Discrimination in neonates of very short CVs

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The experiment reported here explores the ability of 4- to 5-day-old neonates to discriminate consonantal place of articulation and vowel quality using shortened CV syllables similar to those used by Blumstein and Stevens [J. Acoust. Soc. Am. **67**, 648–662 (1980)], without vowel steady-state information. The results show that the initial 34–44 ms of CV stimuli provide infants with sufficient information to discriminate place of articulation differences in stop consonants ([ba] vs [da], [ba] vs [ga], [bi] vs [di], and [bi] vs [gi]) and following vowel quality ([ba] vs [bi], [da] vs [di], and [ga] vs [gi]). These results suggest that infants can discriminate syllables on the basis of the onset properties of CV signals. Furthermore, this experiment indicates that neonates require little or no exposure to speech to succeed in such a discrimination task.

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INTRODUCTION

The perceptual capacities of infants for the sounds of speech have been shown to be remarkably rich. Infants can discriminate many phonetic contrasts corresponding to natural speech categories of voicing, place of articulation, manner of articulation, and vowel quality (Eimas *et al.*, 1971; Eimas, 1974, 1975; Jusczyk, 1977; Jusczyk and Thompson, 1978; Kuhl, 1979, 1983). Moreover, their discrimination abilities seem to be similar to those of adults. They can discriminate acoustic differences that distinguish phonetic categories, yet they are unable to discriminate comparable acoustic differences that do not distinguish these categories (Eimas *et al.*, 1971; Eimas, 1974, 1975). More recent studies have shown that infants are not only able to discriminate contrasting speech sounds, but they are also able to categorize them even in the face of changes in intonation and talkers' voices (Kuhl, 1979, 1983). There is also some suggestion that 6-month-old infants may categorize syllables with respect to phonetic features such as manner and place of articulation (Hillenbrand, 1984; Kuhl, 1980, 1985; Mehler, 1985; Bertoncini *et al.*, in press; Jusczyk and Derrah, in press). Infants also show perceptual trading relations, i.e., a change in the value of one acoustic attribute shifts the perceptual boundary along another acoustic dimension (Miller and Eimas, 1983), and they show a right ear advantage for the perception of speech sounds (Entus, 1977; Segalowitz and Chapman, 1980; Best *et al.*, 1982; Mehler and Bertoncini, 1984). There has been much debate in the literature as to whether the basis for all of these abilities reflects specialized speech processing capacities (cf. Eimas, 1985) or more generalized processes and mechanisms of the human auditory system (Jusczyk, 1985).

In all of these studies, the perceptual abilities of infants have been explored using syllable-sized units. Nevertheless, studies with adults have indicated that they have the capacity to identify consonant and vowel segments when presented with only portions of a full consonant–vowel (CV) syllable. In particular, it has been shown that listeners can identify both place of articulation and vowel quality when presented with only the first 10–20 ms at the release of a stop–vowel syllable (Blumstein and Stevens, 1980; Kewley-Port, 1983). These results have been interpreted in the context of a theory of acoustic invariance for speech (Stevens and Blumstein, 1978, 1981), which hypothesizes that acoustic properties corresponding to the phonetic dimensions of speech can be derived from particular portions of the speech signal, particularly those portions of the signal where there are rapid amplitude and spectral changes. With respect to phonetic features corresponding to place of articulation in stop consonants, it has been suggested that such features can be derived from the gross shape of the onset spectrum at the release of the stop consonant. Thus, listeners can extract information about place of articulation from the onset properties of a stop–vowel syllable.

A number of studies have explored infants' sensitivity to place of articulation in stop consonants (Moffitt, 1971). These studies have investigated the role of formant transitions or noise bursts within syllable-sized units (Morse, 1972; Eimas, 1974; Miller *et al.*, 1977). These studies indicated that infants can discriminate differences in place of articulation cued by changes in either formant transitions or bursts. More recently, Williams and Bush (1978) have shown that infants can discriminate place of articulation contrasts in CV syllables in the absence of the release burst, and Walley *et al.* (1984) have reported similar results with

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infants who were presented with only two formant stimuli without the burst.

In the present study, we explore the ability of infants to discriminate consonant place of articulation and vowel quality in the absence of a full CV syllable. The stimuli in this study are a subset of the synthetic CV stimuli used by Blumstein and Stevens (1980). These shortened CV stimuli contain the initial burst plus 29 ms of transitions moving toward the frequencies appropriate to the following vowel formants. The final portion (approximately 20 ms) of the formant transitions, as well as the vowel steady state (approximately 230 ms), were deleted. We will explore whether infants can discriminate consonant place of articulation and vowel quality in such stimuli. If they can, it would suggest that infants are indeed sensitive to rapid changes in the onset spectrum, as are adults, and that they can resolve differences among stimuli considerably shorter in duration than a CV syllable. Such results would be consistent with the view that neonates are sensitive to those properties of the speech that signal segmental differences, and that they do not need to "learn" these properties from experience with fully formed CV syllables.

The present study uses 4- to 5-day-old neonates as subjects. Until now, most experiments on infant speech perception have been carried out with 2- to 4-month-old subjects, on the assumption that responses observed at this age are excellent estimates of the initial state of perceptual mechanisms. Although most investigators maintain that during the first few months of life discrimination abilities do not appear to be influenced by early linguistic experience (Lasky *et al.*, 1975; Werker and Tees, 1984; Aslin *et al.*, 1983), no one has tested this notion directly. However, Streeter (1976) found that the sensitivity of 2-month-old infants to voicing differences was influenced by exposure to the parental language. Thus, it seems preferable to test infants as young as possible to insure minimal exposure to language, in general, and to the parental language, in particular. The auditory system is functional, although not fully developed, from birth (Schneider *et al.*, 1979; Aslin *et al.*, 1983). A number of experimental procedures involving behavioral responses have been used successfully with very young infants (DeCasper and Fifer, 1980; Mehler, 1981; Bertoncini, 1982; Alegria and Noirot, 1978; Segalowitz and Chapman, 1980; Mehler *et al.*, 1986). In this study, we report on an experiment investigating the ability of 4- to 5-day-old neonates to discriminate synthetic shortened versions of CV syllables varying in place of articulation for stop consonants [b, d, g] in the environment of the vowels [a] and [i].

I. METHOD

A. Stimuli

The stimuli used in this experiment correspond to tape-recorded versions of part of the stimulus set originally generated by Blumstein and Stevens (1980). The original stimuli were generated using a computer simulation of a terminal analog speech synthesizer in which the tuned circuits were connected in cascade (Klatt, 1980). The sampling rate for the synthesizer output was 10 kHz and the output was low-pass filtered with a cutoff frequency of about 4800 Hz. The six stimuli used were shortened versions of exemplar CV stimuli corresponding to the phonetic categories [b], [d], [g] in the environment of the vowels [a] and [i]. They consisted of a 5- or 10-ms noise burst, followed by 20-ms piecewise linear transitions, in which the onset frequencies of the first four formants were appropriate to the consonants [b], [d], [g] and the transitions were moving toward frequencies appropriate to the vowels [a] and [i]. Figure 1 shows a schematization of a spectrographic representation of a typical stimulus.

The fundamental frequency for all stimuli started at 103 Hz and rose in a piecewise linear fashion to approximately 119 Hz at 20 ms. For all stimuli, the duration of the transitions (i.e., duration of voicing) was defined as 20 ms or two glottal pulses. However, because the duration of the glottal pulses varied as a function of the changing fundamental frequency, the effective duration of voicing was 29 ms. To avoid a sudden discontinuity at the end of the glottal pulse, the synthesizer output "rang off" or decayed gradually. Thus, the total duration of the stimulus continued beyond 29 ms, as is shown by the waveform display at the bottom of Fig. 1.

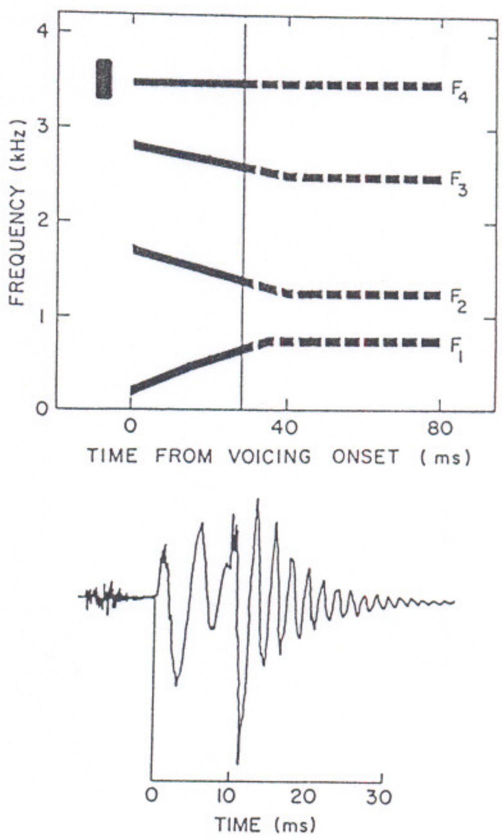

FIG. 1. The top panel shows a schematized spectrographic representation of a test stimulus with formant trajectories appropriate for the syllable [da] (after Blumstein and Stevens, 1980). The trajectories of the first four formants are shown, together with the position in frequency and time of the initial noise burst. The solid lines represent the actual configuration of the test stimulus, with the vertical line indicating the effective termination time of the test stimulus. The dashed lines at the right show how the formant trajectories would continue for the full consonant–vowel stimulus. The bottom panel shows the waveform of a typical stimulus whose formant trajectories are presented in the top panel.

Nevertheless, the actual duration in which there is significant amplitude of voicing is 29 ms. Table I shows the onset frequencies of the formant transitions (in Hz) as well as the frequencies of the first four formants of the vowels toward which the formant transitions moved.

Prior to the onset of voicing, a brief noise burst was inserted by passing a gated 5- or 10-ms burst of white noise through a simple tuned circuit. The stimuli were generated to be as similar to natural speech as possible. Thus, voice-onset time (VOT) varied across the various stimuli, as did the formant frequencies that the burst excited. To vary VOT, onset of the burst was varied relative to the onset of voicing. The [b] burst for all stimuli was inserted 5 ms prior to the onset of voicing, the [d] burst was inserted 10 ms prior to the onset of voicing, and the [g] burst was inserted 15 ms prior to the onset of voicing. The [b] burst excited a resonator centered at the starting frequency of $F2$, the [d] burst excited $F4$ in the environment of [a], and $F4$ and $F5$ in the environment of [i]. The [g] burst excited $F2$ in the environment of [a] and $F3$ in the environment of [i]. In order to make the stimuli sound as natural as possible, the duration of the burst also varied across the stimuli. The duration of the burst was 5 ms for all of the [a] stimuli. For the [i] stimuli, the duration of the burst was 5 ms for [b], and 10 ms for [d] and [g]. The amplitude of the burst was 0–5 dB less than the amplitude of the adjacent formants in the following vowel.

Table II shows the duration characteristics of the test stimuli. Note that the total duration of the stimuli varied from 34 ms for [ba] and [bi] to 44 ms for [ga] and [gi]. The duration differences between stimuli within discrimination pairs will be discussed below.

The overall amplitude of the stimuli varied, as in natural speech, owing to the effects of different formant frequencies on amplitude. As previously indicated, the stimuli used in this study were a subset of those used by Blumstein and Stevens (1980). These stimuli were perceived to be of equal loudness and were presented in the current study maintaining the same relative differences as those which were present in the Blumstein and Stevens (1980) study. It is worth noting that the major amplitude differences in the stimuli are conveyed by differences in the intrinsic amplitudes of the vowels [i] and [a] and, in the particular stimuli used in the current study, the steady-state formants appropriate for the vowels [i] and [a] were deleted.

TABLE I. Onset frequencies of the formant transitions (in Hz) for the stimuli [ba], [bi], [da], [di], [ga], [gi] as well as the frequencies of the first four formants of the vowels [a,i] toward which the formant transitions moved.

	$F1$	$F2$	$F3$	$F4$
[ba]	200	900	2000	3500
[bi]	180	1800	2600	3200
[da]	200	1700	2800	3500
[di]	180	2000	2800	3900
[ga]	200	1640	2100	3500
[gi]	180	2400	3000	3400
[a]	720	1240	2500	3500
[i]	330	2200	3000	3600

TABLE II. Duration characteristics of the test stimuli (in ms).

	VOT	Duration of voicing	Total duration
[ba]	5	29	34
[bi]	5	29	34
[da]	10	29	39
[di]	10	29	39
[ga]	15	29	44
[gi]	15	29	44

B. Subjects

All subjects were recruited at the Baudelocque Maternity Hospital in Paris, France. They were healthy, full-term newborns free from complications during pregnancy and delivery. Their gestational age ranged from 38 to 41 weeks, and was confirmed by a neurological evaluation (Amiel-Tison, 1974) on the first and third day. All subjects weighed more than 2700 g at birth (mean birthweight: 3260 g, s.d.: 405 g), and had 5-min APGAR scores of 10. All subjects displayed positive reactions to an auditory test on their second day. Each ear was tested with stimuli in two frequency bands (1000–4000 and 4000–8000 Hz) of white noise at 80 dB delivered by a Babimètre Veit-Bizaguet.

Seventy-five newborns between the fourth and fifth day after delivery (mean age: 4.2 days) were tested. Of these, 57 (32 males and 25 females) completed the experiment. Eighteen infants were excluded for the following reasons: 10 did not habituate within 12 min, 3 went to sleep, and 5 cried during the experiment.

C. Apparatus

During the experiment, infants sucked on a standard nipple (Remond) that was connected to the pressure transducer, itself part of a specialized nonnutritive sucking device designed by CEMI (Lyon). The output of the pressure transducer was converted to an electric pulse that was fed through a potentiometer circuit that allowed the selection of the high-amplitude sucks by threshold adjustment. Impulsions exceeding the threshold were cumulated on an electronic counter that provided sucking rates per min throughout the experimental session. The same impulsions were used to trigger a Tandberg TD 20A tape recorder. The stimuli recorded on tape loops were binaurally presented with a Scott A 417 stereo amplifier and Sennheiser HD 414 headphones.

D. Procedure

The subjects were taken to a quiet, dimly lit experimental room, about 2 h after feeding. They were gently lifted out of their cradles and awakened either by manipulation or by being held in a face-to-face upright position for a few minutes. They were then returned to their cradles, in a semi-inclined position to maximize the chances of their remaining in a quiet, alert state. A mechanical arm held the nipple in the infant's mouth so that any intervention from the experimenter was avoided during the experimental session.

The high-amplitude sucking technique (HAS) (Siqueland and DeLucia, 1969; Eimas *et al.*, 1971) was used in an habituation–dishabituation paradigm involving three phases: (a) baseline; (b) habituation; and (c) test. During the baseline, no acoustic stimulation was presented. The pressure transducer's sensitivity was adjusted for each subject so that in every case the baseline rate was of 15–25 sucks per min. During the habituation and test phases, the presentation of tape-recorded stimuli was made contingent upon the infant's sucking rate, the maximal rate of presentation being 1 stimulus every 1.5 s. The habituation phase was terminated if, during two successive minutes, the sucking rate decreased by at least 20% of the maximum observed during the five preceding minutes. During the test phase, which lasted 5 min, the control group continued to receive the same stimulus, from the same channel, as was used during habituation. The experimental groups were presented with a new stimulus by switching from channel 1 to channel 2 of the tape recorder.[1] The switch was turned manually by an experimenter unaware of the pair of stimuli under test. The total duration of the experimental session did not exceed 15 min.

Subjects were randomly assigned to three independent groups: consonant group, vowel group, and control group. Table III shows the number of subjects in each group, and the pairs of stimuli presented to them. In the consonant group, infants were exposed to one of the four pair presented in Table III (five Ss for each pair). The habituation and the test stimuli differed phonetically in the place of articulation of the initial voiced stop consonant ([b] vs [d] or [b] vs [g]) in a vowel context of [a] or [i]. For the place of articulation contrasts, the duration differences between pairs of stimuli were either 5 or 10 ms; [ba] vs [da] and [bi] vs [di] differed by 5 ms, and [ba] vs [ga] and [bi] vs [gi] varied by 10 ms (see Table II). The vowel group was given pairs of stimuli varying in the vowel ([a] vs [i]) preceded by [b], [d], or [g]. For all of the vowel contrasts, the stimuli were of equal duration (see Table II). Each pair was presented to seven subjects. Finally, the 16 subjects of the control group were reinforced with the stimuli used to habituate the experimental groups. Each stimulus was presented to four subjects.

E. Results

Data on the habituation and test response rates of the three groups of newborns are given in Table IV, as well as the baseline and maximum scores. Maximal scores are between two and three times higher than sucking rates at baseline. This increase is significant for all three groups ($p < 0.001$ in each case) as tested by t test.

TABLE III. Pairs of stimuli (phonetically transcribed) presented to each group of subjects. Stimuli in the left-hand columns were presented as habituation stimuli, the corresponding stimuli in the right-hand columns were presented as test stimuli.

Groups	Consonant (20 subjects)		Vowel (21 subjects)		Control (16 subjects)	
	Hab.	Test	Hab.	Test	Hab.	Test
	[ba]	[da]	[ba]	[bi]	[ba]	[ba]
	[ba]	[ga]	[da]	[di]	[da]	[da]
	[bi]	[di]	[ga]	[gi]	[ga]	[ga]
	[bi]	[gi]			[bi]	[bi]

TABLE IV. Mean sucking rate (sucks per min) during baseline, maximum, and habituation periods and the 2 min after change for the two experimental groups (consonant, vowel) and the control group.

Groups	Consonant	Vowel	Control
Baseline	16.3	19.2	18.6
Maximum	47.7	45.8	45.2
Habituation (mean of last 2 min)	26.8	25.3	30.4
Test (mean of first 2 min)	32.1	33.4	29.2

Simple analyses of variance on the baseline, the maximum, and the mean of the last two habituation minutes indicated no difference in sucking rates among the three groups before the change $F(2,54) < 1$ in each case. Further analyses are based on the mean sucking rates for the last 2 min of habituation and the means for the first 2 min of test calculated for each subject. Within-group comparisons between these scores reveal a significant difference for each experimental group. The consonant group exhibited a noticeable increase in sucking rate after change ($t = 2.645$, $df = 19$, $p < 0.01$, one-tailed test), and so did the vowel group ($t = 3.454$, $df = 20$, $p < 0.005$). In contrast, there was no reliable change in sucking rate for the control group ($t = 0.459$, $df = 15$). Out of 41 experimental subjects, 33 (15 in consonant group and 18 in vowel group) increased their sucking rate after change, while in the control group only 8 out of 16 subjects increased their response rates after they had attained the habituation criterion. This difference is significant as measured by χ^2 ($\chi^2 = 5.267, p < 0.025$).

Figure 2 shows the mean difference sucking scores for each group. These were calculated by subtracting the mean score before change from the mean score after change, so that positive values indicated an increase in sucking rate that is taken to be a response to the novelty of stimuli in experimental conditions.

An analysis of variance was performed on these difference scores and it confirmed that there was a reliable difference among the three groups, $F = (2,54) = 4.23, p = 0.019$. *Post hoc* comparisons indicated that both experimental groups significantly differed from the control group (consonant versus control, $p < 0.05$, and vowel versus control, $p < 0.01$). As can be seen in Fig. 2, the vowel group seems to be reacting more strongly than the consonant group. These two experimental groups did not, however, differ reliably from one another. Thus, the results clearly show that newborns discriminate the shortened versions of CV syllable pairs differing in either the consonantal place of articulation or in the following vowel.

It should be noted that, in the analyses we have presented above, each experimental group was treated as a whole. In the vowel group there was no evidence of a difference between the subgroups that received various pairs of stimuli varying on the vowel. The three subgroups that received the pairs [ba-bi], [da-di], and [ga-gi] exhibited a comparable

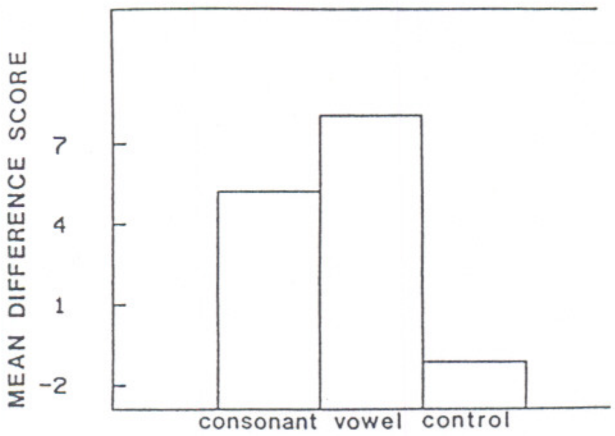

FIG. 2. Mean difference scores for consonant,vowel, and control groups. Each difference score was calculated by subtracting the mean number of sucks during the last two minutes of habituation from the mean number of sucks during the first two minutes of the test.

increase in their sucking rates; their mean difference scores were 8.5, 7.5, and 8.5, respectively.[2]

Detailed results for each experimental subgroup are given in Table V. For the consonant group the pattern of results is less homogeneous. As can be seen in Table III, half of the subjects received the contrast [b-d] or [b-g] in the context of [a], while the other half received the same contrasts in the context of [i]. Comparisons between each subgroup and the control group show that only the [a] subgroup differed reliably from the control group ($p < 0.05$). However, there was no significant difference between the [a] subgroup and the [i] subgroup, whose mean difference scores were 5.9 and 4.6, respectively. Finally, there was no difference between responses to [b-d] and [b-g] contrasts across the two vowel contexts.

II. DISCUSSION

The results of this study show that 4- to 5-day-old neonates can discriminate shortened versions of CV syllables in the absence of complete formant transitions and steady-state information. These same stimuli are correctly labeled by adult listeners for consonant place of articulation and vowel quality between 80%–100% of the time (Blumstein and Stevens, 1980).

TABLE V. Mean sucking rate (sucks per min) during baseline, habituation, and test as a function of stimulus pairs heard by the consonant and the vowel groups.

	Baseline	Habituation (mean of last 2 min)	Test (mean of first 2 min)
		Consonant group	
[ba/da]	18.6	23.6	29.1
[ba/ga]	15.8	26.1	32.4
[bi/di]	15.2	29.7	34.2
[bi/gi]	15.6	27.9	32.7
		Vowel group	
[ba/bi]	18.0	29.4	37.9
[da/di]	23.0	24.0	31.5
[ga/gi]	16.6	22.4	30.9

The consonant group reliably discriminated the stimuli [ba] vs [da], [ba] vs [ga], [bi] vs [di], and [bi] vs [gi], which suggests that complete transition information is not required by neonates to distinguish between voiced stops that differ in place of articulation. The subgroup that received the consonant change in the environment of the vowel [i] and the subgroup that received the change in the environment of the vowel [a] behave marginally different. The latter subgroup manifested a somewhat stronger reaction to the change than the former, but this difference was not significant. The absence of a significant difference between the [i] subgroup and the control group may be in part due to the high variability of our control group.

The results of the vowel group show that infants discriminate a vocalic change ([ba] vs [bi], [da] vs [di], and [ga] vs [gi]) on the basis of the information in the initial portions of brief CV stimuli. Each subgroup exhibited a reliable recovery of sucking rate, indicating that the differences in the onset spectrum are sufficient for neonates to discriminate changes in vowel quality. The presence of the steady-state portion of the signal is not necessary to distinguish the vowel quality of a speech signal.

In order to generate stimuli that were as natural as possible, the discrimination pairs used in this study varied not only in their onset properties, but also in overall duration and amplitude. Specifically, the consonant pairs varied in duration and amplitude, whereas the vowel pairs differed only in amplitude. While it is possible that the neonates were discriminating the stimuli on the basis of these duration and amplitude differences rather than on the onset properties of the signal, we do not think this is very likely. With respect to the duration differences, the stimulus pairs varied by either 5 or 10 ms in duration. In all cases, this duration difference reflects different VOT values for voiced stops. Research results with both infants and adults indicate that they are unable to discriminate within category VOT differences of 5 or 10 ms (Eimas *et al.*, 1971; Liberman *et al.*, 1958). With respect to amplitude differences between the stimulus pairs, we know of no evidence from either the adult or infant literature that would suggest that the magnitude of the amplitude differences in the stimuli used in this study is discriminable. Consequently, we feel reasonably sure that, similar to the abilities of adults in the Blumstein and Stevens (1980) study to label these stimuli, the ability of neonates to discriminate them reflects a sensitivity to the onset properties of the test stimuli.

From birth, infants seem to be sensitive to those properties of speech that signal segmental differences for adults. In particular, they are sensitive to rapid changes in the onset spectrum, changes that have been shown to provide adult listeners with information about the segmental features of CV syllables relating to place of articulation in stop consonants and vowel quality. These results suggest that the adults' capacity to use onset spectrum information when they are required to identify syllable components (Blumstein and Stevens, 1980; Kewley-Port, 1983) does not result from a learning process and experience with fully formed CV syllathe phonetic dimensions of speech.

Nevertheless, further experiments will be needed to de-
crimination studies provide only partial evidence for the categories (if any) into which infants allocate speech sounds (see also Kuhl, 1985). The ability to discriminate phonetic contrasts (see, for example, Eimas, 1974 on place contrasts) in the absence of irrelevant contextual variations does not necessarily mean that the different members of a category will be classified together. More convincing evidence could come from studies examining infants' perceptions of similarities in the presence of irrelevant contextual differences, such as vowel quality (Hillenbrand, 1984) or voicing duration. One way of doing this is to present sets of different (discriminable) exemplars from each category rather than a single item in each category. If the different stimuli within each category share only the hypothesized invariant attribute, infants have to extract this common property to discriminate one set from another. In this case, we would have an indication that infants categorize speech sounds on the basis of their invariant acoustic properties.

In conclusion, the results of the present study suggest that 4- to 5-day-old infants are sensitive to rapid changes in the spectrum, and that they can discriminate stimuli as short as 39–44 ms in duration. From such results, it might be hypothesized that infants use acoustic onset information to sort shortened syllable pairs according to the consonant and vowel features of the full-length syllables from which they were extracted. Future studies could provide information as to how the very young infant categorizes these shortened syllable onsets.

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[1]Since only the experimental groups (and not the control) received the habituation and test stimuli from two different channels of the tape recorder, it could be that the differences obtained between the groups reported in this study reflect differences in the experimental procedure. In particular, it could be that the switch in channels for the subjects in the experimental group could have inadvertently introduced a click or change in amplitude of the stimuli that would not occur for the subjects in the control group. We have tested for this possibility by running another group of 12 control subcontrol group used in the analysis of our results. Thus, any differences between the experimental and control group cannot be attributed to the different experimental procedures used.

to the vowels themselves (i.e., the [i] yielding a higher sucking rate in all cases). This interpretation can be ruled out because some infants in both the control and the consonant groups received an [a] vowel context, and other infants an [i] vowel context, and no difference in their sucking rate was observed.

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