CHILDREN'S PERCEPTION OF [s] AND [ʃ]: THE RELATION BETWEEN ARTICULATION AND PERCEPTUAL ADJUSTMENT FOR COARTICULATORY EFFECTS

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Abstract. When synthetic fricative noises from an [ʃ]–[s] continuum are followed by [a] and [u], adult listeners perceive fewer instances of [ʃ] in the context of [u] (Mann & Repp, 1980). This perceptual context effect presumably reflects adjustment for the coarticulatory effects of rounded vowels on preceding fricatives, and thus implies possession of tacit knowledge of this coarticulation and its consequences. To determine the role of articulatory experience in the ontogeny of such knowledge and the consequent perceptual adjustment, the present study examined the effect of [eɪ] and [u] on the perception of [s] and [ʃ] by children who can and cannot produce these consonants. The stimuli comprised synthetic frication noises from an [ʃ] to [s] continuum adjoined to periodic portions excerpted from natural tokens of "shave" and "shoe." The subjects included adults, five- and seven-year-old children who correctly produce both [ʃ] and [s], and seven-year-old children who misarticulate both fricatives. All three groups of children showed a significant context effect equivalent to that of adults and independent of age and the fricative articulation. Therefore, productive mastery of [s] and [ʃ] is not responsible for children's perceptual adjustment to vowel rounding on the spectra of voiceless fricatives.

Introduction

Among adult subjects, context effects in the perception of spoken consonants are a well-established phenomenon (see Repp, 1982, for a recent review). One acoustic pattern may support different phonetic interpretations in different environments. Examples of such effects can be found in the perception of bursts as cues for stop consonant place of articulation (Liberman, Delattre, & Cooper, 1952), and in the perception of formant transitions as cues to consonant place (Mann, 1980; Mann & Repp, 1981) and manner (Miller & Liberman, 1979). Another example, and the one that concerns us here, involves the place of articulation of voiceless fricative noises: When a synthetic fricative
noise ambiguous between [] and [s] precedes the vowel [u], listeners perceive [s] less often than when the same noise precedes the vowel [a] (Fujisaki & Kuno-
isisaki, 1978; Mann & Repp, 1980).

Like a myriad of other context effects in speech perception, the con-
trasting effect of [u] and [a] on perception of a preceding fricative noise
finds a parallel, and a plausible explanation, in the dynamics of articulatory
gestures and their acoustic consequences. The parallel is that, due to
coarticulation of adjacent phonemes, when [] and [s] precede a rounded vowel,
such as the English [u], they are influenced by anticipatory liprounding. The
effect is a lowering of fricative noise spectra relative to that which occurs
when [] and [s] are produced before an unrounded vowel, such as the English
[a] (Bondarko, 1969; Heinz & Stevens, 1961; Mann & Repp, 1980). The expla-
nation is that, since [s] noises, in general, involve higher spectral frequen-
cies than [] noises, any compensation for the consequences of liprounding
during fricative production would make a given noise appear relatively higher
when it occurs before a rounded vowel, thus decreasing the likelihood that []
will be perceived.

Therefore, the tendency of adult listeners to give fewer [] responses
when synthetic fricative noises occur in the context of [u] is interpreted as
the reflection of a tendency to compensate for the acoustic consequences of
anticipatory liprounding on fricative noise spectra (Mann & Repp, 1980). That
they so take account of the acoustic consequences of articulatory dynamics as
they assign phonetic labels to speech stimuli is not a unique attribute of
fricative perception, but would seem to be a more general and fundamental
property of perception in the speech mode. It is as if speech perception is
guided by some tacit knowledge of the diverse acoustic consequences of arti-
culatory gestures (Repp, Liberman, Ercardt, & Pesetsky, 1978), and of the subtle
changes that necessarily ensue when sequences of such gestures weave and over-
lap in fluent speech (Mann, 1980; Mann & Repp, 1981). The basis of such
knowledge, however, remains unclear, as does its role in young children's
speech perception. To gain insight into these issues, the present study has
explored the effects of [ei] and [u] on the perception of the []-[s] distinc-
tion among children who can produce [s] and [], and those who cannot.

It is possible that tacit knowledge about the articulation of a given
phoneme, and its diverse acoustic consequences, is gathered from listening to
one's own production of that phoneme. If so, experience with the articulation
of [s] and [] might be critical to any articulatory knowledge that allows the
child to compensate for the effects of liprounding on fricative noise spectra.
This hypothesis would be verified were we to find the normal contrasting ef-
fects of [u] and [ei] only in the perception of fricatives by children who can
produce [s] and [], and not in that of children who have yet to produce
these phonemes.

On the other hand, it is likewise possible that children who cannot pro-
duce [s] and [] could nonetheless be just as capable (or incapable, as the
case may be) of perceptually adjusting for the influence of liprounding on
fricative noise spectra. On finding this to be the case, we could reject a
hypothesis that correct fricative articulation is essential to knowledge about
the consequences of fricative-vowel coarticulation, and then turn to consider-
ing three alternative bases of that knowledge. First, any tacit knowledge
underlying the effect of vocalic context on fricative perception might be
instantiated by more general experience with one's own articulation as opposed
to specific experience with fricative articulation. Second, it could be brought about by experience with hearing and seeing the speech of others. Third, given the many findings that at least some knowledge about the acoustic consequences of articulation could be inborn (Kuhl & Meltzoff, 1982; Miller & Elmas, in press), the ontogeny of tacit articulatory knowledge could be largely under genetic control, and relatively independent of specific experience, barring the necessary role of stimulation in the emergence of genetic behaviors.

A review of the literature reveals that, while there are many studies of the ontogeny of speech perception and production, much remains to be learned about fricative perception, and its relation to fricative production. Prelingual infants have been reported to be capable of discriminating synthetic tokens of [seɪ] and [ʃeɪ] (Eilers, 1980; Eilers & Minifie, 1975) and six-month-old infants may distinguish natural tokens of [s] and [ʃ] in the context of [a] and [u] (Kuhl, 1980). Yet when [s] and [ʃ] initiate natural CVC syllables, children aged ten to eighteen months may fail to make a perceptual distinction (Garnica, 1971; Shvachkin, 1973) and children as old as five years of age may show confusions among natural tokens of [s] and other fricative consonants (Abbs & Minifie, 1969). Likewise, although there are reports that children as young as two or three years old may correctly produce [s] and [ʃ] (Prather, Hedrick, & Kern, 1975), there is much evidence that fricatives are produced relatively late in language development, and that fricative misarticulation can be present well into the early elementary grades (Moskowitz, 1975) with considerable individual variability (Ingram, Christiansen, Veach, & Webster, 1980). In short, it is unclear exactly when the [s]-[ʃ] distinction is mastered either in perception or production, nor is the relation between the two abilities apparent. On the basis of the common observation that development of language comprehension precedes that of language production, it might be tempting to discard a hypothesis that mature production of the [ʃ]-[s] distinction is essential to mature perception of that distinction. Nonetheless, there are no reports that falsify this hypothesis, nor has a subtle and sensitive assessment of children's perception of fricatives been undertaken, such as might be supplied through a study using context effects.

With these considerations in mind, we conducted two experiments, each concerned with the contrasting influence of [a] and [u] on young children's perception of the [ʃ]-[s] distinction. Our methodology is drawn from that of Mann and Repp (1980), employing a continuum of synthetic fricative noises (ranging from one appropriate to [ʃ] to one appropriate to [s]) that were followed by vocalic portions from natural syllables containing the vowel [eɪ] or [u]. Their adult subjects were required to label the initial fricative of each syllable as [ʃ] or [s], and the context effect was measured in terms of the number of [ʃ] responses given in the context of each vowel. In Experiment 1, we adapt Mann and Repp's materials and their phoneme labeling task to a forced-choice picture identification task suitable for use with preliterate children, and we provide a test of these adaptations among a population of five- and seven-year-old children who have mastered production of [s] and [ʃ]. Thus we demonstrate the utility of our procedure and discern whether any marked changes in vocalic context effects occur following the mastery of fricative production. In Experiment 2, we turn to a second population of seven-year-old children who are in speech therapy because they have not mastered production of [s] and [ʃ]. In this case, our goal is to discern whether vocalic context effects are present before fricative articulation is fully mastered.
Experiment 1

Method

Subjects. All subjects were native speakers of English who had no prior experience with synthetic speech. Adults were recruited from the Bryn Mawr area and children were recruited from a local day-care center: none of them had any known organic, behavioral, emotional, or intellectual problems. In order to be considered as a potential subject, each adult had to report no known hearing or speech pathologies. Each child had to have normal hearing acuity as determined by preschool screening and to be able to produce correctly the [s] and [ʃ] in "sue," "shoe," "save," and "shave." Chosen according to these criteria, there were ten subjects at each of three age levels in Experiment 1: five-year-olds (mean age 5.6 years), seven-year-olds (mean age 7.5 years), and adults (mean age 22.4 years).

Materials. The stimuli were hybrid syllables consisting of synthetic fricative noises followed by natural vocalic portions to form two [ʃ]-[s] continua: "shoe"-"Sue" and "shave"-"save." To construct them, we began with recordings of the words "shoe" and "shave" that had been read aloud by a native male speaker of American English as part of a list of words containing initial voiceless fricatives. All utterances were digitized at 10 kHz using the Haskins Laboratories Pulse Code Modulation (PCM) system, and the single best tokens of "shoe" and "shave" were chosen for further use. The fricative noise was then removed from each of these (the fricative noise being defined as the signal portion preceding the onset of periodicity), and replaced, in turn, with each of nine digitized synthetic fricative noises created on the Haskins Laboratories OVE IIIc speech synthesizer. The synthetic noises were characterized by two steady-state poles whose center frequencies, as can be seen in Table 1, increased in eight approximately equal steps from Stimulus 1, which approximated a natural [ʃ], to Stimulus 9, which approximated a natural [s]. Noise duration was held constant at 250 ms, with a 150 ms initial amplitude rise, and a 30 ms final amplitude fall.

<table>
<thead>
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<th>Stimulus</th>
<th>Pole 1</th>
<th>Pole 2</th>
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<tbody>
<tr>
<td>1</td>
<td>1957</td>
<td>3803</td>
</tr>
<tr>
<td>2</td>
<td>2197</td>
<td>3915</td>
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<tr>
<td>3</td>
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</tr>
<tr>
<td>9</td>
<td>3917</td>
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</tr>
</tbody>
</table>

Table 1

Pole Frequencies of Fricative Noises (Hz)
Mann, Sharlin, & Dorman: Children's Perception of [s] and [ʃ]

For the purpose of testing perception of the test stimuli, two different magnetic tapes were prepared, a separate one for each stimulus continuum. Each tape consisted of a practice set comprising five tokens of each of the two endpoint stimuli arranged in a random order, followed by a test set comprising a randomized sequence that included five repetitions of each of the nine test stimuli along the continuum. Interstimulus interval was held constant at 5 sec.

Procedure

All testing was conducted individually at the residence (for adults) or daycare center (for children) where the subject was solicited. Each subject listened to stimuli over circumaural earphones at a presentation level of approximately 70 dB SPL. Both tapes were completed within a single session, with the order of presentation counterbalanced across subjects. For each tape, the ten items in the practice set were presented first, followed by presentation of the 45 test items. The procedure involved the subject's listening to each stimulus and then reporting his or her phonetic perception. Whereas adults gave written responses of "s" or "sh," as in the procedure of Mann and Repp (1980), children gave a two-alternative forced-choice pointing responses to pictures that corresponded to the words on the tape—"a shoe" vs. "a girl named Sue" for the [u] context, "a man having a shave" vs. "a piggy-bank in which to save" for the [ə] context—and their responses were transcribed by the examiner, who did not know the identity of the stimulus being presented. To accustom children to this task the experimenter showed two pictures, "tree" and "blue," before the test tape was presented and asked the child to point to the appropriate picture as she said each word aloud. When the child correctly identified five presentations of each of these two words arranged in random order, the task was repeated using pictures for "shoe" and "blue." Finally, the child was shown the pictures for the appropriate experimental task and given practice with the experimenter saying each test word aloud. When the child had touched each picture correctly on five occasions, arranged in random order, presentation of the prerecorded practice and test stimuli followed.

Results and Discussion

The data for Experiment 1 consist of labeling responses of "s" and "sh" for stimuli along each of our two experimental continua gathered directly from adults, and inferred from children's picture verification responses. We will briefly consider the data obtained with adult subjects, then proceed to a report of the results obtained with children at each age, and a brief discussion of their import.

Adults. A summary of the results obtained with the ten adult subjects appears in Figure 1, where the average percent of "sh" responses is plotted as a function of stimulus position along the fricative noise continuum, separately for each vocalic context. Solid lines represent the results obtained when fricative noises initiated a syllable containing the rounded vowel [u], and dashed lines represent those obtained when the same noises initiated the syllable containing the unrounded vowel [ə]. For both continua, listeners were quite consistent in their labeling of the endpoint stimuli. And, as expected, the category boundary for the labeling function obtained in the context of the unrounded vowel from "shave" occurs between stimuli 5 and 6 (at 5.2), whereas that for the unrounded vowel from "shoe" occurs between stimuli 4 and 5 (at
Thus fewer "sh" responses were given in the context of the rounded vowel, $t(18) = 3.1, p < .01$.

![Graph showing percent 'sh' responses for adults](image)

Figure 1. Influence of vocalic context on the labeling of fricative noises by adult subjects.

**Children.** All children successfully learned the procedure, and were 100% correct in identifying the pictures corresponding to spoken versions of the test words and 80% or better correct in responding to the practice endpoint stimuli. The results for five- and seven-year-olds are graphed in Figures 2 and 3, respectively. Here, as in the case of the adult subjects, both the endpoint stimuli were labeled quite consistently, and here, as well, the category boundaries for the two vocalic contexts lie at different locations. The boundary for noises presented in the context of the unrounded vowel lies at 5.5 for five-year-olds, and 5.2 for seven-year-olds, while the boundaries for noises heard in the context of the rounded vowel occur at 4.1 and 4.3, respectively.

An analysis of variance, conducted on the total number of "sh" responses given in each vocalic context by the adults and the children at each of the two age levels, reveals a main effect of vocalic context, $F(1,27) = 59.4, p < .001$, but no main effect of age, and no interaction between the effects of age and vocalic context. Thus, all subjects, adults and children alike, tended to give fewer "sh" responses in the context of the rounded vowel: for five-year-olds, $t(18)=2.31, p < .05$, and for seven-year-olds, $t(18) = 3.37, p < .01$. Moreover, when measured as the difference between the number of "sh" responses given in each context, the extent of the context effect among children was not significantly different from that among adults ($p > .1$).
Figure 2. Influence of vocalic context on the labeling of fricative noises by five-year-olds who can articulate [s] and [ʃ].

Figure 3. Influence of vocalic context on the labeling of fricative noises by seven-year-olds who can articulate [s] and [ʃ].
Using a new set of stimuli, then, Experiment 1 has confirmed previous reports (Fujisaki & Kunisaki, 1978; Mann & Repp, 1980) that when synthetic fricative noises along an [ʃ]-[s] continuum are followed by a vocalic portion that contains the vowel [u], the category boundary is shifted towards a lower noise frequency and fewer "sh" responses, than when the same fricative noises are heard in the context of the vowel [eɪ]. Most importantly, it has demonstrated that this vocalic context effect can be present among five- and seven-year-old children who correctly produce [s] and [ʃ], and that, among such children, the extent and direction of the effect is remarkably similar to that obtained among adults. Thus children as young as five years of age who can produce both [s] and [ʃ] show an adult-like perceptual compensation for the coarticulatory effects of liprounding on the spectra of these fricatives, and we may conclude, therefore, that knowledge of fricative-vowel coarticulation and its acoustic consequences does not markedly lag behind productive mastery of [s] and [ʃ]. Otherwise, we should have found an age-related difference between the children and adults who participated in our study. This leaves us with two possibilities as to the relation between perception and production: Either perceptual mastery precedes production mastery, or the two begin at more or less the same time. To decide between these alternatives, we turn to the second experiment of our study, which asks whether a vocalic context effect is present among children who cannot produce [s] and [ʃ].

Experiment 2

Method

Subjects. The subjects were fourteen children recruited from the second-grade classes of parochial schools in Northeast Philadelphia, who served with the permission of their parents and at the convenience of their teachers. Each of them was selected with the help of speech therapists who worked in their schools. They fulfilled all of the following criteria:

1) Incorrect production of initial [s] and/or [ʃ]; either substituting one for the other, substituting another phoneme instead, or simply omitting [s] and [ʃ] altogether.

2) No difficulty with the production of phonemes other than fricatives or affricates.

3) A maximum of one year in speech therapy.

4) Audiometry scores within the range defined in Experiment 1.

5) No soft neurological signs, cerebral palsy, emotional or behavioral disorders.

Chosen according to these criteria, there were six females and eight males, with an average age of 7.6 years.
Mann, Sharlin, & Dorman: Children's Perception of [s] and [ʃ]

Materials and Procedure

The materials and procedure were as in Experiment 1. Each subject was excused from his or her classroom and taken to the speech room in the school, where the experimenter explained that the child was helping her to study the way children hear language. The subjects were assured that there was no right or wrong answer involved, and that all that was required was to listen carefully. The same procedure as in Experiment 1 was used, with training followed by practice, culminating in presentation of the test trials. Order of the test tapes was counterbalanced across subjects.

Results and Discussion

The data obtained from the seven-year-old children who could not produce [s] and [ʃ] are summarized in Figure 4, which should be compared with Figures 1-3 from Experiment 1. We have combined the results across children who omitted [s] and [ʃ] (N = 8), those who substituted one for the other (N = 4), and those who substituted another phoneme instead (N = 2), as the nature of production errors did not appear to influence the pattern of results. As in the first experiment, all subjects labeled the words spoken during training with an accuracy of 100% correct, and also labeled the endpoint test stimuli with an 80% or better accuracy. Thus, they could clearly distinguish good exemplars of [s] and [ʃ]. Inspection of Figure 4 further reveals that these children also showed vocalic context effects on fricative perception. When the stimuli along the synthetic continuum were followed by the vocalic portion from "shave," the average phonetic boundary lies between stimuli 5 and 6 (5.2), whereas that for the same fricative noises followed by the vocalic portion from "shoe" lies between stimuli 4 and 5 (4.3). Thus, fewer "sh" responses were given in the context of the rounded vowel than in that of the unrounded one, t(26) = 3.79, p .005.

![Figure 4. Influence of vocalic context on the labeling of fricative noises by seven-year-olds who cannot articulate [s] and [ʃ].](image-url)
There are two points to be made in discussing these findings. The first, and most central to our concern, is that perception of [s] and [ʃ] by children who cannot produce both of these phonemes does not differ significantly from that of adults and children of the same age who can produce them. That is, their perception of [s] and [ʃ] is affected by vocalic context in the same manner (i.e., more "sh" responses in the context of the unrounded vowel) and to an equivalent extent. Thus, it would appear that these children can take account of the consequences of coarticulation of a fricative with a following vowel, even though they do not directly control those consequences in their own speech production.

A second point, more pertinent to clinical concerns, is that the exclusive problems with fricative articulation that distinguish the children of our second experiment from those of the first experiment do not appear to be due to aberrant perceptual abilities. This is a conclusion that has been reached in several previous studies of children selectively impaired in producing liquids (Strange & Broen, 1981). Perhaps some developmental delay in motor control is the cause of selective misarticulation of fricatives and affricates, given the distinguishing developmental characteristics of this class as outlined by Ingram et al. (1980). Fricatives are avoided by many very young children, and it is not impossible that certain children merely avoid them longer than others. Also, since fricatives are among the last phonemes to be produced correctly (and there seems little agreement on the span of time involved in acquisition of other phonemes, much less this controversial class), there is ample reason to suspect that many of the children who participated in the present experiment are following a normal pattern, albeit more slowly, of phoneme acquisition.

However, before leaving this second point, we would like to recognize the possibility that certain severe articulatory problems could be based in a perceptual disorder (Strange & Broen, 1981). In this regard, we note that we have examined a group of seven-year-old children who present with multiple articulatory problems spanning three or more manner classes, and we have found them to be quite different from children who selectively misarticulate fricatives and affricates (Mann, Dorman, Strawhun, & Sharlin, 1982; Sharlin, 1982). Subjects who are multiple misarticulators give responses that tend to be more erratic; their attentiveness is also noticeably lower and they "fidget" more than the other children whom we have tested. They behave as if our task is in some way unexpectedly aversive, owing, perhaps, to an inability to competently and confidently make the required perceptual distinction. In addition, and most notably, these children are unique in their tendency as a population to show no significant effect of vocalic context on fricative perception.

General Discussion

The following general conclusions can be drawn from the results of Experiments 1 and 2: 1) Children as young as five years of age who correctly articulate [s] and [ʃ] show vocalic context effects on fricative perception that are commensurate with the context effects observed among adult subjects; 2) Competent production of [s] and [ʃ] is not necessary for the manifestation of vocalic context effects on fricative perception; 3) The exclusive misarticulation of fricative consonants, like other selective problems in speech production (see Strange & Broen, 1981), is not simply attributable to deficits in fricative perception.
Mann, Sharlin, & Dorman: Children's Perception of [s] and [ʃ]

We may now turn to a consideration of our findings as they pertain to the various hypotheses, outlined in the Introduction, about the source of the tacit knowledge of articulation that we hold responsible for the influence of vocalic context on fricative perception, and that we presume to be guiding mature speech perception. Certainly we may reject the hypothesis that experience with the production of fricatives is essential to the acquisition of such knowledge that allows listeners to compensate for the consequences of fricative-vowel coarticulation on fricative noise spectra. Otherwise, we should not have found vocalic context effects to be equally present in the perception of children who can and cannot produce [s] and [ʃ]. Even children who selectively omit fricatives altogether (of which we tested 8) showed vocalic context effects on fricative perception equivalent to those among other children and adults.

This leaves us to consider the remaining three possibilities about the basis of tacit articulatory knowledge. One possibility is that, while there is no simple one-to-one dependence of knowledge about the consequences of fricative-vowel coarticulation on competent production of [s] and [ʃ], some experience with language production may be essential to the acquisition of that knowledge; for example, experience with producing rounded and unrounded vowels and observing their different consequences on sound spectra, in general. A second possibility is that tacit articulatory knowledge does not emerge through feedback from one's own articulation so much as through experience with listening to, and perhaps watching, the articulations of others. A third is that tacit knowledge is not induced by experience with one's own articulation or that of others, but is genetically given so as to be present and functioning by the age of five years, before successful fricative production (contingent, perhaps, on some type of auditory stimulation). Each of these possibilities is equally consistent with the present findings, but, as we shall now argue, they are not equally consistent with certain other findings in the literature.

Considering each possibility in turn, we note that the first is inconsistent with reports that subjects who lack speech production abilities may nonetheless demonstrate apparently normal speech perception (Forcin, 1974), and with a report by Whalen (1981) who shows vocalic context effects for non-native vowels. However, before concluding that feedback from one's own articulation is not a prerequisite for acquiring tacit knowledge about articulation and its consequences, it would be desirable to repeat the present study, using subjects with total congenital inability to speak.

We turn next to the second hypothesis, which stresses experience with the articulation of others. While this is consistent with the perceptual capabilities of inarticulate subjects, and with the late onset of certain speech perception abilities, it is at odds with findings that neonates display adult-like discrimination of many speech sounds (see, for example, Eilers, 1980, and Miller & Elmas, in press, for reviews). One might test this hypothesis by studying children who have recently been corrected for a congenital hearing loss, or by examining congenitally blind children who have not had the opportunity to observe the lip-rounding gestures of others. If subjects in these groups show normal vocalic context effects on fricative perception, it would suggest that experience with the articulations of others does not have a critical role in instantiating knowledge of articulation and its consequences. However, finding that such children fail to show context effects might be interpreted either as evidence that experience instantiates articulatory
knowledge, or as evidence that experience merely facilitates or maintains such knowledge (Gottlieb, 1976). Testing neonates and young children could ultimately decide between these two possibilities.

The third and final possibility is that tacit knowledge of articulation and its consequences is genetically endowed, as opposed to deriving from experience with the consequences of one's own articulation or with those of others. This hypothesis is consistent with findings that neonates prefer to look at a face articulating the same vowel that they are hearing (Kuhl & Meltzoff, 1982), and also display a wide range of speech perception behaviors that are directly analogous to the perceptual capabilities of adult speech perceivers, including certain context effects (Miller & Eimas, in press). It is further consistent with evidence that, although infrahuman species discriminate certain speech sounds much as human listeners do (cf. Kuhl & Miller, 1978; Waters & Wilson, 1976), and may even categorize fricative noises along an [s]-[ʃ] continuum (Sevcik, 1979), they fail to show the present vocalic context effects on fricative perception (Sevcik, 1979). If context effects that involve tacit knowledge of articulatory dynamics are unique to human listeners, then it is likely that the knowledge they depend on is genetically based.

References


126


