Language Experience and the Organization of Brain Activity to Phonetically Similar Words: ERP Evidence from 14- and 20-Month-Olds

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Abstract

■ The ability to discriminate phonetically similar speech sounds is evident quite early in development. However, inexperienced word learners do not always use this information in processing word meanings [Stager & Werker (1997). *Nature*, *388*, 381–382]. The present study used event-related potentials (ERPs) to examine developmental changes from 14 to 20 months in brain activity important in processing phonetic detail in the context of meaningful words. ERPs were compared to three types of words: words whose meanings were known by the child (e.g., ''bear''), nonsense words that differed by an initial phoneme (e.g., ''gare''), and nonsense words that differed from the known words by more than one phoneme (e.g., ''kobe''). These results supported the behavioral findings suggesting that inexperienced word learners do not use information about phonetic detail when processing word meanings. For the 14-month-olds, ERPs to known words (e.g., ''bear'') differed from ERPs to phonetically dissimilar nonsense words (e.g., ''kobe''), but did not differ from ERPs to phonetically similar nonsense words (e.g., ''gare''), suggesting that known words and similar mispronunciations were processed as the same word. In contrast, for experienced word learners (i.e., 20-month-olds), ERPs to known words (e.g., ''bear'') differed from those to both types of nonsense words (''gare'' and ''kobe''). Changes in the lateral distribution of ERP differences to known and unknown (nonce) words between 14 and 20 months replicated previous findings. The findings suggested that vocabulary development is an important factor in the organization of neural systems linked to processing phonetic detail within the context of word comprehension. ■

INTRODUCTION

By their first birthday, children are typically able to recognize and respond appropriately to as many as 100 words (Fenson et al., 1994). Controversy remains as to just what children actually know about words at this time. To fully understand a word and to be a productive member of the language community, the child needs to have a working representation of both the meaning and the phonology (sounds) of the word that matches that of adult native speakers. There is a long and rich history of studies investigating the steps children go through in building semantic representations (for a review, see Naigles, 2002). There have been many fewer empirical studies exploring developmental changes in phonological representations as children build a lexicon. Prior to mapping words on to meaning, attention to phonetic detail is evident. From the first days of life, children can discriminate well-formed syllables differing in only a single phonetic feature (e.g., */ta/* vs. */da/*, Eimas, Siqueland, Jusczyk, & Vigorito, 1971) or in the sequence of segments (e.g., */tap/* vs. */pat/*, Bertoncini & Mehler, 1981). By the end of the first year of life, children's phonetic perception has become finely tuned to the properties of their native language as evident in significantly better discrimination of native over nonnative speech sound differences (e.g., Werker & Tees, 1984). It would be reasonable to expect, then, that the child would use these well-honed speech perception sensitivities when first learning meaningful words. However, recent evidence suggests this may not be the case. The young child may confuse, rather than distinguish, similar sounding syllables when first mapping words to meanings.

One of the first empirical studies investigating this question involved a word recognition study by Hallé and de Boysson-Bardies (1996). Jusczyk and Aslin (1995) had shown that children of 8 months show a preference for listening to word forms they had been familiarized to in the lab (such as ''cup'') over phonetically similar nonsense words (such as ''tup'') in a head-turn preference procedure. Hallé and de Boysson-Bardies (1994) extended this to show that by 11 months, children prefer words that are highly frequent in the input over uncommon

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words, even without pre-exposure in the laboratory. However, children at this age appear to confuse highly frequent known words with phonetically similar nonce words as they also showed a preference for listening to these phonetically similar nonce words, over infrequent words (Hallé & de Boysson-Bardies, 1996). Hallé and de Boysson-Bardies hypothesized that this tendency reveals that in the early stages of word understanding children only represent words globally, and will confuse minimally different words with the standard form. Although of great interest, Hallé and de Boysson-Bardies did not first assess whether or not the children actually knew the meanings of the highly frequent words. Recently, Werker, Cohen, Lloyd, Casasola, and Stager (1998) developed the switch task to directly test whether children use their speech perception sensitivities differently in situations that requires a link to meaning than when in situations that require listening to words as meaningless forms. In this task, children are habituated to two word–object pairings (e.g., AA and BB), and tested on their knowledge of this pairing by comparing looking time to a ''switch'' (e.g., AB) and a ''same'' (e.g., AA) trial. Werker and colleagues found that children of 14 months of age can learn to associate two dissimilar sounding words, such as ''lif'' and ''neem,'' to two different objects, but fail on this task when the words are phonetically similar words, such as ''bih'' versus ''dih'' (Stager & Werker, 1997). A series of control studies confirmed that children of 14 months are capable of discriminating these two nonce words in a discrimination task that does not entail linking the words with a nameable object. This set of experiments is consistent with the suggestion that when children of 14 months listen to words as acoustic forms, discrimination of phonetically similar words is readily apparent but if children of this same age are required to map the words on to meaning, they no longer attend to the fine phonetic detail.

The inattention to fine phonetic detail in newly learned words is short-lived. By 17, and more consistently by 20 months of age, children are able to learn to map similar sounding words such as ''bih'' and ''dih'' on to two different objects (Werker, Fennell, Corcoran, & Stager, 2002; see also Bailey & Plunkett, 2002). Even 14-month-old children with exceptionally large vocabularies perform successfully in this task. On the basis of these results, Stager and Werker (1997; see also Werker & Fennell, 2004; Fennell & Werker, 2003) concluded that because the typical child at 14 months is still a novice word learner; the task of linking words to meanings is still very computationally intensive. This leaves inadequate attentional resources for using the phonetic detail in the word.

These results are not without challenge. In a recent series of studies, Swingley and Aslin (2000, 2002), using a different procedure, provided evidence that children of both 18 and 14 months of age can distinguish correct from incorrect pronunciations of well-known words. Swingley and Aslin presented children pairs of well-known objects (e.g., ''baby'' and ''dog'') on a computer screen. While viewing both objects, the child heard either a correct (e.g., ''baby'') or incorrect pronunciation (e.g., ''vaby'') of one of the object labels. The children's looking times to the visual ''match,'' which was the baby in both conditions, were significantly delayed in the mispronunciation condition as compared to the correct pronunciation condition, thus indicating access to the fine phonetic detail in the word forms. In some conditions, the children also looked longer to the correct picture after hearing the correct pronunciation[1] than after hearing the mispronunciation. This same overall pattern was reported both for children of 18–23 months of age (Swingley & Aslin, 2000) and for children aged 14 months (Swingley & Aslin, 2002), in apparent contradiction to the results of Werker et al. (2002) and Stager and Werker (1997). On the basis of these results, Swingley and Aslin conclude that there is a strong continuity between speech perception and word learning, and that even in the initial stages of word learning children have not only complete representations, but also complete access to the phonetic detail evidenced in speech perception tasks (see also Swingley, 2003).

This interpretation is open to question. First, even though children in the Swingley and Aslin task looked longer at the correct object when the word being spoken correctly matched the object than when the mispronunciation was heard, their looking time to the ''match'' was still greater than chance in the mispronunciation condition. One interpretation of these results is that the children treated both the correct and the mispronounced versions of the word as acceptable labels for the object, but with perhaps a higher level of activation in the recognition of the correct than the incorrect pronunciation. This interpretation would allow for the possibility that children do notice the phonetic detail about the shape of the word at some point in the processing stream, but do not treat it as significant in their final lexical representation of the word. In other words, although their speech perception capabilities are intact, when a decision about the label for the object is required, this phonetic detail is no longer included.

Studies such as these, using looking behavior, have provided insight into child lexical knowledge. They are, nonetheless, open to criticism. This is especially true in the current context. In the many studies using the ''switch'' task, conclusions about lexical representation are drawn on the basis of a lack of a significant difference in looking time to the switch over the same trials in the test phase. It is always problematic to draw a positive inference on the basis of a negative result. In the Swingley and Aslin studies, the looking time measure that revealed the most consistent results differed across age. In the children aged 18–23 months, the most consistent measure was latency to look away from the mismatch, whereas in the children aged 14 months, total looking time to the "correct" object yielded the most consistent results. It is also problematic to draw definitive conclusions when different dependent variables are used with different age groups. Finally, whenever looking behaviors are used as dependent variables, it is difficult to ascertain whether looking time differences reflect differences in detection, encoding, or the final representation.

Electrophysiological measures provide a useful complement to looking time measures. Previous child ERP studies (St. George & Mills, 2001; Mills, Coffey-Corina, & Neville, 1993, 1994, 1997; Molfese, 1989, 1990; Molfese, Wetzel, & Gill, 1993) have shown different patterns of neural activity to known versus unknown words in children as young as 12 months of age. Mills and colleagues compared event-related potentials (ERPs) to words whose meanings the child did and did not comprehend. Results revealed larger amplitude ERPs to the known versus the unknown words at 200–400 msec following word onset. At 13–17 months, this amplitude difference was evident over both hemispheres, over frontal, temporal, parietal, and occipital sites. By 20 months, the ERP difference was limited to temporal and parietal regions of the left hemisphere. The results suggested there were changes in the organization of brain activity linked to word processing within that age range that may be linked to vocabulary size. The children aged 20 months who were post (> 150 words) vocabulary spurt showed more focally distributed ERPs to known words, whereas children with smaller vocabularies (<50 words) showed a more distributed response, indicating that the increasingly local nature of the differential ERP signature seen in older children reflects greater sophistication in word knowledge rather than age per se. Although the 200–400 msec latency may seem early for indexing word meanings in children, looking time paradigms with children have also shown evidence for word recognition by the middle of the word (e.g., Fernald, Swingley, & Pinto, 2001). Moreover, this time window is consistent with ERP studies of lexical access and word comprehension in adults (e.g., Sereno, Brewer, & O'Donnell, 2003; Osterhout & Holcomb, 1995; Holcomb & Neville, 1991; Fischler, 1990; Kutas & Hillyard, 1980). In adults, ERP differences to contextually appropriate versus inappropriate words typically emerge around 200 msec (Brown, Hagoort, & Kutas, 2000; Kutas & Hillyard, 1980), and have been observed as early as 50 msec (Holcomb & Neville, 1991).

In this article, we used an ERP paradigm similar to Mills et al. (1997) to examine the nature of the phonetic detail in lexical representations in children of 14 and 20 months of age with one exception. Instead of presenting the children with randomly varying presentations of 10 known and 10 unknown words, we added 10 unknown words that were phonetically similar to the known words. For example, we presented children with known words such as "dog, cat, shoe, milk," and so forth, and phonetically dissimilar nonsense words such as "neem, blick, zav, kobe." As an extension, we added a set of nonsense words that were phonetically similar to the known words. These "phonemic contrast" nonce words included items such as "bog, gat, zue, and nilk." We predicted that children of 14 and 20 months would show larger amplitude ERPs to the known versus the phonetically dissimilar unknown words, and that this would be seen across most electrode sites at 14 months but would be more localized at 20 months. Of particular interest were ERPs to the phonemic contrast words. We reasoned that if there is sufficient detail in the lexical representation, the ERP signature to these phonemic contrast foils should be like that of phonetically dissimilar unknown words. However, if the lexical representation is not detailed, the phonemic contrast items should be confused with known words.

RESULTS

ERPs for all three word-types over anterior and posterior regions of both the left and right hemispheres are shown for the 14- and 20-month-olds in Figures 1 and

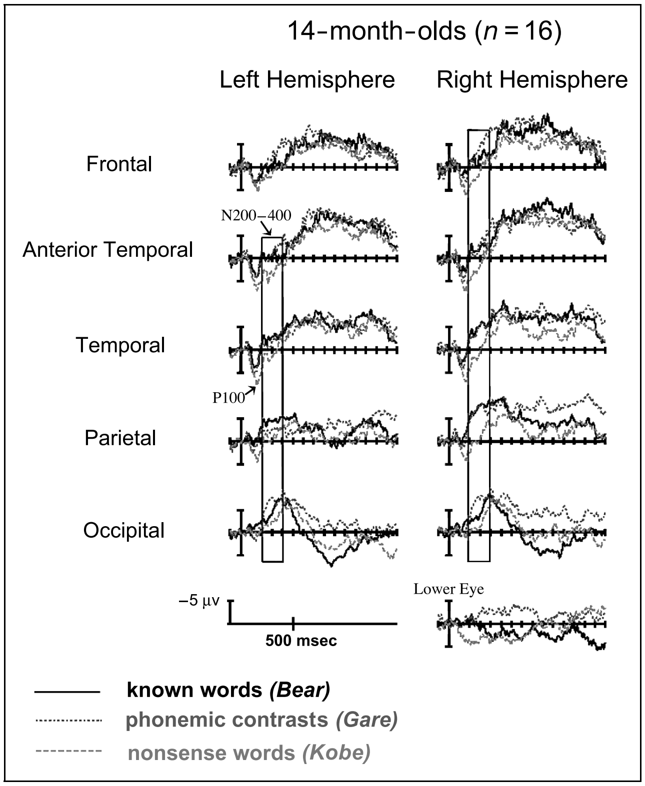

Figure 1. ERPs to all three word-types for the sixteen 14-month-olds over the anterior and posterior regions of the left and right hemispheres. ERPs to known words are shown in the solid lines, to phonemic contrasts in the dotted lines, and to phonetically dissimilar nonsense words in the dashed lines.

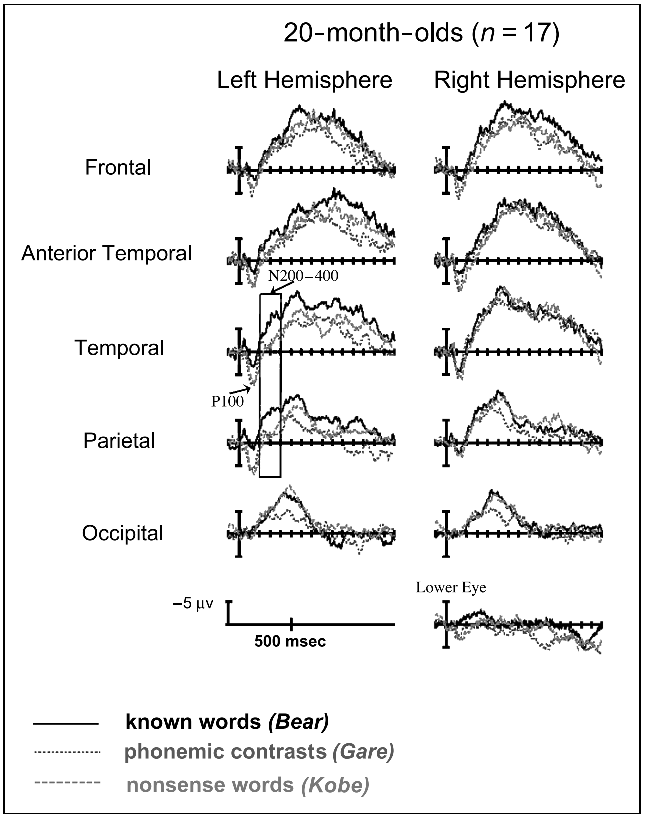

Figure 2. ERPs to all three word-types for the seventeen 20-month-olds over the anterior and posterior regions of the left and right hemispheres. ERPs to known words are shown in the solid lines, to phonemic contrasts in the dotted lines, and to phonetically dissimilar nonsense words in the dashed lines.

2, respectively. The results are presented for two ERP components, the peak amplitude and latency of the first positive component, P100, and the mean area of the negativity between 200 and 400 msec poststimulus onset. These components were chosen because our previous studies found them to be sensitive to vocabulary size and/or word meanings. Also in previous studies, the N600–N900 differed for known and unknown words at 13–17 but not 20 months (Mills et al., 1997). Visual inspection of the present data for the 14-month-olds (Figure 1) suggested differences in this time window between the mean amplitude for the phonetically similar nonsense word and the other two word-types. None of the analyses conducted on the later time window reached significant levels. There were no interactions with age or vocabulary size. Therefore, to conserve space, these analyses were not included.

Data Analysis

A priori hypotheses predicted that the 14-month-olds and 20-month-olds would show different patterns of ERPs to the phonemic contrast words relative to the known and nonsense words. Therefore, the ERP data were analyzed separately for the two age groups in repeated-measures ANOVAs with Word-type (known, phonemic contrast, nonsense words), Hemisphere (left and right), and Electrode site (frontal, anterior temporal, temporal, parietal, and occipital) as the within-subjects factors. Huynh–Feldt corrections were used for all the repeated-measures analyses. We were particularly interested in changes in the lateral distribution of the N200–N400 for the 14- and 20-month-olds to known words compared with the two types of nonsense words. These planned simple effects were analyzed for the 14- and 20-month-olds separately in repeated-measures ANOVAs comparing two word-types (known words vs. phonemic contrasts, known vs. nonsense words, and phonemic contrasts vs. nonsense words), by hemisphere (left and right), and by electrode site (frontal, anterior temporal, temporal, parietal, occipital). Age group differences were analyzed in a two-way ANOVA with Age group as the between-subjects variable and Word-type (known words, phonemic contrasts, nonsense words), Hemisphere (left and right), and Electrode site (frontal, anterior temporal, temporal, parietal and occipital) as the within-subjects factors.

Children Aged 14 Months

P100. The first positive component peaked at 125 msec (P100). The P100 peaked later and was larger over frontal than posterior regions [electrode site: latency, $F(4,50) = 9.34, p < .001$; amplitude, $F(4,60) = 7.53, p < .001$]. There were no main effects or interactions for peak latencies or amplitude among word-types or between the left and right hemispheres.

N200–N400. The mean amplitudes between 200 and 400 msec (N200–N400) were larger over posterior than anterior regions [electrode site: $F(4,60) = 5.14$, $p < .01$] and differed with word-type [$F(2,30) = 3.76$, $p < .05$]. There were no main effects or interactions with hemisphere.

Planned comparisons showed that the N200–N400 was larger for known words than for nonsense words (i.e., ‘‘bear/kobe’’; Figure 3, top) [$F(1,15) = 4.94$, $p < .05$]. Importantly, the N200–N400 amplitude was also greater for the phonemic contrast words than for the nonsense words (‘‘gare/kobe’’; Figure 3, bottom) [$F(1,15) = 6.97$, $p < .05$]. However, the N200–N400 was not significantly different for known words versus phonemic contrast words (i.e., ‘‘bear’’/‘‘gare’’; Figure 3, middle) [$F(1,15) = 0.07$, $p = .80$]. Thus, both known and phonemic contrast words showed the same activity as ‘‘known,’’ and were different from unknown ‘‘nonsense’’ words.

We also predicted age-related differences in the lateral distribution of the N200–N400 effects. As predicted for the 14-month-olds, the N200–N400 mean amplitude differences between the word-types were broadly distributed over anterior and posterior regions of both the

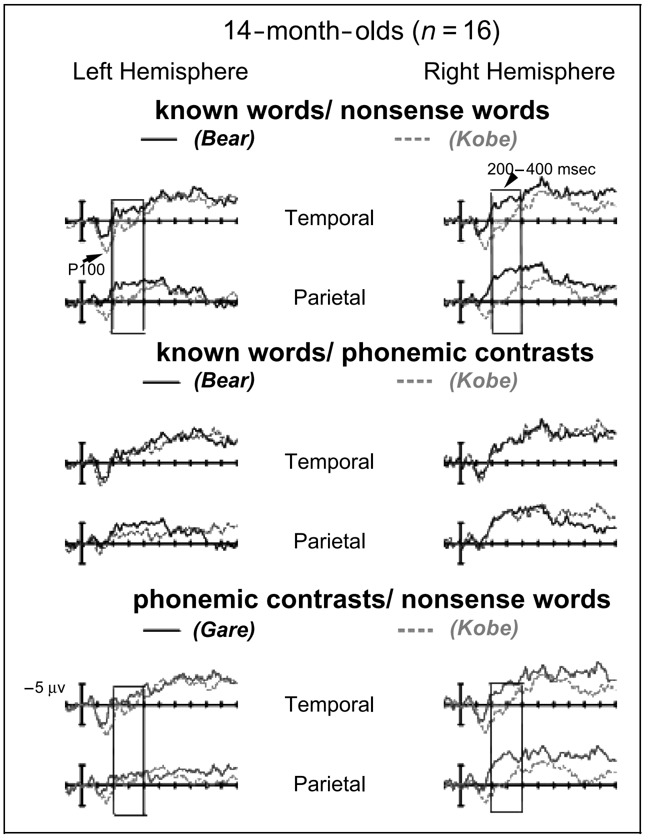

Figure 3. For the 14-month-olds, ERP differences are directly compared to known words and nonsense words (top), known words and phonemic contrasts (middle), and phonemic contrasts and phonetically dissimilar nonsense words (bottom). Significant differences in N200–N400 mean amplitudes are shaded and enclosed in the rectangle. Left and temporal and parietal regions are shown on the left and right sides of the figure, respectively.

left and right hemispheres [known vs. nonsense: left hemisphere, $F(1,15) = 2.30, p < .15$, right hemisphere, $F(1,15) = 7.45$, $p < .05$; phonemic contrasts vs. nonsense words: left hemisphere, $F(1,15) = 4.58$, $p < .05$, right hemisphere, $F(1,15) = 7.97, p < .01$].

Children Aged 20 Months

P100. The P100 peaked later and was larger over frontal than posterior regions [latency, $F(1,16) = 7.00$, $p < .001$; amplitude, $F(1,16) = 14.07, p < .001$]. There was also a main effect of word-type for the P100 amplitude [$F(2,32) = 3.55, p < .05$]. Examination of the amplitude differences across word-types showed that the P100 was larger to known words than to nonsense words [known vs. nonsense, $F(1,16) = 7.07$, $p < .05$] and phonemic contrasts [known vs. phonemic contrasts, $F(1,16) = 6.05$, $p < .05$]. The P100 amplitude was larger over the left than the right hemisphere, but only over temporal and parietal sites [Hemisphere × Electrode site: $F(4,64) = 3.00$, $p < .05$]. There were no other main effects or interactions.

N200–N400. The N200–N400 amplitude differences to the different word-types approached significance [word-type, $F(1,16) = 3.03$, $p = .06$]. The N200–N400 was larger over the left than the right hemisphere at temporal and parietal sites, but larger over the right than the left over the occipital regions [Hemisphere × Electrode site: $F(4,64) = 2.83, p < .05$].

Planned comparisons showed that the N200–N400 was larger to known than nonsense words [$F(1,16) = 5.76$, $p < .05$], but only over left temporal [$F(1,16) = 8.26$, $p < .01$], left parietal [$F(1,16) = 10.62$, $p < .01$], and right frontal [$F(1,16) = 6.02, p < .05$] sites (Figure 4, top). The N200–N400 was also larger to known words versus phonemic contrast words over left temporal [$F(1,16) = 7.24$, $p < .05$] and left parietal [$F(1,16) = 7.09, p < .05$] regions (Figure 4, middle). However, the main effect of word-type for this comparison only approached significance [$F(1,16) = 2.70, p = .10$]. There were no significant differences in N200–N400 amplitudes to the phonemic contrasts and nonsense words (Figure 4, bottom) [$F(1,16) = 0.42$, *ns*]. At 20 months then, the phonemic contrast (nonsense) words were no

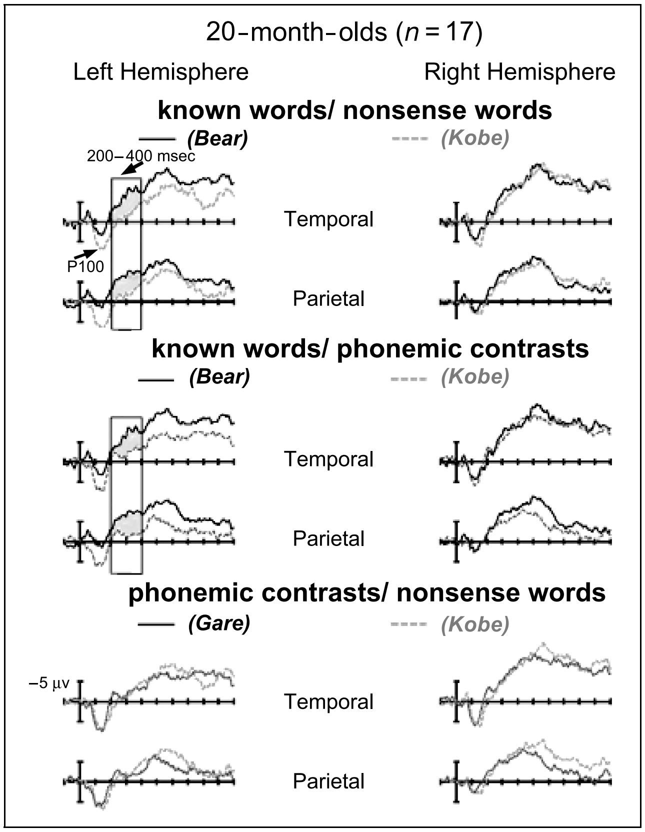

Figure 4. For the 20-month-olds, ERP differences are directly compared to known words and nonsense words (top), known words and phonemic contrasts (middle), and phonemic contrasts and phonetically dissimilar nonsense words (bottom). Significant differences in N200–N400 mean amplitudes are shaded and enclosed in the rectangle. Left and temporal and parietal regions are shown on the left and right sides of the figure, respectively.

longer treated as known words, but were instead treated like other nonsense words.

Age Group Comparisons

There were no main effects or interactions with age when all three word-types and all electrode sites were included in the analyses. Because the 20-month-olds in this study, and in our previous studies, only showed ERP differences in this time window to known versus unknown words at temporal and parietal sites, a separate ANOVA was conducted including only temporal and parietal sites, that is, with two levels of Age group (14 and 20 months) as the between-subjects factor and Word-type (known, phonemic contrasts, and nonsense words), Hemisphere (left and right), and Electrode site (temporal and parietal) as the within-subjects factors. That analysis showed main effects for Word-type [$F(1,31) = 6.59$, $p < .001$] and Hemisphere [$F(1,31) = 3.95 = 4.20$, $p < .05$]. These effects were qualified by two interactions with group, including a Group × Word-type × Hemisphere interaction [$F(6,62) = 3.04$, $p < .05$], and a Group × Electrode site interaction [$F(1,31) = 3.96$, $p < .05$]. These interactions were further validated by the different patterns displayed by the 14- and 20-month-olds separately.

To further support the age-related effects described above, separate ANOVAs were conducted with Age (14 and 20 months) as the between-subjects factor and Word-type (known, phonemic contrasts, and nonsense words), Hemisphere (left and right), and Electrode site (frontal, anterior temporal, temporal, parietal, and occipital) as the within-subjects factors. To conserve space, only main effects of and interactions with age are reported below.

P100. There were no main effects or interactions with age for the P100 latency. The age-related difference in the lateral distribution of the P100 amplitude was supported by an Age × Hemisphere × Electrode site interaction [$F(4,124) = 2.75$, $p < .05$].

N200–N400. There were no main effects or interactions with age when all three word-types and all electrode sites were included in the analyses. Because the 20-month-olds in previous studies, and in this study as described above, only showed ERP differences in this time window to known versus unknown words at temporal and parietal sites, a separate ANOVA was conducted including only temporal and parietal sites, namely, with two levels of Age group (14 and 20 months) as the between-subjects factor and Word-type (known, phonemic contrasts, and nonsense words), Hemisphere (left and right), and Electrode site (temporal and parietal) as the within-subjects factors. That analysis showed two interactions with group, including a Group by Word-type × Hemisphere interaction [$F(6,62) = 3.04$, $p < .05$], and a Group × Electrode site interaction [$F(1,31) = 3.96$, $p < .05$]. These interactions support the findings described above showing different patterns of responsiveness to the different word-types by the 14- and 20-month-olds separately.

Summary

Fourteen- and 20-month-olds showed different patterns of brain activity to known words (e.g., "bear"), phonemic contrasts (e.g., "gare"), and (phonetically dissimilar) nonsense words (e.g., "kobe") (Figure 5). As predicted by Stager and Werker (1997), 14-month-olds showed larger N200–N400 amplitudes to known words compared with nonsense words (e.g., "kobe"). However, the N200–N400 to known words and the phonemic contrast stimuli (e.g., "bear" and "gare") did not differ from each other.

Unlike the pattern seen at 14 months, and as predicted by Werker et al. (2002), the 20-month-olds showed larger amplitude N200–N400 responses to

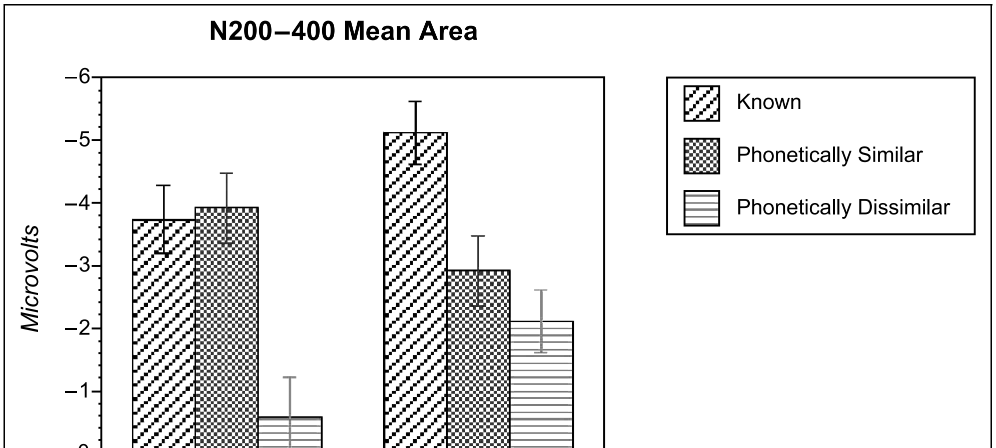

Figure 5. N200–N400 mean areas averaged across temporal and parietal regions of the left and right hemispheres to the three word-types for the 14- and 20-month-olds.

known words (e.g., ''bear'') over both phonemic contrast (e.g., ''gare'') and other nonsense words (e.g., ''kobe''). Moreover, the N200–N400 amplitudes to the phonemic contrast and other nonsense words (''gare'' and ''kobe'') did not differ from each other. These findings also replicated previously observed lateral differences in the N200–N400 amplitudes to known versus unknown words between 14 and 20 months (Mills et al., 1997).

DISCUSSION

The results from the present study were consistent with and expanded on findings observed in previous behavioral and ERP studies. At both 14 and 20 months of age, the pattern of ERP responses seen replicated that previously reported by Mills et al. (1993, 1997) for known versus unknown words. At both ages, there was a larger amplitude negative response from 200 to 400 msec to known versus nonsense words. And, as shown before, at 14 months of age this response was broadly distributed across the scalp, whereas at 20 months it was observed primarily over the left temporal and parietal electrode sites.

The replication of the previous work by Mills and colleagues puts us in a particularly strong position to interpret the results from the phonemic contrast words. At 14 months of age, the ERP signature to phonemic contrast nonsense words (e.g., ''gare'' or ''bog'') is indistinguishable from that to known words (e.g., ''bear'' and ''dog''), and significantly greater in amplitude than that to dissimilar nonsense words (e.g., ''lif''). Thus, at 14 months of age, the neural response appears to indicate a mistaken recognition of a minimal pair mispronunciation of a known word as the word itself. This result is consistent with that seen in the switch task at 14 months (Werker et al., 2002; Stager & Werker, 1997). The results with the ERP task are particularly convincing because here we see a significant increase in the amplitude of the response rather than a failure to increase looking time. At 20 months of age, the ERP response is also consistent with results seen in the switch task at the same age (Werker et al., 2002). At 20 months, the ERP signature to phonemic contrast nonsense words (e.g., ''gare'' and ''bog'') is significantly different from that to their known counterparts (e.g., ''bear'' and ''dog''), and indistinguishable from that to phonetically dissimilar nonsense words (e.g., ''neem'' or ''lif''). Thus, at 20 months, the evoked response indicates that children are showing the ''word recognition'' ERP response only to known words that are phonologically correct in all details. By 20 months then, the confusion with similar-sounding known words is no longer present, indicating that words in the lexicon are not only fully specified in terms of phonological detail, but that such detail is available even when listening to words in tasks that do not provide contextual or pictorial support for the word meaning, and may not even involve full attention to the word.

One difference between the present study and the behavioral studies by Werker and colleagues and Swingley and Aslin, is that the behavioral studies used both pictures and words, whereas the present study presented a series of words without a picture context. A negative going ERP wave within the 200–500 msec time window has also been shown to index word meaning in cross-modal match/mismatch paradigms using pictures and words in 14- and 20-month-old children (Mills, Conboy, & Paton, in press) and real objects and novel trained words in 14-month-old children (Molfese, Morse & Peters, 1990). We chose to use the Mills et al. (1997) paradigm rather than a picture/word match/mismatch paradigm for several reasons. The picture/word match/mismatch paradigm elicits a large amplitude bilateral negative component starting at 200 msec and peaking around 500 msec when the subsequent word does not match the picture at both 14 and 20 months (Mills, Conboy, et al., in press). This ERP effect is most likely within the N400 family observed in children and adults to violations of semantic expectancy (Holcomb, Coffey, & Neville, 1992; Kutas & Hillyard, 1980). In adults, a similar paradigm elicited a phonological mismatch (PMN) to words and nonwords from 250 to 347 msec over right frontal regions, and from 347 to 638 msec over symmetrical centro-parietal regions (Connolly, Service, D'Arcy, Kujala, & Alho, 2001). One concern was that the N400 and PMN effects elicited by a picture/word match/mismatch paradigm might swamp more subtle differences in the latency, amplitudes, and distributions of ERPs related to the different word-types and group differences. The Mills et al. paradigm was chosen because it showed ERP differences to known and unknown words that varied with word-type, age, and vocabulary size. The methodological differences should be taken into consideration when comparing the effects. However, the ERP findings are consistent with and provide additional support for the age-related differences reported by Stager et al. (1997).

The robust differences in the ERP pattern at 14 and 20 months of age could be explained at many levels. Several studies have shown that a negative peak at around 200 msec is sensitive to phonetic variation in voice onset time (Simos, Molfese, & Brenden, 1997; Molfese & Molfese, 1988), place of articulation (Dehaene-Lambertz & Dehaene, 1994; Molfese, Burger-Judisch, & Hans, 1991), and acoustic cues in nonspeech stimuli (Dehaene-Lambertz, 2000; Simos & Molfese, 1997) in very young children and even newborns. One interpretation is that ERP differences between word-types are related to the acoustic or phonological features of the different word-types and that age-related changes are due to differences in the children's ability to memorize the different word lists. Although phonological discrimination can modulate the amplitude of the N200 in certain paradigms, it is not necessarily the only factor that may contribute to the amplitude of this component. Here, we argue that age-related changes in a top-down process linked to word meaning is the dominant factor modulating the amplitude of the N200–N400 rather than phonological discrimination. First, if ERP differences between conditions were due solely to phonological factors, then both age groups would have displayed N200 amplitude differences between the known words and phonetic contrasts. Additionally, the known and phonemic contrasts were balanced for the types of initial consonants in the number of stop consonants, nasals, and fricatives; and did not differ in their phonological neighbors for other words frequently understood by children in this age range (see Methods). Therefore, it is difficult to explain why the phonemic contrasts patterned with the known words at 14 months and the nonsense words at 20 months based solely on acoustical and phonemic differences. A second line of evidence suggesting that the ERP differences observed here cannot be explained by phonological differences between word-types comes from a study of bilingual toddlers using the same paradigm. In that study, the N200–N400 did not differ between Spanish and English for either the known or unknown words (Conboy & Mills, 2000; Conboy, 2003). ERP differences were linked to word meaning (known vs. unknown words), language dominance, and total vocabulary size, but not phonological differences between Spanish and English. If the N200–N400 indexed the phonological aspects of the words, amplitude differences would be expected between Spanish and English. A third, and perhaps the strongest line of evidence, comes from a training study with 20-month-old children in which nonsense words were either repeated or paired with an object (Mills, Plunkett, Prat, & Schafer, in press). After the training phase when objects were no longer present, the amplitude of the N200–N400 to the newly learned words increased relative to before training, but became more positive for nonsense words that were repeated the same number of times. Because the stimuli were counterbalanced across participants, the increased amplitude of the N200–N400 to the newly learned words was modulated by its association with a meaningful stimulus and cannot be explained by phonological differences between word-types.

Another interpretation of the findings is that at 14 months of age the phonetic detail distinguishing one word from another is simply not available in the lexical representation. Such an explanation would be compatible with theories of phonological development that posit an initial under-specification of the information in the lexicon that is only gradually filled in as the vocabulary expands (e.g., Brown & Matthews, 1997). Although possible, we think this explanation is unlikely given the work by Swingley and Aslin (2002) showing that children of 14 months do seem to show some evidence of use of phonetic detail in word recognition tasks via longer looking time to the matching object when a correct versus a mispronounced version of a word is given. The Swingley and Aslin work involves showing the children two objects (e.g., a car and a dog), and asking them to find either the correctly labeled object (e.g., ''dog'') or a mispronunciation of that same object (e.g., ''bog''). More recently, Fennell and Werker (2003) showed that, when tested on two phonemic contrast words that they already know well (e.g., ''ball'' and ''doll'') the child of 14 months can succeed even in the switch task. These two studies show that at some level in the system, full phonetic specification of well-known words is represented even at 14 months.

The successes in the two-choice (Swingley and Aslin) behavioral ''mispronunciation'' task and in the switch task using two well-known words in comparison to both the switch word-learning task and the ERP word recognition task are compatible with the attentional resource limitation hypothesis offered by Werker and colleagues (Werker et al., 2002; Werker & Fennell, 2004; Fennell & Werker, 2003; Stager & Werker, 1997). According to this explanation, the task of linking a word to an object is challenging for a novice word learner. All the detail is picked up, but the computational difficulty of actually mapping the word on to the object makes it difficult to hold all the information in mind. As such, one sees a U-shaped function in the pattern of data. The child of 7–8 months who is not yet actively engaged in mapping words to referents is better able to attend to fine phonetic detail than is the child of 14 months who is attempting to make and remember the link (see Stager & Werker, 1997; see also Hallé & de Boysson-Bardies, 1996; Jusczyk & Aslin, 1995). Becoming a word learner changes the task for the older child. This increases the processing demands and interferes with the child's ability to access detail. The information is picked up in perception; it is just not available for access in lexical recall tasks. After the child becomes a more accomplished word learner and has a working phonemic inventory to guide information access, the relevant phonetic differences ''stand out'' as salient and important to the lexical entry. Or as suggested by Nazzi and Bertoncini (2003), once the child passes a critical juncture in word learning sophistication, moving from a simple associationist to a referential word learner, access to phonological detail becomes possible. Prior to that point, however, any detection of that detail is, at best, fleeting. As such, it may be seen in on-line processing tasks or in tasks that provide full support to recall memory (Fennell & Werker, 2003; Swingley & Aslin, 2002), but is not evident in tasks that involve learning new words (Werker et al., 2002; Stager & Werker, 1997), nor is it evident in word recognition tasks such as the ERP task used here where there is no object to facilitate activation of the full memory trace.

Support for this explanation can be seen in the current ERP study. In this study, children of 20 months (but not 14 months) showed a significant P100 response to the known words over both the nonsense words and the phonemic contrasts words. The P100 is thought to index sensory and attentional processes. This is the first time Mills and colleagues (e.g., Mills et al., 1993, 1997) have observed a significantly greater P100 response to known than to unknown words in the ERP word recognition studies. The amplitude of the P100 is known to be modulated by effects of attention in both adults (Luck & Hillyard, 2000) and children (Richards & Hunter, 2001). One interpretation of this finding is that the inclusion of phonemic contrast words in the dataset increased attention to early phonological differences. To distinguish the known words from the phonemic contrast foils, they had to increase their vigilance to the sensory and perceptual detail, thus yielding a significant P100 response in this ERP word recognition task.

Directions for Further Research

A focus for future work will be to determine precisely what changes between 14 and 20 months allow the more accomplished word learner to access and use full phonetic detail across a wide range of word recognition and word learning situations. In a recent training study, Mills, Plunkett, et al. (in press) addressed this question by examining the effects of experience on the lateral distribution of the N200–N400 differences between known and unknown words. Mills et al. asked whether observed changes in the lateral distribution in ERP differences to known versus unknown words between 13 and 20 months (Mills et al., 1997; and replicated in the present study), reflect the availability of specialized brain systems for word recognition (as might be available in a more accomplished word learner), or increasing knowledge of particular words by testing 20-month-old children who varied in vocabulary size on newly learned words. ERPs to novel words that had been paired with an object during a pretest training phase were compared to ERPs to novel words that had been repeated the same number of times but without the object/word pairing. The results supported a mixed model. ERP differences to newly learned words compared to repeated-but-not-trained words showed a bilateral distribution across the whole sample. This finding was consistent with the hypothesis that the asymmetrical distribution of ERP differences to known and unknown words is linked to the amount of experience with individual words. However, children with the largest vocabularies showed a left greater than right distribution of ERP differences. The latter finding suggested that expertise with word learning might also affect the specialization of language-relevant brain activity even in the service of learning new words.

If a more expert word learning system is becoming available (Nazzi & Bertoncini, 2003) in the older and/or more experienced word learner, this might also permit greater direction of attention to the relevant phonological information in the word learning and access situation. Indeed, as we argued at the beginning of this article, perhaps part of becoming a more expert word learner is knowing just which properties of a word are definitional in a particular linguistic community. It may be the emergence of this greater understanding of just what distinguishes words in our language that allows the older, more accomplished word learner to not only perceive, but also ''mark'' and ''use'' the phonological detail in word learning and word recognition tasks.

In previous studies, Mills and colleagues have reported a link between vocabulary size and the distribution of the N200–N400 amplitude difference to known and unknown words between 14 and 20 months of age. Similarly, Werker et al. (2002) reported a significant correlation between performance on the CDI at both 14 and 17 months and performance in the minimal pair switch task. There was no significant correlation with the CDI in the present study. The lack of a significant correlation here could reflect lack of variability in the data, perhaps because the age groups selected are not yet in transition. We predict that testing of a group of children intermediate in age and vocabulary sizes to the groups tested here would be more likely to reveal such a pattern of findings.

In summary, using an ERP design, we extended and helped explain the pattern of findings seen in early behavioral tasks assessing the phonological detail represented and used in early word learners. The results of the current ERP study indicate that at the earliest stages of word learning, children treat minimal pair mispronunciations of known words as acceptable instances of that word. This provides strong evidence that in the decision stage of word recognition, novice word learners accept a broader range of pronunciations of the word as acceptable than do older children. With increasing age and increasing language sophistication, the amount of phonological detail easily accessed in the representation of words increases, helping to avoid mapping mistakes and to facilitate more rapid acquisition of a vocabulary.

METHODS

Participants and Settings

Participants were tested in three locations: at the University of California, San Diego, at the University of Oregon, Eugene, Oregon, and at the University of British Columbia, Vancouver, Canada. Approximately one-third of the children in each age group were tested at each site. Testing at the Vancouver site was conducted in a mobile ERP lab belonging to the University of Oregon. Children from the San Diego and Eugene areas were recruited through advertisements in a local magazine, posters displayed in the area, requests at play groups, and referrals from parents whose children had participated in our studies. Children from the Vancouver area were recruited through the University of British Columbia child Studies Center database. Parents of all children signed consent forms consistent with the human subjects internal review boards at the university at which they were tested. Parents were given $5.00 to defray transportation costs and children were given a small toy in appreciation of their participation. Only full-term (>36 weeks of gestation) healthy children with monolingual experience with English participated in the study. children with a family history of language impairment were excluded from the study.

Data from 16 children aged 14 months (9 girls, mean age = 14 months 15 days, *SD* = 9.7 days, range = 14 months 1 day to 15 months 1 day) and 17 children aged 20 to 21 months (9 girls, mean age = 20 months 11 days, *SD* = 13.1 days, age range = 19 months 14 days to 20 months 27 days) were retained for analysis in the study. An additional 18 children (12 boys, nine 14-month-olds) were tested but were excluded from the analyses due to too few artifact-free trials (*n* = 10), excessive crying (*n* = 3), reversed polarity of the ERP response (*n* = 3, see note)[2] or refusal to wear the electrocap (*n* = 2).

Stimuli

The stimuli were naturally spoken in a female voice and digitized at 16 bits, 44 kHz sampling rate. The stimuli consisted of three types of words: (a) 10 words whose meanings were understood by the child (known words, e.g., "milk"), (b) 10 nonsense words that differed from the known words in the initial phonemic contrast (phonemic contrast words, e.g., "nilk"), and (c) 10 words that differed phonetically from known words in all vowels and consonants (nonsense words, e.g., "neem"). All stimuli were matched on word duration and number of syllables. The mean durations for the known words, phonetic contrasts, and nonsense words were: 783 msec, *SD* = 144; 865 msec, *SD* = 169; 861 msec, *SD* = 96 [$F(2,27) = 1.09$, $p = .34$]. Ideally, all word-types would be matched on manner of articulation (e.g., all stop consonants, all nasals, all laterals, all fricatives, or all balanced). However, children at this age have very small vocabularies and we were limited to common words that almost all children at this age would know. Among children first words are a disproportionate number of words that begin with stop consonants. For many of those words, minimal pair differences are still words (e.g., "ball"–"doll"). Thus, we were constrained in our selection of stimulus items. For the known words, there were seven stop consonants, two nasals, and one fricative. For the phonemic contrasts, there are also seven stop consonants, two nasals, and one fricative. For the nonsense words, there are three stop consonants, one affricative, two nasals, two fricatives, and two laterals. A complete list of words is shown in Table 1.

Table 1. Stimuli

Known Words	*Phonemic Contrasts*	*Nonsense*
Bear	Gare	Kobe
Ball	Pall	Lif
Book	Dook	Neem
Bottle	Pottle	Fipe
Cup	Tup	Mon
Cat	Gat	Tek
Dog	Bog	Riss
Milk	Nilk	Keed
Nose	Mose	Jud
Shoe	Zhu	Zav

To evaluate at what point the known words could physically be distinguishable from the other word-types, we examined two aspects of uniqueness: (a) at what point the phonetically dissimilar nonsense words become unique from their real word counterparts (e.g., when does "bear" become unique from "gare"), and (b) when the words might become unique from other words that would be in a baby's vocabulary at this age. The uniqueness point for initial consonants (the point that separates that consonant from other consonants) was within 20 msec of the beginning of the word for fricatives (s, z, f) , 40 msec for stop consonants (b, d, g, p, t, k), 60 msec for affricatives (j), and 20 msec for nasals (m, n) and laterals (l, r). To further examine the uniqueness points, we compared each stimulus used in the study relative to other words that might be in the child's vocabulary with the words in the MacArthur CDI that would be considered close phonological neighbors. To this end, we compared our stimuli to the number of words in the CDI with: (a) the same consonant including consonant clusters and (b) the same consonant excluding consonant clusters, and (c) the same consonant plus the vowel. For comparisons a and b, there are the most neighbors for the known words (a = 474; b = 375), an intermediate amount for the phonemic contrast words (a = 371; b = 298), and the least for the nonsense words (a = 275; b = 233). The best comparison is to count the number of items that begin with the same consonant plus vowel (CV). There were no significant differences in the number of CV neighbors for the three word-types (known = 16, phonemic contrasts = 12, nonsense = 18). Additionally, because of co-articulatory effects, the acoustic energy for a given consonant varies as a function of the following vowel (Jusczyk, 1997). Thus, even words beginning with the same consonant (e.g., "book" and "bottle") differ in shape and spectral frequencies and can be discriminated from each other, as well as their close phonological neighbors, from the beginning of the word.

Procedure

Language Assessment

Within one week prior to testing, parents were asked to complete the MacArthur CDI (Fenson et al., 1994), which provided an estimate of the child's vocabulary size and percentile ranking relative to other children of the same age. To ensure that the words to be used in the study as "known" were comprehended by the child, parents also completed a vocabulary checklist rating scale indicating how sure they were that their child understood and/or produced each word on a scale of 1 (very sure they did not know that word) to 4 (very sure their child understood/produced a given word in a variety of different contexts and with different exemplars). Additionally, the children were asked to identify a picture of each word to be used as a known word from a two-choice picture book. All "known" words used had received a rating of 4 and were correctly identified in the picture-pointing task.

Electrophysiological Recording

The EEG was recorded using tin electrodes affixed to an elastic cap (Electro-Cap International) from sites over frontal (F7 and F8), anterior temporal (50% of the distance from F7/8 and T3/4), temporal (33% of the distance from T3/4 to C3/4), parietal (50% of the distance between T3/4 and P3/4), and occipital (O1 and O2), regions of the left and right hemispheres. Additionally, the electrooculogram was recorded from electrodes placed over and under the eye to reject trials on which blinks and vertical eye movement occurred, and from left and right frontal electrodes to reject trials on which horizontal eye movement occurred. Impedances were kept below 5 kΩ and were balanced (within 1 kΩ) across the left and right hemispheres at any given position. The EEG was amplified by SA Instruments amplifiers with a bandpass of 0.1 to 100 Hz and sampled continuously every 4 msec. All electrodes were referenced to linked mastoids.[3] Averages of the EEG were conducted using 2-sec epochs (i.e., 100 msec prestimulus and 1900 msec poststimulus). The averaged ERPs were also digitally filtered off-line with a 60-Hz low-pass filter.

Testing

Ten known, 10 phonetically similar nonsense words (referred to as phonemic contrasts), and 10 phonetically dissimilar nonsense (referred to as nonsense words) words were each presented six times in random order, for a total of 60 trials per condition. During testing, children sat on their parent's lap and listened to words presented from a speaker located behind a moving puppet in a puppet theater. Words were presented at a variable rate between 1800 and 3000 msec SOA.

Artifact Rejection

Artifact rejection was conducted off-line using a computer program to reject blinks and horizontal eye movement and amplifier blocking. Individual thresholds were set for each child based on visual inspection of the EEG epochs time-locked to each stimulus. A mean of 50% of the trials were rejected due to eye and movement artifact. The number of artifact-free trials per word-type retained for analysis ranged from 12 to 53 (SD = 11.3), out of a possible 60 trials per condition. There were no significant differences in the percentage of trials rejected for the different experimental conditions, age groups, or sex.

Measurement of ERP Components

Peak latencies and amplitudes were quantified by computer with reference to the 100-msec prestimulus baseline for the maximum negative or positive point in a specified time window. The time windows for each component were set according to the criteria used in our previous studies: the first positive component, called the P100, was defined as the most positive deflection between 50 and 175 msec. The P100 indexes auditory sensory processing. Moreover, the lateral distribution of the P100 has been shown to vary with percentile ranking on the MacArthur CDI score. Children who score at the 50th percentile or higher for their age show a P100 left greater than right asymmetry. The mean amplitude within the time window 200–400 after word onset was quantified by computer with reference to the 100-msec prestimulus baseline. This time window was chosen because it had been shown to differ for known and unknown words in our previous studies.

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Notes

1. Unlike the switch task, the visual fixation task is an on-line task with two simultaneously presented choices. The two indicators of success are: shorter latency to look away from the incorrect object and longer looking times overall to the correct match. The habituation phase in the ''switch'' task leads to the prediction of a novelty preference in the test phase (i.e., longer looking to the incorrect pairing).
2. In previous studies, Mills and colleagues typically find approximately 10–15% of children show a reversed ERP response, with a larger amplitude ERP response to unknown than to known words. In previous work, Mills and colleagues have treated those children as noise in the data and have kept them in for the data analyses. Ultimately, we want to understand the nature of lexical representations in this group of children showing an aberrant ERP response. For the current study, however, in order to compare the ERP response to phonemic contrasts to known words, we felt it necessary to include in our sample only those children who showed the much more typical pattern of response, resulting in the exclusion of three children. All effects reported here show the same pattern with these children included, but the variability from their inclusion did reduce the differences in some comparisons.
3. We are aware of the controversies surrounding the use of linked mastoids. Linked mastoids were used here to increase the number of active cites given the number of amplifiers available and to provide consistency with previous studies. A pilot study using similar auditory stimuli was conducted to examine possible distortions in the distribution of scalp activity resulting from forced linkage. This was determined by recording from one mastoid, using the other as a reference, and linking the mastoids off-line. These pilot data were compared with the data recorded using linked mastoids and did not yield significant differences.

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