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Context Effects in Two-Month-Old Infants' Perception of Labiodental/Interdental Fricative Contrasts

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We investigated 2-month-old infants' perception of a subset of highly confusable English fricatives. In Experiment 1, infants discriminated modified natural tokens of the voiceless fricative pair [fa]/[θa] but only when the syllables included their frication noises. They also discriminated the voiced pair [va]/[ða] both with and without fricative noises. These results parallel those found with adults by Carden, Levitt, Jusczyk, and Walley (1981). In Experiment 2 [f] and [θ] noises were appended to [a], and the same [f] noise was appended to the previously indiscriminable fricationless versions of [fa] and [θa]. Infants discriminated both pairs of stimuli, indicating that (a) the frication is a sufficient cue for [fa]/[θa] discrimination and that (b) it provides a context for discriminating the [f] and [θ] formant transitions. We conclude that infants' perception of labiodental/interdental fricative contrasts show evidence of context effects similar to those observed with adults.

Throughout much of its early history, infant speech perception research was directed at cataloging the kinds of contrasts that infants are capable of discriminating (e.g., Eimas, 1975; Eimas, Siqueland, Jusczyk, & Vigorito, 1971; Lasky, Syrdal-Lasky, & Klein, 1975; Miller & Eimas, 1979; Morse, 1972; Streeter, 1976; Trehub, 1976; Werker, Gilbert, Humphrey, & Tees, 1981). The accumulation of such knowledge about the extent of the infant's capacities was an important step forward in understanding speech perception in that it suggested that at least some of the underlying mechanisms are operative from birth. More recent investigations in the field have moved away from questions concerning the variety of contrasts that infants can discriminate to a consideration of the nature of the mechanisms themselves (e.g., Jusczyk, Pisoni, Reed, Fernald, & Myers, 1983; Kuhl & Meltzoff, 1982; Miller & Eimas, 1983). Thus, there have been a number of investigations aimed at determining whether the mechanisms underlying the infant's discriminative capacities are speech-specific or general auditory ones (Eimas, 1974; Eimas & Miller, 1980; Jusczyk, Pisoni, Walley, & Murray, 1980). Such studies are informative in that they produce an indication of the range of acoustic signals to which the underlying mechanisms respond.

One recent discovery that holds promise with respect to furthering our understanding of perceptual mechanisms is the demonstration of context effects and trading relations in speech processing (e.g., Best, Morrongiello, & Robson, 1981; Oden & Massaro, 1978; Repp, 1982). Multiple cues figure in the categorization of speech along phonetic continua. There is evidence that the cues themselves enter into trading relations in such a way that the presence of one cue can serve either to reinforce or offset the presence of another cue. For example, first formant onset frequency has been shown to enter into a trading relation with voice onset time information in determining the locus of the voiced/voiceless category boundary in English (Summerfield, 1982; see also Pastore, Wielgus, & Szczesiul, 1984). The existence of such effects raises questions about the nature and origins of the mechanisms responsible for them.

There are several possible explanations for trading relations in speech perception. One possibility is that such context effects are the result of specific experience with a particular language. In effect, the listener learns how the cues are traded to ensure meaningful contrasts between words in his or her native language. In this case, some higher level decision rule might be imposed upon the perceptual output (e.g., see Oden

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& Massaro, 1978, for an account along these lines). The second possibility is that such trading relations are innately prewired either in the form of speech-specific or general auditory processing mechanisms. In fact, there is evidence that at least one type of context effect may be prewired, given that Miller and Eimas (1983) found evidence of context effects in infants as young as 3 months old. Specifically, they found evidence that changes in speech rate resulted in systematic shifts in the perception of cues to voicing and manner (stop/glide) distinctions.

Given the limited data available with infants, it is premature to conclude that trading relations and context effects are a consequence of the inherent organization of the underlying perceptual mechanisms. For while some such effects follow from the way in which the human auditory system is structured, others may have a different origin. In particular, some types of context effects may involve decision level processes that draw upon the listener's experience in producing and perceiving speech. One such possibility has been reported by Carden, Levitt, Jusczyk, and Walley (1981) in their investigation of the fricative contrast [f] (as in *fin*) and [ɵ] (as in *thin*). These researchers noted the existence of context effects in the perception of the place of articulation distinction that occurs between the syllables [fa] and [ɵa]. Specifically, the fricative noise and formant transition portions of these syllables interact in a way which gives rise to this distinction. Although the formant transition differences appear to function as the critical cue in distinguishing [fa] from [ɵa], they require a fricative context. Carden et al. (1981) demonstrated this in a series of experiments. First, they found that removing the fricative noise from [fa] and [ɵa] caused the resulting truncated syllables to be perceived as the same sound, [ba].[1] This result suggested that the fricative noise plays a critical role in signaling the [fa]–[ɵa] distinction. Yet further experimentation showed that it is not the information in the fricative noise per se that serves to distinguish [fa] from [ɵa]. In a separate unpublished study, Carden and colleagues found that the addition of an identical fricative noise to both the truncated syllables for certain speakers was sufficient to reinstate the perception of these syllables as [fa] and [ɵa]. In other words, the fricative noise provided a necessary context for perceiving the minimal formant transition differences that distinguish [fa] and [ɵa] (cf. Harris, 1958).

To this point, these results are in line with the pattern typically observed for context effects. The suggestion that the effects might stem from decision level processes came as a result of another experiment (Carden et al., 1981) using synthetic speech sounds based on their natural tokens. By extending the range of the formant transition differences between [fa] and [ɵa], Carden et al. (1981) produced a synthetic speech continuum. Removing the fricative noise from this extended continuum resulted in a continuum that was perceived as extending from [ba] to [da]. Although composed of identical formant transitions, the two continua (one with and one without frication) had significantly different category boundary locations in a forced choice task. Thus, information about manner of articulation (i.e., whether the stimuli were stops or fricatives) affected subjects' decisions about place of articulation. This point was illustrated forcefully in a test condition in which subjects were presented with stimuli from the [ba]/[da] series but asked to label them as either [fa] or [ɵa], the resulting category boundaries matched those of the original [fa]/[ɵa] series. A comparable pattern of results was observed for subjects presented with the [fa]/[ɵa] stimuli but asked to label them as [ba] or [da]. Thus, the context effects observed in labeling the formant transitions could occur even when the contextual cues were not physically appropriate. The results suggest that listeners employ different criteria in evaluating formant transition differences for stop and fricative distinctions. A possible factor in developing such criteria may well be the listener's own experience with the way in which such sounds are produced. If so, then this type of effect may be one that emerges only after considerable experience in producing and perceiving speech.

The present study was undertaken to examine the perception of fricative contrasts by young infants. More specifically, we sought answers to a number of questions, such as (a) do 2-month-olds discriminate contrasts between labiodental and interdental fricatives? (b) what kinds of information are critical for the infant's discrimination of such contrasts? and (c) do infants exhibit context effects for fricative contrasts similar to those observed by Carden et al. (1981) with adult subjects?

Experiment 1

That infants might experience difficulty in discriminating an [f]/[ɵ] contrast would not be surprising, given that measures of speech intelligibility rank these sounds among the most highly confused in English (Miller & Nicely, 1955). The source for the confusability of these segments apparently lies in the similarity of their acoustic properties. Measurements made of the fricative portions of [f] and [ɵ] show that both are characterized by a rather uniform distribution of spectral energy (Klatt, 1986; Strevens, 1960), although the overall intensity may be somewhat lower in [ɵ] (Klatt, 1986). This suggests that some other portion of the signal, such as the formant transitions, may play the key role in distinguishing these segments. These observations are borne out by the results of perceptual studies suggesting that formant transition cues are sufficient in the productions of some speakers to distinguish [f] from [ɵ] (e.g., Harris, 1958; Heinz & Stevens, 1961).

Two previous studies have examined the perception of the labiodental/interdental fricative distinction by infants. However, both studies (Eilers, Wilson, & Moore, 1977; Holmberg, Morgan, & Kuhl, 1977; see also Kuhl, 1980) examined infants who were 6 months old or older. By this age, infants have already had considerable experience listening to speech as well as some experience producing speechlike sounds. It is possible that even this limited experience is sufficient to allow infants to employ contextual cues in discriminating formant transi-

[1] Although there was some individual variation in the way in which truncated versions of tokens from different speakers were identified by listeners in Carden et al.'s (1981) study, they all showed the same pattern.

tion differences. Nevertheless, even at this age the infants gave some evidence of difficulty in discriminating these contrasts. For example, Holmberg et al. (1977) noted that their subjects required on average about twice as many trials to achieve a criterion for distinguishing [f]/[ɵ] as they did for a comparable contrast between [s]/[ʃ].[2] Given such considerations, it is reasonable to ask whether infants at a younger age and with considerably less experience are capable of discriminating a labiodental/interdental fricative contrast.

As in previous investigations, the present study focused on the ability of infants to discriminate between the voiceless fricative pair [fa] and [ɵa]. Moreover, following the work of Carden et al. (1981) with adults, we also decided to examine the voiced counterpart to this distinction (i.e., [v] as in *vat* and [ð] as in *that*). The fricative noise portion of this latter pair tends to have a considerably lower amplitude than that of the voiceless pair. For this reason, the formant transition differences may take on even greater importance for discrimination. To explore further the contribution that formant transition differences might make to the infant's discrimination of fricative contrasts, two other types of contrasts were also examined. The stimuli involved in these contrasts were modified versions of the voiced and voiceless fricative pairs. The modification involved removing the fricative noise from the [fa]/[ɵa] and [va]/[ða] pairs, leaving the formant transitions and vocalic portions of the syllables intact. In line with the observations of Carden et al. (1981), removing the frication from the [fa]/[ɵa] pair resulted in a pair of syllables that both sounded like [ba] to adult listeners, whereas the modification of the [va]/[ða] pair produced syllables that preserved place of articulation information. This difference in subject response to the truncated versions of the voiceless and voiced fricative pairs is apparently due to the greater perceptual salience of the voiced formant transitions used to signal [va] and [ða].

To the extent that infants perceive the full and truncated versions of the syllables as do adults, they should discriminate both the full and truncated versions of the voiced [va]/[ða] pair, but only the full version of the voiceless [fa]/[ɵa] pair. Such a result would indicate that not only do the infants discriminate fricative contrasts differing in place of articulation but that they may also experience context effects in that the same set of formant transition differences are discriminable only in the presence of an appropriate fricative noise. On the other hand, if sensitivity to such context effects develops only after considerable experience in producing and listening to speech and if the difference in the fricative noise spectrums is not a sufficient cue, then infants would not be expected to discriminate either version of the voiceless [fa]/[ɵa] pair, because the adult data suggest that formant transitions for these stimuli all fall within the same category. Under this second hypothesis, the predictions for the discriminability of the voiced pair are less clear. It may be that the formant transition differences are large enough, in which case both the full and truncated versions would be discriminated, in line with the adult data. Or it may be that the formant transition differences are not sufficiently large, in which case neither pair would be discriminated.

Method

Procedure. Each infant was tested individually in a small laboratory room. The infant was seated in a reclining chair approximately 0.5 m away from a rear projection screen. An image of brightly colored flowers was projected on the screen for the entire test session. The projection screen was situated directly above a loudspeaker through which the auditory stimuli were presented. Each infant sucked on a blind nipple, held in place by an experimenter who wore headphones and listened to recorded music throughout the test session. A second experimenter in an adjacent room monitored the apparatus.

The experimental procedure was a modification of the high-amplitude sucking (HAS) technique developed by Siqueland and DeLucia (1969). For each infant, the high-amplitude sucking criterion was established before the presentation of any stimuli. The criterion was set so as to produce a response rate of 15–30 sucks/min. Once a baseline rate of high-amplitude sucking was established, the presentation of stimuli was made contingent upon the rate of high-amplitude sucking. Because the stimuli ranged from 325 to 530 ms in duration, with an interstimulus interval of approximately 500 ms, there was a maximum presentation rate of about one stimulus per second. If the infant produced a burst of sucking responses with interresponse times of less than 1 s, then each response did not produce one presentation of the stimulus. Rather, the timing apparatus was reset so as to provide continuous auditory feedback for 1 s after the last response of the sucking burst. Use of a programmable logic board ensured that all stimulus presentations were uninterrupted.

The criterion for satiation to the first stimulus was a decrement in sucking rate of 25% for 2 consecutive minutes compared with the rate of sucking in the immediately preceding minute. Once this criterion was met, the auditory stimulus was changed without interruption by switching channels on the tape recorder. For infants in the experimental conditions, the change was to an acoustically different stimulus. For infants in the control condition, the channels on the tape recorder were switched, but no acoustic change occurred because the same signal had been recorded on both channels. The postshift period lasted for 4 min. The infant's sensitivity to the change in auditory stimulation was inferred from comparisons during the postshift period.

Stimuli. Naturally produced syllables ([fa], [ɵa], [va], and [ða]) were selected from one of the adult male talkers (PN) who produced the tokens used in the Carden et al. (1981) study. The tokens were recorded by using an Ampex AG500 tape recorder. Each token was digitized at a 10-kHz sampling rate and low-pass filtered at 4.9 kHz (to prevent aliasing), using the Haskins Laboratories pulse code modulation (PCM) system (Cooper & Mattingly, 1969). As Carden et al.'s study demonstrated, the resulting syllables were clearly identifiable for adult listeners. The PCM system was also used to remove the posttransition vocalic portions of the [ɵa] and [ða] stimuli and to replace them by the vocalic portions of the [fa] and [va] stimuli, respectively. This step was taken to ensure that the only difference between the stimuli lay in the frication and formant transitions. There was no indication of any perceptible spectral discontinuity in the resulting [ɵa] and [ða] tokens. The total duration of the [fa] and [ɵa]

[2] Note that Eilers et al. (1977) reported that 6- and 12-month-old infants were unable to discriminate a [fa]/[ɵa] contrast. Jusczyk (1981) suggested that one possible reason for this result was that the tokens used by Eilers et al. were correctly identified by adults only 70% and 60% of the time for [fa] and [ɵa], respectively, whereas PN's [fa] was correctly identified 92% and his [ɵa] 69% of the time. Some explanation along these lines seems reasonable, given the success reported by Holmberg et al. (1977) with infants in this age range.

stimuli was 530 ms. The frication portions of these tokens had durations of 165 ms. This was achieved by removing the initial 20 ms of low amplitude frication from the [fa] to equate the fricative noise portions of the stimuli. The total duration of the voiced fricatives ([va] and [ða]) was 425 ms, with the frication portions accounting for 100 ms. Truncated versions of the syllables were prepared by using the PCM system to delete the frications from the digitized natural syllables cutting at the point of zero or near-zero amplitude nearest to the end of the frication. Here, again, the vocalic portion was the same for each pair of stimuli. The resulting truncated (fricationless) stimuli are designated as [fa]−, [θa]−, [va]−, and [ða]−.[3] The output of the PCM system was then used to prepare the audio tapes employed in this experiment.

Design. Each infant in the study was seen for one session. Twelve subjects were assigned randomly to each of four groups, and 16 subjects were assigned randomly to a fifth (control) group. Infants in Group 1 were tested for their ability to detect the [fa]/[θa] distinction, whereas subjects in Group 2 heard the truncated versions of these syllables (i.e., [fa]−/[θa]−). Groups 3 and 4 were presented with contrasts involving [va]/[ða] and [va]−/[ða]−, respectively. The presentation order of the items in a given stimulus pair was counterbalanced across subjects for each group. Two each of the 16 subjects in Group 5 were randomly assigned one of the eight stimuli for the entire test session.

Apparatus. A blind nipple was attached to a Grass PT5 volumetric pressure transducer, which in turn was connected to a Type DMP-4A Physiograph. A Schmitt trigger provided digital output of criterial high-amplitude sucking responses. Additional equipment included a Teac 3340 tape recorder, a Kenwood (KA-3500) amplifier, an ADS loudspeaker, a Grason-Stadler (Model 1200) programmable logic board, a power supply, two relays, a counter, and Physiograph DC preamplifier. Each criterial response activated the timer on the logic board for a 1-s period or restarted the period. Auditory stimulation at a level of 72 dB (A) SPL (approximately 15 dB above the background noise level caused by the ventilation system) was available whenever the timer was in an active state. The use of the logic board to monitor the auditory signals on the tape ensured that the timer was never activated in the middle of a stimulus.

Subjects. The subjects were 64 infants (36 males and 28 females). Mean age was 9.5 weeks (range: 6–12 weeks). In order to obtain complete data on 64 subjects, it was necessary to test 136. Subjects were excluded for the following reasons: crying (42%), falling asleep (32%), ceasing to suck during the course of the experiment (3%), failure to meet the habituation criterion within 24 min (9%), failure to acquire the response (3%), equipment failure and experimenter error (4%), and miscellaneous (hiccups, etc.; 7%).[4]

Results

For purposes of statistical comparison, an examination was made of each subject's rate of sucking during five intervals: baseline minute, 3rd min before shift, average of the last 2 min before shift, average of the first 2 min after shift, and average of all 4 min after shift. Difference scores were then calculated for each subject for each of the following comparisons: (a) acquisition of the sucking response: 3rd min before shift minus baseline; (b) satiation: 3rd min before shift minus the average of the last 2 min before shift; (c) release from satiation: average of the first 2 min after shift minus the average of the last 2 min before shift; (d) release from satiation for the full 4 min: average of the 4 min after shift minus the last 2 min before shift.

Subjects in all conditions acquired the high-amplitude response and satiated to the first stimulus prior to shift. An indication of the mean change in response rate during the period following shift for each of the five groups is provided in Table 1. Randomization tests for independent samples (Siegel, 1956) were used to assess postshift performance of each of the experimental groups in comparison with the control group for the first 2-min and full 4-min release from satiation measures. Because the pattern of significant results ($p < .05$ or better, one-tailed) was the same for both the 2- and 4-min postshift periods, the subsequent discussion will not distinguish between them (see Table 1). The statistical analysis revealed that Groups 1, 3, and 4 ([fa]/[θa], [va]/[ða], and [va]−/[ða]−) displayed significant increases in sucking relative to the control group. Group 2 ([fa]−/[θa]−) did not differ from the control group. Thus, the infants behaved in accordance with the adultlike pattern in that they discriminated both of the voiced fricative contrasts, but only the voiceless fricative contrast in which frication noise was present.

Discussion

The present results indicate that infants as young as 2 months old are capable of discriminating place of articulation contrasts in voiced and voiceless fricative pairs. To the best of our knowledge, the present study is the first to show discrimination of the voiced pair, [va]/[ða], by infants. The finding that infants also discriminated the voiceless pair is consistent with the finding by Holmberg et al. (1977) that 6-month-old infants can discriminate an [f]/[θ] contrast.

The present study also explored the role of formant transitions in the infant's perception of fricative contrasts. Formant transition differences do appear to provide a sufficient basis for the infant's discrimination of the voiced fricative contrast as evidenced by the fact that both the versions with (i.e., [va]/[ða]) and without (i.e., [va]−/[ða]−) the appropriate frication noise are discriminated. A different picture is presented by the results with the voiceless fricatives. Formant transition differences for these items proved to provide sufficient basis for discrimination only when accompanied by the appropriate frication noise. One possible reason for the infants' failure to discriminate the [fa]−/[θa]− pair is that the fricative noises provide the distinctive cues for signaling the contrast. This would not be surprising, given that the overall amplitude of fricative noise for voiceless fricatives is considerably higher than for their voiced counterparts. Moreover, as noted earlier in the discussion of Carden et al.'s (1981) results, the formant

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[3] In the case of talker PN, when the [fa]− and [θa]− tokens were identified as stop consonants, they were labeled as *ba* 99% and 91% of the time, respectively.

[4] The dropout rate for this experiment is typical for experiments with infant subjects. Furthermore, subjects were eliminated only during the preshift portion of the experiment and not after, so that it might be more accurate to say that the infants who completed the preshift portion of the test were assigned randomly to the experimental groups.

Table 1
Mean Change in Response Rate After Shift

		Release from satiation (minutes after shift)	
Group	Stimulus pair	First 2	Full 4
1	fa/ɵa	7.04*	7.40*
2	fa–/ɵa–	0.71	0.42
3	va/ða	5.71*	4.15*
4	va–/ða–	9.96*	6.56*
5	Control	−1.47	−1.59

* Indicates a reliable difference ($p < .05$ or better) according to randomization tests when compared with performance in the control session.

transition differences seem to be less distinctive for voiceless than for voiced fricatives. Nevertheless, there is a second possibility that needs to be considered, namely, that the fricative noise provides a necessary context for discriminating the formant transition differences. By this latter view, it is not that there are distinctive cues inherent in the frication noises of [fa] and [ɵa], but rather that the processing of the formant transitions as cues to a place of articulation difference depends upon their being perceived as part of an articulatory gesture relating to fricative production.[5] Indeed, the results of Harris (1958) demonstrating that frication noises from [fa] and [ɵa] syllables can be interchanged with no apparent change in their identification supports the view that the noise may provide only the necessary context as opposed to distinctive information.[6] In any event, the present results do not allow us to distinguish between these two alternative explanations for the infants' failure to discriminate the [fa]–/[ɵa]–contrast. For this reason, we decided to undertake a more systematic investigation of the role that fricative noises play in infants' discrimination of voiceless fricative contrasts.

Experiment 2

The notion that [f] and [ɵ] noise may play primarily a contextual role in the perception of voiceless fricative contrasts stems from the findings that interchanging these fricative noises apparently does not change the perceived identity of the resulting sounds for adult listeners (Harris, 1958). By extension, one would expect that appending the same fricative noise (e.g., one appropriate to [fa]) to fricationless versions of [fa] and [ɵa] syllables would have much the same effect, namely, that these syllables would be heard as [fa] and [ɵa], respectively. Thus, if fricative noise merely serves as a necessary context for discriminating the formant transition differences between [fa] and [ɵa], then the addition of a common fricative noise to the [fa]–/[ɵa]– tokens should allow infants to discriminate them. On the other hand, if the role of the fricative noise is to provide distinctive cues to the identity of [fa] and [ɵa], then the presence of [fa] versus [ɵa] frication differences may be a sufficient basis for discrimination, even in the absence of any accompanying formant transition differences. The present experiment was designed to test both of these possibilities. Hence, one group of infants heard a contrast between [fa]– and [ɵa]– tokens to which a common [f]–fricative noise had been appended. A second group of infants was presented with a contrast between items consisting of the frication portions of [fa] and [ɵa] plus the vowel with the distinctive formant transitions removed.

Method

Procedure. The HAS procedure was employed as described in the previous experiment.

Stimuli. The [fa] and [ɵa] tokens employed in Experiment 1 were modified for use in the second experiment. The PCM system was used to make the necessary modifications. One pair of stimuli consisted of the original [fa] stimulus plus a hybrid stimulus produced by taking the [ɵa] token, removing its frication by cutting at the point of zero amplitude nearest to the end of fricative noise and substituting the comparable frication noise from [fa] token. Because the posttransition vocalic portions of the original [fa] and [ɵa] tokens were identical, this new token, "Fn+ɵa–" ([f] noise + fricationless [ɵa]), differed from the [fa] stimulus only in its formant transitions which were appropriate for [ɵa]. Its overall duration was 530 ms, the same as the [fa] token. Note that there were no obvious acoustic discontinuities in this sound.

The second pair of items was produced by using the PCM system to remove the formant transitions of the vocalic portion of the [fa] token used in Experiment 1. The frication noises from [fa] and [ɵa], obtained by cutting the stimuli just prior to the first pitch pulse, were appended to the common vocalic portion. The resulting tokens, designated as "Fn+a" ([f] + [a]) and "ɵa+a" ([ɵ] noise + [a]), had overall durations of 475 ms.[7] The output of the PCM system was then used to prepare the audio tapes employed in this experiment.

Design. Each infant in the study was seen for one session. Twelve subjects were assigned randomly to each of two experimental groups, and an additional 12 subjects were assigned randomly to a control group. Infants in one group were tested for their ability to detect a distinction between [fa] and Fn+ɵa-, while infants in a second group were tested on the Fn+a/ɵn+a contrast. The presentation order of the items in a given stimulus pair was counterbalanced across subjects for each group. Three each of the 12 control subjects were assigned at random to one of the four stimuli for the entire test session.

Apparatus. The same equipment was employed as described for the previous experiment.

[5] Thus, one possible source for such an effect may lie in peripheral auditory processing. Delgutte and Kiang (1984) have argued, based on single unit auditory nerve recordings, that fricative noise modifies the coding of the following consonant transitions. On the other hand, this explanation, in terms of an auditory contrast effect, does not easily account for Carden et al.'s (1981) results, where subjects showed a boundary shift on a transition continuum when they were merely instructed to assign fricative labels to the stop (i.e., fricationless) series.

[6] Our preliminary studies confirm the results of Harris (1958) but also indicate that there is a great deal of speaker variation.

[7] The neutral [a] context was included because it did not appear that infants would suck to hear the fricative noise portions in isolation. We do not wish to make any claim for the naturalness of these tokens or for the absence of discontinuity between the frication and vocalic portions of these stimuli, although no such discontinuity was perceptible to us. Suffice it to say that any discontinuities would be the same for both members of the pair.

Subjects. The subjects were 36 infants (18 males and 18 females). Mean age was 10.1 weeks (range: 7.6–11.6 weeks). In order to obtain complete data on 36 subjects, it was necessary to test 75. Subjects were excluded for the following reasons: crying (59%), falling asleep (28%), equipment failure (5%), failure to acquire the response (5%), and miscellaneous (hiccups, etc.; 3%).

Results

Difference scores were calculated for each subject as per Experiment 1 for (a) acquisition of the sucking response; (b) satiation to the preshift stimulus; (c) release from satiation during the first 2 postshift minutes; and (d) release from satiation for the full 4 postshift minutes. As in the previous experiment, subjects in all groups acquired the conditioned response and satiated to the preshift stimulus. An indication of the mean change in response rate during the postshift period is displayed in Table 2. Randomization tests for independent samples were again employed to analyze postshift performance for both the 2- and full-4-min periods. The pattern of significant results ($p < .025$ or better, one-tailed)[8] was identical for both the 2- and full-4-min periods. Both of the experimental groups (i.e., [fa]/Fn+θa and Fn+a/θn+a) exhibited significant increases in postshift sucking relative to the controls. Thus, fricative noise evidently contributes to the infant's perception of fricative contrasts in two ways—both as a source of distinctive information and as a context for discriminating formant transition differences.

Discussion

The present experiment investigated the role which fricative noise plays in infants' discrimination of fricative contrasts. Specifically, does the importance of the fricative noise lie in distinctive cues which it embodies, or does it merely provide an appropriate context for formant transition cues in signaling a place of articulation contrast between fricatives? The somewhat surprising answer seems to be that it does both. Consider first the notion that distinctive cues are inherent in the frication. The present experiment demonstrated that the addition of only the frication portion of [fa] and [θa] to the same vocalic segment ([a]) resulted in discriminably different tokens for infants. Given this result and the demonstration from the previous experiment that infants did not discriminate truncated fricative syllables lacking the appropriate frications, one might be tempted to conclude that the distinctive fricative noises are both the necessary and sufficient cues for infants. However, this conclusion must be rejected, given the results for the second experimental group in the present study. Infants were able to discriminate the [fa]/Fn+θa− contrast despite the fact that both items included an identical frication portion. Instead, the two members of this pair differed only in their formant transitions.[9] This latter result parallels the sorts of context effects observed by Carden et al. (1981) using synthetic stimuli with adult subjects. Thus, under the proper circumstances, it appears that infants are able to utilize either formant transition or fricative noise differences to signal the [fa]/[θa] contrast.

Table 2
Mean Change in Response Rate After Shift

Group	Stimulus pair	Release from satiation (minutes after shift)	
		First 2	Full 4
1	θn + a/Fn + a	6.29*	6.52*
2	Fn + θa−/fa	11.29*	10.75*
3	Control	−4.42	−4.29

* Indicates a reliable difference ($p < .025$ or better) according to randomization tests when compared with performance in the control session.

Further statistical support for this conclusion comes from an additional analysis that we conducted comparing the performance of some of the groups across the two experiments. Note that across these experiments all crucial combinations of differences in fricative spectrum and formant transitions were tested. Thus, Group 1 in Experiment 1 (fa/θa) received stimuli that differed in both the frication spectrum and formant transitions, whereas Group 2 (fa−/θa−) received stimuli that differed on formant transitions without any accompanying frication. In Experiment 2, Group 1 (θn+a/Fn+a) received stimuli that differed only in their frication portion, but without any formant transition, and Group 2 (Fn+θa−/fa) received stimuli that differed in formant transitions but which included the same frication context. A Kruskal-Wallis one-way analysis of variance (ANOVA) indicated the main effect for groups was significant, $\chi^2(3, N = 48) = 7.84$, $p < .05$. Post hoc analyses conducted with randomization tests for independent samples revealed that the relatively poor discrimination response of the fa−/θa− group was largely responsible for the effect. Specifically, both Fn+a/θn+a and the Fn+θa−/fa groups had significantly higher postshift sucking scores, $t(22) = 3.17$, $p < .005$, and $t(22) = 1.72$, $p < .05$, respectively, than the fa−/θa− group. Similarly, the postshift performance of the fa/θa group was in the same direction, although marginal, $t(22) = 1.69$, $p < .06$. None of the other group comparisons remotely approached significance.

General Discussion

The present study was designed to examine several aspects of young infants' perception of place of articulation for fricatives. In particular, we asked whether the [fa]/[θa] and [va]/[ða] contrasts were discriminable for 2-month-olds, given the reports that such contrasts were relatively difficult for older infants (Eilers et al., 1977; Holmberg et al., 1977). In

[8] One-tailed tests are typically used in this type of experimental study with infant subjects, because the prediction is always that the infants in the test groups will show greater release from satiation, not less, than those in the control group. Nonetheless, these results were also significant in a two-tailed test ($p < .05$ or better).

[9] Informal testing with adults showed that the particular token we used of Fn+θa− was not strongly perceived as an interdental. Thus, it is all the more striking that infants made this discrimination, lending strong support for interpreting such results as a context effect.

this matter, the results were unambiguous in indicating that such contrasts are discriminable for 2-month-olds.

Having established that infants have the capacity to discriminate such contrasts at an early age, we sought to determine the nature of the information that infants were responding to. The first experiment suggested that formant transition differences alone were not a sufficient basis to account for infants' discrimination of the [fa]/[θa] contrast because there was no evidence of discrimination in the absence of an appropriate fricative noise context. Indeed, this parallels the results found with adults (Carden et al., 1981). This led to an investigation of the role that fricative noise plays in the discrimination of the contrast. Despite the fact that most acoustic analyses reveal great similarities in the spectral characteristics of the frication portions of [fa] and [θa], there must be some distinctive components because infants were able to discriminate the frications in the absence of any other distinctive cues.

At the very least, the frication portion of the signal provides a necessary context for discriminating the kinds of formant transition differences found in natural utterances of [fa] and [θa]. This was demonstrated by the fact that the addition of a common fricative noise to a previously indiscriminable formant transition contrast served to render it discriminable. This result parallels the kinds of context effects observed in connection with adults' perception of fricative contrasts (Carden et al., 1981). It indicates that the context effects themselves do not depend on a long apprenticeship in producing and listening to speech. Rather, the source of these effects appears to be a consequence of the inherent organization of the underlying perceptual mechanisms.

The present findings point to a number of potentially useful directions for research toward understanding the mechanisms responsible for context effects. First, recall that the suggestion that some context effects may have a basis in linguistic experience stemmed from Carden et al.'s (1981) observation that simply instructing subjects to use a fricative or stop context was sufficient to produce category boundary shifts along synthetic speech continua. Given the present results, it may be that what is acquired with linguistic experience is not the different boundary locations for stop and fricative continua, but the ability to infer the necessary context when the cues are not physically present. Consequently, one would anticipate that infants would display different category boundary locations for stop and fricative continua produced by varying formant transitions. If so, this would be further evidence that the context effects themselves are inherent in the underlying perceptual mechanisms. We are currently investigating this possibility and undertaking further studies to see whether infants can be induced to shift boundaries in the absence of the appropriate physical context.

A further direction for research is to attempt to establish whether the underlying perceptual mechanisms are general auditory ones or whether they are specific to speech processing. In the case of previous reports of context effects in the processing of speech contrasts (i.e., Miller & Eimas, 1983), there was evidence of comparable perceptual boundary shifts for certain nonspeech stimuli (Jusczyk et al., 1983). It would be useful to know whether effects comparable to the ones observed in the present study occur in the infant's perception of nonspeech sounds.

In summary, the present study demonstrates that infants as young as 2-months old do have the capacity to discriminate place of articulation differences in labiodental and interdental fricatives. The results also suggest that the presence of an appropriate fricative noise context is a critical factor in the way in which the distinctive formant transition cues to such contrasts are perceived.

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