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Increased Brain Activity to Infant-Directed Speech in 6- and 13-Month-Old Infants

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This study explored the impact of infant-directed speech (IDS) versus adult-directed speech (ADS) on neural activity to familiar and unfamiliar words in 6- and 13-month-old infants. Event-related potentials were recorded while infants listened to familiar words in IDS, familiar words in ADS, unfamiliar words in IDS, and unfamiliar words in ADS. The results indicated that IDS elicited increased neural activity compared to ADS for both age groups. Six-month-olds showed a boost in neural activity to IDS for familiar words only. Thirteen-month-olds exhibited increased brain activity to IDS for both familiar and unfamiliar words. The results suggested that IDS changed as a function of development and word familiarity and served as an attentional spotlight to increase brain activity to potentially meaningful words.

Human speech sounds are fascinating for infants, especially those specifically addressed to them. It is well known and has been demonstrated by numerous studies that adults use a number of consistent linguistic and prosodic modifications when they talk to infants. This speech register is referred to as infant-directed speech (IDS)—a code Darwin (1877) referred to as "the sweet music of

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Supplementary materials to this article are available on the World Wide Web at http://www.infancyarchives.com

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the species"—as opposed to adult-directed speech (ADS). The tendency for adults to use IDS seems to be independent of the culture, the language, or the experience of the parents (Albin & Echols, 1996; Cooper, Abraham, Berman, & Staska 1997; Fernald et al., 1989; Papousek, Papousek, & Symmes, 1991; Werker & Pegg, 1994).

The widespread use of IDS in interaction with infants raises the question of its significance for infant speech perception and later language development (for a detailed discussion see Fernald, 1992). As for speech perception, the majority of studies investigating infant responses to this speech style have demonstrated that infants, typically under 1 year of age, prefer listening to IDS over ADS. However, the influence of IDS on older infants' learning, including word recognition and word learning, is not well understood. It is not yet known how the infant brain responds to words spoken in different speech registers before and around the onset of early language comprehension. To address this issue directly, we designed a cross-sectional study measuring brain activity to familiar and unfamiliar words spoken in IDS and ADS in English-learning infants at 6 and 13 months of age using the event-related potential (ERP) technique. The motivation for this study was to investigate the impact of IDS at two different time points with respect to children's language development (at 6 months and 13 months)—once before children are reported to consistently understand spoken words, and once as they begin to understand more and more spoken words shortly after their first birthday. Because parents use IDS both before and after the child starts to interpret spoken language meaningfully (Kitamura & Burnham, 2003; Newport, Gleitman, & Gleitman, 1977), the two age groups tested here are presumably highly familiar with IDS. However, 6- and 13-month-olds differ from each other in an important respect: 6-month-olds are on the verge of recognizing familiar words in fluent speech (Jusczyk & Aslin, 1995), especially when they are heard in familiar, routinely used sentence frames (Bortfeld, Morgan, Golinkoff, & Rathbun, 2005). Thirteen-month-olds, on the other hand, have begun to understand frequently heard words, responding meaningfully to fluent speech. Given these developmental differences between the two age groups, the broad goal of this study was to examine changes in the functional specialization of neural activity to IDS and ADS as language novices become increasingly familiar with words in their ambient language.

ERPs are averages of electrical activity time-locked to specific stimuli. They reflect changes in brain activity over time on a millisecond-by-millisecond basis. They are characterized by a series of positive and negative deflections in voltage called components. The amplitude of the ERP components reflects differences in the amounts of neural activity, whereas the component latencies reflect information about the timing of neural events (Coles & Rugg, 1995). Although the ERP technique has been widely used to investigate speech processing in adults (see Brown & Hagoort, 2001), it has only more recently been used with infants and young children (for reviews, see Molfese, Narter, & Modglin, 2002; Nelson & Monk, 2001). The ERP technique has additional benefits for infant research in that it does not require an overt response. It is safe, noninvasive, and currently the most practical technique for studying brain activity in infants.

Characteristics of IDS

To understand the effects of IDS on language development it is important to discuss the particular structural characteristics that make ID speech salient for the developing infant. IDS differs from ADS by a specific set of features, which can be observed at the word, sentence, and discourse levels. The characteristics of IDS include a higher overall pitch, a more expanded pitch range, more distinctive pitch contours, higher pitch maxima and minima, more repetitions, elongated vowels, and a slower tempo relative to ADS (Fernald et al., 1989; Garnica, 1977; Grieser & Kuhl, 1988). Research on IDS suggests that even very young infants are sensitive to prosodic changes in the speech signal such as syllable and vowel lengthening, intensity contours, pitch patterns, frequency ranges, and the structure and sequencing of syllables or syllable-like units and stress patterns (Bertoncini, 1998; Christophe, Dupoux, Bertoncini, & Mehler, 1994). Newborns are already able to detect pitch changes in a sequence of standard, repetitive tones as documented by an ERP study by Alho, Sainio, Sajaniemi, Reinikanien, and Naatanen (1990). Importantly, this suggests that the brain can detect certain changes in the acoustic signal from birth onward.

Attention, Prosody, and Response to IDS

One of the functions attributed to IDS is to elicit and maintain the infant's attention to important aspects of the speech signal. Numerous studies found that infants not only differentiate IDS from ADS, but actually prefer IDS over ADS from as early as the first few weeks after birth (Cooper & Aslin, 1990; Fernald, 1985; Papousek, Bornstein, Nuzzo, Papousek, & Symmes, 1990). IDS preference was operationalized by increased looking or listening times to IDS relative to ADS. Research also suggests that IDS enhances the perception and segmentation of speech sounds and highlights particular units in the speech stream, which may subsequently facilitate word recognition (Bertoncini, 1998; Christophe et al., 1994; Fernald, 2000; Hirsh-Pasek et al., 1987; Jusczyk et al., 1992).

Behavioral evidence for preferential attentional responsiveness to IDS over ADS raises the question of whether the acoustic and affective salience of IDS has a specific impact on the infant's developing neural system. Previous ERP studies document that attention modulates the amount and timing of brain activity to both auditory and visual stimuli from a very early age (Ackles & Cook, 1998; Kurtzberg, Stone, & Vaughan, 1986; Nelson & Collins, 1991; Richards, 2003;

Wentworth, Haith, & Karrer, 2001). In particular, a negative-going ERP component peaking around 800 msec after stimulus onset that is largest over frontal regions is specific to infancy, the Nc (Courchesne, 1977). The Nc has been linked to the allocation of attention. A larger amplitude Nc component is thought to be associated with a greater allocation of attentional resources (Nelson & Monk, 2001). The Nc linked to attention to visual stimuli has been localized in young infants to prefrontal cortex and the anterior cingulate (Reynolds, & Richards, 2005). This finding is consistent with the observed frontal distribution in infants of neural generators of attention as well as localization of attentional modulation in these regions in adult imaging studies. Thus, if IDS serves to increase attention to specific words, as suggested by behavioral research, the amplitudes of ERPs to words presented in IDS will be larger than those to words presented in ADS within the latency range of the Nc component.

The Infant's Age, Word Familiarity, and IDS

Although preference for IDS has been demonstrated over a variety of ages, it is not as clear-cut as previously proposed. Preference for IDS over ADS seems to change with increasing age of the child (Cooper & Aslin, 1994; Hayashi, Tamekawa, & Kiritani, 2001; McRoberts, 2000; Spence & Moore, 2003). For example, McRoberts (2000) reported that younger infants prefer more pronounced ID speech relative to older infants, who prefer ID speech with less exaggerated pitch contours. If the infant's sensitivity to IDS indeed changes with age, it seems plausible to assume that potential differences in brain activity to IDS versus ADS might also vary with age and language proficiency. Therefore, these differences might not be due solely to hard-wired responses to the acoustic characteristics of IDS, but influenced by experiential factors such as familiarity with the individual words. As for word familiarity, previous ERP studies with infants and toddlers showed that neural activity elicited by spoken words varied according to familiarity, age, and vocabulary size (Mills, Coffey-Corina, & Neville, 1993, 1997; Mills, Plunkett, Prat, & Schafer, 2005; Mills et al., 2004; Thierry, Vihman, & Roberts, 2003). In children between 13 months and 20 months of age, Mills and colleagues found that by 200 msec to 400 msec, ERPs to familiar words were larger in amplitude than to unfamiliar words, and suggested that the N200–400 indexes word meaning (see Mills, Conboy, & Paton, 2005, for a complete discussion). A later peak from 600 msec to 900 msec, referred to as the N600–900, also differed for familiar versus unfamiliar words, but only for the younger group of children. The N600–900 was largest over frontal regions similar to the distribution of the infant-specific Nc component, and was thought to index sustained attention to the familiar words. Moreover, neural responses also differ with respect to semantically appropriate versus semantically anomalous sentences at least by 19 months, suggesting that by that age language novices are sensitive to the context in which familiar words are heard (Friedrich & Friederici, 2005).

Of particular interest here was to examine the impact of IDS on brain activity in relation to the child's familiarity with the word as well as increasing age. Because recent behavioral studies suggest that there are developmental changes in children's responses to IDS, ERPs elicited to words in IDS might also change over time. If it is the familiarity of a word that modulates processing, then patterns of brain activity to IDS should change in response to familiar versus unfamiliar words. This in turn suggests that familiarity is important in determining the influence of IDS on neural responses in early language processing. Different effects of speech register on the N200–400 amplitude would lend further support to the hypothesis that IDS may facilitate language comprehension as is suggested by behavioral studies (Golinkoff & Alioto, 1995; Pence, Golinkoff, Brand, & Hirsh-Pasek, 2005). This hypothesis predicted that infant sensitivity to speech register would not only differ for familiar and unfamiliar words, but that the pattern of ERP differences to ADS versus IDS would change with increasing age and language development for both the N200–400 linked to word meaning, and the N600–900 linked to continued attentional processing.

Hemispheric Specialization and Prosodic Processing

The extent of hemispheric specialization in prosodic processing is not only an open question in young infants, but also in mature, adult listeners. In the adult literature, results on hemispheric specialization in prosodic processing are inconclusive. Although it has often been proposed that the right hemisphere is more attuned to process prosodic information, whereas the left hemisphere is thought to be more attuned to process more analytic linguistic information, there is still no conclusive evidence to support this proposal. Some adult studies show a greater right hemisphere contribution for certain types of prosodic information (Ross, Thompson, & Yenkosky, 1997; Shipley-Brown, Dingwall, & Berlin, 1988); others show that both hemispheres play a role in processing prosodic information (Gandour, 2000; Gandour, Wong, & Hutchins, 1998; Van Lancker & Sidtis, 1992). The lack of uniform results regarding the lateralization of prosodic processing may be partially explained by differences in the design, task complexity, and subject populations. It is evident that a cautious approach to this question is necessary, one that takes into account that the two hemispheres may have distinct processing strengths and that hemispheric contribution may be task dependent (for details on the lateralization of prosodic processing in normal adults and brain-damaged individuals, see Baum & Pell, 1999).

In infants, research addressing hemispheric specialization for prosodic processing is even more limited. An exception is a study by Shafer and colleagues using ERPs to study infant brain activity to speech varying in its prosodic contours (Shafer, Shucard, & Jaeger, 1999). Shafer et al. (1999) reported that for 3-month-old English-learning infants, both the left and right hemispheres were sensitive to differences between the prosodic features of English and two foreign languages, Dutch and Italian. Familiar information, in the form of the prosodically similar contours of English and Dutch, showed a greater contribution of the left hemisphere. Unfamiliar information—that is, the prosodically unfamiliar contours of Italian—showed a greater contribution of the right hemisphere. They suggested that the familiar characteristics of speech elicit a more left-lateralized brain response, whereas novel aspects of speech elicit a more right-lateralized brain response. This familiarity hypothesis is similar to the argument used by Mills et al. (1993) to explain the right hemisphere asymmetry to unknown words observed in 20-month-old infants. This study directly addresses and extends the question of a potential interaction of hemispheric contribution and familiarity in infants beyond 3 months of age. The relevant question here is whether IDS influences the lateral distribution of brain activity differentially for familiar versus unfamiliar words.

This study investigated neural responses to IDS versus ADS, addressing three central questions:

1. Does IDS elicit different patterns of brain activity than ADS in young infants? We propose that if the function of IDS is to increase attention to specific units in the acoustic stream as suggested by previous behavioral studies, IDS prosody should serve to boost the neural activity elicited by certain words. That is, words in IDS should result in larger amplitude ERPs than words presented in ADS.
2. Do ERP differences to IDS versus ADS differ as a function of age or word familiarity? We predict that consistent with the behavioral literature showing changes in infant preferences to IDS over ADS, and developmental changes in the role IDS plays in language development, the patterns of neural activity to IDS versus ADS will vary with age. If IDS serves to focus attention to frequently heard sounds, we predict that at 6 months IDS may have a more pronounced effect on familiar than unfamiliar words. If IDS facilitates word learning, we predict that 13-month-old but not 6-month-old infants will show increased activity to IDS relative to ADS for familiar words in the 200 msec to 400 msec time window, which has been linked to word meaning in our previous studies.
3. Do differences in speech register (i.e., IDS vs. ADS) result in different patterns of lateral ERP asymmetries, and if so, do these asymmetries change with age? We propose that both hemispheres play a role in processing IDS and expect bilateral effects of IDS. If Schafer et al. (1999) are correct that left-lateralized responses reflect greater familiarity with speech, one would predict increased left greater than right asymmetry linked to IDS. However, if IDS conveys primarily affective information, one might predict a right hemisphere asymmetry for ERP differences to IDS relative to ADS.

METHODS

Participants

Infants were recruited through advertisements in local parent magazines, visits at postnatal information classes, posters displayed in local day care centers, and cards filled in by parents whose children previously participated in studies at another infant laboratory. Based on a medical history questionnaire and phone screening, only healthy, full-term infants with monolingual exposure to English were included in this study. None of the infants had pre- or postnatal complications, nor a history of hearing disorders.

Participants included 19 6-month-olds (7 girls, 12 boys; *M* age = 203 days, *SD* = 10) and 17 13-month-olds (8 girls, 9 boys; *M* age = 417 days, *SD* = 26). There were no significant differences in age between the boys and girls in each age group. An additional 10 6-month-olds (3 girls, 7 boys), and 12 13-month-olds (7 girls, 5 boys) were tested but excluded because of excessive eye or body movement during the testing session (*n* = 8), excessive crying or refusal to wear the cap before testing (*n* = 5), failure to complete the testing session due to fussiness (n = 8), or experimenter error (*n* = 1). Prior to testing, the parents of all children signed informed consents according to the National Institutes of Health human subjects guidelines. The infants were given a small toy and parents were given $5 for reimbursement for travel expenses.

Language Assessment

MacArthur–Bates Communicative Development Inventory. The MacArthur–Bates Communicative Development Inventory: Words and Gestures (CDI; Fenson et al., 1993) was collected prior to testing only for 13-month-old infants. The measure of receptive vocabulary was the number of words understood by the child as reported on the CDI, ranging from 27 to 199 words for the 17 children retained in the final sample (*M* = 125 words, *M* percentile = 61.2). The measure of vocabulary production was the number of words the child "understands and says" as reported by parents, ranging from 0 to 67 words (*M* = 15.9 words, *M* percentile = 53.2).

Vocabulary rating scale. A 4-point parental confidence rating scale was used to assess familiarity for 55 nouns reported to be frequently understood by young children determined from CDI norms (Fenson et al., 1993). Parents rated each word for familiarity on a scale of 1 (*the child never, or almost never, heard that word*) to 4 (*the child heard the word daily or several times per week*). Familiarity was defined as the number of times the child heard the word on average per week. These ratings were used to select the experimental stimuli for each child. For familiar words, only words with the highest familiarity ratings were chosen for creating the word lists. Overall 85% of the "familiar" words used across all the word lists were ranked as 4; the remaining 15% of the words used were ranked as 3. Words that are generally not frequent in speech to children were used as unfamiliar words (e.g., barrel, morph). Note that these familiarity ratings apply to both age groups and measure familiarity rather than comprehension, as 6-month-olds typically do not understand words.

Stimuli

To create the stimuli, a total of 110 words (55 familiar, 55 unfamiliar) were recorded once in IDS and once in ADS, resulting in 220 different tokens. The potentially familiar words were those included in the vocabulary rating scale and were words for food, toys, body parts, familiar household items, and animals. The potentially unfamiliar words contained English words that are rare in speech to children. To ensure that low-level acoustic and phonetic differences did not account for differences between conditions, familiar and unfamiliar words were matched for place of articulation at the onset of the word, always starting with the same phoneme such as in *juice* and *judge*. Also, the number of mono- and bi-syllabic words was matched comprising a total of 18 monosyllabic and 2 bisyllabic tokens within the familiar and unfamiliar word types. Furthermore, the majority of the familiar and unfamiliar words that were monosyllabic ended in stops ($n = 8$) and fricatives or affricates ($n = 5$ for familiar words, $n = 7$ for unfamiliar words). All stimuli were recorded in a sound-attenuated chamber using a high-quality microphone. An adult female native speaker of English was instructed to speak the words pretending she was talking to an infant (IDS tokens) and again pretending she was talking to another adult (ADS tokens). The stimuli were digitized using Sound Designer software for the Macintosh at a sampling rate of 11.025 kHz with a 16-bit quantization. Each word token was edited for precise time of onset and offset; careful onset editing guaranteed the synchronization with the digitization of the ERPs. To ensure that the 220 different samples of target words were appropriate tokens for both IDS and ADS, all tokens were first played back to 38 undergraduate students of the Communicative Disorder course at San Diego State University. They ranked each of the ADS and IDS items on a 4-point scale in terms of appropriateness as speech directed to an infant or speech directed to an adult. Only the best ratings were selected for the final stimulus list (i.e., for IDS ratings of 4 where 1 = *ADS* and 4 = *IDS*; for ADS ratings of 1 where 1 = *ADS* and 4 = *IDS*). Less appropriate examples were rerecorded and ranked again until a high rating level was achieved for all stimuli. Across both age groups, the mean rating for the familiar words was 3.8 and 1.3 for the unfamiliar words.

Based on previous studies (Cooper & Aslin, 1990; Werker & McLeod, 1989) the IDS and ADS target words were analyzed for the following parameters: average fundamental frequency (F0), pitch maximum (F-Max), frequency range (F-range), and duration. Pitch and duration analyses of the recordings were conducted using Signalyze (Keller, 1994). Statistical analyses were then conducted using two-tailed *t* tests. The analyses, shown in Table 1, indicated that the fundamental frequency and pitch maximum of words in IDS were significantly higher than those of words in ADS. Words in IDS also had a higher frequency range and were longer in duration than words in ADS. There were no significant differences between familiar and unfamiliar words within each speech register, that is, within either IDS or ADS.

At testing, each child heard 40 different stimuli: 20 words his or her parents rated as highly familiar or comprehended (10 in IDS and 10 in ADS) and 20 unfamiliar words (10 in IDS and 10 in ADS). These stimuli were selected individually for each child from the larger list of 110 words. Two standard lists were created based on parental ratings and used whenever possible. These two standard lists were counterbalanced across participants, so that a word presented in ADS in List 1 was presented in IDS in List 2 and vice versa. If a child did not know one of the familiar words on the standard list, it was replaced by another word reported as familiar on the parental rating scale. Appendix A shows the standard word list, including 20 familiar and 20 unfamiliar words, 10 in IDS and 10 in ADS for each condition (the sound files for these words are available at http://www.infancyarchives.com).

Procedure

Electrophysiological recording. The EEG was recorded from 14 tin electrodes affixed to a cap appropriately sized for each participant (Electro-Cap

TABLE 1
Prosodic Analyses of Adult- and Infant-Directed Speech Stimuli

		Prosodic Features			
Register	*Word Type*	*Duration (msec)*	*M F0*	*F0 Range*	*F0 Maximum*
IDS	Familiar	1058.13	257.62	126.70	304.55
	Unfamiliar	989.29	264.18	167.95	335.65
ADS	Familiar	629.22***	226.93**	97.40*	261.55***
	Unfamiliar	670.39***	225.95**	74.15***	252.40**

Note. IDS = infant-directed speech; ADS = adult-directed speech; F0 = fundamental frequency (Hz). The *p* values refer to two-tailed *t* tests of a difference between IDS and ADS within each word type.

*$p < .01$. **$p < .001$. ***$p < .000$.

International), with an additional electrode placed under the left eye. Eight of the sites were from standard 10/20 placements at left and right fronto-central (Fp1/Fp2), frontal (F7/F8), occipital (O1/O2), and midline positions (Cz/Pz). Six were nonstandard locations designed to record activity from areas along the perisylvian fissure. These included left and right anterior temporal (L22/R22, which was situated half the distance between F7/F8 and T3/T4), temporal (L41/R41, which was situated 33% of the distance from T3/T4 to C3/C4), and left and right temporo-parietal (WL/WR, which was 50% of the distance between T3/T4 and P3/P4). In addition, the electrooculogram (EOG) was recorded from over (Fp1) and under the left eye (Le) to monitor blinks and vertical eye movements. Horizontal eye movement was monitored through a bipolar recording from left and right frontal regions (F7 referenced to F8). All electrodes were referenced to linked mastoids.[1] Impedances were maintained below 5 KOhms. The EEG was amplified at a gain of 10,000 using SA Instrument amplifiers (input impedances of 1,000 Meg Ohms per channel), recorded continuously at 250 Hz, and filtered with a band pass of .1 to 100 Hz. The averaged ERPs were also digitally filtered offline with a 60-Hz low-pass filter.

Due to the configuration of the infant electrocap, recordings from the midline at Cz and Pz were often not reliable and were not included in the analyses. Recordings from Fp1/Fp2 were used for artifact rejection and were also not included in the analyses. Only the 10 lateral sites, over frontal, anterior temporal, temporal, parietal, and occipital regions were retained for analysis (Figure 1).

Averaging and artifact rejection. ERPs were averaged separately for familiar and unfamiliar words presented in IDS and ADS using 1.6-sec epochs starting 100 msec prior to the onset of the stimulus, and ending 1,500 msec after stimulus onset. Artifact rejection was conducted offline using a custom computer program, Event Related Potential Software System (ERPSS), which was used to reject trials containing blinks, vertical and horizontal eye movement, and amplifier blocking.[2] Visual inspection of the EOG and EEG channels was used to set individual thresholds for use in the artifact rejection program. Approximately

[1]We are aware of the controversies surrounding the use of linked mastoids (Picton et al., 2000). Linked mastoids were used here to increase the number of active sites given the number of amplifiers available and to provide consistency with previous studies. To examine possible distortions in the distribution of scalp activity resulting from forced linkage, data were compared with those from a separate study (Huot et al., 2005) using identical stimuli that recorded from one mastoid, using the other as a reference, and linking the mastoids offline. These data were compared with the data recorded using linked mastoids and did not yield significant differences.

[2]Amplifier blocking occurs when slow voltage shifts, typically caused by changes in impedances, result in saturation of the amplifiers and cause the EEG to be flat. Artifact rejection thresholds varied slightly across individuals due to differences across participants in the size and shape of deflections in voltage caused by blinks, vertical eye movements, and so on. Infant brain activity especially over

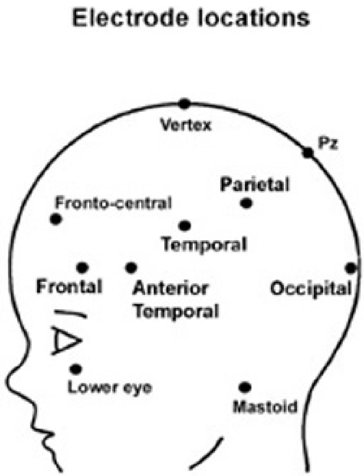

FIGURE 1 Electrode placements for frontal, anterior temporal, temporal, parietal, and occipital regions. Diagram is shown from the left hemisphere perspective.

64% of the trials were artifact-free and were retained for analysis. For both 6- and 13-month-olds, between 30 and 32 trials were retained in each of the four conditions (number of trials retained per condition: 6-month-olds: M = 31, SD = 11.8; 13-month-olds: M = 32, SD = 10.4). There were no significant differences in the number of trials retained related to age, gender, or experimental condition.

Electrophysiological testing. Words were presented serially over a Bose speaker located behind the curtain of a puppet theater with a stimulus onset asynchrony of approximately 2,000 msec (range = 1,800–3,000 msec). A puppet moved as the words were presented. Approximately every 15 to 20 trials the puppet was changed to keep the child's attention (see Mills et al., 1993, for more details). Each child heard 40 different words presented in four conditions: 10 familiar words in ADS, 10 familiar words in IDS, 10 unfamiliar words in ADS, and 10 unfamiliar words in IDS. Each word was repeated 5 times randomly throughout the experiment for a total of 50 trials per condition (a total of 200 trials). IDS and ADS were switched in blocks of 10 words per speech register.

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the frontal regions can be quite large and variable. Setting the same rejection threshold for all individuals can result in large amplitude brain activity being rejected. Blinks elicit potentials that are opposite in polarity over and under the eye. The amplitude of the blink response was used to set the individual thresholds to retain as many artifact-free trials as possible. A standard threshold was used for most infant participants (see Luck, 2005, for a complete discussion of these issues).

Within the 10 trials familiar and unfamiliar words were chosen semirandomly with a constraint of three per word familiarity; that is, no more than three familiar or unfamiliar words could follow each other. Blocks of IDS and ADS presentations were counterbalanced across participants. The entire procedure lasted about 20 min.

Measurement of ERP components and predictions. All measurements were taken relative to the 100-msec prestimulus baseline. The first positive component peaked at approximately 100 msec (P100), defined as the most positive peak between 50 msec and 200 msec. The P100 is thought to index auditory sensory processing. The first negative going wave peaked between 200 msec and 400 msec and was measured as the mean amplitude across that window. In previous ERP studies with infants 13 to 20 months of age, words with meanings that were understood by the child elicited larger amplitude negative going ERPs between 200 msec and 400 msec (N200–400) than did unknown words (Mills et al., 1993, 1997; Mills et al., 2004; Mills, Plunkett, et al., 2005). If IDS facilitates the processing of familiar words, it is likely that the amplitude of the N200–400 will be increased more for familiar words presented in IDS over unfamiliar words, than for familiar words over unfamiliar words in ADS. Because 6-month-olds did not understand the meanings of these words, we predicted that N200–400 mean amplitude differences to familiar words would be observed at 13 months, but not at 6 months.

Mills and colleagues also found that the mean negative amplitude from 600 msec to 900 msec or 600 msec to 1,200 msec (N600–900) was larger to known than unknown words in 13- to 17-month-olds (Mills et al., 1997). The N600–900 is similar in latency and distribution to the Nc, which has been linked to attentional processing (Ackles & Cook, 1998; Courchesne, 1977, 1978; Karrer & Ackles, 1988). Preliminary analyses of the 6-month-old averages showed a decline of the amplitude differences by 800 msec. In this study, the 600- to 800-msec time window was chosen as a common window for both age groups, called the N600–800. If the role of IDS is to increase attentional focus, we expect the mean amplitude of the N600–800 to be increased for IDS relative to ADS for meaningful or potentially meaningful words at both 6 and 13 months.

Data analysis. The data for each age group and each ERP component were analyzed in separate analyses of variance (ANOVAs) using the BMDP 4V program with Hyundt–Feldt corrections for repeated measures. Within-subjects factors consisted of two levels of speech register (IDS, ADS), two levels of word familiarity (familiar, unfamiliar), two levels of hemisphere (left, right), and five levels of electrode site (frontal, anterior-temporal, temporal, parietal, occipital). Simple effects analyses were used to test planned comparisons for the effects of IDS versus ADS for familiar and unfamiliar words separately (speech register × hemisphere × electrode site: separately for familiar and unfamiliar words) and for differential sensitivity to speech register in the left and right hemispheres (word familiarity ×

speech register × electrode site: for the left and right hemispheres separately). Tukey's honestly significant difference tests were used for post-hoc comparisons. Effect sizes were calculated for partial eta-squared (η_p^2) to determine the proportion of total variance attributed to each significant effect η_p^2 = SSeffect/(SSeffect + SSerror).

RESULTS

To conserve space and make the results easier to parse, we focused on results showing differences to ADS versus IDS. We reported all main effects and simple interactions, but only reported three- and four-way interactions that occurred with speech register. Preliminary analyses revealed no main effects of sex, or interactions with sex and speech register. That is, the ERP differences for ADS and IDS were the same for boys and girls. Therefore, the analyses were collapsed into a single group for each age. For each age group, the results are organized by presenting the anterior–posterior and lateral distributions of each component first, followed by main effects and interactions with speech register.

There were no main effects or interactions in P100 latency or amplitude related to IDS versus ADS for either age group. Thus, the P100 analyses were not included.

Sensitivity to IDS in 6-Month-Olds

Figures 2 and 3 display the ERPs averaged across all participants for familiar and unfamiliar words respectively at 6 months of age.

N200–400. For the 6-month-olds, the mean amplitude between 200 msec and 400 msec was more negative than the preceding positive peak, but this negative peak was predominately below the baseline (i.e., it had a positive polarity). Nevertheless we maintained the nomenclature of N200–400 because the component was negative going relative to the first positive peak and to provide consistency across age groups. The N200–400 was larger (more negative) over the back than the front of the head electrode site, $F(4, 72) = 97.36, p < .001, \eta_p^2 = .84$, and did not differ for the left (*M* amplitude = 4.84 μv and right (M amplitude = 4.23 μv hemispheres, hemisphere, $F(1, 18) = 1.23, p = .28, \eta_p^2 = .06$.

As predicted, for the N200–400 there were no main effects of, nor interactions with, familiarity, $F(1, 18) = .59, p = .45, \eta_p^2 = .03$, or speech register, $F(1, 18) = .05$, $p = .83, \eta_p^2 = .003$.

N600–800. The N600–800 mean amplitudes were similar across frontal, anterior-temporal, temporal, parietal, and occipital regions, main effect of electrode site, $F(4, 72) = .87, p = .43, \eta_p^2 = .05$. There were no main effects of hemisphere, $F(1, 18) = .21, p = .65, \eta_p^2 = .01$, or familiarity, $F(1, 18) = .15$,

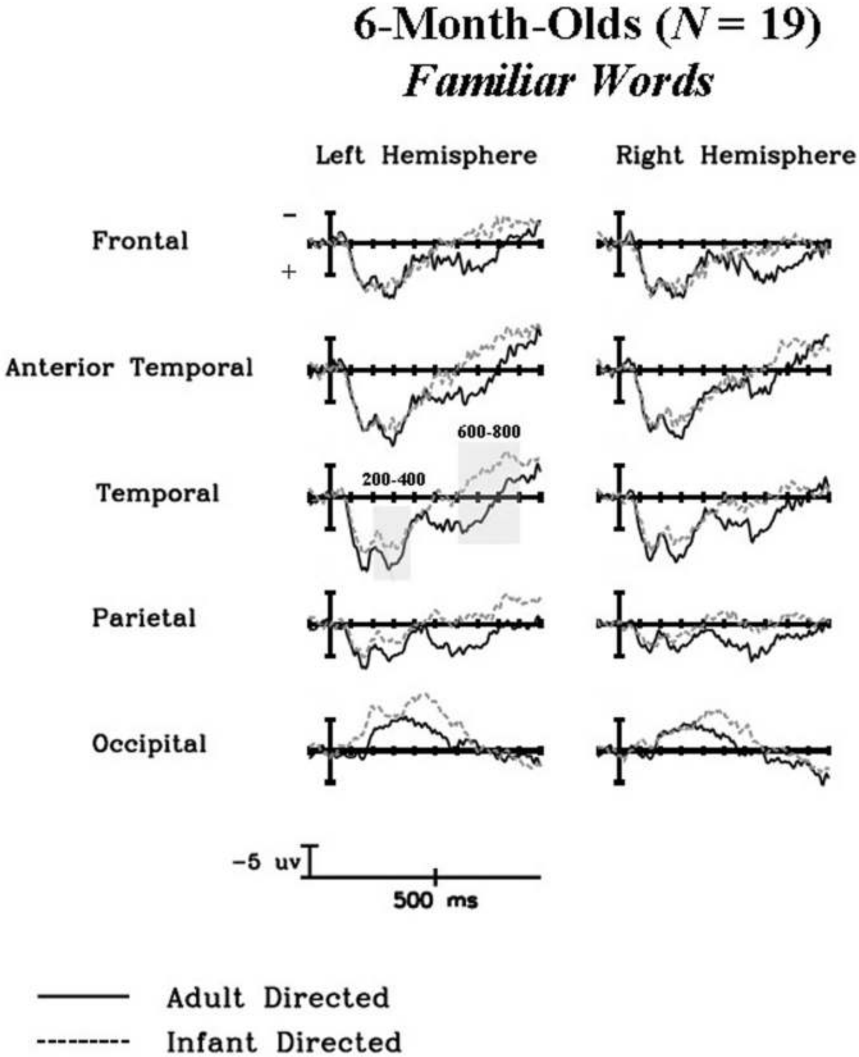

FIGURE 2 Event-related potentials to familiar words presented in ADS (solid lines) versus IDS (dashed lines) from 6-month-old infants over anterior and posterior regions of the left and right hemispheres. Note that for this and all subsequent figures negative voltage is plotted up. The shaded boxes for the areas between 200 msec and 400 msec and 600 msec and 800 msec at one site highlight the time windows measured and do not necessarily reflect areas for significant differences. ERP differences to IDS versus ADS were significant from 600 msec to 800 msec only over the left hemisphere.

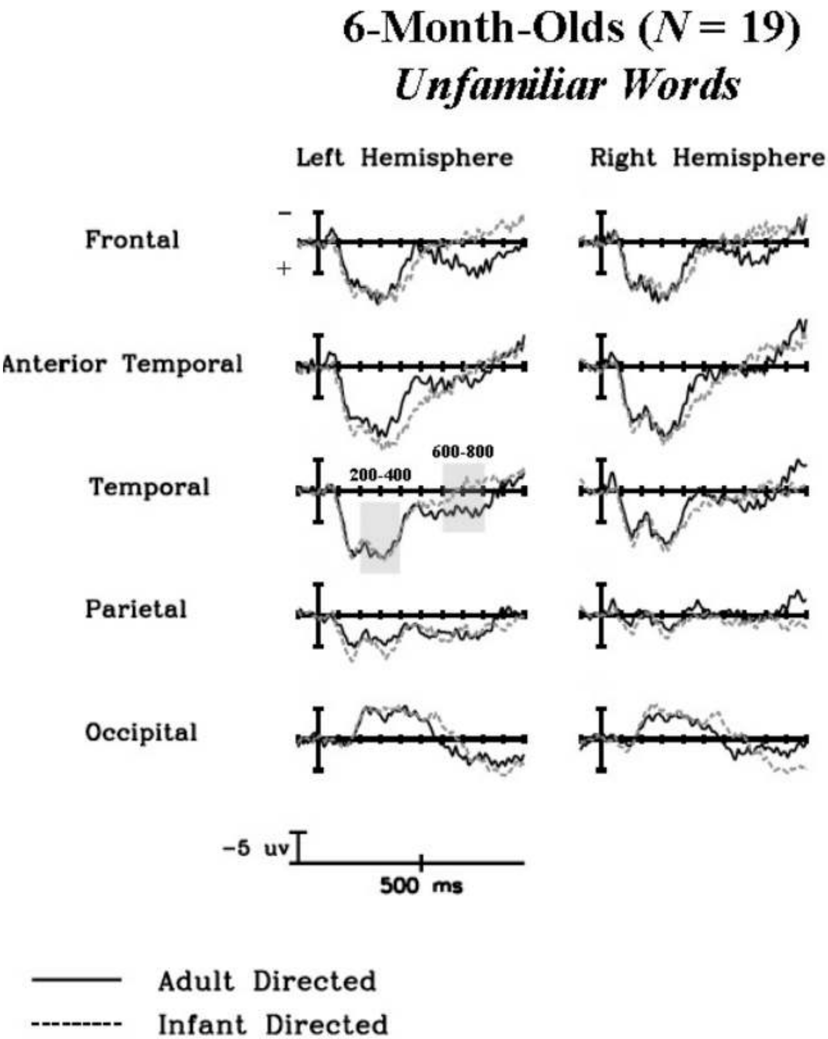

FIGURE 3 Event-related potentials to unfamiliar words presented in ADS (solid lines) versus IDS (dashed lines) from 6-month-old infants over anterior and posterior regions of the left and right hemispheres. There were no significant ERP differences elicited by IDS versus ADS for unfamiliar words.

p = .70, η_p^2 = .006. The lateral distribution of the N600–800 went in opposite directions for the familiar and unfamiliar words, Familiarity × Hemisphere, *F*(1, 18) = 8.44, $p < .01$, $\eta_p^2 = .32$. The N600–800 amplitude did not differ for familiar and unfamiliar words, *F*(1, 18) = .15, $p = .70$, $\eta_p^2 = .008$.

Of particular interest was whether the N600–800 would differ for words presented in IDS versus ADS. If IDS increases attention to words as suggested by behavioral studies, and the N600–800 indexes attention as suggested by other infant ERP studies, the N600–800 amplitude should be larger to IDS than ADS. There was a trend in this direction, but it did not reach significance, main effect of speech register, *F*(1, 18) = 3.09, $p = .10$, $\eta_p^2 = .15$. If IDS serves to increase attention specifically to potentially meaningful words, IDS might only affect neural activity to familiar words. Again, there was a trend in that direction that failed to reach significant levels, simple effects analysis for familiar words, speech register, *F*(1, 18) = 3.69, $p = .07$, $\eta_p^2 = .17$; for unfamiliar words, speech register, *F*(1, 18) = .91, $p = .35$, $\eta_p^2 = .05$. Visual examination of the ERPs (Figures 2 & 3) suggested that the N600–800 differed for ADS and IDS for familiar words only in the left hemisphere. Simple effects analyses showed that for familiar words, the N600–800 was larger to IDS than ADS, but only in the left hemisphere; left hemisphere, speech register, *F*(1, 18) = 4.30, $p = .05$, $\eta_p^2 = .19$; right hemisphere, speech register, *F*(1, 18) = 2.21, $p = .15$, $\eta_p^2 = .11$ (Figure 4, left side). There were no significant N600–800 amplitude differences between IDS and ADS for the unfamiliar words in either the left or right hemispheres (Figure 5, left side); for unfamiliar words: speech register at left hemisphere, *F*(1, 18) = 1.67, $p = .21$, $\eta_p^2 = .09$; speech register at right hemisphere, *F*(1, 18) = .29, $p = .60$, $\eta_p^2 = .02$.

Summary of effects of IDS versus ADS in 6-month-olds. There were no main effects or interactions with speech register for the N200–400. As predicted, the N600–800 was larger in amplitude to IDS than to ADS for familiar words, but only over the left hemisphere.

Sensitivity to IDS in 13-Month-Olds

Figures 6 and 7 show the ERPs to IDS and ADS averaged across all participants for familiar and unfamiliar words, respectively, at 13 months of age.

N200–400. The N200–400 was larger over the back than the front of the head, electrode site, *F*(4, 64) = 5.81, $p = .01$, $\eta_p^2 = .27$, and was larger over the right than the left hemisphere, *F*(1, 16) = 31.01, $p < .001$, $\eta_p^2 = .66$. The right greater than left asymmetry was more pronounced for the familiar than the unfamiliar words, Hemisphere × Familiarity, *F*(1, 16) = 6.68, $p = .02$, $\eta_p^2 = .29$; but was significant for both the familiar and unfamiliar words: simple effects for familiar words, hemisphere, *F*(1, 16) = 36.79, $p = .0001$, $\eta_p^2 = .68$; for unfamiliar words, hemisphere, *F*(1, 16) = 10.34, $p = .01$, $\eta_p^2 = .39$.

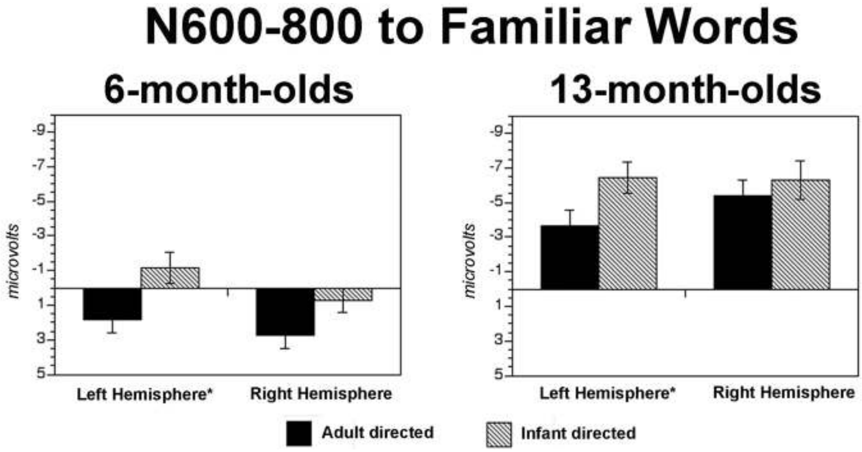

FIGURE 4 N600–800 mean amplitudes to familiar words presented in ADS (solid bars) versus IDS (striped bars) averaged across frontal, anterior temporal, temporal, and parietal regions, for the left versus right hemispheres for 6-month-old infants (left side) and for 13-month-old infants (right side). The N600–800 was larger to IDS than ADS over the left hemisphere for both age groups (as indicated by *).

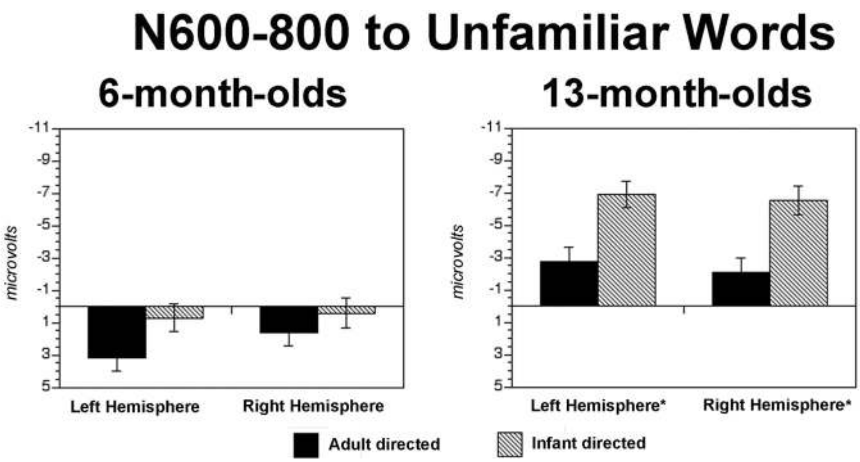

FIGURE 5 N600–800 mean amplitudes to unfamiliar words presented in ADS (solid) versus IDS (stripes) averaged across frontal, anterior temporal, temporal, and parietal regions for the left versus right hemispheres, for the left versus right hemispheres in 6-month-old infants (left side) and in 13-month-old infants (right side). There were no significant effects for the 6-month-olds for unfamiliar words. At 13 months, the N600–800 was larger to IDS than ADS over both the left and right hemispheres (as indicated by *).

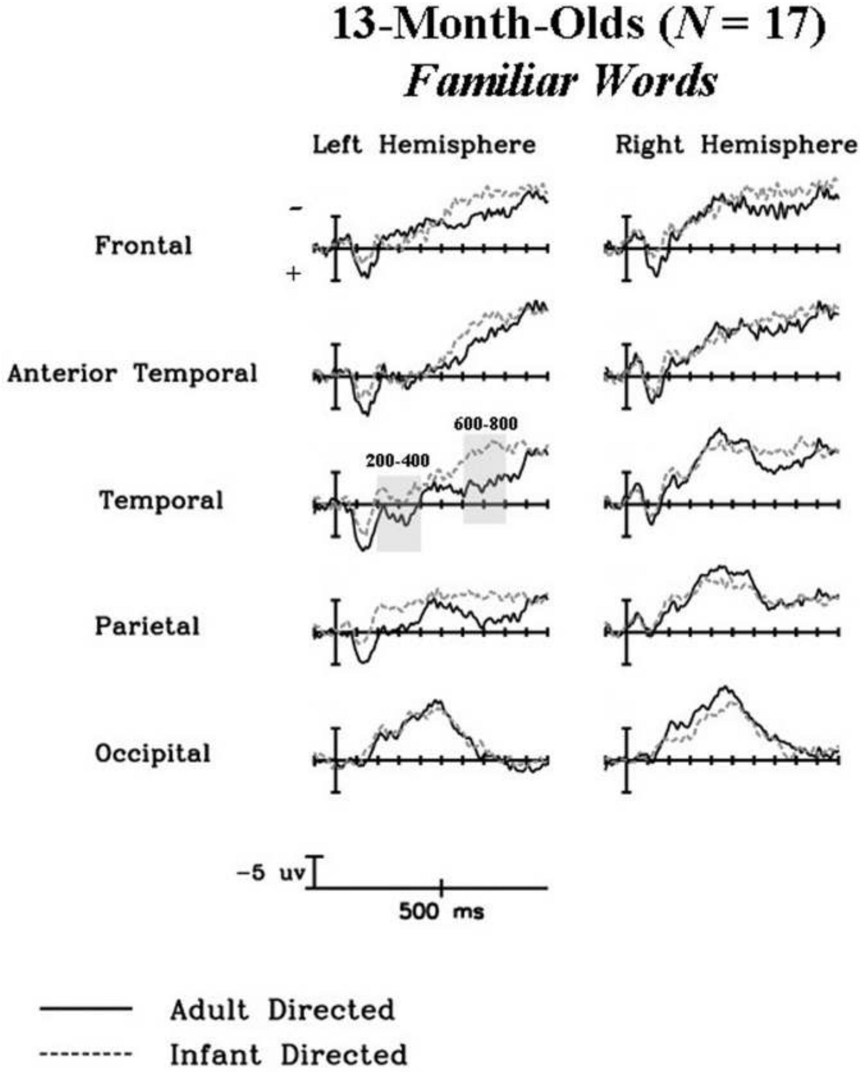

FIGURE 6 Event-related potentials (ERPs) to familiar words presented in ADS (solid lines) versus IDS (dashed lines) from 13-month-old infants over anterior and posterior regions of the left and right hemispheres. ERP differences between IDS and ADS were significant from 200 msec to 400 msec over left temporal and parietal regions and from 600 msec to 800 msec over the left hemisphere.

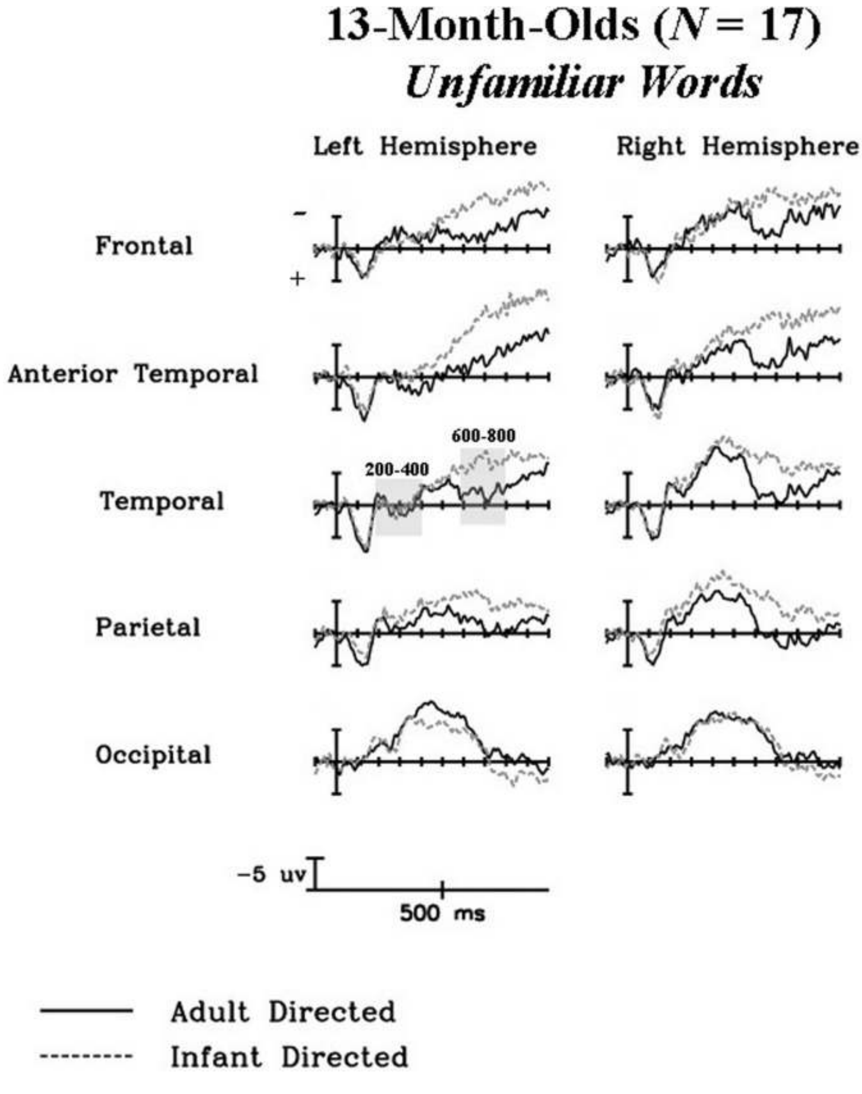

FIGURE 7 Event-related potentials (ERPs) to familiar words presented in ADS (solid lines) versus IDS (dashed lines) from 13-month-old infants over anterior and posterior regions of the left and right hemispheres. ERP differences between IDS and ADS were significant from 600 msec to 800 msec over the left and right hemispheres.

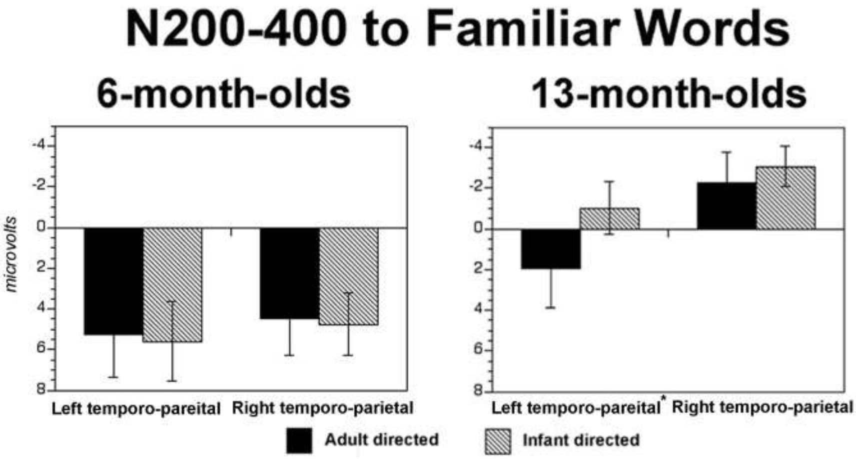

FIGURE 8 N200–400 mean areas to familiar words presented in ADS (solid bars) versus IDS (striped bars) averaged across temporal and parietal regions of the left versus right hemispheres for 6-month-olds (left side) and 13-month-olds (right side). Differences between words in ADS versus IDS were significant only for 13-month-olds and here only over the left temporal and parietal regions (as indicated by *).

Of particular interest were N200–400 differences for speech register that interacted with word familiarity. We hypothesized that if IDS facilitates word comprehension, the N200–400, which has been linked to word meaning in our previous studies, should be larger to IDS than to ADS, particularly for familiar words. The results were consistent with this prediction. For familiar words, but not unfamiliar words, the N200–400 was larger to IDS than ADS only at temporal and parietal regions of the left hemisphere (Figure 8, right side & Figure 9); simple effects for familiar words, Speech Register × Hemisphere × Electrode Site, $F(4, 64) = 3.24$, $p = .03$, $\eta_p^2 = .21$. There were no effects of IDS on the amplitude of the N200–400 for unfamiliar words at any location (Figure 9).

N600–800. The N600–800 was larger over the front than the back of the head, electrode site, $F(4, 64) = 9.29$, $p = .001$, $\eta_p^2 = .37$. Unlike the pattern observed in the 6-month-olds, the N600–800 averaged across word types was symmetrical; hemisphere, $F(1, 16) = .06$, $p = .81$, $\eta_p^2 = .003$.

As predicted for the 13-month-olds and consistent with the findings from the 6-month-olds, the N600–800 was larger to IDS than to ADS, $F(1, 16) = 7.53$, $p < .01$, $\eta_p^2 = .32$, but only for frontal, anterior temporal, temporal, and parietal regions (Figure 10, right side); Speech Register × Electrode Site, $F(4, 64) = 4.35$, $p < .05$, $\eta_p^2 = .21$. Visual inspection of the ERP plots (Figures 6 & 7) suggested that N600–800 amplitude differences to IDS and ADS were limited to the left hemisphere

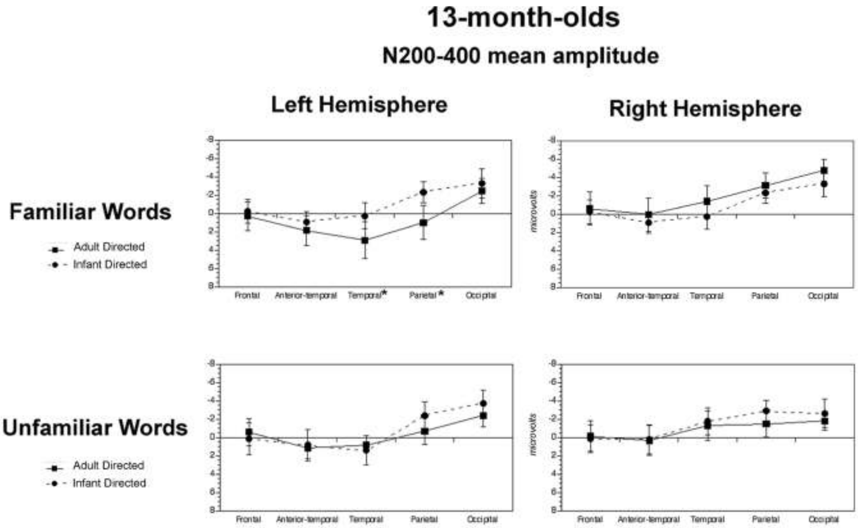

FIGURE 9 N200–400 mean amplitudes to familiar and unfamiliar words presented in ADS (squares with solid lines) versus IDS (circles with dashed lines) over frontal, anterior temporal, temporal, parietal, and occipital regions averaged across the left and right hemispheres. Differences between words to IDS versus ADS were only significant for familiar words over the left hemisphere for temporal and parietal regions (as indicated by *).

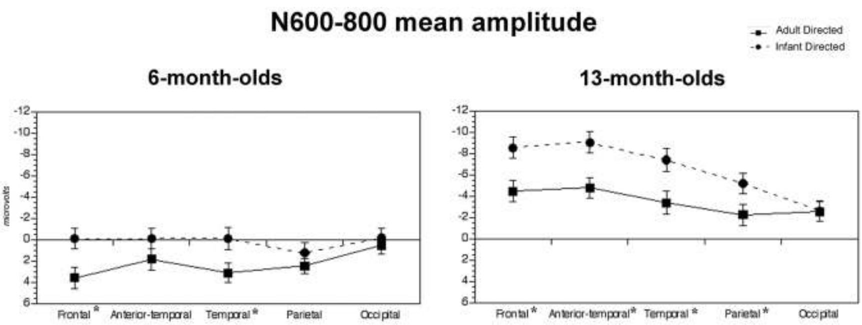

FIGURE 10 N600–800 mean amplitudes averaged across familiar and unfamiliar words presented in ADS (squares with solid lines) versus IDS (circles with dashed lines) for 6-month-old (left side) and 13-month-old infants (right side) over frontal, anterior temporal, temporal, parietal, and occipital regions averaged across the left and right hemispheres. For 6-month-olds differences between words in ADS versus IDS were significant over frontal and temporal regions. For 13-month-olds' words, differences between words in ADS versus IDS were significant over all but occipital sites (as indicated by *).

for familiar words and symmetrical for unfamiliar words. To examine this pattern, planned simple effects analyses were conducted for familiar and unfamiliar words. For familiar words, the N600–800 amplitude was larger to IDS than to ADS only in the left hemisphere (Figure 4, right side): left hemisphere, speech register, $F(1, 16) = 5.83$, $p = .03$, $\eta_p^2 = .27$; right hemisphere, speech register, $F(1, 16) = .25$, $p = .63$, $\eta_p^2 = .02$. For unfamiliar words, the N600–800 amplitude was larger to IDS than to ADS in both the left, $F(1,16) = 4.77$, $p = .04$, $\eta_p^2 = .23$, and the right, $F(1, 16) = 7.82$, $p = .01$, $\eta_p^2 = .33$, hemispheres (Figure 5, right side).

Summary of effects of IDS versus ADS in 13-month-olds. For the 13-month-olds, the N200–400 was larger to IDS than ADS for the familiar words. This effect was limited to temporal and parietal regions of the left hemisphere. The N600–800 was also larger to IDS than to ADS.[3] For the familiar words this effect was observed only in the left hemisphere, but for unfamiliar words it was observed in both the left and right hemispheres.

DISCUSSION

This study investigated the extent to which neural responses were sensitive to the acoustic properties of IDS and whether there were differences in patterns of brain activity linked to IDS as a function of age and word familiarity. Table 2 provides an overview of each component by comparing 6- and 13-month-old infants. In the introduction we raised three issues that serve as the framework for the discussion. The first question raised was whether IDS elicits different patterns of brain activity than ADS. Specifically, we proposed that if the function of IDS is to increase attention to specific units in the speech stream, IDS prosody should serve to boost the neural activity elicited by auditory word forms. More specifically, auditory word forms spoken in IDS should result in larger amplitude ERPs than words spoken in ADS.

A major finding of the study was that differential patterns of neural activity were observed for IDS and ADS. Although there were interactions with age and familiarity, when the effects of speech register were observed, the N600–800 was always larger to IDS than to ADS in both age groups. The larger ERP amplitudes are a direct index of increased neural activity to IDS. Increased neural activity to IDS over ADS suggests that the infant brain is especially sensitive to the rich acoustic

[3]A sustained negativity beyond 800 msec (N800–1,500) evident at 13 months was captured by additional measurements carried out for 100-msec epochs until 1,500 msec (i.e., 800–900 msec, 900–1,000 msec, 1,000–1,100 msec, etc.). These analyses revealed that for the 13-month-olds the main effects of speech register were sustained throughout most of the rest of the 1,500-msec epoch, but these effects were not significant for the 6-month-olds at any of these time windows.

TABLE 2
Summary of Event-Related Potential Mean Amplitude Effects for ADS and IDS in 6- and 13-Month-Olds

	6-Month-Olds	*13-Month-Olds*
P100	None	None
N200–400	None	Familiar words: IDS > ADS for LH at temporal and parietal sites Unfamiliar words: None
N600–800	Familiar words: IDS > ADS for LH Unfamiliar words: None	Familiar words: IDS > ADS for LH Unfamiliar words: IDS > ADS for LH and RH

Note. LH = left hemisphere; RH = right hemisphere; IDS = infant-directed speech; ADS = adult directed speech.

envelope of IDS, as suggested by Fernald and Kuhl (1987). The timing of this effect was similar to the findings from other infant ERP studies showing that the allocation of increased attentional resources is correlated with increased amplitudes of a negative going peak around 800 msec, the Nc (for a more complete discussion see Karrer & Ackles, 1988; Nelson & Collins, 1991; Nelson & Monk, 2001). Based on these studies, we infer that relative amounts of brain activity observed in this time window can be used as a measure of attention. It is also possible that increased brain activity to IDS indexes some other mediator response, such as arousal or affective response to IDS, which in turn directs the infant's attention. If general arousal levels were the cause of increased neural activity, one would expect increased amplitudes to IDS across conditions and ages. That question is beyond the scope of this article, so we do not hold to a strong causal direction. Instead we interpret the results as suggesting that the observed ERP amplitudes are correlated with increased attention. However, these findings are consistent with the position offered in the behavioral literature that IDS serves to increase attention to those words, and that observed increased neural activity is the result of increased attention, as has been shown in other infant ERP studies of attention.

The contention that the Nc serves as an index of attention rather than as a novelty detector has not been without controversy. The Nc is typically elicited in an oddball paradigm in which one stimulus is presented much more frequently than another. The amplitude of the Nc is usually larger to novel or infrequent stimuli than to frequently presented stimuli. This raises the question of novelty and infant attention in this study and how novelty might explain increased neural activity to IDS over ADS. According to the effects of novelty observed on the Nc, the N600–800 amplitude should have been smaller in response to the familiar than unfamiliar words, and smaller to words presented in the less frequently heard ADS than IDS speech register. However, the opposite results were found. In paradigms where stimuli are presented with equal probability, as was the case in this study, the observed Nc amplitudes have not typically differed for familiar and unfamiliar stimuli (Nelson & Collins, 1991). The Nc has also been shown to be larger to highly familiar stimuli, such as a favorite toy or the infant's mother's face, than to unfamiliar toys and faces, respectively (de Haan & Nelson, 1997, 1999). It is possible that familiar words presented in IDS have a privileged status, like highly familiar faces and objects, for recruiting attentional resources in the infant. If that is the case, one would expect the largest ERP amplitudes elicited to familiar words in IDS and the smallest amplitudes to unfamiliar words in ADS. Although there was a tendency for the N600–800 to be largest for familiar words in IDS, in 6-month-olds the trend did not reach significance, and the effects of IDS for unfamiliar words varied with age. Therefore, in this study familiarity alone cannot explain the results. It is more likely that the special features of IDS served to enhance attention paid to these words.

The second question addressed to what extent word familiarity and age interact with ERP differences to IDS and ADS. Age-related differences between ADS and IDS were seen in the latency of the effect, the size of the effect as reflected by differences in amplitude, and distribution (i.e., differences in the specific electrode sites showing significant ERP differences to IDS vs. ADS). Differential electrophysiological responsiveness to IDS at different ages is in accordance with our hypothesis that the sensitivity to IDS is subject to change with increasing age and language proficiency, indexed by vocabulary size. Also, as predicted, differential ERP responses between ADS and IDS emerged depending not only on the child's age but also the familiarity with individual words. Taking the results of both 6- and 13-month-olds together, the following differences in ERP effects in relation to IDS emerged:

(i) At 6 months, ERP responses from 600 msec to 800 msec to IDS were larger than to ADS, but only in response to familiar words. This pattern suggested that IDS is linked to increased attention only to certain words: those the infant has been frequently exposed to and the acoustic formats with which he or she has become familiar. ERPs to unfamiliar words did not differ between ADS and IDS.

(ii) At 13 months, IDS elicited increased neural activity to both familiar and unfamiliar words. The ERP differences between ADS and IDS were observed earlier in the waveform with increasing age. At 13 months, differences were observed from 200 msec to 400 msec and 600 msec to 800 msec. The onset of amplitude differences between IDS and ADS varied with word familiarity. For familiar words, increased amplitude ERPs were observed for both the early and later time windows. For unfamiliar words, the IDS–ADS amplitude difference was seen only in the later time windows.

Differences in neural activity to IDS versus ADS across age and word familiarity suggest that responses to IDS are dynamic and change over time. This is in line with recent behavioral studies by McRoberts (2000) and was also observed by Hayahsi et al. (2001). Although these two studies differ in the design and technique from the research reported here, the common ground is that the potential developmental functions IDS may have for young listeners seem to change with their age and language proficiency. Another explanation for these results could be that infants at 6 months and 13 months have different levels of exposure to IDS as a function of word familiarity. Kitamura and Burnham (2003) showed that mothers indeed adjust their pitch and other aspects of prosody to match their child's age and developmental status across the first year of life. Therefore, in this study the physical characteristics of the IDS used may have been more familiar to one age group than another. A direct comparison across studies for pitch is not possible because Kitamura and Burnham reported mean fundamental frequency and pitch range as proportional scores to normalize across mother's voices rather than in Hz. They also reported sex differences, with mothers using different prosody to girls than boys across ages. However in this study, both boys and girls showed the same responses to IDS. If ERP amplitudes were due to familiarity with particular features of IDS suited to their sex, we should have seen differences in patterns of activity between boys and girls. However, the preliminary analyses revealed that boys and girls showed the same patterns of results at each age. To explain the results according to age-related differences in input, one would need to propose that adults use IDS with 6-month-olds primarily for familiar words, and use IDS with 13-month-olds for both familiar and unfamiliar words. Although possible, this explanation requires further research. At 6 months it is possible that unfamiliar words block the boost in neural activity to IDS because the infant's attention is first directed to the content of the word and only later can the prosodic form of the word (i.e., IDS) play a facilitating role in processing the word. Another possibility is that if parents only speak to their 6-month-old infants in IDS, then the effect of ADS is to transform even a familiar word into a novel stimulus. That is, the representation of the word might be coded as content plus register, and changing the register effectively makes the familiar word novel. Here, we adopt the position consistent with behavioral studies, that age-related changes in neural responses to IDS versus ADS reflect changes in the development of language and interactions with other domain- general cognitive capacities. That is, the limited attentional resources available at 6 months are focused on auditory stimuli that are most familiar (i.e., familiar words in IDS). All other variations of the word plus register are processed as novel. At 13 months, the child has increased attentional and working memory capacity and can use the properties of IDS to increase attention to both familiar and unfamiliar words. In addition by 13 months, children have started to map meanings onto words and may treat a variety of word-like sounds as potentially meaningful. This is less likely for younger children who have few, if any, comprehended words.

A second age-related difference was in the increased amplitude of the N200–400 to familiar words in IDS for the 13-month-olds but not the 6-month-olds. If a child hears primarily IDS, then familiar words presented in IDS may be even more familiar than familiar words in ADS. However, if the N200–400 amplitude is linked only to acoustic familiarity, one would expect similar effects of familiarity and IDS for both 6- and 13-month-olds. It is our working hypothesis that the increased negativity to IDS around 200 msec to 400 msec may reflect a facilitative function of IDS in early word learning in children who are beginning to map meanings onto words. In a recent training study Mills, Plunkett, et al. (2005) showed that the amplitude of the N200–400 increases when meaning is attached to the sound. In that study, novel words were either paired with an object or simply repeated the same number of times. That is, given the same amount of exposure to a particular sound pattern, meaning rather than familiarity increased the amplitude of the N200–400. Those findings further support our previous studies showing that the N200–400 is larger to words whose meanings the child understands than does not understand in the 13- to 20-month age range (Mills et al., 1993, 1997). Therefore, we propose that the special properties of IDS may be beneficial in early word learning by increasing neural activity in this time window to highly familiar and potentially meaningful words, thus increasing the strength of the neural association between the word and its referent. Additional research with children at the earliest phase of language comprehension and infants with different amounts of exposure to IDS are needed to further examine this hypothesis.

The third question we addressed was whether speech register elicits different patterns of lateral asymmetries in brain activity and, if so, whether asymmetries interact with word familiarity or change with age. For familiar words, the N600–800 amplitude differences to IDS versus ADS were left-lateralized in both age groups. For the 13-month-olds this difference was also observed earlier, from 200 msec to 400 msec after word onset, but only over temporal and parietal regions of the left hemisphere. The asymmetrical, left hemisphere amplitude differences in the N600–800 in response to IDS versus ADS to familiar words may reflect a general left hemisphere bias of processing routinized, more automatic codes. It may also indicate that the left hemisphere plays an important role for familiar words with a positive emotional content (for a discussion of the lateralization of affective speech processing, see Pihan, Altenmueller, Hertrich, & Ackermann, 2000). Shafer et al. (1999) also reported that familiarity of information might account for differential hemispheric contribution in processing prosodic information. In our research, listening to words that were unfamiliar to the child resulted in increased neural activity in both the left and right hemisphere, but only in the 13-month-olds. The increased neural activity to unfamiliar words in both hemispheres in 13-month-olds may be correlated with an increase in the allocation of attentional resources with increasing age and the increased attention of older children for novel linguistic stimuli. One question is why the effect of IDS was bilaterally distributed for unknown words in contrast to the effect for known words, which was limited to the left hemisphere. In our previous studies (Mills, Plunkett, et al., 1993, 1997), unknown words elicited a right greater than left asymmetry. We proposed that the asymmetry was due to a right hemisphere advantage for integration of new information. It is also possible that familiarity with specific words leads to a more focal distribution of brain activity within the left hemisphere. In a recent study of novel word learning, differences in the lateral distribution of ERPs were associated with the amount of experience with individual words rather than absolute vocabulary size as had been previously suggested (Mills et al., 2005). Another possibility is that although the effect appears bilateral, the processes mediating this effect might differ for the left and right hemispheres. Additional research is needed to test these competing explanations.

A cautionary note must be made here that the presentation of the stimuli may have an impact on the hemispheric contribution in the processing of IDS. In our study, words were presented in isolation and as such IDS prosody was limited to the word level. It is possible that presenting words in the context of an entire sentence or longer stretch of speech, rather than in isolation, may result in a different pattern of hemispheric contribution for processing IDS. However, presenting words in isolation to the young listener is not uncommon in everyday caretaker–child interaction and thus is a discourse mode the child encounters in everyday situations, at least in the early stages of language learning. In fact, a study by Fernald and Morikawa (1993) demonstrated that words occur in isolation at about 8% to 10% more frequently than in adult interaction and new or focused words are continuously put in the final position of utterance.

CONCLUSIONS

This study makes an important contribution to existing research in IDS. It provides the first neurobiological evidence for a differential responsiveness in brain activity to IDS versus ADS in early language processing. Moreover, the findings support the hypotheses that the special features of IDS serve to increase attention to relevant aspects of the speech stream. The results of this study indicate that IDS prosody modulates brain activity during word processing in the young listener and that the magnitude of the modulation differs with age and word familiarity. At both 6 months and 13 months, IDS functions as a neural spotlight that increases brain activity to specific words. To the young listener, IDS at first draws attention to potentially meaningful words for which the child may already have some form of phonological representations. After increasing experience with language, as indexed by increasing vocabulary size, IDS serves to increase the neural activity to familiar as well as to unfamiliar words. Word-familiarity-induced changes over age in IDS processing may in part be driven by developmentally changing attentional thresholds to familiar versus novel acoustic and phonetic representations. This may serve as an important function in learning more about individual words.

If one agrees with this assumption, then it is in line with the plausibility hypothesis put forward by Bates and her colleagues (Bates, Bretherton, Beeghly-Smith, & McNew, 1982), which assumes that IDS has evolved as an aid for the language-learning infant because of its exaggerated form.

Although the results from this study cannot address the facilitative function of IDS in early word learning directly, the specific characteristics of IDS seem to provide perceptual advantages for the linguistically inexperienced infant. This study also suggests several directions for future research using ERPs to help clarify issues relevant to the use of IDS in early infant interaction. An unresolved and interesting question is how and to what extent the robustness of lexical representations influences the preference of IDS over ADS. If the use of IDS becomes less important, the more familiar the child is with the word and the more solid its lexical representation is, then older, linguistically more advanced children are expected to show a different pattern in processing familiar words. Contrary to the younger children, they may show a decrease in neural activity related to familiar words uttered in IDS as they may no longer find IDS perceptually more salient or more interesting than ADS. It is our working hypothesis that the acoustically exaggerated form of IDS becomes less important the older the child gets and the more robust the underlying knowledge of the word and its meaning is in the child's lexicon.

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APPENDIX
Standard Word List:
Adult-Directed Speech (10 Familiar Words, 10 Unfamiliar Words) and Infant-Directed Speech (10 Familiar Words, 10 Unfamiliar Words)

Adult-Directed Speech		*Infant-Directed Speech*	
Familiar Words	*Unfamiliar Words*	*Familiar Words*	*Unfamiliar Words*
bottle	barrel	diaper	domain
ball	breed	book	bias
cup	court	dog	dent
juice	judge	car	code
nose	nerve	keys	clutch
shoe	shrub	milk	maze
cat	clone	bird	blame
foot	flood	mouth	morph
door	dove	bed	board
brush	bay	eye	oak