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Children's Perception of Sibilants: The Relation between Articulation and Perceptual Development

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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 the rounded vowel [u] (Mann & Repp, 1980). This perceptual context effect presumably reflects adjustment for certain coarticulatory effects and implies tacit knowledge of coarticulation and its consequences. To clarify the role of articulatory experience in the ontogeny of such knowledge and the consequent perceptual adjustment, the present study examined the effect of rounded and unrounded vowels on the perception of [s] and [ʃ] by adults, 5-, and 7-year-old children who produce [ʃ] and [s] and 7-year-old children who misarticulate these phonemes. All three groups of children showed a context effect equivalent to that of adults and independent of age and articulation ability. Therefore, productive mastery of [s] and [ʃ] is not critically responsible for perception of the [s]–[ʃ] distinction, nor for perceptual sensitivity to the consequences of sibilant–vowel coarticulation.

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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 an influence of vocalic context on the perceived place of articulation of voiceless fricative noises: When a synthetic fricative noise ambiguous between [ʃ] and [s] is followed by the vowel [u], listeners are less likely to perceive that noise as [ʃ] than when the following vowel is [a] (Fujisaki & Kunisaki, 1978; Mann & Repp, 1980).

Like a myriad of other context effects in speech perception, the contrasting 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 [ʃ] and [s] precede a rounded vowel, such as the English [u], they are influenced by anticipatory lip rounding. As a consequence, there is a lowering of fricative noise spectra relative to that which occurs when [ʃ] and [s] are produced before an unrounded vowel, such as the English [a] (Bondarko, 1969; Heinz & Stevens, 1961; Mann & Repp, 1980). The explanation is that, since [s] noises, in general, involve higher spectral frequencies than [ʃ] noises, any compensation for the consequences of lip rounding during fricative noise production would make a given noise appear relatively higher when it occurs before a rounded vowel. Consequently, there would be a decrease in the likelihood that [ʃ] is perceived.

The tendency of adult listeners to give fewer [ʃ] 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 lip rounding on fricative noise spectra (Mann & Repp, 1980). That listeners so take account of the acoustic consequences of articulatory dynamics as they assign phonetic labels to speech stimuli is not a unique attribute of sibilant perception. Rather, it appears to be a more general and fundamental property of perception in the speech mode (Liberman, 1982; Mann & Liberman, 1983). It is as if speech perception is guided by some tacit knowledge of the diverse acoustic consequences of articulatory gestures (Repp, Liberman, Eccardt, & Pesetsky, 1978) and of the subtle changes that necessarily ensue when sequences of such gestures weave and overlap 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. The purpose of the present study was to gain insight into these issues, while addressing the general question of how sibilant perception develops and how it relates to sibilant production. In it, we have explored the effects of rounded and unrounded vowels on the perception of the [ʃ]–[s] distinction among children who can produce [s] and [ʃ], and those who cannot. It is possible that perceptual mastery of [s] and [ʃ], including reliance on tacit knowledge about articulation and its diverse acoustic consequences, is gathered from listening to one's own production of those phonemes. If so, specific experience with the articulation of [s] and [ʃ] might be critical to the ability to compensate for the effects of lip rounding on fricative noise spectra, and thus to the existence of the present context effect. On the other hand, correct sibilant articulation may not be essential to perceptual mastery and to the present context effect. In that case, perceptual mastery, including the tacit knowledge underlying the effect of vocalic context, might be instantiated by more general experience with one's own articulation (as opposed to specific experience with the articulation of [ʃ] and [s]), or by experience with the speech of others. It could even be inborn.

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 the maturation of sibilant perception and production. Prelingual infants have been reported to be capable of discriminating synthetic tokens of [sa] and [ʃa] (Eilers, 1980; Eilers & Minifee, 1975) and 6-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 10 to 18 months may fail to make a perceptual distinction (Garnica, 1971), and children as old as 5 years of age may show confusions among natural tokens of [s] and other fricative consonants (Abbs & Minifee, 1969). Similarly, although there are reports that children as young as 2 or 3 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, Christensen, Veach, & Webster, 1980). In short, it is unclear exactly when the [s]–[ʃ] distinction is mastered either in perception or production, nor is any causal relation between the two abilities apparent. On the one hand, mature production of the [ʃ]–[s] distinction could be essential to mature perception of that distinction. On the other, it could be the case that the late onset of fricative production owes to the relatively late development of fricative perception. The common observation that in language development comprehension precedes production, could be grounds for rejecting the first hypothesis. Similarly, the second appears at odds with the ability of certain congenitally deaf speakers to produce voiceless fricatives (McGarr & Löfqvist, 1982), although it is consistent with evidence that fricatives are especially difficult for deaf children to produce (Levitt, Stromberg, Smith, & Gold, 1980; Nober, 1967). At present, there are no reports that directly falsify either 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 all of these considerations in mind, we conducted two experiments, each concerned with the contrasting influence of a rounded vowel [u] and an unrounded vowel [eɪ] on young children's perception of the [ʃ]–[s] distinction. Our methodology was drawn from that of Mann and Repp (1980), who employed 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 [a] 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 adapted 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 provided a test of these adaptations among a population of 5- and 7-year-old children who have mastered production of [s] and [ʃ]. Thus, we demonstrated the utility of our procedure and discerned that no marked changes in vocalic context effects occur following the mastery of sibilant production. In Experiment 2, we turned to a second population of 7-year-old children who were in speech therapy because they had not mastered production of [s] and [ʃ]. In this case, our goal was to discern whether vocalic context effects are present before sibilant 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 at both ages 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 10 subjects at each of three age levels in Experiment 1: 5-year-olds (mean age 5.6 years, range 5.0–5.9 years), 7-year-olds (mean age 7.5 years, range 7.0–7.9 years), and adults (mean age 22.4 years, range 18–33 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 male native speaker of American English as part of a list of words containing initial voiceless sibilants. All utterances were digitized at 10 kHz, using the Haskins Laboratories Pulse Code Modulation (PCM) system, and one clear token of "shoe" and "shave" was 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.

For the purpose of testing perception of the test stimuli, two different audio 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 s.

TABLE 1
POLE FREQUENCIES OF SYNTHETIC FRICATIVE NOISES (Hz)

Stimulus	Pole 1	Pole 2
1	1957	3803
2	2197	3915
3	2466	4148
4	2690	4269
5	2933	4394
6	3199	4655
7	3389	4792
8	3591	4932
9	3917	5077

Procedure

All testing was conducted individually at the residence (for adults) or day-care center (for children) where the subject was solicited. Each subject listened to stimuli over TDH-390 dichotically balanced, circumaural earphones at a presentation level of approximately 70 dB SPL. Both tapes were completed within a single session, with the order or presentation counterbalanced across subjects. For each tape, the 10 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 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 [eɪ] context—and their responses were transcribed by the examiner, who did not know the identity of the stimulus being presented. To acquaint children with this task, the experimenter first 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 chidren's picture verification responses. They are represented, together with the data from Experiment 2, in Fig. 1. We will briefly consider the results obtained with adult subjects (Fig. 1a), then proceed to a report of the results obtained with children at each age, (Figs. 1b and 1c), followed by a statistical analysis of the data and a brief discussion.

Adults. A summary of the results obtained with the 10 adult subjects appears in Fig. 1a, 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

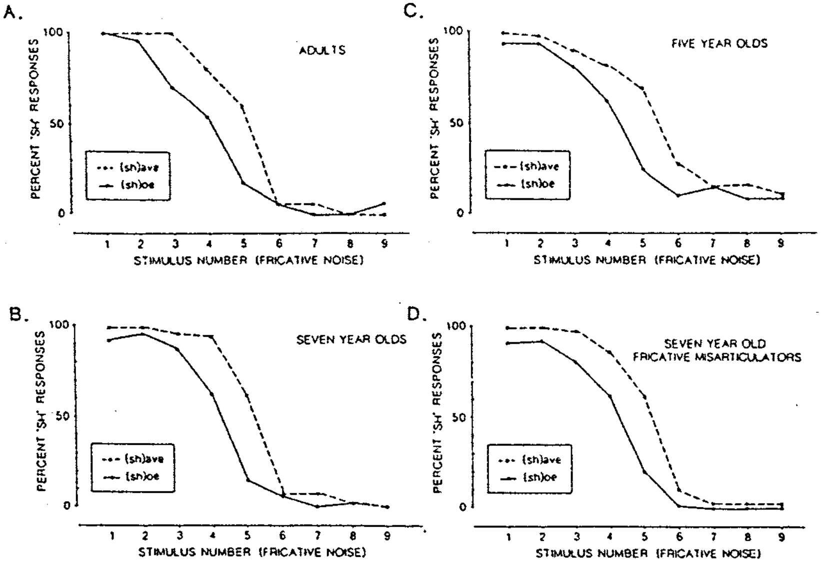

FIG. 1. Influence of vocalic context on the labeling of fricative noises by (a) adult subjects, (b) 5-year-olds who can articulate [s] and [ʃ]. (c) 7-year-olds who can articulate [s] and [ʃ], and (d) 7-year-olds who cannot articulate [s] and [ʃ].

noises initiated a syllable containing the unrounded vowel [eɪ]. For both continua, listeners were quite consistent in their labeling of the endpoint stimuli. As expected, the mean 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 rounded vowel from "shoe" occurs between Stimuli 4 and 5 (at 4.2). Nine of the 10 subjects tested yielded a category boundary for the "shoe" context which was shifted to the left of that for the "shave" context.

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% correct or better in responding to the practice endpoint stimuli. The results for 5- and 7-year-olds are graphed in Figs. 1b and 1c, respectively. Here, as in the case of the adult subjects, both endpoint stimuli were labeled quite consistently, and here, as well, the category boundaries for the two vocalic contexts lie at different locations. The mean boundaries for noises presented in the context of the unrounded vowel lie at 5.5 for 5-year-olds, and 5.2 for 7-year-olds, while the boundaries for noises heard in the context of the rounded vowel occur at 4.1 and 4.3, respectively. Inspection of individual data indicates that all ten of the 5-year-olds showed this boundary shift, as did nine of the ten 7-year-olds.

For statistical evaluation of these results, an analysis of variance was conducted on the number of "sh" responses given to the various stimuli along the continuum in each vocalic context by the adults and the children at each of the two age levels. It reveals a main effect of vocalic context, $F(1, 27) = 36.05$, $p < .001$, a main effect of stimulus number, $F(3, 216) = 303.96$, $p < .00001$, and an interaction of vocalic context and stimulus number, $F(3, 216) = 15.29$, $p < .00001$. There was no main effect of age, and no interactions between the effects of age, stimulus number, and vocalic context. Thus, all subjects, adults and children alike, tended to shift their category boundaries in favor of fewer "sh" responses in the context of the rounded vowel, and the extent of the context effect among children was not significantly different from that among adults.

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 rounded vowel [u], the category boundary is shifted toward a lower noise frequency and fewer "sh" responses, than when the same fricative noises are heard in the context of an unrounded vowel [eɪ]. Most importantly, it has demonstrated that this vocalic context effect can be present among 5- and 7-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 5 years of age who can produce both [s] and [ʃ] show an adultlike perceptual compensation for the coarticulatory effects of lip rounding on the spectra of these sibilants. We may conclude, therefore, that their perceptual mastery of the [s]–[ʃ] distinction, and their knowledge of sibilant–vowel coarticulation and its acoustic consequences does not markedly lag behind productive mastery of [s] and [ʃ]. Otherwise, we should have found some age-related difference between the chidren 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 shed some light on these alternatives, we turn to the second experiment of our stuy, which asks whether a vocalic context effect is present among children who are candidates for speech therapy because they cannot produce [s] and [ʃ].

EXPERIMENT 2

Method

Subjects. The subjects were 14 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. On the basis of routine screening of elicited (on at least three occasions) and spontaneous production, 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 1 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 90 months (7.6 years, range 7.0–7.9 years).

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 7-year-old children who could not produce [s] and [ʃ] are summarized in Fig. 1d, and can be compared with the other three panels of Fig. 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 Fig. 1d 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). Thirteen of the 14 subjects individually showed this boudary shift, and an analysis of variance reveals a main effect of vowel context, $F(1, 13) = 12.30$, $p < .01$, stimulus number, $F(3, 104) = 139.96$, $p < .00001$, and an interaction between these two factors, $F(3, 104) = 3.94$, $p < .0004$. Thus, fewer "sh" responses were given in the context of the rounded vowel than in that of the unrounded one.

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 sibilants 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). Thus, it would appear that these children can take account of the consequences of coarticulation of a sibilant 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 sibilant 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 impaired in producing liquids and other speech sounds (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 case as outlined by Ingram et al. (1980). Fricatives are among the last phonemes to be produced correctly (and there seems to be little agreement on the span of time involved in acquisition of other phonemes, much less this controversial class), thus there is ample reason to suspect that many of the children who participated in the present experiment are following a normal pattern of phoneme acquisition, albeit more slowly. Nonetheless, we would like to recognize the possibility that although the present data are not a case in point, certain severe articulatory problems could be based in a perceptual disorder (Broen, Strange, Doyle, & Heller, 1983).[1]

GENERAL DISCUSSION

The following general conclusions can be drawn from the results of Experiments 1 and 2: (1) Children as young as 5 years of age who

[1]In this regard, we note that we have used the present materials and procedure to examine a group of 7-year-old children ($N=8$) who present with multiple articulatory problems spanning three or more manner classes. These children tend to be quite different from children who selectively misarticulate fricatives and affricates (Mann, Dorman, Strawhun, & Sharlin, 1982; Sharlin, 1982). They often give responses that are more erratic; their attentiveness is also noticeably lower and they "fidget" more than the other children whom we have tested. In short, 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 significiant effect of vocalic context on sibilant perception

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 is not simply attributable to deficits in perception.

These findings speak to the relation between the development of sibilant perception and sibilant production. Apparently, mature production of [s] and [ʃ] is not always essential to perception of these sounds, as we have obtained no evidence that mature sibilant production is a necessary prerequisite of mature sibilant perception. Rather, our finding is that a group of children who have a specific problem with sibilant production can still perceive sibilants in a fashion indistinguishable from normal adults and comparably aged children. This is certainly suggestive that perceptual mastery can precede productive mastery among children who must undergo speech therapy. Whether perception always precedes production, as opposed to onsetting at more or less the same time, is an issue which may be addressed by a longitudinal study of normal children in the process of mastering [s] and [ʃ]. Such a study may also inform us as to whether delayed perceptual mastery is a factor behind certain children's production difficulties.

Our findings also bear on hypotheses about the source of the tacit knowledge of articulation that we hold responsible for the influence of vocalic context on sibilant perception, and that we presume to be guiding mature speech perception. Certainly we may reject a hypothesis that experience with the production of sibilants is essential to the acquisition of such knowledge as allows listeners to compensate for the consequences of sibilant–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 these sibilants altogether (of whom we tested eight) showed vocalic context effects on sibilant perception equivalent to those among other children and adults.

There remain three possible bases of tacit articulatory knowledge. One possibility is that, while there is no simple one-to-one dependence of knowledge about the consequences of sibilant–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. This view, however, is inconsistent with reports that subjects who lack speech production abilities may nonetheless demonstrate apparently normal speech perception (Forcin, 1974). Two other possibilities appear more likely. One 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. After all, infants may possess a proclivity to integrate speech sounds with the sight of a speaker's mouth (Kuhl & Meltzoff, 1982; MacKain, Studdert-Kennedy, Spieker, & Stern, 1983). Another is that tacit knowledge is not induced by experience with one's own articulation or that of others, but is genetically given (contingent, perhaps, on some type of auditory stimulation) so as to be present and functioning by the age of 5 years, before successful fricative production. This would be in accord with the adultlike abilities of neonates to distinguish various classes of speech sounds (Miller & Eimas, 1983). At present, each of these possibilities is equally plausible; future research may help to decide between them.

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