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Infants' Developing Competence in Recognizing and Understanding Words in Fluent Speech

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Again and again in research on early cognitive development, infants turn out to be smarter than we thought they were. The refinement of experimental techniques for reading infants' minds has been extremely productive, enabling us to study developing capabilities which are not yet observable in spontaneous behavior. When the task demands are made simple enough, infants demonstrate implicit knowledge across diverse domains ranging from understanding of the physical world and numerical concepts to social cognition (see Wellman & Gelman 1998). In the domain of language understanding as well, such techniques have been used to reveal the early emergence of linguistic competence before it is evident in overt behavior, and many ingenious experiments have demonstrated the considerable speech processing savvy of infants in the first year. These studies show that certain perceptual skills essential for spoken language understanding emerge gradually over the first year, often months before infants are able to display their linguistic knowledge through speech production (see Aslin, Jusczyk & Pisoni 1998). Our own recent research on word recognition by older infants provides further evidence for gradual growth over the second year in aspects of speech comprehension which were previously inaccessible to observation (Fernald, Pinto, Swingley, Weinberg & McRoberts 1998).

This emphasis on the "competent infant" in the field of cognitive development has its potential downside, as Haith (1998) makes clear in a thoughtful essay on the recent baby boom in developmental research. By searching for cognitive sophistication at ever-younger ages, and by interpreting data suggesting precursors of knowledge in a particular domain as evidence for mature capacities, we run the risk of overlooking the really interesting developmental stories. Haith makes a plea for developing models for the gradual acquisition of "partial knowledge", instead of thinking in dichotomous terms that infants at a certain age either have or do not have a mature ability. We need to develop graded concepts to document progress toward cognitive competence, models with many steps along the way. Maratsos (1998) makes a related point in discussing methodological difficulties in tracking the acquisition of grammar. Much of language acquisition goes on "underground", he argues, since intermediate stages of developing knowledge systems rarely show up directly in the child's behavior. To understand how the system progresses to mature competence, it is necessary to gain access somehow to these underground stages of partial knowledge.

The good news is that in research on early language understanding, the goal of revealing partial accomplishments on the way to mastery may be more attainable than in other domains of cognitive development where criteria for competence are harder to define. Neuropsychological research on infants' responses to known and unknown words reveals a major shift in cerebral organization between the ages of 13 and 21 months (Mills, Coffey-Corina & Neville 1993). Over this period the patterns of brain activity associated with infants' responses to familiar words become more lateralized and similar in other ways to those of adults in speech comprehension tasks. However, it is not known whether such developmental changes in neural responses reflect maturation of brain systems dedicated specifically to speech processing, or maturation of brain systems related more broadly to memory and other cognitive capabilities supporting language understanding. While imaging methods provide increasingly powerful tools for investigating graded changes in brain development, establishing functional connections between neuropsychological findings and the emergence of language competence requires the kinds of detailed behavioral experiments that explore infants' imperfect knowledge as they gradually develop competence. For example, careful parametric studies on the phonetic factors influencing young infants' success in segmenting sequences of speech sounds are documenting consistent developmental patterns (see Jusczyk 1997). In our own research, the use of on-line measures of spoken word recognition also allows us to analyze fine-grained developmental changes in infants' speech processing efficiency that are meaningfully related to changes in speech production. Moreover, it is possible to show how variations in features of the input speech can influence infants' success in recognizing familiar words. The outcome of these and many other research efforts in this area will be an increasingly differentiated picture of the emergence of partial knowledge in receptive language competence.

Overview

Our focus in this chapter is on the graded nature of developmental change? spoken word comprehension by infants in the second year. We also consider how particular features of the speech directed to infants may interact with these changes, enabling infants to recognize familiar words more easily in continuous speech. The next seven sections cover the following points:

Across the first year infants develop certain perceptual and cognitive skills necessary for language understanding. By the age of 8 months they adept at recognizing recurrent sound patterns in fluent speech, although yet able to associate sound patterns with meanings. The rudimentary segmentation skills evident at this age are necessary but not sufficicient capabilities for understanding speech.

- By the beginning of the second year infants gain proficiency in associating sound sequences with referents and in using these sound patterns as they occur in varying contexts to access meanings. Between 15 and 24 months of age, infants improve dramatically in the speed and accuracy of spoken word recognition.

During this period infants also become more efficient in word recognition By 18 months of age they are capable of processing speech increments recognizing spoken words very rapidly on the basis of the initial acousic-phonetic information sufficient to distinguish the word from other alternatives.

One explanation for these developmental gains in the speed, accuracy, and efficiency of spoken word recognition over the second year is that they reflect changes in infants' lexical representations.

These developmental gains may also reflect changes in cognitive capabilities such as attention, memory, auditory/visual integration, and categorization, capacities which are not specific to language processing but which are essential for spoken word recognition.

When interacting with infants, adults tend to modify their speech along several dimensions. One common characteristic of infant-directed speed in English, the placement of focused words in utterance-final position, facilitates access to familiar words in fluent speech, thus compensating to some extent for cognitive limitations which influence infants' speech processing capabilities.

An account of the gradual emergence of receptive language skills in infancy should be concerned not only with the nature of developing lexical representations, but also with the contribution of other factors influencing the accessibility of spoken words to the novice listener. These include intrinsic factors such as non-linguistic perceptual and cognitive capabilities involved in understanding speech, as well as extrinsic factors such as characteristics of language input which enhance or hinder comprehension.

"Word recognition" without comprehension

In the language acquisition literature it was not so long ago that infants under 10 months of age were referred to as "prelinguistic" (e.g., Ziajka 1981), a term that now sounds downright disrespectful. Given the observational data available at the time, it was reasonable to assume that infants who can't speak and who show few signs of understanding what they hear are not yet engaged in linguistic activity, Only at the onset of speech production was there unambiguous observable evidence of a transition from a "prelinguistic" to a "linguistic" mode of processing language. We know better now. Just as in research on other domains of cognitive development, a reliance on overt behavior as the criterion for knowledge led to an underestimation of infants' language competence. Using habituation and auditory preference procedures, many studies have shown that even very young infants are attentive to some levels of linguistic organization in speech. By the age of 8 months infants are attuned to aspects of the phonological system of the language they are hearing (e.g., Kuhl, Williams, Lacerda, Stevens & Lindblom 1991; Polka & Werker 1994), and are able to recognize recurrent patterns in sequences of speech sounds (Jusczyk & Aslin 1995). Moreover, when identifying word-size units embedded in fluent speech, infants use parsing strategies that reflect awareness of typical sound patterns in the ambient language. For example, English-learning infants more readily extract embedded words that have the strong-weak stress pattern prevalent in English than words with a weak-strong stress pattern (Jusczyk 1997). Even when familiarized only briefly with syllable strings that do not represent actual language samples, 9-month-old infants appear to extract word-like units by noticing which syllables regularly co-occur (Saffran, Aslin & Newport 1996).

What such studies show is that over the first year infants are becoming skilled listeners, capable of making detailed distributional analyses of acoustic-phonetic features of spoken language. Although such accomplishments are often cited as evidence for early "word recognition", they are more appropriately viewed as evidence of pattern detection abilities which are prerequisite for recognizing words in continuous speech. Identifying sequences of sounds as coherent acoustic patterns is obviously an essential step in word recognition, but this can occur without any association between particular sound patterns and meanings. Halle and de Boysson-Bardies (1994) found that French-learning infants showed a listening preference for words likely to be familiar to them in the speech they were hearing, as compared to words less common in infants' experience. These results indicate that by the age of 10 months, infants have some kind of acoustic-phonetic representation for certain frequently heard sound patterns. However, this selective response to familiar words constitutes word recognition in only a limited sense since it can occur with no evidence of comprehension.

Between the ages of 10 and 14 months, infants typically do begin to associate words with meanings. Parents report on vocabulary inventories that infants in this age range speak several words and appear to understand many more. Such checklist data are often interpreted as indicating how many words a child "has acquired" in his or her lexicon, a conclusion which may be reasonable but which masks the graded nature of the accomplishment. A parent filling out monthly checklists might report at 11 months that the infant does *not* understand the word *shoe,* and then report at 12 months that the infant *does* understand the word *shoe,* just the kind of apparently all-or-none (or none-to-all) transition from ignorance to mastery that Haith (1998) and Maratsos (1998) regard with skepticism. What has happened between 11 and 12 months? The check in the box means that on one or more recent occasions in the intervening month the parent saw the infant look toward, act on, or in some other way behave selectively toward a shoe just after the word *shoe* was spoken. Although it's possible that this observable act of understanding reflected a sudden epiphany, at this early stage of word learning it is much more likely that the child's spontaneous demonstration of competence was preceded by gradual developments in several domains that are not as easily observed.

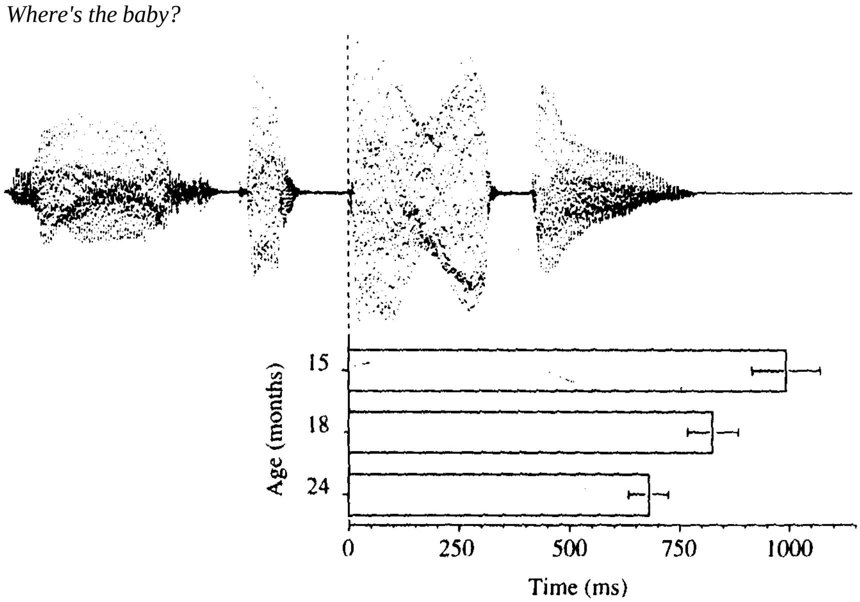
New experimental approaches are helping to illuminate some of the underground changes occurring during this period. For example, three recent studies suggest that infants begin to listen to sounds differently around the time when they start making links between spoken words and meanings. Halle and de Boysson-Bardies (1996) used an auditory preference method to show that 11-month-old infants appear to ignore phonetic detail in familiar words. Since infants at much younger ages are able to make fine-grained phonetic distinctions, they conclude that by 11 months infants are attending to words in a new "lexical mode" in which reduced attention to phonetic detail can be regarded as an advantage rather than as a deficiency. In a related study, Hohle and Weissenborn (1998) found that infants 7-9 months old responded differently than infants 10-15 months old when listening to fluent speech containing familiar words, a difference which they see as reflecting a transition from a purely acoustic-phonetic form of representation in the younger infants to a more mature form of lexical representation incorporating semantic information. The research of Stager and Werker (1998) with 8- and 14-month old infants also suggests that when infants move from syllable perception to word learning, they are less attentive to the phonetic detail in a new word heard in association with an object, perhaps because. Of the additional cognitive demands involved in pairing sound patterns with meanings. The findings of these studies have been interpreted as evidence that as infants begin to learn that words have meanings, they begin to tolerate greater variability in the fine acoustic detail. A shift in attentional priorities during this period is a good example of a potentially important underground process which could not be detected without the use of experimental methods revealing gradual changes in infants' listening biases.

Recognizing and understanding words in the second year

At one level it's obvious that the development of infants' ability to understand words in continuous speech is a gradual process: at 12 months, infants typically understand only a few words, and by 24 months they may speak hundreds of words and understand many more. The rate of learning new words may accelerate, and sometimes particular words in a child's vocabulary appear and then briefly disappear, but in general there is steady increase and stability in the words learned. If the parent filling out a vocabulary checklist indicates that *ball* is "understood and said" at 15 months, then *ball* will most likely be reported as "understood and said" in subsequent months. Such measures of receptive language competence track age-related changes in the estimated size of the child's lexicon; however, they reveal nothing about the much less obvious changes in the efficiency with which known words are comprehended. Although *ball* is produced and understood at 15 months, the child's ability to recognize that familiar word in continuous speech continues to improve in ways that are not apparent in spontaneous behavior. The use of new high resolution measures of speech comprehension have enabled us to show that between the ages of 15 and 24 months, infants become much faster, more reliable, and more flexible in recognizing familiar words (Fernald et al. 1998).

The procedure for assessing infant word recognition developed in our laboratory derives from the auditory-visual matching technique introduced by Golinkoff, Hirsh-Pasek, Cauley and Gordon (1987). Seated on the parent's lap in a test booth, the infant is shown pairs of pictures while listening to speech. Two colorful images depicting objects familiar to the infant are presented on adjacent computer monitors at the beginning of each trial. After a brief period of looking at the pictures in silence, the infant hears a sentence naming one of the objects. Infants' patterns of fixations to the two pictures on each trial are recorded by a video camera located between the two monitors and then coded off-line (see Swingley, Pinto & Fernald 1998). Patterns of visual fixation have proved to be a valuable measure of spoken language understanding by adults, enabling researchers to monitor the rapid mental processes involved in sentence comprehension (e.g., Tanenhaus, Spivey-Knowlton, Eberhard & Sedivy 1995). However, in previous research with infants, fine-grained analyses of eye movements have been used in only a few studies of infants' response to visual stimuli in non-linguistic contexts (e.g., Haith, Hazan & Goodman 1988; Hood & Atkinson 1993). In our research, the close observation of infants' scanning patterns in response to speech enables us to track the time course of word recognition. We use frame-by-frame analysis to identify the point at which the infant initiates a shift in gaze from one picture to the other, measuring eye movements from the beginning of the spoken target word on each trial.

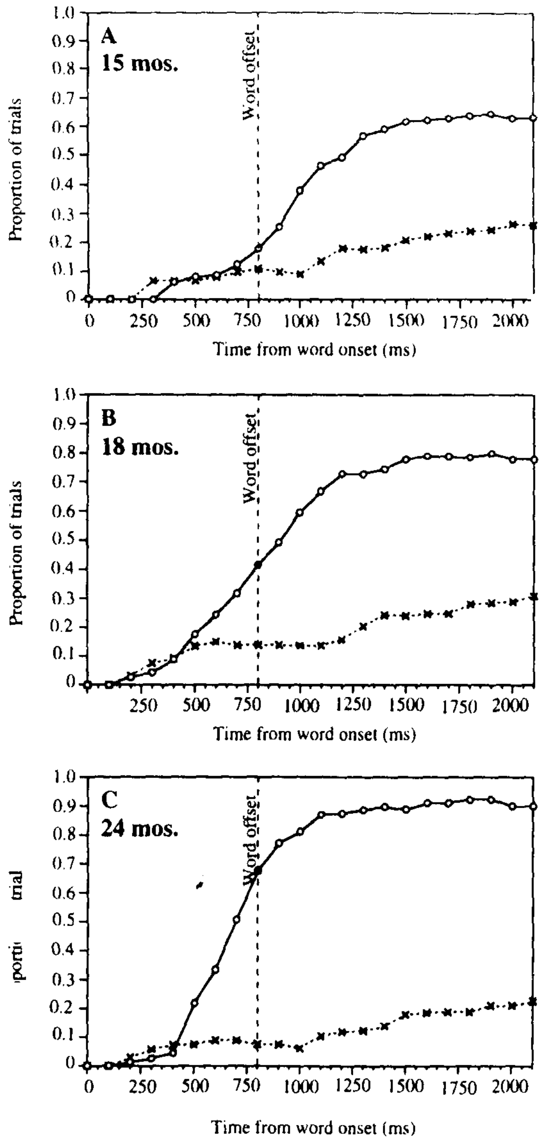
In a cross-sectional study of infants at 15, 18, and 24 months of age, we explored developmental changes in the speed of word recognition, calculating infants' latency to shift to the correct picture in response to a familiar spoken target word (Fernald et al. 1998). The subjects were 72 infants from monolingual English-speaking families, 24 in each age group, and all were reported by their parents to understand the four target words: *doggie*, *baby*, *ball* and *shoe*. The target words were comparable in duration and were always presented in the same two carrier phrases: *Where's the*______*? See the*______*?* Visual stimuli were presented in pairs (ball/shoe or dog/baby) with side of presentation of the objects in each pair counterbalanced across trials, and with each object serving as target on two trials and as distractor on two trials. Since infants could not anticipate the side of presentation of the target object on a given trial, they were equally likely to be looking at the target or distractor object at the onset of the target word. Using only those trials on which the infant was initially looking at the distractor object, we calculated the reaction time to the target word by measuring the infant's latency to initiate a shift in gaze from the distractor to the target object when the target word was spoken. As shown in Figure 1, the mean response latency decreased reliably with age. The mean RT at 15 months (995 ms) was significantly slower than at 18 months (827 ms) and at 24 months (679 ms).



This analysis included only those trials on which the infant was initially looking at the incorrect picture and then shifted to the correct picture when the target word was spoken. The graph is aligned with an amplitude waveform of one of the stimulus sentences (Fernald et al. 1998, with permission from APS).

Figure 1. *Mean latencies to initiate a shift in gaze from the distractor picture to the target picture, measured from the beginning of the spoken target word, for 15-, 18-, and 24-month-old infants*

Another way of looking at the data in this study is to compare shifts in gaze on distractor-initial trials, when the correct response is to shift to the other picture, with shifts on target-initial trials, when the correct response is to continue fixating the target object after it has been named. The graphs in Figure 2 show shifts in gaze on distractor-initial and target-initial trials in response to the target word for infants at all three ages. Solid lines show correct responses, while dashed lines show incorrect responses. Note that the increasing distance between the two lines in these graphs reflects increasing accuracy in infants' ability to recognize target words across the three age groups. Given perfect



Solid lines represent correct responses, shown as the proportion of trials on which infants were initialy fixating the distractor object at the onset of the target word and then shifted to the target picture (distractor-to-target shifts); dashed lines represent incorrect responses, shown as the proportion of trials on which infants were initially fixating the target object and then shifted to the distractor picture (target-to-distractor shifts) (Fernald et al. 1998, with permission from APS).

Figure 2. *Shifts in gaze from one picture to the other in response to the target word, for infants at (A) 15 months, (B) 18 months, and (C) 24 months*

performance in this procedure, the solid line would asymptote at 1.0 (i.e., on distractor-initial trials subjects would always shift to the other picture), and the dashed line would remain at 0 (i.e., on target-initial trials subjects would never shift to the other picture). Although the 24-month-old infants did not perform perfectly, their tendency to shift accurately from distractor to target picture in response to the target word was much greater than for the younger infants. While response accuracy is reflected in the distance between the two lines in each graph, response speed is reflected in the point of divergence. Consistent with the analysis of mean reaction times, the graphs in Figure 2 show that on trials when infants started out on the distractor picture, the older infants also shifted to the target picture more quickly than did the younger infants as the target word was spoken.

These findings show that during their second year infants make impressive improvement in the speed and accuracy with which they are able to recognize familiar words in fluent speech. During the period known as the vocabulary burst, measures of productive vocabulary show that around the age of 18 months many infants begin to acquire new words more rapidly (e.g.. Bloom 1973). Spanning this period, our research using on-line measures of infants' word recognition skills from 15 to 24 months of age revealed parallel developments in spoken language understanding that would be impossible to observe with precision in natural behavior. Progress is evident not just in the acquisition of new vocabulary words, but also in the increased efficiency with which long-familiar words are recognized and understood.

Incremental processing in infant word recognition

If a child can speak the word *baby* by the age of 15 months and demonstrates understanding by choosing the appropriate picture when hearing the word, what accounts for further improvement over the following months in the ability to recognize that word when it is spoken? According to one prevalent view in the literature on early word recognition, the lexical representations that enable infants and young children to understand spoken language are relatively impoverished in comparison with those of adults. From this perspective, performance differences in the speed and reliability of word recognition at 15 and 24 months most likely reflect differences in the nature of lexical representations available at these ages. In addition to representational differences, it is possible that other cognitive abilities developing rapidly at this time are critical in the emergence of word recognition skills. Here we review recent studies from our laboratory which explore the ability of infants to recognize words using a minimum of acoustic-phonetic detail. The findings of these studies may help us to understand how these different factors contribute to the increase in speech processing efficiency over the second year.

The idea that young children's lexical representations are poorly specified was originally based on observations of speech production and perception errors. For example, researchers using tasks which tested word understanding found that infants around 18 months often failed to discriminate phonetic contrasts which much younger infants can easily differentiate (e.g., Shvachkin 1973/1948; Garnica 1973). Psycholinguistic experiments with preschoolers showed that older children also perform much worse than adults when asked to detect mispronunciations and do other tasks requiring rapid identification of familiar words (e.g., Cole 1981; Walley 1987). For example, Walley (1988) found that children needed to hear relatively more acoustic-phonetic information than did adults before they were able to identify known words correctly, a result which was interpreted as evidence for immature holistic representations. These and other related findings have led some researchers to conclude that lexical representations are still relatively underspecified and lack segmental detail even at 3 to 4 years of age (e.g., Charles-Luce & Luce 1990; Walley 1993).

If young listeners need to hear an entire word before lexical access can occur, then we would not expect infants to show the same efficiency as adults in identifying known words in continuous speech. A robust characteristic of spoken language understanding by adults is the ability to process speech incrementally. Because adults make continuous use of acoustic-phonetic information, they are able to identify familiar words as soon as sufficient detail is available to enable them to disambiguate the word from other alternatives (e.g., Marslen-Wilson 1987). For example, a word onset such as */el/* activates several English words including *elf. else, elbow, elevator, elegant, elephant,* and others consistent with the initial segments. When the adult listener hears */ele/,* most of these candidates can be rejected; a few milliseconds later when the */f/* is heard, the word *elephant* can be uniquely identified before the end of the word is spoken. According to Walley (1993), young children are not yet able to process speech continuously in this fashion. Because immature lexical representations are "holistic" in nature, she argues, children only slowly develop the ability to process speech incrementally.

The Fernald et al. (1998) findings suggested that we should not underestimate infants' abilities in this regard. As shown in Figure I, the mean latency to identify familiar words decreased substantially between 15 and 24 months of age. Although the 15-month-olds demonstrated word recognition by looking reliably at the correct picture in response to naming, they typically did not initiate a shift in gaze from the distractor to the target picture until after the target word had been spoken. In contrast, the 24-month-olds typically began to shift to the correct picture *before* the end of the target word. These findings gave preliminary and indirect support to the idea that the older infants were identifying the spoken word based on word-initial information, just like adults. However, it was not clear from these results how much acoustic-phonetic information infants needed to hear in order to recognize the target word.

To address this question more directly, Swingley, Pinto and Fernald (1999) presented 24-month-old infants with paired pictures of familiar objects whose names overlapped substantially *(doggie/doll)* or did not overlap (e.g., *doggie/tree)* at word onset. While *doggie* could potentially be distinguished from *tree* right from the beginning of the word, *doggie* and *doll* were not distinguishable until the occurrence of the second consonant 300 ms into the word. If two-year-olds can process words incrementally, their reaction times should be slower in the case of phonetic overlap. Thus the question of interest was whether infants hearing the target word *doggie* would be slower to shift to the correct picture when the dog was paired with the doll than when the dog was paired with the tree. The results showed that this was indeed the case: infants rapidly distinguished *doggie* from *tree,* but their response was delayed by about 300 ms when distinguishing *doggie* from *doll.*

The Swingley et al. (1999) study showed that by 24 months of age, children are able to monitor speech continuously, taking advantage of word-initial information to identify a familiar word. The fact that the 300 ms lag in reaction time corresponded to the amount of phonetic overlap between *doggie* and *doll* suggested that infants' responses were roughly time-locked to the occurrence of the phonetic information relevant to distinguishing the two words. However, the mean response latency in this case was around 1000 ms, more than half a second after the point when the target word diverged from the name of the distractor object. Thus it could not be concluded from these results that hearing the first portion of the word, just up to the point of the disambiguating consonant, provided infants with enough information for word recognition, as is often the case for adults. Of course, reaction times in this procedure include not only the time it takes to identify the target word, but also the time required to initiate a shift in gaze. Based on research on infants' eye movements (e.g., Haith, Hazan & Goodman 1988) we can estimate that oculomotor programming requires around 200-300 ms, but this is a very rough estimate. In any case, given the mean response latencies in this study, it was possible that infants continued to listen for half a second beyond the point where the word became uniquely identifiable, rather than responding as soon as disambiguating information became available.

In the next study we explored this question more directly, by presenting infants with truncated target words in which only the first part of the word was available (Fernald, Swingley & Pinto, under review). If infants can identify familiar words when only the word-initial information is presented, this would provide convincing evidence for the early development of incremental processing. The subjects in this study were 64 infants at 18 and 21 months of age, the period associated with the onset of the vocabulary burst. Since our on-line procedure yields continuous measures of speed and accuracy in word recognition, we hoped to be able to document gradual changes in receptive language skills across this period of rapid development in speech production. With this goal in mind, we also explored the relation of our speech processing measures to infants' productive vocabulary size, as assessed by parental report on the Mac Arthur Communicative Development Inventory (CDI). The question of interest was whether infants who are faster and more accurate in word recognition are also more advanced in vocabulary development.

The auditory stimuli used in this experiment were sentences containing one of six Whole target words known to children of this age *(baby, doggie, kitty, birdie, car, ball),* or one of six Partial target words, constructed by deleting the final segments of the Whole words (*/bei/, /daw/, /ki/, /ber/, /ka/, /baw/).* Through careful editing of the waveforms, it was possible to make all the Partial target words comparable in duration (range: 291-339 ms). As described earlier, infants' responses were analyzed using high resolution coding of infants' fixation patterns to the target and distractor pictures as the Whole or Partial target word was spoken.

Three main findings emerged from this study. First, we found that 18- and 21-month-old infants were able to recognize spoken words rapidly and reliably on the basis of partial segmental information. The mean reaction times to both Whole and Partial target words were around 800 ms, as shown in Figure 3. Although the 21-month-old infants were faster overall than the 18-month-old infants, there was considerable overlap in mean response latencies. Moreover, there were no age-related differences in accuracy, although infants performed better overall on Whole word trials (77% correct) than on Partial word trials (70%). Extending the findings of Swingley et al. (1999), these results showed unambiguously that word-initial acoustic-phonetic information was sufficient to enable infants to identify known words. Second, we found that speed of word recognition was associated with accuracy in this task. For this analysis, we divided infants into a Fast group and a Slow group based on their average response latency on Whole word trials. Infants in the Fast group responded more

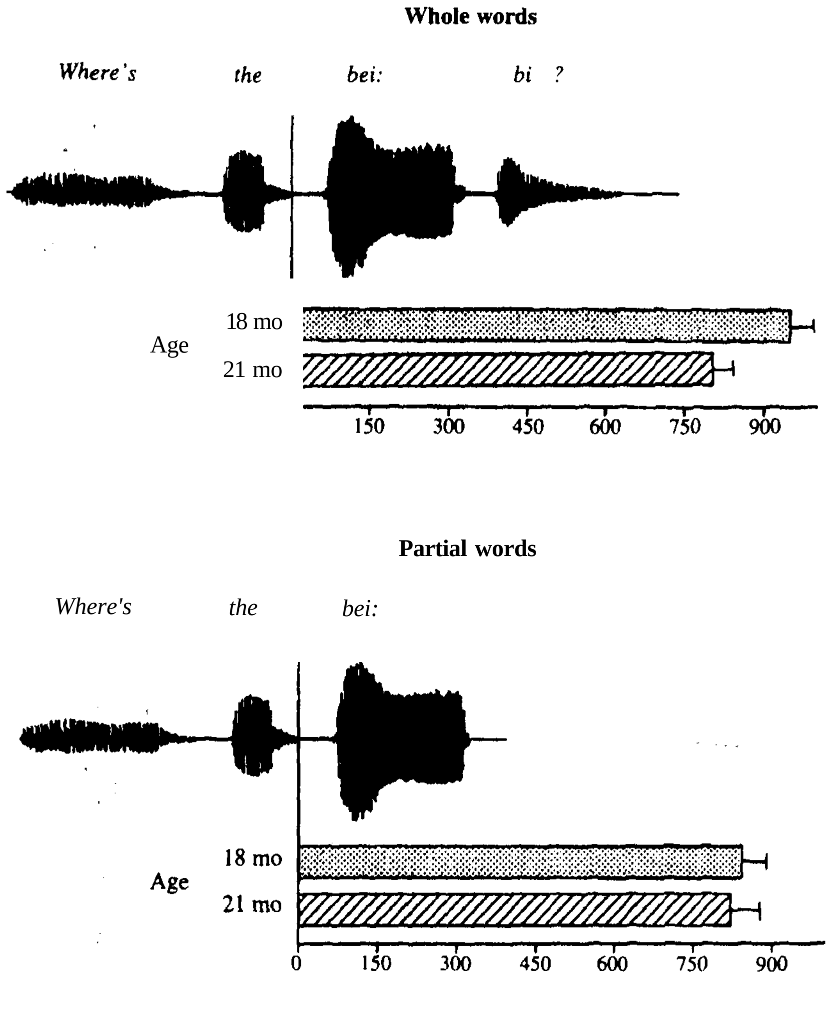


Figure 3. *Mean latencies to initiate a shift in gaze from the distractor picture to the target picture on Whole and Partial word trials for 18- and 21 -month-old infants*

reliably as well as more rapidly to Whole and Partial target words, as compared to infants in the Slow group. Finally, we found that speed of word recognition was also related to lexical development. Those infants who could identify Whole words more rapidly also tended to have larger spoken vocabularies.

We know from the Ferhald et al. (1998) study that both speed and accuracy tend to increase with age between 15 and 24 months. Although the Slow/Fast grouping did not map exactly onto the 18- and 21-month age groups in this experiment, the majority of younger infants were in the Slow group and the majority of older infants were in the Fast group. Infants in the Fast group were also more advanced in their vocabulary development. For these reasons it seems appropriate to characterise the performance of the Fast group infants as a more mature or advanced pattern of responses than that of the Slow group infants. In the next two sections we consider what factors might account for the increases in speed, accuracy and efficiency associated with the development of these more mature abilities in spoken word comprehension.

What develops as word recognition abilities improve?

One explanation for developmental changes in word recognition skills is that older and more advanced infants have lexical representations mat are more detailed and complete than those of younger infants. If so, then younger infants with incompletely specified lexical representations should require relatively more acoustic-phonetic information in order to identify a familiar word. But this was not what we found: Infants did perform better overall on Whole word trials man on Partial word trials, perhaps because hearing the truncation in the Partial word stimuli sometimes inhibited the tendency to shift to the target. However, there was no interaction between trial type and either age or the Fast/Slow grouping. That is, Fast and Slow group infants were not differentially affected by the Partial word manipulation, indicating that the Slow group infants were not at a greater disadvantage than Fast group infants on Partial word trials. These findings do not support the idea that lexical representations at this age are phonetically underspecified. Other recent results also suggest mat infants around this age have well-specified lexical representations, at least for words with which they are very familiar. Swingley et al. (1999) showed that 24-month-olds reliably distinguished *ball* and *doll* when tested in this procedure. And working with even younger infants, Swingley and Aslin (1999) found that 17-month-olds could distinguish correct and incorrect pronunciations of familiar words.

The results of these studies appear to contradict two bodies of research cited earlier which both suggest that young children's lexical representations are somehow qualitatively different from those of adults. First, there are the claims that infants at the end of the first year shift from purely acoustic-phonetic representations to lexical representations which incorporate semantic information but with loss of phonetic detail (e.g., Halle & de Boysson-Bardies 1996; Stager & Werker 1998; Hohle & Weissenborn 1998). The proposal that infants from 10 to 14 months attend less to phonetic detail when processing speech in a "lexical mode" focuses on the period when infants are just beginning to associate words with meanings. Our findings showing efficient use of phonetic detail by infants in the second year are not inconsistent with this hypothesis, since the infants we studied were older and linguistically more advanced, and we tested them only on highly familiar words. Although our data on incremental speech processing by 18-month-olds do not support the idea that infants at this age have lexical representations for known words that are different in degree of phonetic specification from those of adults, it is possible that such differences would become apparent under more challenging conditions. For example, it could be that when hearing unfamiliar rather than well known words, 18-month-olds would have more difficulty establishing representations for new words that are phonetically similar than for words that are phonetically distinct, a task that would not be challenging for an adult. This is an area where graded models will be helpful, to document intermediate stages in infants' progression toward building a lexicon in which new words are increasingly likely to overlap phonetically. The use of on-line comprehension measures should enable us to assess whether representations for unfamiliar words are initially less well specified phonetically than those for familiar words already established in the child's spoken vocabulary.

The second set of studies potentially inconsistent with our word recognition findings are those showing that older children recognize spoken words less reliably and less efficiently than do adults, and appear to need relatively more acoustic-phonetic information to identify a familiar word (e.g., Walley 1987, 1993). Of course, it is obvious from their spontaneous behavior that most children by two years of age can distinguish and understand hundreds of words, although such observations don't give any indication of speed or efficiency of processing. Our findings that infants are able to process speech quickly and continuously do pose a challenge to Walley's more negative conclusions. It seems clear that children's competence in spoken word recognition was underestimated to some extent in her experiments, in light of the evidence that 18-month-old infants can use incremental word recognition strategies comparable to those of adults. However, Walley's conclusion that children continue to develop in this domain is quite plausible. For example, she found that 4-year-old children were able to make use of word-initial information in word recognition in situations where the context was highly constraining, but were less successful when the context was not constraining. The word recognition task used in our research provided a very restricted and supportive context, since only two pictures were presented and one was labeled. In less narrowly constrained circumstances, infants' speed and accuracy might be less impressive. This too is an area where graded models will be valuable, as we explore the range of contextual factors that influence lexical access at different points in development. Once again, the appropriate question is not "When can the child identify this particular word in an adult-like fashion?" but rather "As the child becomes more competent in word recognition, what are the factors influencing the accessibility of well known and newly learned words?"

The contribution of other cognitive functions to competence in word recognition

Whether or not improvement in the ability to recognize spoken words reflects developmental differences in the nature and robustness of lexical representations, other factors are undoubtedly involved. More advanced performance in word recognition also reflects the maturation of cognitive processes which are not specifically associated with speech processing, but which are required for successful performance in this task. For example, in our study of infants' ability to recognize partial words (Fernald et al., under review), we found patterns of differential accuracy on distractor-initial and target-initial trials which could be related to such factors. When the correct response on Whole word trials was to shift from the distractor to the target picture, the less advanced Slow group infants failed to shift on 23% of the trials, while the more advanced Fast group infants failed to shift on only 9% of the trials. On target-initial trials, however, when the correct response was to remain on the target picture, there were no differences between groups.

Given that both kinds of response are correct, does shifting appropriately from the distractor to the target picture reveal more about an infant's word recognition abilities than staying appropriately on the target picture as the word is spoken? Consider what the infant must know and do in order to respond correctly on target-initial and distractor-initial trials. The processing demands are initially the same regardless of what picture the infant is looking at when the trial begins. The infant must encode the visual image, listen to the stimulus sentence with attention to the target word, and decide whether the spoken word matches the fixated picture. If the target word matches the name of the picture in view, the appropriate response is to remain on that picture; however, if there is a mismatch, it is appropriate to reject the picture in view and shift to the alternative picture. The process of recognizing that a spoken target word matches the picture in view and then staying put on the target picture is cognitively less demanding than rejecting a mismatch between the target word and the distractor picture and then initiating an eye movement to the other picture. In either case a correct response requires recognition of the picture in view and would not occur reliably if the name of the object were not represented in some way in the infant's mental lexicon. However, a correct response in the case of a mismatch also imposes additional processing demands beyond word recognition, which may involve any or all of the following capabilities: attentive engagement in the task, rapid encoding of the visual images, ability to integrate the visual and auditory input, association of the pictures with the appropriate words, ability to disengage from one picture in order to attend to the other, and mobilization of a shift in gaze. In addition, developmental differences in infants' ability to form categories, as well as in their experience with particular objects, could also influence the speed and accuracy of their word recognition performance. For example, the more advanced infants may have been more adept and thus quicker in identifying the pictures of babies used in this procedure as exemplars of the category "baby".

These are only some of the perceptual, cognitive, and motor skills which could contribute to the greater speed, accuracy, and efficiency of the more advanced infants in studies using this word recognition procedure, and all involve processes which are not specifically tied to language understanding. This is not to say that these non-linguistic capabilities are unrelated to language development more broadly, since all may be involved in spoken language understanding in the child's daily life as well as in the experimental procedure used in our research. For example, research on the relation of early cognitive skills to later intellectual functioning has shown that individual differences in visual information processing in infancy are related to receptive language abilities in childhood (Rose, Feldman, Wallace & Cohen 1991). Another study implicating basic cognitive skills in language acquisition found that developmental changes in the ability to form object categories are related to the rate of vocabulary acquisition in the second year (Gopnik & Meltzoff 1987). The point to be made here is that the speed, accuracy, and efficiency with which infants recognize familiar words in fluent speech improve with age and experience not only because of increasing detail and stability in emerging lexical representations, but also because many other cognitive processes supporting spoken word recognition are developing at the same time.

Does infant-directed speech facilitate recognition of familiar words in fluent speech?

The view that there are multiple factors influencing the emergence of word recognition skill implies that perceptual and cognitive limitations may account in part for the poorer performance of younger infants in identifying familiar spoken words. Is it possible that speech to infants can be presented in ways that mitigate to some extent the effects of these processing limitations? An obvious place to begin looking for an answer is in the naturally occurring linguistic and prosodic modifications characteristic of adult speech to infants. Across many cultures, infant-directed (ID) speech shares common features when compared to adult-directed (AD) speech. For example, ID utterances tend to be shorter and more repetitive, and are often spoken more slowly and with exaggerated intonation (e.g., Fernald, Taeschner, Dunn, Papousek, Boysson-Bardies & Fukui 1989). Noting the prevalence of such modifications in speech to children across diverse languages, Ferguson (1977) speculated that this special speech register might serve both an "affective" and a "clarification" function. More recent research on the nature of ID speech and its effects on infant listeners provides support for both of these hypothesized functions. Evidence for the affective influence of ID speech comes from perceptual studies showing that the melodic qualities of ID prosody engage attention and elicit emotion in young infants (e.g., Fernald 1985; Werker & McLeod 1990). Research on the "clarification" function has focused primarily on descriptive analyses of acoustic-phonetic properties of mothers' speech. Several studies have found that adults enunciate words more clearly when speaking to an infant than when speaking to another adult (e.g., Bernstein-Ratner 1984; Kuhl et al. 1997). These results suggest that words in ID speech might be perceptually more accessible to infants, consistent with Ferguson's hypothesis that one function of the modifications in speech to children is to enhance understanding.

A prominent characteristic of speech addressed to infants in English is that object words especially relevant to the conversation are frequently placed at the end of the utterance rather than in the middle. In a study of speech to 14-month-old infants and adults, Fernald and Mazzie (1991) asked English-speaking mothers to make up a story using a picture book in which six target objects were the focus of attention. When speaking to an infant, mothers used more exaggerated intonation and consistently positioned focused words in utterance-final position, whereas in speech to an adult mothers used more variable strategies to mark focused words. In the ID speech sample, 75% of the focused words were introduced as the last word in the utterance, while only 53% of the focused words occurred in this position in AD speech. An even higher proportion of focused words occurring in final position was found in a study by Aslin, Woodward, LaMendola and Bever (1996). When English-speaking mothers were asked to teach three new words to their 12-month-old infants, 89% of the target words came at the end of the utterance. Femald and Mazzie also conducted a control experiment to see whether adults used strategies similar to those in ID speech when asked to teach another adult how to do an unfamiliar assembly task. Indeed, when teaching new technical terms to another adult, subjects very frequently placed the unfamiliar words in utterance-final position, just as they did when highlighting new words in speech to infants. By positioning focused noun labels at the ends of utterances, speakers seem to be intuitively exploiting listening biases that make final elements in an auditory sequence easier to detect and remember, a phenomenon that is well established in research on auditory processing and memory (e.g., Watson 1976). If even adults can benefit from having new auditory information presented in this format, it seems likely that infants facing the challenges of word segmentation in continuous speech would benefit even more.

Although several studies such as those described above have documented features of mothers' speech which could plausibly help the infant in the task of word recognition, there has been very little research which tests this hypothesis directly. Here we review an experiment in which we investigated the influence of word position on infants' ability to identify familiar spoken words in fluent speech (Femald, McRoberts & Herrera 1992). The findings of this study provide further evidence for the gradual emergence of word recognition capabilities over the second year. They also demonstrate how variations in the structure of the input speech can influence the infant's success in understanding spoken words at different points in development.

The hypothesis tested in this study was that infants would recognize words in utterance-final position more reliably than words in utterance-medial position. Subjects were eighty 15- and 19-month-old English-learning infants, tested in the word recognition procedure described earlier. In a between-subjects design, six target words familiar to the infants at both ages were presented either in utterance-medial or in utterance-final position. The carrier phrases for the Medial condition *(There's a_____over there)* and the Final condition *(Over there there's a_____)* contained exactly the same words, differing only in order. As predicted, we found that infants at both 15 and 19 months were more successful in recognizing Final target words than Medial target words. Figure 4 shows the proportions of looking time to the target picture averaged over two 1000 ms intervals following the onset of the target word. This way of presenting the data allows comparison of accuracy in relation to speed in the Final and Medial conditions at the two ages. The results in the Final condition are consistent with those of the Fernald et al. (1998) study, in which target words were also presented in utterance-final position. For the 19-month-old infants, the mean looking time to the target picture in response to Final target words was already significantly above chance in the first 1000 ms following target word onset, and rose to 77% during the second 1000 ms interval. The 15-month-old infants responded less rapidly and less accurately, although their mean looking time in response to Final words eventually reached 66% in the second interval, significantly above chance. In the Medial condition, however, the younger infants were at chance for both the first and second intervals; in contrast, the older infants were above chance in both intervals, indicating that they responded relatively quickly as well as accurately to target words in utterance-medial position. To summarize, infants recognized Final target words more reliably than Medial target words, and the older infants were faster and more accurate overall than the younger infants. Although 15-month-olds performed well when familiar target words were presented at the end of the utterance, they were unable to recognize the same familiar words embedded in the middle of the utterance. By the age of 19 months, infants could identify medial target words quickly and correctly, but this was still a harder task than identifying words in final position.

Several kinds of perceptual factors could contribute to the increased difficulty of recognizing words embedded in the middle of an utterance. Medial words may be masked by subsequent words in the utterance, and it could be that younger infants are more vulnerable to such masking effects. Relative duration may also play a role, since words in medial position are typically shorter than words in final position (e.g., Delattre 1966). Indeed, the utterance-final target words used in this experiment were around 60% longer than the equivalent words in utterance-medial position. Thus it is not clear from these results whether the poorer performance on medial target words was an effect of word position *per se,* or whether it occurred because the medial target words were shorter than the final target words. It is interesting to note that English-speaking mothers regularly increase the duration of vowels in content words when talking to children, and this lengthening occurs with words in utterance-medial as well

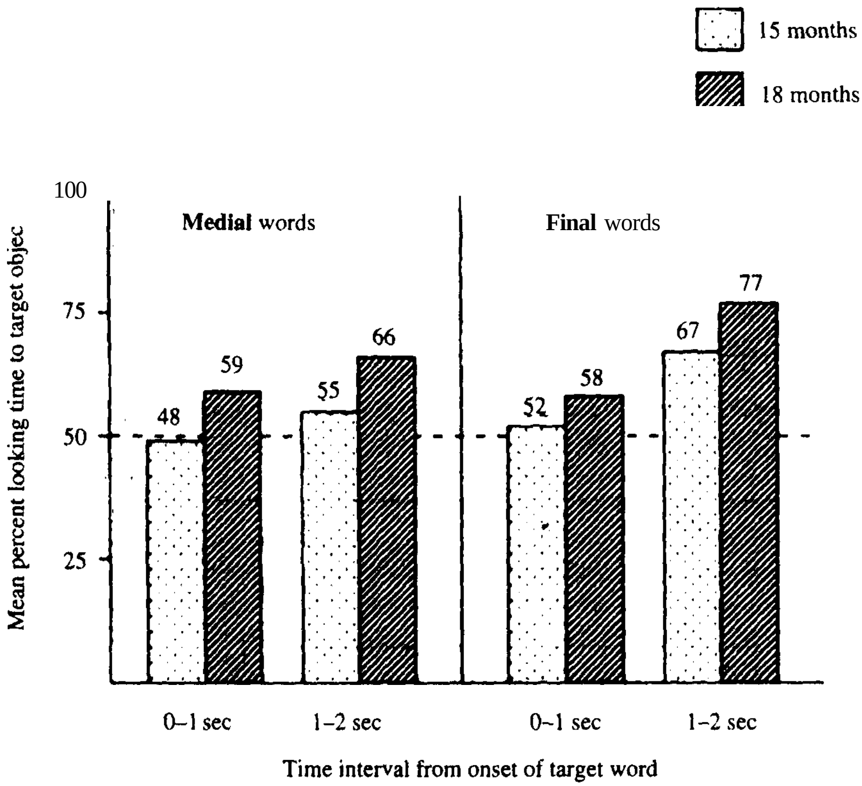


Figure 4. *Mean percent looking time to target picture in response to Medial and Final target words*

as utterance-final position (e.g., Albin & Echols 1996; Swanson, Leonard & Gandour 1992). While we need further experimental evidence to determine whether vowel lengthening enhances recognition of embedded target words, our data clearly show that the strategy of positioning focused words in final position in ID speech has perceptual advantages for the infant. This common pattern of word order in ID speech could serve as a kind of support system for the inexperienced listener, compensating for processing limitations that make it difficult for infants to succeed in segmenting, recognizing, and understanding a familiar word when it is followed by other words in continuous speech.

Summary and conclusions

Learning to understand spoken language is a long, slow process. Documenting children's progress toward more mature competence in speech comprehension has been challenging for researchers because progress often consists of gradual changes in processing efficiency which are difficult to observe in spontaneous behavior. Using fine-grained temporal measures of infants' response to spoken words, our research has shown that the speed and accuracy of understanding increase steadily over the second year (Femald et al. 1998). We have also found that infants are able to process the speech signal incrementally in some contexts, identifying familiar words on the basis of word-initial information (Femald et al., under review; Swingley et al. 1999). These results reveal that by the end of the second year, children's speech processing capabilities are surprisingly mature in some respects. However, other results make it clear that these capabilities are far from mature in other respects. We found that infants' success at word recognition was strongly influenced by the position of the word in the utterance, even when familiar words were repeatedly presented in the same short carrier phrase (Fernald et al. 1992). Target words occurring in the middle of the phrase were recognized much less reliably than target words at the end of the phrase, a variation in word order that would pose no problem for an adult listener.

The difference in infants' performance on medial and final target words provides an interesting example of what Haith (1998) refers to as "partial knowledge". At 15 months, infants were unsuccessful in understanding a familiar word embedded in the middle of the sentence, although they could recognize the same word reliably when they heard it at the end of the utterance. Since these infants clearly had a lexical representation for the word which could be accessed sucessfully under more favorable conditions, other perceptual and cognitive factors must account for the difficulty of the task. Were the 15-month-olds unable to identify the boundaries of the target word when it was followed by other sounds rather than by silence? Since Jusczyk and Aslin (1995) have shown that much younger infants can recognize a word embedded in continuous speech as familiar, it seems unlikely that segmentation was the problem for the 15-month-old infants, especially since all the target words were highly familiar. However, given the shorter duration of words in medial position, as well as the potential for masking or other forms of interference resulting from the words that followed, medial target words undoubtedly posed a greater perceptual challenge than final target words. And under perceptually more difficult conditions, the additional demands of accessing the meaning of the spoken word and deciding which object it matched were too much for the 15-month-old infants.

According to this view, an account of the gradual emergence of competence in spoken language understanding in young children should be concerned not only with the development of lexical representations, **but** also with the contribution of other perceptual and cognitive factors which influence the accessibility of spoken words to the listener. When adults listen to speech under unfavorable signal-to-noise conditions, word **recognition becomes effortful** and fewer resources are available for other **concurrent and subsequent** processes necessary for discourse comprehension **(Pichora-Fuller, Schneider** & Daneman 1995). Conversely, as **the** infant **gradually develops the ability to** identify words in continuous speech a **little more reliably and a little more quickly, more** cognitive resources become available for **attending to other words in the utterance** and the relations among them. Understanding speech is **a complex process that** involves much more **than** detecting **and identifying individual words, since the** listener must also integrate successively **heard words into phrases and sentences to arrive at a coherent and correct representation of the speaker's meaning. Small, gradual** gains **in** the speed **and** efficiency of **speech processing can have large benefits for the language learner.**

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