. Mahwah, NJ: Lawrence Erlbaum Associates, Publishers; 2003.

Cooper RP, Aslin RN. Preference for infant-directed speech in the first month after birth. Child Dev. 1990; 61:1584–1595. [PubMed: 2245748]

Cristià A, Seidl A. The hyperarticulation hypothesis of infant-directed speech. Journal of Child Language. 2014; 41(04):913–934. [PubMed: 23406830]

Davidson LS, Geers AE, Nicholas JG. The effects of audibility and novel word learning ability on vocabulary level in children with cochlear implants. Cochlear Implants Int. 2014; 15(4):211–221. [PubMed: 23998324]

Fenson, L., Marchman, V., Thal, DJ., et al. MacArthur-Bates Communicative Development Inventories. 2. Baltimore, MD: Brookes Publishing Company; 2006.

Fernald A. Four-month-old infants prefer to listen to motherese. Infant Behav Dev. 1985; 8:181–195.

Fernald A. Intonation and communicative intent in mother's speech to infants: Is the melody the message? Child Dev. 1989; 60:1497–1510. [PubMed: 2612255]

Fernald A. Approval and disapproval: Infant responsiveness to vocal affect in familiar and unfamiliar languages. Child Dev. 1993; 64:657–674. [PubMed: 8339687]

Fernald A, Kuhl PK. Acoustic determinants of infant preference for motherese speech. Infant Behav Dev. 1987; 10:279–293.

Fernald A, Marchman VA. Individual differences in lexical processing at 18 months predict vocabulary growth in typically developing and late-talking toddlers. Child Dev. 2012; 83(1):203–222. [PubMed: 22172209]

Fernald A, Simon T. Expanded intonation contours in mother's speech to newborns. Dev Psychol. 1984; 20:104–113.

Fernald A, Taeschner T, Dunn J, et al. A cross-language study of prosodic modifications in mothers' and fathers' speech to preverbal infants. J Child Lang. 1989; 16:477–501. [PubMed: 2808569]

Fernald, A., Zangl, R., Portillo, A., et al. Looking while listening: Using eye movements to monitor spoken language comprehension by infants and young children. In: Sekerina, I.Fernandez, EM., Clahsen, H., editors. Developmental psycholinguistics: On-line methods in children's language processing. Amsterdam: John Benjamins; 2008. p. 97-135.

Garnica, O. Some prosodic and prelinguistic features of speech to young children. In: Snow, CE., Ferguson, CA., editors. Talking to children: Language input and acquisition. Cambridge, MA: Cambridge University Press; 1977.

Gilbertson M, Kamhi AG. Novel word learning in children with hearing impairment. J Speech Lang Hear Res. 1995; 38:630–642.

Graf Estes K, Edwards J, Saffran J. Phonotactic constraints on infant word learning. Infancy. 2011; 16(2):180–197. [PubMed: 21297877]

Graf Estes K, Evans JL, Alibali MW, Saffran JR. Can infants map meaning to newly segmented words? Statistical segmentation and word learning. Psychological Science. 2007; 18:254–260. [PubMed: 17444923]

Graf Estes K, Hurley K. Infant-directed prosody helps infants map sounds to meanings. Infancy. 2013; 18(5):797–824.

Hansson K, Forsberg J, Lofqvist A, et al. Working memory and novel word learning in children with hearing impairment and children with specific language impairment. Int J Lang Commun Disord. 2004; 39(3):401–422. [PubMed: 15204448]

Hayashi A, Tamekawa Y, Kiritani S. Developmental change in auditory preferences for speech stimuli in Japanese infants. J Speech Lang Hear Res. 2001; 44:1189–1200. [PubMed: 11776357]

Hay JF, Pelucchi B, Graf Estes K, Saffran JR. Linking sounds to meaning: Infant statistical learning in a natural language. Cognitive Psychology. 2011; 63:93–106. [PubMed: 21762650]

Hayes H, Geers AE, Treiman R, et al. Receptive vocabulary development in deaf children with cochlear implants: Achievement in an intensive auditory-oral educational setting. Ear Hear. 2009; 30(1):128–135. [PubMed: 19125035]

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(3):448–461. [PubMed: 22490184]

Jacobson JL, Boersman DC, Fields RB, et al. Paralinguistic features of adult speech to infants and small children. Child Dev. 1983; 54:436–442.

Kemler Nelson DG, Hirsch-Pasek K, Jusczyk PW, et al. How the prosodic cues in motherese might assist language learning. J Child Lang. 1989; 16(1):55–68. [PubMed: 2925815]

Kishon-Rabin L, Harel T, Hildesheimer M, et al. Listening preference for the native language compared to an unfamiliar language in hearing and hearing-impaired infants after cochlear implantation. Otol Neurotol. 2010; 31(8):1275–1280. [PubMed: 20818285]

Kondaurova MV, Bergeson TR, Xu H. Age-related changes in prosodic features of maternal speech to prelingually deaf infants with cochlear implants. Infancy. 2013; 18(5):825–848.

Lederberg AR, Spencer PE. Word-learning abilities in deaf and hard-of-hearing preschoolers: Effect of lexicon size and language modality. J Deaf Stud Deaf Educ. 2009; 14(1):44–62. [PubMed: 18495655]

Lew-Williams C, Fernald A. Young children learning Spanish make rapid use of grammatical gender in spoken word recognition. Psychol Sci. 2007; 18(3):193–198. [PubMed: 17444909]

Liu HM, Kuhl PK, Tsao FM. An association between mothers' speech clarity and infants' speech discrimination skills. Dev Sci. 2003; 6(3):F1–F10.

Ma W, Golinkoff RM, Houston DM, et al. Word learning in infant- and adult-directed speech. Lang Learn Dev. 2011; 7:209–225.

Marchman VA, Fernald A. Speed of word recognition and vocabulary knowledge in infancy predict cognitive and language outcomes later in childhood. Dev Sci. 2008; 11:F9–F16. [PubMed: 18466367]

Marnane V, Ching TY. Hearing aid and cochlear implant use in children with hearing loss at three years of age: Predictors of use and predictors of changes in use. Int J Audiol. 2015; 54:544–551. [PubMed: 25816866]

Mayne AM, Yoshinaga-Itano C, Sedey AL, et al. Expressive vocabulary development of infants and toddlers who are deaf or hard of hearing. Volta Rev. 2000; 100:1–28.

McMurray B, Kovack-Lesh KA, Goodwin D, McEchron W. Infant directed speech and the development of speech perception: Enhancing development or an unintended consequence? Cognition. 2013; 129(2):362–378. [PubMed: 23973465]

McRoberts GW, Best CT. Accommodation of mean Fo in mother-infant and father-infant social interactions: A longitudinal case study. J Child Lang. 1997; 27:1–18.

Muñoz K, Preston E, Hicken S. Pediatric hearing aid use: How can audiologists support parents to increase consistency? J Am Audiol. 2014; 18:14–23.

Muñoz KOlson WA, Twohig MP, et al. Pediatric hearing aid use: Parent-reported challenges. Ear Hear. 2015; 36:279–287. [PubMed: 25303862]

Nation, P., Waring, R. Vocabulary size, text coverage, and word lists. In: Schmitt, N., McCarthy, M., editors. Vocabulary: Description, Acquisition and Pedagogy. Cambridge: Cambridge University Press; 1997. p. 6-19.

Papousek M, Papousek H, Symmes D. The meanings of melodies in motherese in tone and stress languages. Infant Behav Dev. 1991; 14:415–440.

Pater J, Stager C, Werker J. The perceptual acquisition of phonological contrasts. Lang. 2004; 80(3): 384–402.

Pegg JE, Werker JF, McLeod PJ. Preference for Infant-Directed Over Adult-Directed Speech: Evidence from 7-Week-Old Infants. Infant Behav Dev. 1992; 15:325–345.

Pittman AL, Lewis DE, Hoover BM, et al. Rapid word-learning in normal-hearing and hearing impaired children: Effects of age, receptive vocabulary, and high-frequency amplification. Ear Hear. 2005; 26(6):619–629. [PubMed: 16377997]

Robertson S, von Hapsburg D, Hay JS. The effect of hearing loss on the perception of infant- and adult-directed speech. J Speech Lang Hear Res. 2013; 56:1108–1119. [PubMed: 23798510]

Segal O, Kishon-Rabin L. Listening preferences for child-directed speech versus nonspeech stimuli in normal-hearing and hearing-impaired infants after cochlear implantation. Ear Hear. 2011; 32(3): 358–372. [PubMed: 21512353]

Singh L, Nestor S, Parikh C, et al. Influences of infant-directed speech on early word recognition. Infancy. 2009; 14:654–666.

Sininger Y, Grimes A, Christensen E. Auditory development in early amplified children: Factors influencing auditory-based communication outcomes in children with hearing loss. Ear Hear. 2010; 31(2):166–185. [PubMed: 20081537]

Stager CL, Werker JF. Infants listen for more phonetic detail in speech perception than in word-learning tasks. Nature. 1997; 388:381–382. [PubMed: 9237755]

Stelmachowicz P, Pittman AL, Hoover BM, et al. Novel-word learning in children with normal hearing and hearing loss. Ear Hear. 2004; 25:47–56. [PubMed: 14770017]

Stelmachowicz P, Pittman AL, Hoover BM, et al. The importance of high-frequency audibility in the speech and language development of children with hearing loss. Arch Otolaryngol Head Neck Surg. 2004; 130(5):556–62. [PubMed: 15148176]

Stern DN, Spieker S, Barnett RK, et al. The prosody of maternal speech: Infant age and context related changes. J Child Lang. 1983; 10(1):1–15. [PubMed: 6841483]

Swingley D. 11-month-olds' knowledge of how familiar words sound. Dev Sci. 2005; 8(5):432–443. [PubMed: 16048516]

Swingley D, Aslin RN. Lexical neighborhoods and the word-form representations of 14-month-olds. Psychol Sci. 2002; 13:480–484. [PubMed: 12219818]

Thiessen ED, Hill EA, Saffran JR. Infant-directed speech facilitates word segmentation. Infancy. 2005; 7:53–71.

Vitevitch MS, Luce PA. A web-based interface to calculate phonotactic probability for words and nonwords in English. Behav Res Methods Instrum Comput. 2004; 36:481–487. [PubMed: 15641436]

Walker EA, McCreery RW, Spratford M, et al. Predictors of longitudinal hearing aid use in children who are hard of hearing. Ear Hear. 2015; 36(Suppl 1):38S–47S. [PubMed: 26731157]

Werker JF, Cohen LB, Llyod VL, et al. Acquisition of word-order associations by 14 month old infants. Dev Psychol. 1998; 34(6):1289–1309. [PubMed: 9823513]

Werker JF, McLeod PJ. Infant preference for both male and female infant-directed talk: A developmental study of attentional and affective responsiveness. Can J Psychol. 1989; 43(2):230–246. [PubMed: 2486497]

Werker JF, Hensch TK. Critical periods in speech perception: new directions. Psychology. 2015; 66(1): 173–196.

Yoshida KA, Fennell CT, Swingley D, et al. Fourteen-month-old infants learn similar sounding words. Dev Sci. 2009; 12(3):412–418. [PubMed: 19371365]

Yoshinaga-Itano C, Sedey AA, Coutler DK, et al. Language of early-and later-identified children with hearing loss. Pediatrics. 1998; 102(5):1161–1171. [PubMed: 9794949]

Yoshinaga-Itano C, Baca RL, Sedey AL. Describing the trajectory of language development in the presence of severe-to-profound hearing loss: A closer look at children with cochlear implants versus hearing aids. Otol Neurotol. 2010; 31(8):1268–1274. [PubMed: 20818291]

Zangl R, Mills DL. Increased brain activity to infant-directed speech in 6-and 13-month-old infants. Infancy. 2007; 11(1):31–62.

REFERENCE NOTES

Tournis, E. Data-logging in pediatric cochlear implant recipients. Paper presented at the 14th Symposium on Cochlear Implants in Children; Nashville, TN. 2014 Dec.

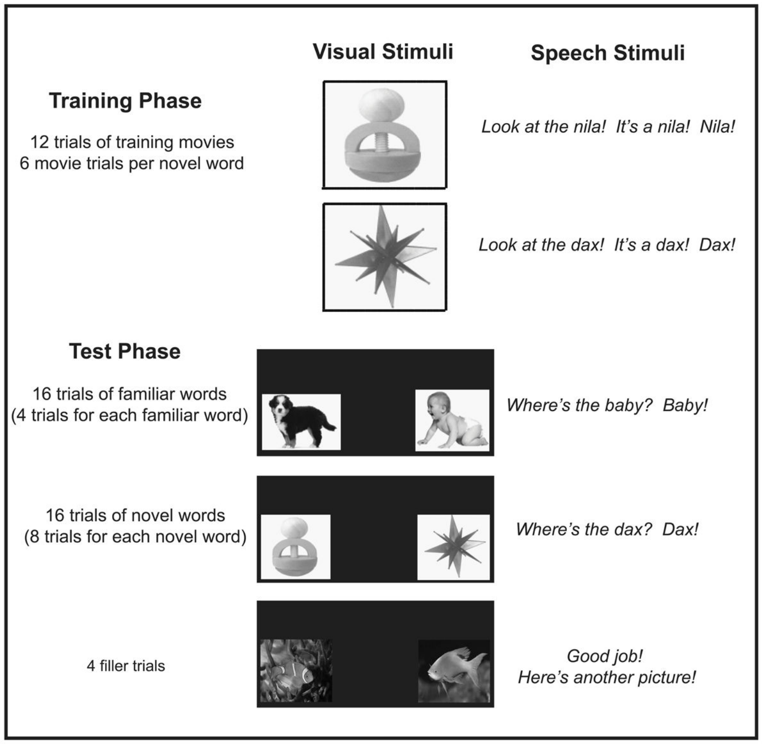

Fig 1.

Overview of the experimental protocol used in the experiments.

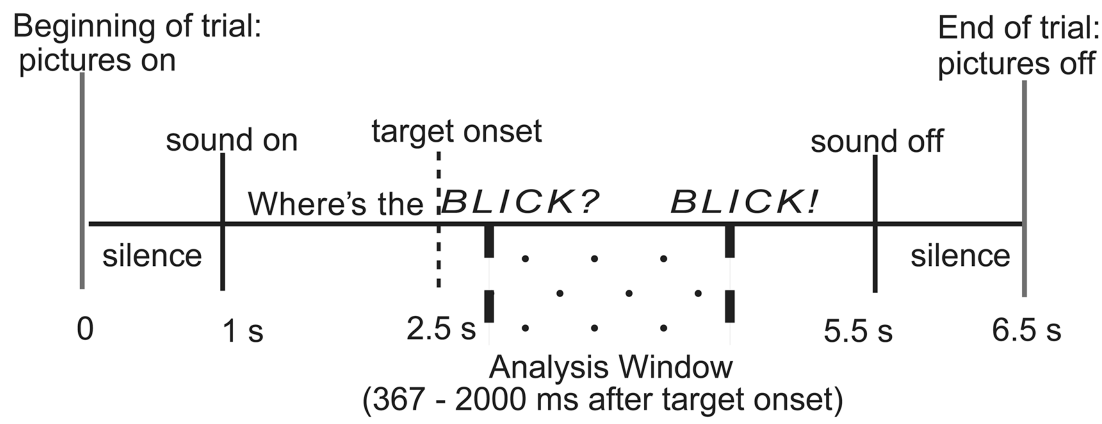

Fig 2.
Schematic of the timeline for a test trial.

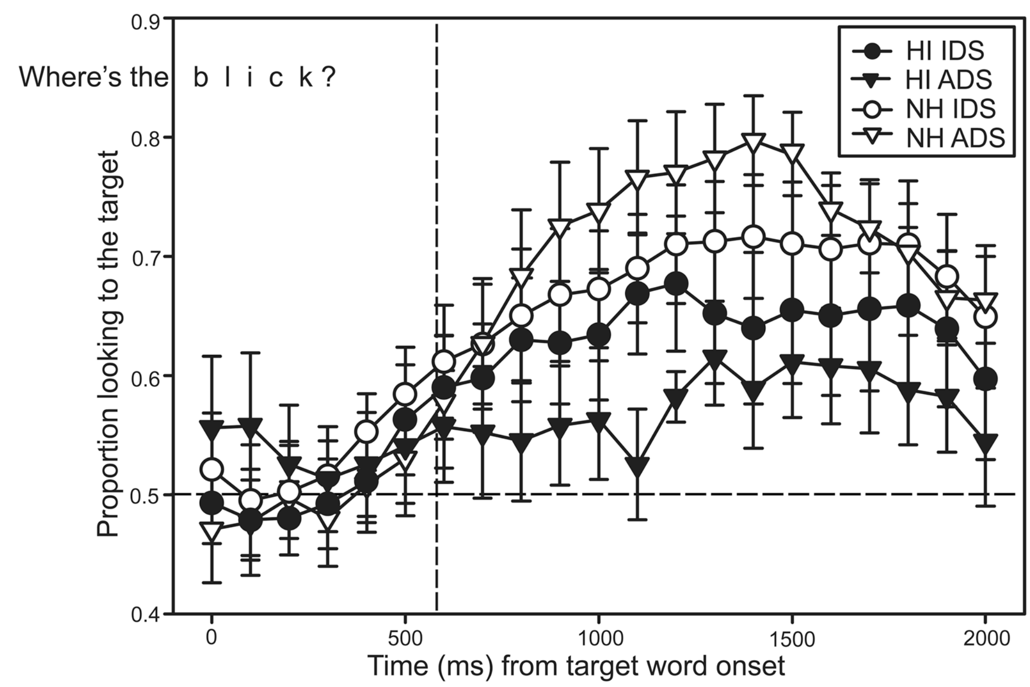

Fig 3.

Proportion of looking time to target object (i.e., accuracy) for individual participants in IDS and ADS, by Hearing Status and Device Type. Symbols with error bar (standard error of the mean) represent average group accuracy, collapsed across Device Type for children with HI.

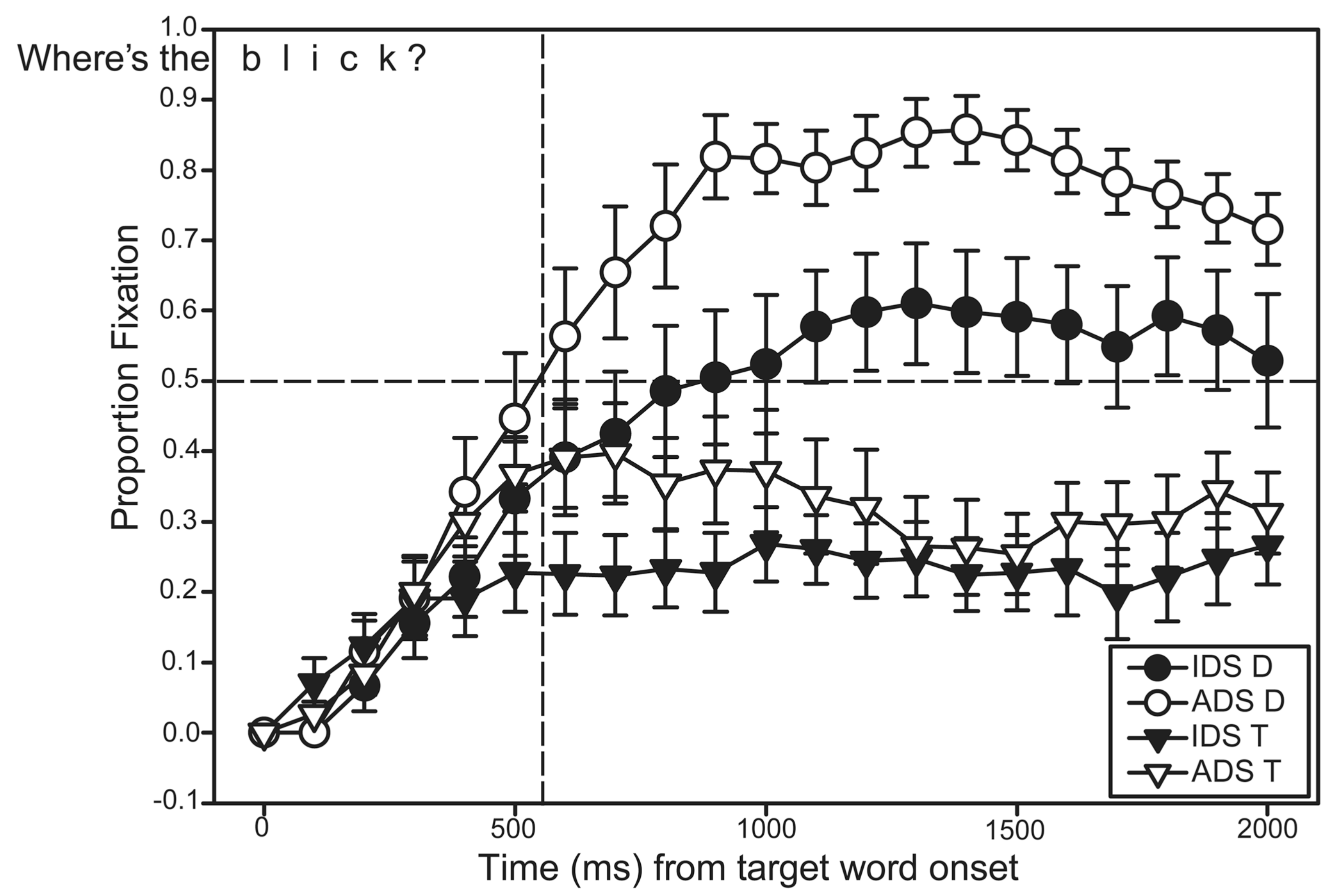

Fig 4.

The profile plots showing the mean proportion of looking time to the target, measured from the onset of the target word, for the NH and HI groups. The dashed horizontal line represents the 50% chance level. The dashed vertical line represents the offset of the target word. Error bars represent standard error of the mean.

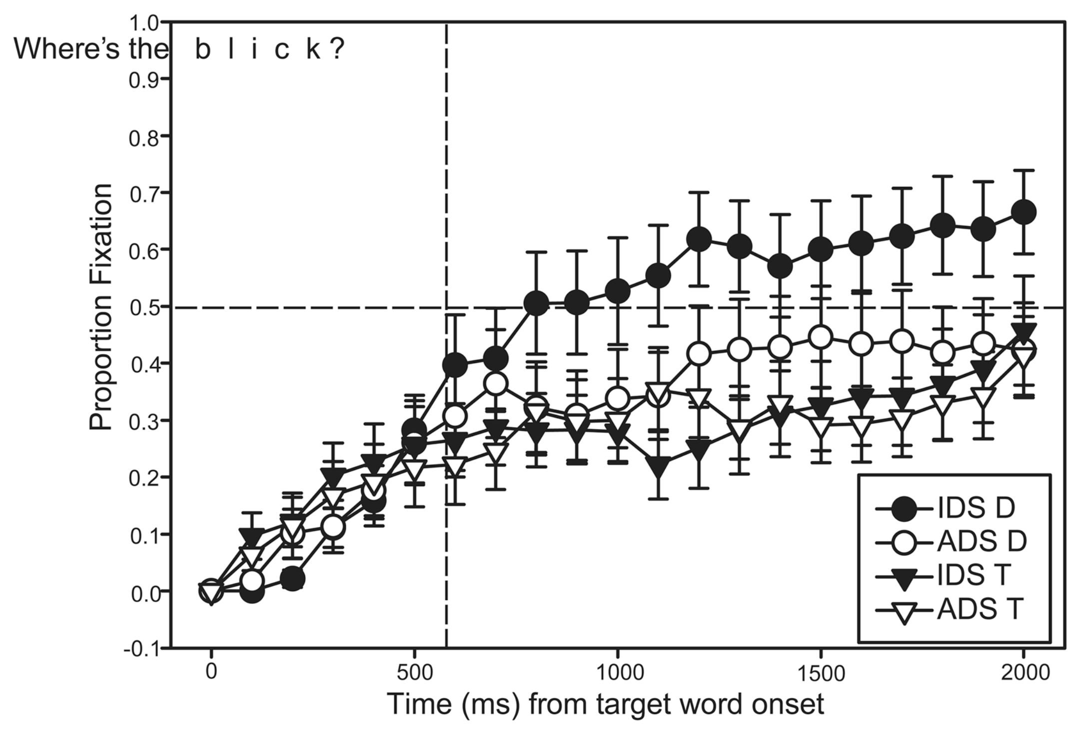

Fig 5.
Onset-contingent (OC) plot for the NH Group.

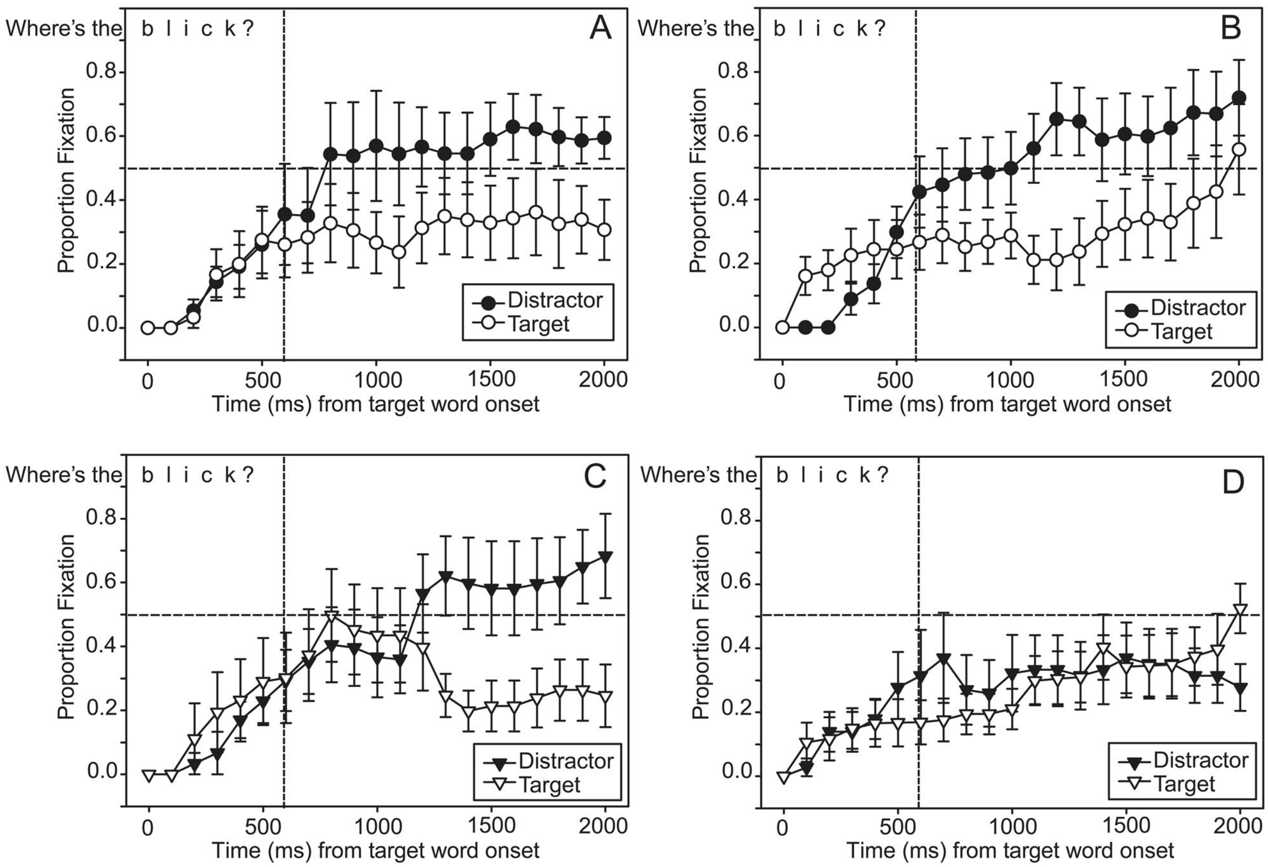

Fig 6.
Onset-contingent (OC) plot for the HI Group.

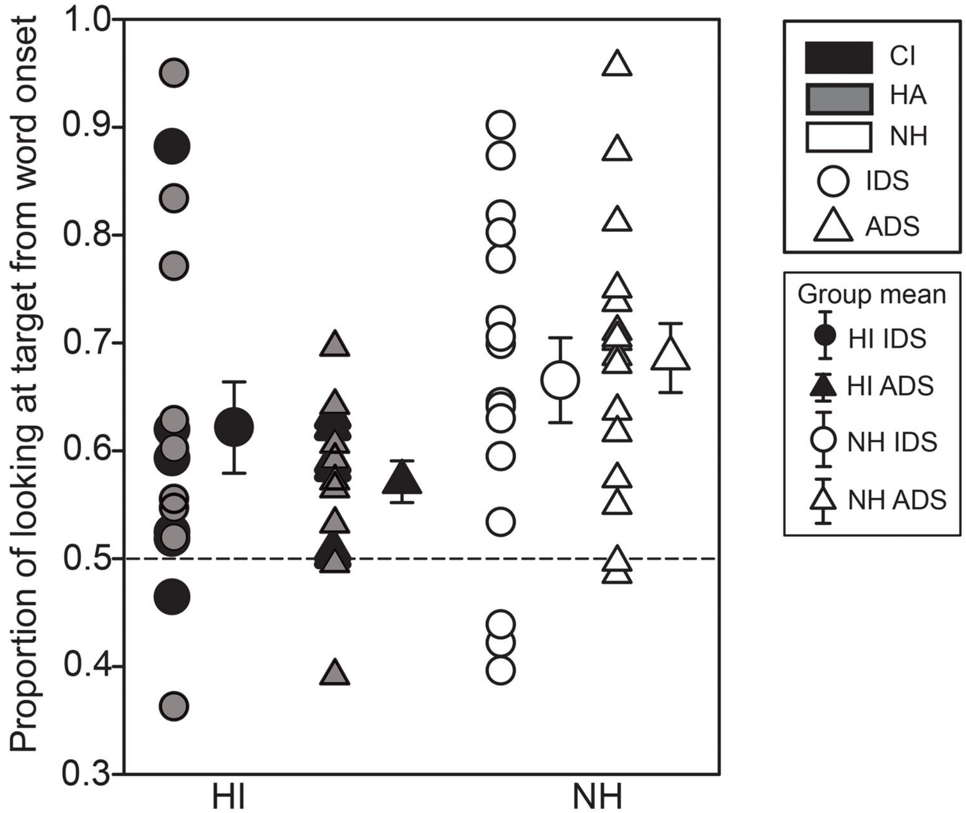

Fig 7.

Onset-contingent (OC) plots. The OC plots show the distractor-initial trials (D) and the target-initial trials (T) for (A) the CI group in the IDS condition, (B) the hearing aid group in the IDS condition, (C) the CI group in the ADS condition, and (D) the hearing aid group in the ADS condition.

Table 1

Demographic information for participants

Children with hearing impairment												Normal hearing controls					
Sub	Gender	CA (mo)	Gest Age (weeks)	Hrg age (mo)	Device Type	Device Model	PTA (dB)	SII (dB)	Com	Maternal Education (yr)	CDI score	Sub	Age at test	Gest Age (weeks)	Gender	Maternal Education (yr)	CDI score
H1	F	40.6	38.4	20.5	HA	Phonak Cassia Micro M	27	91	OC	14	624	N1	40.9	37.4	F	18	671
H2	F	42.1	28.1	27.4	HA	Oticon Safari 300P	34	81	OC	12	675	N2	42.1	28.1	F	12	665
H3	F	28.6	40.3	23.5	HA	Widex Baby BB4	55	NA	OC	16	634	N3	29.3	38.4	F	15	540
H4	M	26.8	38.0	13.6	CI	Cochlear Nucleus 5	N/A	NA	TC	14	264	N4	26.8	40.1	M	14	531
H5	F	38.8	27.0	7.6	HA	Oticon Safari 300 Power	30	88	OC	14	598	N5	38.3	40	F	16	457
H6	F	27.7	38.3	17.4	CI	MedEl Opus	N/A	NA	OC	18	578	N6	28.5	39	F	16	600
H7	F	28.9	39.3	6.3	HA	Phonak Bolero	25	65	OC	14	139	N7	29.3	38.4	F	15	564
H8	M	35.7	38.9	26	HA	Phonak Maxx 311 Cassia SP	40	49	TC	16	107	N8	35.2	41	M	14	673
H9	F	23.2	39.4	18.3	HA	Oticon Safari	35	72	TC	11	98	N9	23.1	40	F	16	411
H10	F	25.8	35.3	12	CI	Cochlear Nucleus 6	N/A	NA	TC	16	254	N10	26.1	39.3	F	16	620
H11	M	39.6	37.0	34.9	HA	Oticon Safari 900	41	45	OC	18	494	N11	39.1	39.4	M	14	411
H12	M	30.4	39.4	8.7	CI	Advanced Bionics	N/A	NA	TC	17	40	N12	30	40.7	M	16	655
H13	F	25.9	41.3	18.2	HA	Phonak Bolero	52	82	OC	16	33	N13	24.1	41.1	F	16	396
H14	F	31.7	38.1	6.5	CI	Cochlear Nucleus 6	N/A	NA	OC	17	21	N14	32.6	39	F	16	679
H15	F	24.9	40.0	11.7	CI	Advanced Bionics	N/A	NA	OC	12	106	N15	26.1	38.1	F	17	536
H16	M	28.3	41.3	21.3	HA	Oticon Sensi	34	80	OC	12	159	N16	28.4	39.4	M	13	476
Mean		**31.2**	**37.5**	**17.1**				**72.6**		**14.8**	**301.5**		**31.2**	**38.7**		**15.3**	**555.3**
SD		**6.2**	**4.2**	**8.3**				**16.5**		**2.3**	**250.7**		**6.1**	**3.0**		**1.5**	**101.6**

CA, chronological age; CDI, vocabulary score; CI, cochlear implant; Com, type of communication mode; dB, decibels SPL; F, female; Gest, gestational; HA, hearing aid; Hrg, hearing; M, male; mo, months; NA, not available; OC, oral-only communication; PTA, better-ear pure tone average .5k,1k,2k,4k); SII, better-ear speech intelligibility index; Sub, subject; TC, combined English and Signed-Exact English); yr, years.

Table 2

Acoustic analysis of speech stimuli

Category	Prosodic Measures		
	Mean F0 (Hz)	F0 range(Hz)	Mean Duration (msec)
Infant-directed speech:			
Training phrases	306 (41)	140–628	
Test carrier phrases	216 (6)	153–346	
Test phrase target word:			
Nila	284	139–618	509
Modi	308	136–567	614
Dax	458	322–562	638
Blick	473	355–592	414
Adult-directed speech:			
Training phrases	172 (16)	111–368	
Test carrier phrases	172 (6)	140–243	
Test phrase target word:			
Nila	158	141–215	466
Modi	167	127–238	509
Dax	311	152–591	576
Blick	235	147–510	357

Standard deviations are shown in parentheses; F0, fundamental frequency; Hz, Hertz; msec, milliseconds.