We propose the following model for the role of *Sos* in R7 development (Fig. 5). The *Sos* gene product may be activated by the tyrosine kinase encoded by *sev*. This facilitates the activation of Ras. Ras, in turn, acts upon as yet unidentified substrates and leads to a commitment to the R7 cell fate. A GAP-like molecule has not yet been found in this pathway but is proposed in this model by analogy to other Ras pathways. The data presented here do not rule out the possibility that sevenless also acts through a molecule other than Sos.

Previous work in mammalian systems suggests the Ras pathway might operate downstream of receptor tyrosine kinases. A dominant-negative *ras* gene, for example, was able to interfere with oncogenic transformation by several tyrosine kinase–encoding oncogenes (*21*). Furthermore, genetic analysis has demonstrated a function for Ras in *Caenorhabditis elegans* vulval development. A *ras* gene, *let-60*, has been shown to act downstream of a receptor tyrosine kinase encoded by the *let-23* gene (*22, 23*). Results presented here implicate Ras in *Drosophila* neuronal development as well. Thus the Ras pathway may be a general component of many developmental systems.

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Linguistic Experience Alters Phonetic Perception in Infants by 6 Months of Age

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Linguistic experience affects phonetic perception. However, the critical period during which experience affects perception and the mechanism responsible for these effects are unknown. This study of 6-month-old infants from two countries, the United States and Sweden, shows that exposure to a specific language in the first half year of life alters infants' phonetic perception.

At the beginning of life, human infants exhibit a similar pattern of phonetic perception regardless of the language environment in which they are born (*1*). They discern differences between the phonetic units of many different languages, including languages they have never heard, indicating that the perception of human speech is strongly influenced by innate factors. However, by adulthood, linguistic experience has had a profound effect on speech perception. Exposure to a specific language results in a reduction in the ability to perceive differences between speech sounds that do not differentiate between words in one's native language (*2, 3*). Adult native speakers of Japanese, for example, have great difficulty in discriminating between words containing English /r/ and /l/, phonetic segments that belong to the same underlying category in Japanese (*2*). Adults thus exhibit a pattern of phonetic perception that is specific to their native language, whereas infants initially demonstrate a pattern of phonetic perception that is universal. At what point in development does linguistic experience alter phonetic perception, and what is the nature of the change brought about by experience with a particular language?

Previous studies suggested that the effects of linguistic experience on phonetic perception occur at about 1 year of age (*3*), coinciding with the age at which children begin to acquire word meanings (*4*). It was thus proposed that the change from a language-universal pattern of phonetic perception to one that is language-specific was brought about by the emergence of a milestone in the child's linguistic development, namely, the child's understanding that phonetic units are used contrastively to specify different word meanings (*3*).

We show here that by 6 months of age, well before the acquisition of language (*4*), infants' phonetic perception has been altered by exposure to a specific language. Infants in America and Sweden were tested with both native- and foreign-language vowel sounds. Infants from both countries exhibited a language-specific pattern of phonetic perception. Thus, linguistic experience alters phonetic perception at an unexpectedly early age, and this has implications for theories of speech perception and the development of language.

The present test focused on phonetic "prototypes," speech sounds that are identified by adult speakers of a given language as ideal representatives of a given phonetic category. Experiments with adults have shown that phonetic prototypes function like "perceptual magnets" in speech perception (*5*). The magnet effect causes other

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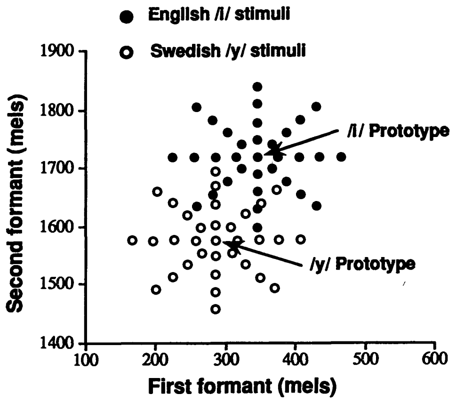

Fig. 1. Six-month-old infants from America and Sweden were tested with two sets of vowel stimuli, American English /i/ and Swedish /y/. Each set included an exceptionally good instance of the vowel (the prototype) and 32 variants that formed four rings (eight stimuli each) around the prototype (*8*).

nonprototypic members of the category to be perceived as more similar to the category prototype than to each other, even though the actual physical differences between the stimuli are equal (*5*).

It has been shown that 6-month-old American infants tested with a prototype and a nonprototype of an American English vowel duplicate the magnet effect shown in adults (*5*). A critical question for theory is whether this infant effect reflects language-specific or language-universal perception. Is experience with a specific language necessary, or would 6-month-olds show the magnet effect for all vowel prototypes regardless of language experience? We examined this question by conducting a cross-language study in 6-month-old infants from two countries using both native- and foreign-language sounds.

We tested infants in the United States and Sweden on two vowels. One vowel (American English /i/, the front unrounded vowel in the word "fee") constituted a native-language prototype for American adults and a nonprototype for Swedish adults; the other vowel (Swedish /y/, the front rounded vowel in the Swedish word "fy") constituted a native-language prototype for Swedish adults and a nonprototype for American adults (*6*). If experience with language in the first half year of life alters phonetic perception, a specific pattern is predicted in which the two groups of infants differ: (i) American infants would treat the American English /i/ as a prototype and the Swedish /y/ as a nonprototype, exhibiting a stronger magnet effect for American English /i/, (ii) Swedish infants would treat the Swedish /y/ as a prototype and the American English /i/ as a nonprototype, exhibiting a stronger magnet effect for Swedish /y/. However, if the results show any other pattern (if both groups of infants exhibit the magnet effect equally for both vowels or more strongly for the same one of the two vowels), then we would have no evidence that linguistic experience alters phonetic perception by 6 months.

We computer-synthesized prototypes of the American English /i/ and Swedish /y/ vowels (7). Each prototype was then modified to create 32 additional variants that were acoustically similar, but not identical, to each prototype (Fig. 1) (*8*). The magnet effect was assessed by testing infants' perception of the similarity between each prototype and its variants.

Infants sat on a parent's lap and watched an assistant, seated on the infant's right, manipulate silent toys. Each infant listened to one of the vowel prototypes (either American English /i/ or Swedish /y/), continuously repeated every 2 s from a loudspeaker located on the infant's left. In the training phase infants learned to produce a head-turn (HT) toward the loudspeaker when they heard the prototype vowel change (*9*). Two kinds of 6-s trials occurred. During change trials the prototype vowel was changed to one of its variants and infants' HT responses were rewarded by the activation of a toy bear that pounded a miniature drum. An equal number of control trials occurred in which the prototype vowel was not changed and infants' false-positive HTs were tabulated. Safeguards against bias on the part of the parent, the experimenter, and the assistant were stringent to ensure that these individuals did not influence infants' HTs (*5*). The test phase consisted of 64 trials, 32 change trials (one for each variant), and 32 control trials, presented in random order. The perceptual magnet effect was indicated by the degree to which infants responded to each prototype's variants as though they were identical to it, that is, trials in which infants did not detect a difference between a prototype and its variants.

Sixty-four 6-month-old infants were tested, 32 in the United States and 32 in Sweden. In each country, 16 infants were trained and tested with the American English /i/ prototype, and 16 were trained and tested with the Swedish /y/ prototype (*10*). Except for the critical variable of the language experience of the infants, all components of the experimental test remained the same in the two countries. The speech testing apparatus, computer equipment, and the three experimenters were physically moved from one site (the University of Washington, Seattle, Washington) to the other (Stockholm University, Stockholm, Sweden) for the duration of the tests. The same test protocol and stimuli were used.

The results confirmed that linguistic experience in the first half year of life alters infants' perception of speech sounds. Infants from both countries showed a significantly stronger magnet effect for their native-language prototype (Fig. 2). American infants perceived the American English /i/ prototype as identical to its variants on 66.9% of all trials; in contrast, they perceived the Swedish /y/ prototype as identical to its variants on 50.6% of the trials. Swedish infants perceived the Swedish /y/ prototype as identical to its variants on 66.2% of all trials; in contrast, they treated the American English /i/ prototype as identical to its variants on 55.9% of the trials. Infants' responses to the two sets of stimuli were submitted to a two-way analysis of variance to assess the effects of infants' language environment (American English versus Swedish) and the prototype vowel tested (American English /i/ versus Swedish /y/). The interaction between the two factors was highly significant

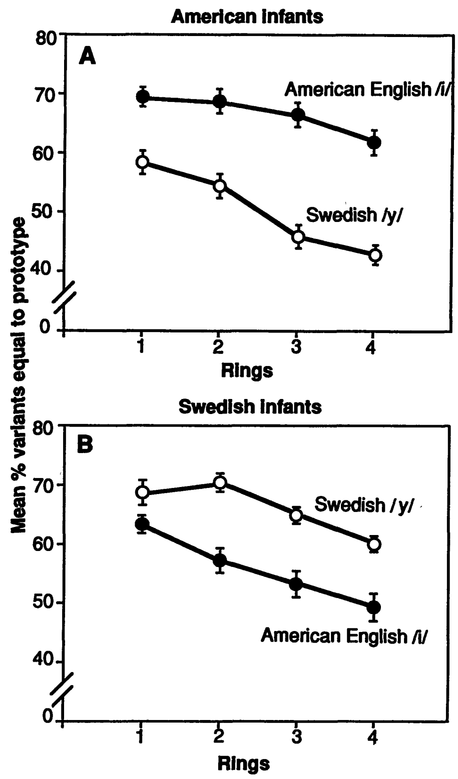

Fig. 2. Results showing an effect of language experience on young infants' perception of speech. Two groups of 6-month-old infants, (**A**) American and (**B**) Swedish, were tested with two different vowel prototypes, American English /i/ and Swedish /y/. The mean percentage of trials in which infants equated variants on each of the four rings to the prototype is plotted. Infants from both countries produced a stronger magnet effect (equated variants to the prototype more often) for the native-language vowel prototype when compared to the foreign-language vowel prototype. (Error bars = standard error.)

[$F(1, 60) = 20.107$, $P < 0.0001$]; neither of the main effects was significant [language environment: $F(1, 60) = 0.526$, $P > 0.40$; vowel: $F(1, 60) = 0.978$, $P > 0.30$] (*11*).

The findings demonstrate that by 6 months infants exhibit a strong magnet effect only for native-language phonetic prototypes. By this age foreign-language prototypes have begun to function like nonprototypes in the native language (*12*). The results show that the initial appearance of a language-specific pattern of phonetic perception does not depend on the emergence of contrastive phonology and an understanding of word meaning. Rather, infants' language-specific phonetic categories may initially emerge from an underlying cognitive capacity and proclivity to store in memory biologically important stimuli (*13*) and from the ability to represent information in the form of a prototype (*5*).

The findings also suggest the process by which linguistic experience alters phonetic perception. Linguistic experience shrinks the perceptual distance around a native-language prototype, in relation to a nonprototype, causing the prototype to perceptually assimilate similar sounds (*5*). The native-language prototype's magnet effect may help explain why older children and adults fail to discriminate two speech sounds from a foreign language when both sounds resemble a native-language prototype for the subject (such as /r/ and /l/ for native Japanese speakers) (*2, 3*).

Infants demonstrate a capacity to learn simply by being exposed to language during the first half year of life, before the time that they have uttered meaningful words. By 6 months of age, linguistic experience has resulted in language-specific phonetic prototypes that assist infants in organizing speech sounds into categories. They are in place when infants begin to acquire word meanings toward the end of the first year. Phonetic prototypes would thus appear to be fundamental perceptual-cognitive building blocks rather than by-products of language acquisition.

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6. The status of the two vowel prototypes in American English and Swedish was experimentally assessed. Adult native speakers of American English and Swedish were asked three questions about each prototype: (i) whether it was a sound used in their language, (ii) the category it belonged to, and (iii) its representativeness as a member of that category using a scale from "1" (poor) to "7" (good). American listeners unanimously judged the /i/ prototype as an English vowel, giving it an average rating of 5.4 as a member of the English /i/ category. They unanimously rated the Swedish /y/ prototype as not in their language. Swedish adults unanimously judged the /y/ prototype as a Swedish vowel, giving it an average rating of 4.7 as a member of the category /y/. They rated the American English /i/ prototype as present in the language but ambiguous with regard to category; /i/ was given an average rating of 2.6 as a member of the Swedish /e/ category and 1.8 as a member of the Swedish /i/ category. These ratings are typical of native-language nonprototypes (*5*).
7. The five formant frequencies of English /i/ were 270, 2290, 3010, 3300, and 3850 Hz; for Swedish /y/, 220, 1980, 2640, 3340, and 3720 Hz.
8. Variants were created by manipulating the first two formant frequencies [scaled in mels (*5*)] in uniform, psychophysically equal steps. The variants formed four rings that were 30, 60, 90, and 120 mels, respectively, from each prototype.
9. During change trials in training, the prototype vowel was changed to a variant from the fourth ring around the prototype and this stimulus change was paired with the reinforcer, causing infants to turn toward the reinforcer. Once infants were producing HTs reliably on change trials, control trials were introduced. Infants had to meet a criterion of seven out of eight consecutive correct trials (including both change and control trials) during training, and produce no more than 35% false-positive responses once the test started, to be included in the study.
10. Mean age of infants: 6.5 months (range = 6.1 to 6.9) for American infants tested on /i/; 6.5 months (range = 6.0 to 7.0) for Swedish infants tested on /i/; 6.7 months (range = 6.2 to 7.1) for American infants tested on /y/; 6.6 months (range = 6.1 to 6.9) for Swedish infants tested on /y/.
11. Follow-up tests indicated that for both the American and Swedish infants there was a significant difference between the vowels, $P < 0.05$.
12. We have not yet determined whether prototypes for all vowels (or a subset of them) exist at birth and are modified by 6 months due to linguistic experience or whether prototypes are initially absent and subsequently formed by 6 months as a result of language experience.
13. Studies suggest that infants under 3 months are capable of remembering faces, voices, and certain acoustic characteristics of speech [M. E. Barrera and D. Maurer, *Child Dev.* **52**, 714 (1981); A. J. DeCasper and W. P. Fifer, *Science* **208**, 1174 (1980); J. Mehler *et al.*, *Cognition* **29**, 143 (1988); A. N. Meltzoff, P. K. Kuhl, M. K. Moore, in *Newborn Attention*, M. J. S. Weiss and P. R. Zelazo, Eds. (Ablex, Norwood, NJ, 1991), pp. 377–411].

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