

BABY STEPS TO LEARNING LANGUAGE

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Young infants show remarkable speech perception sensitivities, and during the first year of life narrow these initial capabilities to reflect enhanced sensitivity to the sounds and structures used in their native language. This article reviews critical research illustrating how infants tune their perceptual sensitivities during the first year of life and how the language-specific changes in perception help “bootstrap” them into language. Specific discussion centers on recent research from our lab showing a link between the advances in speech perception and subsequent word learning in both normally developing and clinical populations, including research on the impact of early nutrition. The article ends with suggestions for new ways in which the milestones in speech and language processing seen in infancy can serve to help assess the role of early nutrition on subsequent development. (*J Pediatr* 2003;143:S62-S69)

Language is one of our quintessential human characteristics. It differs from the communication systems that are broadly evident across the animal kingdom in a number of attributes.¹ First and foremost, human language is a rule-governed system, with a grammar at each of several different levels. For human language to be effective, both the speaker and the receiver need to share the rules for translating form into meaning. For example, in creating a sentence, a speaker needs to have not only the meaning of individual words stored in her lexicon, but the rules for assigning words to specific grammatical classes, and for stringing those words together into a sentence that conveys the intended meaning, as well as the rules for pronouncing each of the individual words. Similarly, the listener needs to be able to perceive not only the overall sentence but the individual words. As will be sketched out in greater detail below, knowledge of the sound pattern of the native language is required to properly segment and individuate words. Following successful segmentation, the listener needs to recover both the meaning of the individual words and the meaning that ensues from the arrangement of words in the sentence. Finally, to communicate successfully, the listener needs to have entries in her mental lexicon that share features with those of the speaker. Above and beyond those perceptual and cognitive tasks, to fully recover the intended meaning, the speaker and listener need to share an understanding of the social rules governing language use.

The rules for translating form into meaning can be characterized at four primary levels. Phonology refers to the rules describing the sounds of language and their combinations. Syntax refers to the grammar describing the relations between words and how they should be combined to convey meaning. To apply the rules of syntax, listeners need to use the rules of phonology (and the interaction between phonology and syntax) to assign words to their appropriate grammatical classes (ie, what is a noun, what is a verb). Semantics refers to the rules describing the meaning of words and how that meaning is represented and recovered during language use. Finally, pragmatics refers to the rules describing the appropriate use of language, including social exchange. This includes the rules for recovering “intended meaning” from utterances such as “Can you reach the salt?”

If language acquisition were transparent, the child would be able to perceive words directly, to recover and store the meaning and grammatical class of those words, and to

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CDI	The Communicative Development Inventory	LCPUFA	Long-chain polyunsaturated fatty acids
DHA	Docosahexaenoic acid	MMN	Mismatched negativity
ERP	Event-related potentials		



Fig 1. The Conditioned Head Turn procedure. In this task, infants are conditioned to turn their heads toward the source of sound when they detect a change in the background sound or category of sounds. Correct head turns are reinforced with illumination of the dark box and activation of an electrical toy animal.

quickly learn the rules for how words are strung together to form meaningful sentences. All of these processes are easy if the perceiver already has a sizeable vocabulary. But without knowledge of the words of the language, this process is not transparent at all. Although we, as accomplished language users, use our knowledge of individual words to segment words from ongoing speech, the acoustic wave form shows that there are actually not pauses between words in a sentence. Indeed, words overlap, and the pauses that are apparent within the waveform are as likely to be within a specific word as between. Remember for a moment how difficult it is when you are in a foreign country and have studied your little phrase book, to segment the words from a native speaker's utterances. Without established knowledge of at least some words, it is very difficult. Clearly, to even get started in language acquisition, it is essential that the child be able to segment words. Perceptual knowledge of the sound properties of the native language (phonology) can assist the child in this otherwise difficult task. In this article, I will focus on how infants use what they can pick up and learn about the native language through perception to "bootstrap" into language. I will examine as well the relation between the perceptual categories established in infancy and later advances in language acquisition. This will then be followed by a brief summary of some of the research investigating the link between advances in speech processing and word learning in infancy and clinical populations. I will end with suggestions for ways in which the milestones in speech and language processing in infancy might serve as benchmarks for assessing the impact of essential fatty acids in the diet on neural and cognitive development.

Infant Speech Perception

Starting with a classic study by Eimas and colleagues in 1971, it has been known that young infants have remarkable speech perception capabilities. In the first few months of life, they can discriminate the subtle but relevant differences

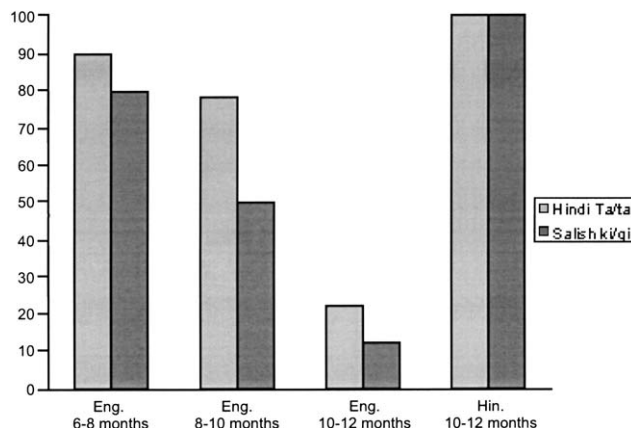


Fig 2. Proportion of English-learning infants at each of three ages reaching criterion on two non-English speech contrasts in comparison to infants learning languages in which those contrasts are used.

between similar-sounding consonants (eg, /b/ vs /p/)² and between similar sounding vowels (eg, /ee/ vs /oo/).³ Their sensitivity to these fine differences is such that they are able to discriminate sounds used not only in the native language, but in other languages as well.^{4,5} Reports of this high level of sensitivity to differences that distinguish very similar non-native sounds stood in contrast to studies with adults showing a decided difficulty discriminating similar sounding consonants not used in their native language.^{6,7} To reconcile these two literatures and to make sure that the different conclusions had not simply resulted from the use of different testing procedures or different language sounds, we tested infants and adults in a comparable procedure on their ability to discriminate the same native and nonnative consonant differences. We used the Conditioned Head Turn procedure with infants⁸ (Figure 1) and a button-press variant of the same procedure with adults. We compared English-learning infants of 6 to 8 months of age with both English-speaking and Hindi-speaking adults on their ability to discriminate both the English /ba/-/da/ and the Hindi /da/-/Da/ distinction.^a Confirming the claims from the two bodies of literature cited above, we found that although English-learning infants of 6 to 8 months and Hindi adults could discriminate both contrasts, English adults had difficulty with the Hindi /da/-/Da/ distinction.⁹ In subsequent work using both the Hindi /da/-/Da/ distinction and a consonant contrast involving two "k-like" sounds from an Interior Salish (First Nations) language from British Columbia, we explored the age at which listeners stop easily discriminating nonnative sounds. Our results, as illustrated in Figure 2, show that this decline in nonnative perception and resultant tuning to the native language occurs during the first year of life, with the sharpest cutoff between 8 and 10 months of age.¹⁰

^aThe symbol d refers to the "dental" /d/ that is produced by placing the tongue against the teeth and the symbol D refer to the "retroflex"/d/ that is produced by curling the tongue back and placing the underside of the tip against the roof of the mouth. In English we produce an alveolar /d/ by constricting the airflow at the alveolar ridge. Our /d/ is between the two Hindi "d" sounds.

Similar results showing changes in native and nonnative speech perception in the first year of life have been reported in other labs as well, using other techniques. This has been shown using a habituation/dishabituation looking procedure¹¹ and the MMN (mismatched negativity ERP response).¹² In a series of studies, Kuhl and colleagues showed that infants show a language specific prototype effect in their perception of vowels and that this might be evident as early as 6 months of life. Specifically, Kuhl first showed that infants, like adults, are better able to discriminate two sounds from within a single phoneme category if they are familiarized with a “poor” exemplar of the category and then given a more central exemplar than if they are tested in the opposite direction.¹³ In a subsequent study, Kuhl and colleagues reported that infants only show this asymmetry in their perception of native vowel sounds. Comparing English- and Swedish-learning infants of the same age, they found that American-English infants showed the asymmetry for English but not Swedish vowels, whereas Swedish infants showed the reverse pattern.¹⁴ This language specific asymmetry is not evident for all nonnative sounds, however.¹⁵ Indeed, in some instances, non-native contrasts remain discriminable across the infancy period.¹⁶ Still, in many cases, younger infants seem better able to discriminate non-native consonant and vowel contrasts than do older infants and adults.¹⁷

How are native language speech sound categories established? And why do some nonnative distinctions remain discriminable both to the older infant and to the adult? Several theoretical models have been proposed to account for this pattern of results.¹⁸ One possible mechanistic answer to this question comes from the recent work on statistical learning by infants. This work, pioneered by Saffran, Aslin, and Newport, shows that human infants (like many other animals) are exquisitely sensitive to statistical regularities in the speech that they hear.¹⁹ Saffran and colleagues presented infants with 3-minute sequences of syllables with no pauses in between, but with the transitional probabilities between syllables manipulated. Some syllable sequences had transitional probabilities of 1.0 (eg, every time the syllable “ti” was presented, it was followed by “go” and “la”), whereas other sequences had transitional probabilities of only .33 (eg, “la” was only followed by “bu” 33% of the time and was followed by other syllables the rest of the time). Following this familiarization, infants showed—by their looking time—that they had learned that “tigola” was a unit, a possible word, as distinct from a nonword with low transitional probabilities like “labuge.”

We built from this logic to see if infants could use distributional information to learn the category structure of the sounds of their native language. In her PhD work with LouAnn Gerken, Jessica Maye had shown that adults will change their phonetic category boundaries on the basis of the distribution of sounds in the input.²⁰ Maye came to my lab to see if infants show the same kind of sensitivity. To understand the logic of this experiment, it is useful to think back to our Hindi retroflex versus dental work above. An infant growing up in an English-speaking environment hears all of their “d” sounds distributed around a central alveolar /d/ category, whereas infants growing

up in a Hindi-speaking environment hear their “d” sounds distributed around two different categories, the more fronted, dental /d/ and the more back, retroflex /D/. Perhaps it is experience with these two disparate distributions that leads to recategorization during the first year of life.

To explore this question, Maye created an 8-step continuum of sounds that spans a da-Da continuum.^b Infants of 6 and 8 months of age were then tested using this set of 8 different “da” type syllables. All infants heard stimuli from all 8 steps of the continuum. One group of infants heard more instances of stimuli 2 and 7, close to the end points of the continuum. The other group of infants heard the most repetitions of stimuli 4 and 5, the middle of the continuum. It was reasoned that group 1 infants were receiving “bimodal” input and that should lead to a division in the category, whereas group 2 infants were receiving “monomodal” input, which should lead to a collapse of the category. After familiarization, infants were tested, using a preference procedure, on their sensitivity to the presence of two categories by testing them on their ability to discriminate the end points, stimuli 1 and 8, from one another. Infants in the bimodal group showed a sensitivity to two categories, whereas infants in the monomodal group did not. These results suggest that infants might indeed be able to use the distributional properties of heard speech to tune their speech perception categories.²¹

In addition to the changes in phonetic perception, infants also tune to many other properties of the native language during the first year of life. By 9 months of age, infants show a preference for listening to nonce words that correspond to the stress patterns of the native language; for example, in English, that means items like Hable, which have the stress on the first syllable.²² They show a preference for listening to nonce words that conform to the phonotactic rules of the native language; for example, preferring to listen to a word beginning in “str” over one beginning with “rst.”²³ Newborn infants can categorically discriminate the two fundamental grammatical classes of words: function words (like determiners, prepositions, conjunctions); from content words (like nouns, verbs, and adjectives)²⁴ and by 6 months of age show a preference for listening to content words.²⁵

Linking Speech Perception to Word Learning

The remarkable changes in speech perception sensitivity that occur during the first year of life would suggest that as the infants learn about the sound structure of their native language, they might be able to use that to help “bootstrap” into language proper.²⁶ But, does knowledge of the sound properties of the native language actually help in language acquisition proper?

^bThis was actually a different d-D difference than the retroflex-dental. This continuum was based on differences in an acoustic-phonetic dimension called voicing and is like the difference in the “d” produced in initial position in words like “day” and the sound that is created if you strip the “s” off of a word like “stay.” Although we use a t in spelling, when it follows an s, this sound surfaces more like a d.

One relevant body of research is work on word segmentation in infancy. This work shows that by 7.5 months of age, infants can segment words from ongoing speech in their native language. After being presented with passages that contain the words “dog” and “cup” in several different sentence contexts, infants of 7.5 months of age will listen preferentially to those items in a simple word list over unfamiliar items such as “cat” and “ball.” They also show the reverse pattern: After being familiarized to the bare words “dog” and “cup” for approximately 2 minutes, infants will listen preferentially to passages containing those words over passages containing “cat” and “ball.”²⁷ At 7.5 months of age, however, infants can only accurately segment words that conform to the dominant Strong-Weak pattern of English words. They can perform successfully on words like “DOCtor” and “HAMlet” but not on words like “guiTAR.” In the latter case, they show a preference for listening to “TAR” alone over “guiTAR.” By 10 to 11 months of age, however, English-learning infants have learned enough about the isolated consonants and vowels of words, the characteristics of what those phones sound like in context, and the stress pattern of the language to accurately segment even Weak-Strong words like “guitar.”²⁸ This would suggest that the perceptual learning that has occurred during the first year of life might provide a guide into subsequent word learning, or at least in that crucial first step of word segmentation.

In our work, we have asked whether infants use the phonetic categories established during the first year of life to guide them in word learning. In other words, if a child can discriminate the difference between a “b” and a “d” sound and hear those words in the presence of two unfamiliar objects, will that help them to learn that those two objects have different labels? In the word segmentation tasks described above, Jusczyk and colleagues found that infants of 7.5 months are sensitive to the fine differences between words. If familiarized to a passage containing words like “dog” and “cup,” the infants would not treat “bog” and “tup” as familiar, showing that they were using their speech perception sensitivities in the word segmentation task.²⁷ In a similar task with slightly older infants, however, Hallé and de-Boysson-Bardies reported that infants of 11 months do confuse similar-sounding words in word recognition tasks and would confuse the above word types as familiar.²⁹ These results were intriguing, but because recognizing a familiar word form is not at all the same as mapping a word to a referent in the world, it was necessary to develop a procedure that would involve more explicit learning of sound-meaning mappings. Only in this way could we test if infants use their native language speech sound categories when they are in the initial stages of learning to map words on to meaning.

To develop such a procedure, I collaborated with Les Cohen from the University of Texas at Austin. We built on earlier methodological innovations he had created for studying infants’ ability to discriminate and categorize visual stimuli, but rather than examining infants’ ability to detect correlations among attributes within a sensory domain, we extended the procedure to examine their ability to learn the association among attributes across sensory domains.



Fig 3. Experimental set-up for the “switch” associative word-learning task.

In our cross-modal, word-object associative learning task, we teach infants two pairs of word-object pairings (eg, A-A and B-B) and then test them on their ability to detect a switch in the pairing (eg, A-B). We teach them the associative link by presenting them with repeated instances of the word-object pairings (up to 24, 14-second trials). Infants are seated on their parent’s lap in a sound-attenuated room and view a video monitor on which the moving objects are displayed. The parents wear headphones delivering music so that they cannot influence the infant (see Fig 3 for the experimental setup).

Accompanying the display is the repeated presentation of the appropriate word, produced in an “infant-directed” style of speech. Each block of four trials includes two instances of each pairing type (eg, A-A, B-B, B-B, A-A). As is typical in a habituation task, infants tend to look for quite a long time during the first block of trials, but as they “learn” about the stimuli, their looking time declines. When their looking time per trial block declines to a criterial amount (typically 65% of that in the highest block), we infer that they have “habituated,” and that learning has occurred. At this point, two test trials are presented. In the “same” trial, infants hear a familiar word and see a familiar object in a familiar pairing, for example, A-A. In the “switch” trial, infants hear a familiar word and see a familiar object, but in a new pairing, for example, A-B. If the infants have learned the word and the object but have not learned to link them together, both trials should be equally familiar, and they should look equivalently at the display during both the “same” and the “switch” trials. However, if they have learned the associative link between the word and the object, they should notice that the pairing has been violated in the “switch” trial and should look longer than during the “same” trial.

Using this procedure, we found that infants of 14 months of age could learn to link the word and the object. With attractive, moving objects and the nonsense words “lif” and “neem,” infants of this age looked longer during the “switch” than during the “same” trials. This effect was not seen, however, if the objects were stationary. Infants younger than this age were unable to form the link between the words and the objects and looked equivalently during both the “same” and the “switch” trials. To ensure that they had indeed learned about both the words and the objects, we tested them

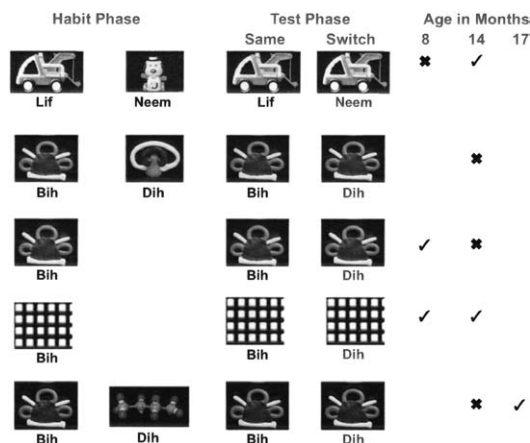


Fig 4. Success and failure in the switch task across three sets of studies. In the first two lines the ages at which infants can succeed in the standard two-object, and control single-object versions of the switch task using dissimilar sounding nonsense words are indicated. Lines 3, 4, and 5 show performance on the minimal pair word-learning task with the initial visual stimuli. Line 6 shows performance across age with the visually more distinct objects.

in a simpler version of the task in which they were familiarized to a single word-object pairing (eg, A-A). After habituation, they were then tested on their ability to detect a change in the word (B-A), a change in the object (A-B), or both (B-B). Their looking time on these three different types of “switch” trials was compared with their looking time on a repeated instance of the habituation stimulus (A-A). Infants as young as 8 months of age showed that they could indeed learn both the word and the object. They looked longer to a change in either the word or object than they did to the “same” trial, and longest of all to the change in both (the primary results of this and the next two sets of studies are shown in Fig 4). On the basis of this series of experiments, we concluded that in this procedure, where no contextual support is provided, infants of 14 months but not younger are able to independently learn the associative link between a spoken word and a moving object and will notice a violation in that link.³⁰ This finding is in accord with other attempts to teach infants new words without social support, in which somewhere around 13 to 15 months is the youngest age at which infants succeed.³¹⁻³³

Having established a task that could be reliably used to assess infant word learning, we were ready to return to our question of whether infants in the early stages of word learning use their speech perception sensitivities to direct them in mapping sound onto meaning. In this endeavor, we created a new set of visual stimuli and paired them with the minimally different nonsense words “bih” and “dih,” again, using the habituation “switch” design. To our surprise, although we had shown in multiple studies that infants of 14 months easily learn to map two phonetically dissimilar words (“lif” and “neem”) as evident by longer looking time to a “switch” over a “same” trial in the test phase,³⁰ they failed when the phonetically similar words “bih” and “dih” were used.³⁴ Looking times to both “same” and “switch” trials were equivalent. Our next step was to simplify the task and use the single object discrimination

variant described above. Even when habituated to a single moving object paired with either the nonsense word “bih” or “dih” and then tested on a switch to the other word, infants of 14 months of age failed to show a recovery in looking time. Yet, in this easier version of the task, infants of 8 months easily succeeded, just as they had done for the dissimilar sounding words “lif” and “neem.” To ensure that infants of 14 months can still discriminate the minimal phonetic difference between /b/ and /d/, we completed a control study in which infants this age were shown an unbounded, stationary checkerboard paired with either “bih” or “dih” and then tested on their ability to discriminate a change to the other word after habituation. Under these testing conditions, infants of 14 months showed a significant increase in looking time to the “switch,” revealing that they still can in fact discriminate the two word forms.^{29,30,34-36}

On the basis of these results, we concluded that the task of associating words with objects is computationally difficult for infants of 14 months, and when faced with a word-learning task, they need to drop information in order to succeed. In this case, it appears that the information they drop is the fine phonetic detail specifying the precise characteristics of the word form. We reasoned further that the infants of 14 months fail even in the single object condition because by this age they are poised to attempt to associate words with objects. Thus, as soon as an object is presented along with the word, even if a mapping is not required (yet importantly, still possible), as in the single object condition, infants of 14 months fail to distinguish the words. Younger infants, who are not yet able to form associative links and for whom this single object condition is merely a discrimination task, do discriminate the minimally different words in this condition.

If our explanation for the difficulty seen at 14 months is correct, one would expect that infants who are more accomplished word learners would succeed. To assess this prediction, we recently completed a follow-up study in which infants of 17 and 20 months were tested in the “switch” task, using almost identical stimulus materials and testing parameters. As predicted, we found that these older, more accomplished word learners had no difficulty in the “switch” task, even in the two-objects condition. They reliably habituated to the repeated presentations of object 1 paired with “bih” and object 2 paired with “dih” and showed longer looking on the “switch” than on the “same” trial.³⁷ However, we did use more dissimilar objects than in the earlier work and we habituated the infants to a stricter habituation criterion (a 50% decline). Thus we retested a group of infants 14 months of age to ensure that it was indeed age rather than the change in testing conditions that accounted for the success of the 17- and 20-month infants. The infants 14 months old still failed; they showed equivalent looking time to “switch” and to “same” trials.

As another test of our hypothesis, in the Werker, Fennell, Corcoran, and Stager study, we also administered the MacArthur Communicative Development Inventory (CDI).³⁷ The CDI is a vocabulary check-list that parents complete. The “toddler” version (Words and Sentences) is for infants 16 to 30 months old. The vocabulary component

includes 680 words, and parents are required to indicate, by a checkmark, how many of the words their infant produces. The “infant” version (Words and Gestures) is for infants from 8 to 16 months of age. The vocabulary component includes 396 words, and parents are required to indicate, by a checkmark, how many of the words their infant produces as well as how many of the words their infant comprehends.³⁸ We asked parents of infants 14 months old to complete the Infant CDI only, parents of infants 20 months old to complete the Toddler CDI only, and parents of infants 17 months old to complete both. We then correlated vocabulary scores on the CDI with success in the “switch” task, using as our variables number of words understood or produced for the CDI and the difference in looking time to the “switch” minus the “same” trial for the word-learning task. We found a significant correlation between the two in infants 14 months old (for comprehension, $r(14) = .403$, $P = .061$; for production, $r(14) = .656$, $P = .004$), a marginal correlation at 17 months (comprehension, $r(14) = .408$, $P = .066$; production, $r(14) = .301$, $P = .128$), and no relation at 20 months (production only as comprehension is not measured by the toddler CDI; $r(14) = -.099$, $P = .362$). These results are fully consistent with the explanation that the reason infants 14 months old, as a group, have difficulty in the minimal pair word-learning task is that they are not accomplished word-learners and thus do not have the computational resources to attend to the fine phonetic detail in words. The correlations show that those infants, even at 14 months, who are better word-learners, are successful even at learning very similar sounding words. By 20 months of age, when most infants are relatively accomplished, a ceiling effect is evident and the correlation is no longer seen.

Taken together, this set of studies shows that the speech perception categories established in infancy may eventually guide infants in word learning, but not at the initial stages of word-learning. Only after they are more accomplished word-learners can infants use the categories they established during infancy to direct them in the word-learning process. Our work would predict as well, that once they have access to these categories the task of word-learning should be made less problematic. This, in turn, may help the child more rapidly acquire new words and may contribute to the onset of the “spurt” in word-learning that is often seen at around 17 to 19 months of age.^{39,40}

Of interest, Mills, Coffey-Corrina, and Neville have recently identified an ERP signature for word comprehension.⁴¹ Briefly, they have shown that infants as young as 13 months of age show a higher amplitude ERP response to known over unknown words from 200 to 450 ms after the presentation of the words. This response is seen over frontal, temporal, and parietal sites in both hemispheres in infants 13 to 17 months of age but is restricted to temporal and parietal sites in the left hemisphere only in infants 20 months and older. The more mature ERP pattern is seen with infants younger than 20 months who have exceptionally large vocabularies as measured by the CDI. This pattern of findings suggests that as infants become more accomplished word learners, they establish more efficient recognition or representational neural

systems. Mills, Neville, and I are currently completing a set of studies extending this ERP work to known and unknown words that are phonetically similar.

Using Infant Speech Perception and Word Learning to Identify Individual Differences

Recent work from both our laboratory and others suggests that the tools used to assess speech perception and early word learning in infancy might be usefully extended to helping to reveal individual differences in the infancy period in the language learning capacity in general, and phonology in particular, and may thus also be useful for identifying in infancy those individuals who are likely to subsequently develop a language delay. Although there are a number of tests of overall infant development, some of which (eg, the Bayley Scales) include a subscale for assessing language development, these tests are primarily used to identify children who are not developing normally. They are less useful for identifying individual differences in normally developing children, or even for identifying those infants with more subtle language difficulties. Currently the most widely used test for identifying individual differences in infancy in language development is the MacArthur Communicative Development Inventory.⁴² The CDI is a parent-report instrument, involving a list of words and gestures for the parent to tick if their child either understands or produces the item in question. A recent study by Feldman, Dollaghan, Campbell, Kars-Lasky, Janosky, and Paradise confirmed that the CDI is a useful measure of toddler language development, but showed that it is not adequately sensitive to identify individual children at risk for language deficits, because the correlations between scores at young ages and scores at older ages are too low.⁴³ The CDI is especially problematic with children with language delay from 24 to 32 months of age.⁴⁴ It is more accurate by the time children reach 3 years of age, but by that time, there are many other instruments which can be used as well.⁴⁵ Moreover, by that age it is already becoming late for early intervention to be optimally effective. A test of speech perception or word learning in the infancy period that could more accurately assay language ability would help not only in early identification but would also help in studying the effects of diet in early infancy on the development of the language system.

Recently, Barbara Bernhardt, Carolyn Johnson, Linda Siegel, and I followed some of the children who had been tested in the minimal pair Switch task at 17 to 20 months of age, testing them at 2 to 3 and 3 to 4 years on a number of tasks of phonological and language development.⁴⁶ We used as our predictor the difference score in looking to the “switch” versus the “same trial” in the test phase. We found this to correlate with vocabulary size as measured on the CDI at 2 to 3 years of age, but the correlation was no better than that between the CDI itself at 17 to 20 months and at 2 to 3 years.⁴⁷ When we tested the children again at 3 to 4 years of age, the “switch”-“same” score from 17 to 20 months continued to predict performance on a number of standardized tests of language development with correlations of between .6 and .77 (eg,

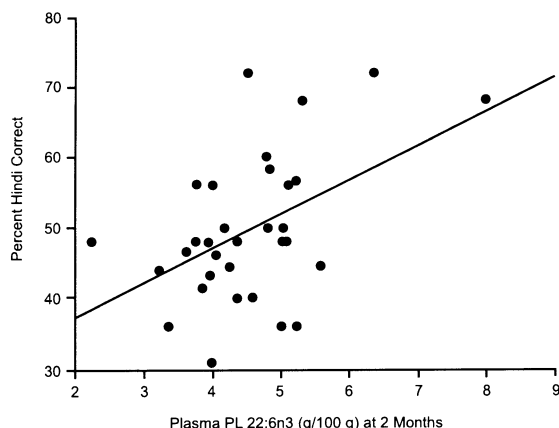


Fig 5. The correlation, after adjusting for confounding variables, between the plasma 22:6n-3 (DHA) at 2 months of age and percent correct on the nonnative (Hindi) speech contrast at 9 months of age ($P = .02$). Adapted from Innis et al, 2001.

Peabody Picture Vocabulary Test-Revised, Preschool Language Scale-3, phonological awareness tasks), whereas the CDI at 17 to 20 months no longer did.⁴⁸ These data raise the possibility that speech perception and word learning tasks in infancy can usefully be applied for ascertaining early differences in the trajectory of language development.

Linking Age-Related Changes in Speech Perception and Word-Learning to Diet

The kinds of changes described above in speech perception and word-learning in early infancy provide a means for investigating whether or not there are individual differences in these achievements as a function of one or another dietary regimen. Of particular interest to this set of papers is whether relative amounts of essential fatty acids in the diet lead to individual differences in performance on these various speech and language tasks.

In a recently published paper, we found a significant correlation between essential long-chain polyunsaturated fatty acids in the diet (in this case, DHA) and performance on the cross-language speech perception task at 9 months of age.⁴⁹ Specifically, in this study, we prospectively followed 83 infants who had been exclusively breast-fed for at least the first 3 months of life. Blood samples from the babies at 2 months of age were used as the predictors, and the number of correct responses to change trials in the nonnative (Hindi dental d vs retroflex D) was used as the outcome. After adjusting for confounding variables, there was a significant correlation between both plasma phospholipid DHA ($r = 0.48$; $P < .02$) and red blood cell phosphatidylethanolamine DHA ($r = .26$; $P < .02$). The range of DHA in the red blood cell DHA in the infants at 2 months of age was 6.3 to 13.0 g/100 g fatty acids, thus showing a 2-fold range in DHA status among the infants that we tested. Infants with higher DHA levels at 2 months were better at discriminating the non-English, Hindi speech contrast at 9 months (see Fig 5). Across the first year of life,

particularly between 8 and 10 months of life, there is a decrease in performance on nonnative speech discrimination tasks. Ultimately, this narrowing in on the phonetic categories of the native language will allow the infant to more efficiently map sound on to meaning when they move on to word learning. However, given the delay in the use of perceptual categories in word-learning situations, it is not immediately obvious whether better performance on this task indicates a positively or a negatively valenced individual difference. Our current bias would be to suggest that a slightly longer openness to non-native category structures might be beneficial rather than detrimental to the developing infant.

A focus for future research will be to see whether LCPUFA levels in early infancy are related to other language milestones. To date, there is only one published study showing a significant relation, and this study indicates a negative correlation between infants given formula supplemented with DHA and subsequent scores on the CDI.⁵⁰ Clearly, this study needs replicating and supplementing with some of the different measures of language development described above. We believe that the kinds of changes seen in infancy in speech perception, statistical learning, and associative word-learning reflect both maturational and experiential factors and that they set the stage for subsequent language acquisition. Thus, in future work, it will be of great interest to use these speech and language tasks to index potential influences of LCPUFA in the diet on brain and cognitive development.

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