Developmental Neurocognition: Speech and Face Processing in the First Year of Life

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INNATE PREDISPOSITIONS AND THE EFFECTS OF EXPERIENCE IN SPEECH PERCEPTION: THE NATIVE LANGUAGE MAGNET THEORY

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ABSTRACT. Developmental theories of face perception and speech perception have similar goals. Theorists in both domains seek to explain infants' early sophistication with regard to the detection and/or discrimination of facial and speech stimuli and to determine whether infants' early abilities are due to mechanisms dedicated to the processing of specific biologically relevant stimuli or more general sensory/cognitive mechanisms. In addition, theorists in both domains seek to explain how experience with specific faces and speech sounds modifies infants' perception. In this chapter, studies showing enhanced discriminability at phonetic *boundaries*, as well as studies on the perception of phonetic *prototypes*, exceptionally good instances representing the centers of phonetic categories, are described. The studies show that although phonetic boundary effects are common to monkey and man, prototype effects are not. For human listeners prototypes play a unique role in speech perception. They function like "perceptual magnets," attracting nearby members of the category. By 6 months of age the prototype's perceptual magnet effect is language-specific. Exposure to a specific language thus alters infants' perception prior to the acquisition of word meaning and linguistic contrast. These results support a new theory, the Native Language Magnet (NLM) theory, which describes how innate factors and early experience with language interact in the development of speech perception.

1. Introduction

Evidence supports the view that faces and speech sounds are "special" stimuli, and that the perception of faces and speech by young infants depends on mechanisms that are present at birth (Meltzoff & Kuhl, 1989). The case for faces has been described by Johnson and Morton (1991) and by others in this volume (see chapters by Johnson; Kleiner; Meltzoff; Morton). The case for speech is discussed in this chapter and by others in this volume (see Best; Jusczyk; Werker, this volume).

A role for innate mechanisms in speech perception is supported by evidence showing that human infants begin life with perceptual abilities that enhance the distinctiveness of phonetically different signals (for recent reviews see Eimas, Miller, & Jusczyk, 1987; Kuhl, 1987a). Recent work in my lab shows, however, that by 6

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months of age exposure to a specific language has altered infants' perception of speech. By 6 months, infants' perception of speech reflects the phonetic structure of the specific language that has served as input to the infant (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992).

This chapter focuses on two behavioral phenomena in infants. The first is infants' demonstration of enhanced discriminability near the boundaries that separate phonetic categories (e.g., Eimas, Siqueland, Jusczyk, & Vigorito, 1971). The second is infants' perception of phonetic prototypes, the best or most representative instances of speech categories (Grieser & Kuhl, 1989; Kuhl, 1991; Kuhl et al. 1992). Infants' demonstration of enhanced discriminability at phonetic boundaries is initially "language-general" (Werker & Lalonde, 1988; Werker & Tees, 1984). It is exhibited for phonetic units the infant has never heard and thus does not depend on language experience. Enhanced discrimination at the locations of phonetic boundaries is also demonstrated by non-human animals (for review see Kuhl, 1987b). Based on these data, I will argue that infants' demonstration of enhanced discriminability near phonetic boundaries reflects an innate ability to partition the acoustic events underlying speech into gross categories, and that this ability is attributable to infants' *general* auditory perceptual processing mechanisms. In contrast to these boundary effects, I will show that infants' perception of phonetic prototypes is unique to humans and "language specific" by 6 months of life. Moreover, I suggest that infants' acquisition of native-language prototypes is an "experience-expectant" process (Greenough & Black, 1992; Greenough & Alcantara, this volume), one in which there is neurological preparation for species-typical experience. These data and arguments are used to develop a new theory of developmental speech perception called the Native Language Magnet (NLM) theory.

1.1. CATEGORY BOUNDARIES AND LANGUAGE EXPERIENCE

Tests of categorical perception (CP) show that infants' abilities to discriminate among speech stimuli located on a continuum between two phonetic categories is not equivalent across the continuum. Infants' discrimination abilities, like those of adults, are enhanced in the region of the phonetic boundary, the location of the division between speech categories. Tests of CP use a series of computer-generated speech sounds that are created by altering some acoustic variable in small steps. On one end of the series the sounds are identified as one syllable, such as the syllable /ba/, while sounds on the other end are identified as /pa/ (Fig 1). When listeners are tested in a discrimination task to see whether they can hear the difference between adjacent sounds in the series, stimuli drawn from opposite sides of the phonetic boundary are more easily discriminated than stimuli falling on one side of the boundary, even though the physical difference in the two cases is the same. Infants show the effect both for consonants (e.g., Eimas et al. 1971) and for vowels (Swoboda, Kass, Morse, & Leavitt, 1978). Moreover, young infants demonstrate the phenomenon not only for the sounds of their own native language, but also for sounds from foreign languages (Streeter, 1976). Thus infants' initial discrimination abilities are language-general – independent of linguistic experience.

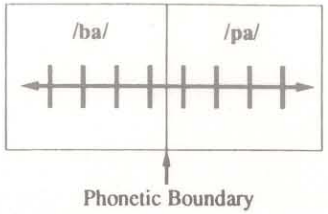

Figure 1. Classic categorical perception Stimuli are heard by adults as a series of /ba/'s that changes abruptly to a series of /pa/'s. Discrimination for both adults and infants is enhanced in the region of the phonetic boundary between /ba/ and /pa/.

Studies in my laboratory have also revealed, however, that this boundary phenomenon is not unique to human listeners. Enhanced discriminability in the region of the phonetic boundary is displayed by nonhuman animals (Kuhl & Miller, 1975, 1978; Kuhl & Padden, 1982, 1983). I have elsewhere argued that the tendency to partition sounds into gross categories is one that is deeply embedded in our phylogenetic history, and one that played a role in the selection of candidates for a phonetic inventory in evolution (Kuhl, 1987b, 1988; see also Lieberman, 1991). Thus, the boundary effect in infants is the result of the auditory system's ability to resolve fine differences and the fact that in the evolution of speech, existing auditory abilities were exploited in the selection of linguistically contrastive sounds (Kuhl, 1988).

The boundary phenomenon is modified by linguistic experience (Abramson & Liser, 1970; Miyawaki, et al., 1975). For example, when Japanese listeners are tested on a series of sounds that range from /ra/ to /la/, a distinction that is not phonemic in Japanese, they do not show enhanced discrimination at the phonetic boundary between the two sounds. American listeners do show the boundary effect for the /ra-la/ stimuli. When and how are these changes in phonetic perception brought about? What is the nature of the change that occurs in phonetic perception (for discussion see Aslin & Pisoni, 1980)?

Previous research indicates that the infants' perception of foreign-language contrasts changes near the end of the first year. Important studies by Werker and her colleagues (Werker & Lalonde, 1988; Werker & Tees, 1984; this volume) show that 10- to 12-month-old-infants fail to discriminate certain foreign-language contrasts, ones that they discriminated earlier in life. The fact that the language-general pattern of perception appeared to give way to a language-specific pattern near the end of the first year, coinciding with infants' production and comprehension of first words, led to the hypothesis that the change in phonetic perception might reflect infants' initial acquisition of word meaning and contrastive phonology (Werker, 1991). The new data presented here give rise to a different view. I will argue that early language input results in infants' development of representations of native-language phonetic categories. This process precedes word acquisition and contrastive phonology. I will argue that infants' speech representations constitute the first step towards language-specific speech processing and underlie the subsequent change in their perception of foreign-language contrasts.

1.2. CATEGORY CENTERS AND LANGUAGE EXPERIENCE

The boundary effect just described, which examines infants' *discrimination* abilities, can not fully explain infants' *categorization* abilities (Kuhl, 1980, 1985). Phonetic categorization requires more than simple discrimination. Phonetic categories are composed of stimuli that are discriminably different from one another. When listeners recognize that the initial consonants in words like "date," "deal," and "dude" are the same, they are recognizing phonetic similarity in spite of fairly dramatic acoustic differences in the physical realization of the consonant /d/. Thus, the perception of stimulus *differences* is not the key issue. The central problem is *similarity*. Do infants perceive similarity between discriminably different members of a phonetic category?

Studies done in my laboratory with 6–month–old infants suggest that infants are capable of recognizing phonetic categories. The results indicate, for example, that infants detect the vowel categories produced by a variety of different talkers, such as the categories /a/ versus /i/ (Kuhl, 1979), /a/ versus /ɔ/ (Kuhl, 1983), and /a/ versus /æ/ (Kuhl, Williams, & Green, in preparation). Infants also demonstrate an ability to perceive categories based on the initial or the final consonant of sets of syllables, such as those beginning with /s/ as opposed to /sh/ (Kuhl, 1980), or /m/ versus /n/ (Hillenbrand, 1984). Finally, infants detect category membership based on a featural distinction separating nasals and stops (Hillenbrand, 1983). These data suggest that infants possess an ability to recognize at least some phonetic categories by 6 months of age (Kuhl, 1985; though see Jusczyk & Derrah, 1987 for a lack of supporting evidence in 2–month–olds).

The categorization abilities of infants is what we sought to explain when we began a series of studies on phonetic prototypes (Grieser & Kuhl, 1983, 1989; Kuhl, 1986, Kuhl, 1991). Our early work suggested that infants' abilities to categorize were increased when they were trained with good instances of phonetic categories. Our focus on the prototypes of speech categories was based on the assumption that prototypes exemplify the *centers* of speech categories, optimum stimuli that may be used as referents in the categorization process, and the notion that prototypes tap listeners' mental representations for speech categories (Kuhl, 1990, 1992a, 1992b).

1.3. PHONETIC PROTOTYPES AND THEIR FUNCTION IN PERCEPTION

The approach we adopted was to ask adult listeners to rate the category goodness of individual exemplars from a phonetic category (see also Miller & Volaitis, 1989). Stimuli that were rated as the best exemplars – these best exemplars were called "prototypes" – were then used in tests that compared the perception of prototypes to the perception of nonprototypes from the same category.

We used vowels in the initial tests on phonetic prototypes (Grieser & Kuhl, 1989; Kuhl, 1991), and have recently extended the tests to consonants (Davis & Kuhl, 1992). To conduct the vowel tests, many instances of the vowel /i/ were computer synthesized and then rated. The findings showed that adults' category goodness ratings were very consistent. There was a particular location in the /i/ vowel space that produced better ratings. As one moved away from that "hotspot," the ratings became consistently worse.

Two /i/ vowels were selected from the large set of stimuli that adults had rated. One was the vowel given the highest average category goodness rating by adults. It was designated the prototype (P). The second one was an /i/ that had been given a relatively poor average rating; it was designated the nonprototype (NP). Both P and NP were always rated as /i/ vowels by listeners. The poor /i/ was simply judged to be produced less well. The P and of NP stimuli were manipulated to create 32 variants of each of the two vowels. To create the variants the first and second formants of the two vowels were altered (formants three, four and five were held constant). The 32 variants formed four rings around each vowel, each a controlled distance from the center stimulus (Fig. 2A).

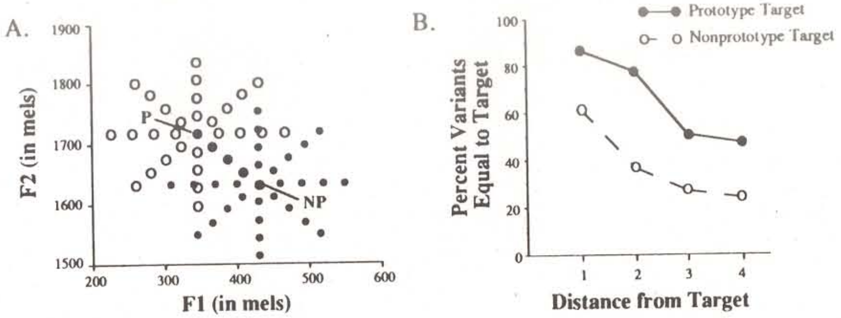

Figure 2. (A) The prototype /i/ (P) and its 32 variants (open circles) and the nonprototype /i/ (NP) and its 32 variants (closed circles). (B) Results showing that the prototype is equated to its variants more often than is the case for the nonprototype.

These stimuli were used to test the hypothesis that category goodness (typicality) has an effect on speech perception. A discrimination test was used to test the degree of perceptual similarity between each variant and its referent (P or NP). Adults, 6–month–old infants, and rhesus macaques were tested in a discrimination task that was virtually identical for the three groups of subjects (Kuhl, 1991). The question was: Is the prototype perceived as more similar to its variants than is the case for the nonprototype?

Human adults and infants showed the same pattern of results, that shown in Figure 2B. The plot shows the percentage of variants on the four rings that were equated to the P or NP. As shown, the prototype produced a stronger magnet effect. A greater number of variants were equated to the prototype than to the nonprototype, even though distance was controlled in the two sets of stimuli. The results suggested that the prototype perceptually assimilates surrounding stimuli to a greater extent than is the case for the nonprototype. The prototype appears to draw other stimuli towards it, effectively reducing the perceptual distance between the prototype and surrounding stimuli. I have described the prototype as functioning like a *perceptual magnet* (Kuhl, 1991).

Monkeys demonstrated a strikingly different pattern of response. They exhibited no magnet effect. Monkeys treated the variants surrounding the prototype and the nonprototype in exactly the same way. In both cases, variants were discriminated from the target at a particular distance from the target. These results are interesting because they reveal a dissociation between humans and monkeys in a test of phonetic perception, unlike the case of categorical perception (Kuhl, 1987b, 1988). Thus, the perceptual magnet effect differs in significant ways from the phenomenon of categorical perception (Kuhl, 1990).

2. The Effects of Linguistic Experience On The Magnet Effect: A Cross-Language Study

The existence of the magnet effect in 6-month-old infants raised interesting questions: What makes a particular vowel a prototype? And regarding development, how might the prototype's magnet effect come about in the baby?

The developmental question can be answered in two different ways, and each makes a prediction about the nature of the magnet effect. The first answer regarding development is that phonetic prototypes are part of infants' biological endowment for language. An alternative is that prototypes depend on linguistic input. The two models make different predictions about infants' perception of vowels from a foreign language. The first hypothesis – that vowel prototypes are innately "fixed" – predicts that the prototype's magnet effect would exist for vowels that the infant has never heard. The second hypothesis predicts that the magnet effect would result only when vowels in the infant's own language were tested.

An international research team examined the two hypotheses in a cross-language test. Infants from the United States and Sweden were tested on two vowel prototypes, the American English vowel /i/ used in our previous tests and the Swedish vowel /y/. The Swedish /y/ prototype was synthesized and then modified to create 32 additional variants in the same way as previously described (see Kuhl et al., 1992, for data showing that the American and Swedish vowels were perceived as prototypes by native speakers and poor instances, or nonprototypes, by foreign speakers).

The results demonstrated that infants from both countries showed a significantly stronger magnet effect for their native-language prototype (Fig. 3), confirming the hypothesis that linguistic experience in the first half-year of life alters phonetic perception. American infants perceived the American English /i/ prototype as more similar to its variants than was the case when Swedish infants listened to the same stimuli. Swedish infants perceived the Swedish /y/ prototype as more similar to its variants than was the case when American infants listened to the same stimuli. Infants' responses were analyzed using a 2-way ANOVA to assess the effects of language environment (American English versus Swedish) and the vowel tested (American English /i/ versus Swedish /y/). The interaction between the two factors was highly significant ($p < .0001$); neither of the main effects approached significance.

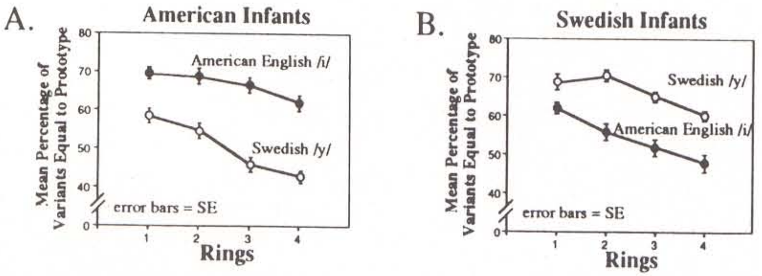

Figure 3. American (A) and Swedish (B) 6-month-old infants were tested on two vowel prototypes, American English /i/ and Swedish /y/. Infants from both countries equated variants to their native-language vowel prototype more often (produced a stronger magnet effect) than was the case for the foreign-language vowel prototype.

3. Magnet Effects and Speech Representation

The findings reviewed here show that by 6 months of age, infants' perception of the sounds of their native language differs from their perception of the sounds of a foreign language. Native language prototypes exhibit the magnet effect while foreign sounds are treated as nonprototypes in the native language. This result allows the inference that infants have had sufficient listening experience with the ambient language to alter some aspect of the speech representational system of the young child. How do we explain the magnet effect? What is the mechanism that underlies it?

3.1. THEORIES OF CATEGORIZATION AND REPRESENTATION

Traditional concept formation literature defined categories in terms of criterial attributes, properties that were both necessary and sufficient to define category membership. In contrast, Rosch (e.g., Mervis & Rosch, 1981) emphasized the structural characteristics of categories. Rosch argued that most categories do not have defining properties. Instead, categories are represented in terms of properties that are only characteristic of the category as a whole. Category members are related by overlapping sets of properties. No one attribute is shared by all members of a category. Category membership is thus graded rather than all-or-none. Some exemplars are better than others in that they have more of the features that are characteristic of the set of category members. By this account categories are represented in terms of their clearest cases, or prototypes.

Prototype theory asserts that people calculate and store some sort of summary statistic that characterizes a category as a whole (Posner & Keele, 1968). As people experience new items from a category, a generalization about those items as a group is formed, such as an average of all the experienced exemplars. As the number of instances grows, the details of individual stimuli that generated the average are not as prominent in memory as the average itself. Category decisions are made by comparing newly encountered items to this summary representation. Prototype abstraction thus reduces memory load.

Recently, an alternative to prototype theory has been described (Hintzman, 1986; Medin & Barsalou, 1987; Nosofsky, 1987). According to the "exemplar-based" models of categorization, classification can be accounted for by the storage and retrieval of individual exemplars. Exemplar theories maintain that newly encountered items act as retrieval cues to access stored individual exemplars from a category. Since the most representative stimuli (prototypic) are similar to a large number of individual exemplars, they are more likely to be accessed quickly, thus the exemplar model offers an alternative explanation for the results of studies showing superior or more efficient recognition of prototypic items from a category. There is nothing, of course, that precludes the human information processor from having access to both systems.

3.2. INFANTS' PERCEPTION OF VISUAL PATTERNS: FACES AND DOTS

Studies on young infants using faces and dot patterns show that at an early age infants have the ability to abstract a central category representation (Quinn & Eimas, 1986). In the studies on faces, schematic facial patterns were varied along a number of dimensions: face length, nose length, nose width, and amount of separation between the eyes. Research on adults suggested that after experiencing a set of schematic faces, adults recognize as most familiar a face whose dimensions are composed of the mean or the mode of the set of values they experienced during the experiment (Goldman &

Homa, 1977; Neumann, 1977). Recognition of the mean as opposed to the mode appeared to depend on the discriminability of the dimensional values presented. If the individual values are highly discriminable, then the modal face is recognized as most familiar. If the dimensions are difficult to discriminate, then the mean face is recognized as most familiar.

Strauss (1979) presented 10-month-old infants with a number of schematic faces in the familiarization phase of an habituation experiment. After familiarization, infants were presented with pairings of the following stimuli the mean face, the modal face, or a completely novel face. The results showed that infants treated the average face, a face that they had not seen during the experiment, as more familiar than either the modal face or the novel face that was not the average. Pairings of the modal face and the novel face revealed no preference for either one. This result suggests that infants summarize the faces that they were exposed to in the form of an average of all the faces they experienced. Additional studies suggested that infants at the same age treated the modal face as more familiar when fewer exemplars were used (Sherman, 1985). The data thus demonstrate that as memory load is increased, infants rely on an average stimulus.

Research on the perception of dot patterns suggests a similar conclusion. Bomba & Siqueland (1983) tested 3- and 4-month-old infants' with dot patterns. Infants were shown distorted dot patterns that were generated from a symmetrical form (triangle, square, or diamond). After familiarization of the patterns from a single category, infants were tested with the previously unseen prototype from the category paired with the prototype of one of the novel categories. Infants treated the prototype from the experienced category as more familiar, even though they had never seen it. Infants were also tested with the previously unseen prototype of the category paired with an experienced exemplar. With no memory delay infants treated the previously experienced exemplar as more familiar; however, when a 3-min delay was imposed, infants treated the previously unseen prototype as more familiar than an experienced exemplar.

Infants' coding of visual stimuli does not determine what infants do when they hear speech. However, the work supports the idea presented here that infants are capable of forming representations of stimuli that they experience. The type of long-term memory and representation involved in the speech case also fits together with recent work demonstrating long-term memory for human body movements (Meltzoff, 1990). The parallels between infant speech perception and the representation of faces and human action are quite interesting (Meltzoff & Kuhl, 1989; Meltzoff, Kuhl & Moore, 1991), and suggest that a powerful representational system is in place at birth.

At the present time we do not take a position on whether the prototype-abstraction view or the exemplar-based view best describes infants' or adults' speech representations. The magnet effect can be accommodated by either form of representation. Modeling the magnet effect using two other approaches will assist us in determining what form speech representations take. A signal-detection approach, as described by the Theory of Intensity Resolution (Durlach & Braida, 1969), separates sensory effects from those involving long-term memory. Nosofsky's (1986, 1987) Generalized Context Model, employing multidimensional-scaling techniques, examines how psychological space can be stretched and shrunk due to selective attention on particular stimulus dimensions. The magnet effect offers a way of testing the utility of these models in the domain of speech perception.

Previous data show that infants can learn the prosodic properties of sound - perhaps even in utero - as evidenced by the newborns' preference for mother's voice (DeCasper & Fifer, 1980) and their preference for the stress pattern typical of their mother's language (Mehler, et al., 1988). The data presented here showing infants' early learning of the phonetic properties of language show that infants' abilities to perceive and store information is not limited to prosodic patterns. Infants are apparently able to learn specific spectral patterns, such as those that would typify a particular vowel. Further studies will need to be done before we can specify what information is stored when infants learn properties of their native language.

4. A Theory Of Development

The studies described here suggest a new theory of the development of speech perception, called the *Native Language Magnet (NLM)* theory. The theory accounts for the early period of speech perception covering roughly the first year of life, prior to the time that infants acquire word meaning and contrastive phonology. The theory holds that infants' early representations of speech information constitute the beginnings of language-specific speech perception and play a critical role in infants' perception of native- and foreign-language sounds.

4.1. WHAT IS GIVEN BY NATURE AND GAINED BY EXPERIENCE?

A model of speech perception development has to account for infants' early speech perception abilities as well as changes in those abilities that accompany language experience in the first year. What constitutes the biological endowment at the phonetic level of language? What, on the other hand, is acquired in ontogeny?

NLM theory holds that what is "given by nature" is the ability to partition the sound stream into gross categories separated by natural boundaries, as schematically illustrated in Figure 4. These boundaries, shown here as divisions in a two-formant vowel space, convey the fact that infants are born with a capacity to resolve the acoustic differences between sounds that belong to different phonetic categories. On the view presented here, the boundaries do not derive from innate processes that are dedicated to speech, such as "phonetic feature detectors" (Eimas, 1982) or mechanisms that prespecify all phonetically relevant gestures used in speech (Liberman & Mattingly, 1985). These are results produced by the general auditory processing mechanism.

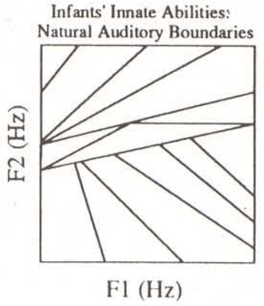

Figure 4. At birth infants perceptually partition the acoustic space underlying phonetic distinctions in a universal way.

Given that the acoustic space is initially divided by natural psychophysical boundaries, boundaries that are also shared by certain nonhuman animals, what is acquired in human ontogeny? Based on the data gathered in the perceptual magnet studies reported here, we can now say that by 6 months of age, infants have something more than the "basic cuts" they were born with. By 6 months of age infants show evidence of language-specific magnet effects. This is illustrated in the plots shown in Figure 5. Here I schematically portray the acquired magnets in vowel space of infants being raised in Sweden, America, and Japan. The graphs are not meant to be precise with regard to the locations of vowel magnets. They convey in conceptual terms the idea that linguistic experience in the three different cultures has resulted in magnets that differ in number and location for infants growing up listening to the three different languages.

The acquired magnets shown in Figure 5 are the result of infants' analysis of language input. They are derived from the distributional properties of vowels produced by native speakers of the language. Infants' perceptual boundaries helps this process of magnet acquisition: They set bounds on what the infants' representation must organize. Infants' speech experience is thus organized such that category representations (magnets) summarize a restricted area rather than the entire vowel space.

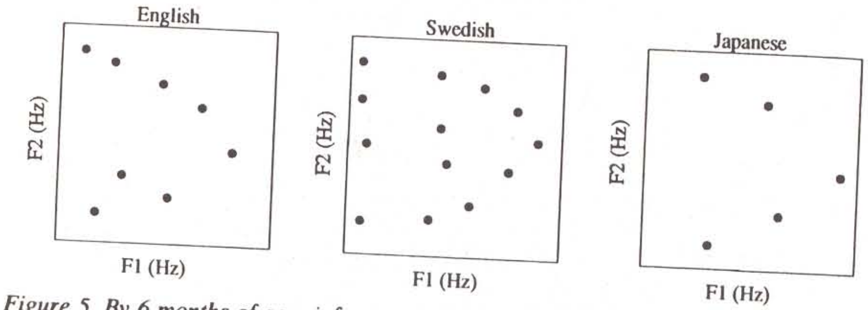

Figure 5. By 6 months of age, infants reared in different linguistic environments show an effect of language experience. They have acquired language-specific magnets that reflect the ambient language input.

The NLM theory thus explains how native-language speech perception comes about in the absence of word acquisition and linguistic contrast. If the theory is correct, infants' initial language-specific perception is the natural result of their build-up of a speech representational system that codes the input of native-language speakers. If language input is to play this role increased attention will need to be directed towards describing its phonetic content (Kuhl, 1992a; Lindblom, Brownlee, Davis & Moon, in press).

What about infants' perception of foreign-language sounds? The theory holds that acquisition of native-language magnets subsequently alters the perception of differences in phonetic space. Perceptual magnets warp the acoustic space underlying phonetic distinctions by shrinking the perceived distance between a magnet and its surrounding stimuli, and stretching the perceived distance in the region of the phonetic boundary. This will cause certain perceptual distinctions to be maximized (those near the boundaries between two magnets) while others are minimized (those near the magnet attractors themselves). The effects of infants' acquisition of perceptual magnets on the boundaries that divide the underlying phonetic space is shown in the schematic diagrams of Figure 6. In essence, magnets cause certain boundaries to disappear as the perceptual space is reconfigured to incorporate a language's particular magnet placement.

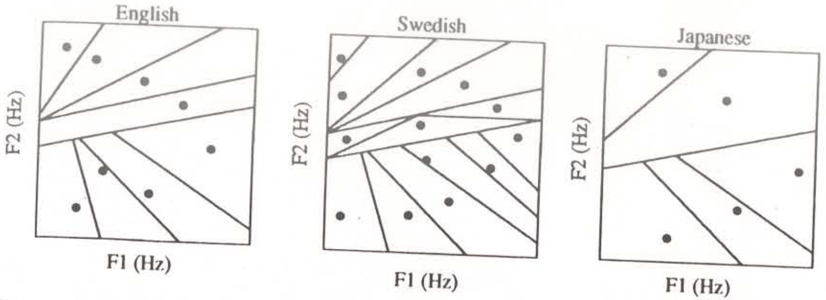

Figure 6. Language-specific magnets cause certain phonetic boundaries to disappear for each group of infants.

When boundaries "disappear," infants exhibit a failure to discriminate sounds that they earlier discriminated. Werker (this volume) has shown that infants aged 10–12 months fail to discriminate foreign-language contrasts that they once discriminated. According to NLM, the developing magnet pulls sounds that were once discriminable towards a single magnet, making them no longer discriminable. On this account, magnet effects occur first, before the failure to discriminate; they will developmentally *precede* and underlie the changes in infants' perception of foreign-language contrasts. Preliminary data by Werker and Polka (see Werker, this volume) are in line with this hypothesis. NLM theory thus offers a *mechanism* that explains the "reorganization" Werker observed.

Thus far I have focused on the auditory aspects of magnet effects. However, NLM theory is not a modality-specific model of infant speech perception. The results of experiments in my own lab on both adults (Green & Kuhl, 1989, 1991; Green, Kuhl, Meltzoff, & Stevens, 1991) and infants (Kuhl & Meltzoff, 1984; Kuhl, Williams, & Meltzoff, 1991) show that their perception of speech is not modality specific. I have argued that the speech representational system is polymodally mapped very early in life (Kuhl & Meltzoff, 1982, 1988). NLM theory holds that speech representations are initially auditory but that they become polymodal as infants acquire information about articulation. Infants' perceptual representations serve as targets for their acquisition of phonetically relevant gestures (see Boysson-Bardies, Halle, Sagart & Durand, 1989).

Identifying effects of experience at the segment level raises questions about the unit of analysis in speech. The results suggest that the representation of speech in infants is not limited to unanalyzable "wholes" constituted as syllables or words (Kuhl, 1986). Magnet effects for segments indicate that speech representations must be comprised of units that are sufficiently fine-grained to allow segment-level effects to occur.

We cannot as yet specify the state of the initial mechanism with regard to the magnet effect. Is the magnet effect present at birth for at least some vowels or does it emerge with exposure to a particular language? We are at present testing younger infants with prototype and nonprototype vowels. These studies will reveal whether or not infants initially show a magnet effect for all prototypes in the absence of language experience, or whether magnet effects are initially absent and develop only with language experience.

Finally, it is tempting to speculate that the development of language-specific magnets is, in Greenough's terms, an "experience-expectant" process (Greenough & Black, 1992). Greenough (this volume) has argued that certain developmental changes are underlain by an overproduction of synaptic connections which are subsequently pruned to achieve a more efficient neural organization. Synaptic overproduction is seen in situations in which a certain kind of experience is highly reliable in the environment of the organism. Greenough and Black (1992) describe the case of binocular vision. Patterned binocular stimulation is always available in the normal environment. The visual system can use this reliable source of visual information to establish normal binocular neurons. They explain:

> "Our terminology for this synapse overproduction process reflects the apparent fact that the synapses are produced in the evolutionarily-based *expectation* that appropriate experience will provide the information that the nervous system needs in order to select the appropriate subset of synaptic connections. . . The sensitive period is largely defined as a period during which excess connections exist, such that their selective survival depends on experience." (p. 163).

The idea that magnets are built up through an experience-expectant process is attractive. Native language input is a reliable feature of infants' early postnatal experience. The prosodic pattern of language, its rhythm and intonation structure, is available in utero. Infants' early automatic learning may be due to an evolutionarily-based expectation that infants of the species will experience language input from the onset of auditory function.

In summary, we have shown that linguistic experience has an effect prior to the time that infants utter or understand their first words. Infants' abilities to learn simply by listening to the ambient language suggests a powerful linguistic representational system that responds automatically given proper input (Chomsky, 1982). Nature's initial structuring in the form of natural boundaries, combined with the role experience plays in defining the centers of phonetic categories, provides infants with a strong foundation for higher language processes. The process of acquiring a language-specific phonology commences in the first half-year of life with the formation of language-specific magnets that define the centers of phonetic categories. The Native Language Magnet theory describes how innate abilities interact with infants' early experience to produce a language-specific pattern of speech perception. This view accounts for a large set of available data in infant speech perception and makes predictions that can be tested in future research.

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