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Infants' Discrimination of the Duration of a Rapid Spectrum Change in Nonspeech Signals

Abstract. *Two-month-old infants discriminated complex sinusoidal patterns that varied in the duration of their initial frequency transitions. Discrimination of these nonspeech sinusoidal patterns was a function of both the duration of the transitions and the total duration of the stimulus pattern. This contextual effect was observed even though the information specifying stimulus duration occurred after the transitional information. These findings parallel those observed with infants for perception of synthetic speech stimuli. Specialized speech processing capacities are thus not required to account for infants' sensitivity to contextual effects in acoustic signals, whether speech or nonspeech.*

More than a decade of research has demonstrated infants' capacities for processing speech sound (*1*). Early beliefs that these capacities reflected innate linguistic abilities were based exclusively on findings demonstrating discrimination of various speech contrasts in an adultlike manner analogous to categorical perception (*2, 3*). At the time, such categorical discrimination effects were thought to occur only for speech stimuli. However, subsequent research with both adults and infants indicated that similar effects could be obtained with certain nonspeech signals (*4, 5*). Instead of being specific to speech processing, it seemed that the infant's speech processing could be accounted for in terms of general auditory processing capabilities (*6*).

Recently, arguments for proposing specialized innate speech processing capacities in humans have relied on phenomena such as context effects and trading relations in which perceptual boundaries for phoneme categories were shown to depend on multiple sources of information relating to factors such as speaking rate and the nature of the surrounding phonemes in the utterance (*7*). For example, Miller and Liberman (*8*) found that changes in duration related to different speaking rates affected the interpretation of the acoustic correlates of the stop-glide contrast between /ba/ and /wa/: the perceptual boundary for formant transition duration (an acoustic correlate of the stop-glide distinction) was affected by the overall duration of the stimuli (*9*). For stimuli of short durations (ones generated during rapid speech), the perceptual boundary along a continuum of formant transition durations occurred at shorter durations than when stimuli of long duration (corresponding to slower rates of speaking) were used. Miller and Liberman argued that an explanation of their results in terms of the psychophysical properties of the stimuli was inadequate, and hence, that the only possible explanation for these perceptual adjustments was one that invoked specialized speech processing capacities. This hypothesis has gained some additional support from a recent study of infants by Eimas and Miller (*10*). They reported that 2-month-old infants' discriminations of synthetic consonant-vowel syllables differing in formant transition durations were affected by the overall durations of the syllables so that pairs of short syllables were discriminated at shorter transition durations than were pairs of long stimuli. Eimas and Miller interpreted their results as evidence for the operation of context effects in infant speech perception analogous to those observed with adults (*8*). The implication is that infants are equipped with specialized speech processing capacities that permit them to respond to speech sounds in a "relational" and "nonlinear" fashion (*11*).

Although these studies suggest that both infants and adults are sensitive to factors relating to speaking rate, they do not necessarily demonstrate that the underlying perceptual mechanisms are specific to processing speech signals. Neither study tested whether similar effects might be present for the perception of nonspeech signals (*12*). Such a test is critical to an understanding of the underlying perceptual mechanisms. For example, a demonstration that nonspeech sounds are processed differently would support the notion that the observed context effects in speech perception are the result of specialized speech processing capacities. On the other hand, a demonstration of context effects for nonspeech sounds that parallels those observed for speech stimuli would contradict a specialized mode of speech processing. A more parsimonious explanation of both the speech and nonspeech results could then be framed in terms of general perceptual constraints on the human auditory system (*13*).

We sought to determine whether a general auditory processing account can account for the infant's sensitivity to changes in speaking rate. Previous research with adults by Carrell *et al.* (*14*) used nonspeech control stimuli to demonstrate effects comparable to those reported by Miller and Liberman (*8*). Perceptual judgments of the initial frequency transition durations of nonspeech stimuli varied with changes in the overall durations of the stimuli. Thus, these results are consistent with an auditory processing account of context effect in speech perception. A specialized speech processing account cannot be entirely ruled out, because it is still possible to argue that the adults' performance derived in some way from a covert labeling strategy involving specialized speech processing capacities. For example, adults might have covertly assigned verbal labels such as "ba" and "wa" to the nonspeech stimuli and then processed them using special speech processing capacities (*15*). This alternative explanation would be countered if the parallels

Table 1. Mean response rates (number of high-amplitude responses per minute) ± standard errors as a function of condition.

Group (N = 20)	Response measures				
	Preshift			Postshift difference scores*	
	Baseline	Minute 3 before shift	Two minutes immediately before shift	Minutes 1 and 2	Minutes 1 to 4
15–35S†	25.7	53.5	30.3	12.8 ± 3.8‡	11.0 ± 2.8‡
35–55S§	23.5	55.1	31.9	6.3 ± 1.9	4.9 ± 1.7‡
15–35L§	26.5	50.3	27.7	5.4 ± 2.2	6.9 ± 2.1‡
35–55L†	26.4	51.8	31.2	7.6 ± 2.4‡	5.5 ± 2.3‡
Control	25.4	49.7	28.7	1.1 ± 2.7	−0.4 ± 2.5

*Difference scores were obtained by subtracting the average response rate during the 2-minute period preceding shift from the average first 2- or entire 4-minute response rate after the shift. †Different perceptual categories. ‡Randomization test for independent samples (one-tailed) on the difference from the control group, $P < 0.05$. §Same perceptual category.

between speech and nonspeech processing hold during infancy, before the opportunity arises to use any covert labeling strategy (*16*). We undertook this investigation to test Eimas and Miller's proposal that the existence of context effects in infant speech processing is evidence for the operation of specialized speech processing mechanisms.

The stimuli were sine-wave analogs of the synthetic speech syllables corresponding to /ba/ and /wa/ and used by Eimas and Miller (*17*). Two sets of stimuli were generated corresponding to the long (295 msec) and short (80 msec) syllables. The stimuli in each set contained identical formant transitions and differed only in their overall stimulus durations. Within a given set, the stimuli differed only in the durations of their initial frequency transitions. Three initial transition durations (15, 35, and 55 msec) were chosen from each series. Five groups (four experimental and one control) of 2-month-old infants (20 subjects per group) were tested (*18*). For the 80-msec [short (S)] stimuli, subjects in the 15–35S group received contrasts having initial transition durations of 15 and 35 msec and those in the 35–55S group, 35 and 55 msec. (For adults, the former pair contrasts stimuli chosen from different perceptual categories, whereas the latter pair contrasts stimuli from the same category). The remaining two experimental groups were presented with comparable pairings of the 295 msec [long (L)] stimuli. For the L groups, however, the 15–35 pairing consisted of stimuli chosen from the same perceptual category for adults, and the 35–55 pairing was of stimuli from different perceptual categories. For subjects in the control group, only a single stimulus chosen randomly from the two test series was presented for the entire test session. These five groups were comparable to those studied by Eimas and Miller.

The infants were tested with a version of the high-amplitude sucking procedure that has been used extensively in studies of infant speech perception (*2, 4*). After the determination of a baseline rate of high-amplitude sucking the presentation of one member of the test pairs was made contingent on the rate of high-amplitude sucking so that each criterial response resulted in a 1-second presentation of the sound plus silence, with the restriction that any responses that occurred during the presentation of a stimulus reset the timer controlling the stimulus feedback. This contingency was available until the infant's sucking rate had declined by 25 percent for two consecutive minutes. When this decrement criterion was achieved, subjects in the experimental groups were shifted to the other member of the stimulus pair. Subjects in the control group continued to receive the same stimulus after they had reached the criterion. The postshift period lasted for 4 minutes. Discrimination of the stimulus pairs was inferred from comparisons of the performance of the experimental and control groups during the postshift period (Table 1).

No statistically significant differences were observed in response rates among the groups before the shift. By contrast, several differences were observed after the shift. During the initial 2 minutes, the response rates of the between-category groups (combined, 11.25 ± 2.56) were significantly higher than those of the within-category groups (5.73 ± 2.56) ($P < 0.05$) and, individually, than the control group ($P < 0.05$, one-tailed tests)—a finding that parallels the results reported by Eimas and Miller (*19*). Thus, the infants in our study not only discriminated differences in duration of frequency transitions in nonspeech sounds, but they displayed a pattern of discrimination that was both relational and categorical and therefore directly comparable to the findings obtained by Eimas and Miller with synthetic speech stimuli.

Our findings provide further evidence that categorical discrimination by infants is not limited solely to the processing of speech sounds and demonstrate that relational processing (the tendency for perception to be influenced by later events) is not restricted to the infant's perception of speech sounds, but appears to be a general characteristic of the way infants process certain kinds of auditory signals. We do not deny that such relational processing may play a useful and important role in speech perception where such a capacity might enable the infant to recognize phonetic segments whose acoustic cues are modified or conditioned by the surrounding environment. However, our results demonstrate that the perceptual mechanisms underlying this capacity are not likely to be specific to speech. Instead, these perceptual capacities seem to be more general ones recruited for use in speech perception (*20*). Whether and to what extent their use in speech processing involves the modification and specialization of these basic auditory capacities remains to be seen (*4, 21*).

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9. Specifically, they found that their effect depended not only on factors relating to the overall duration of the syllable but also to its internal structure as well. Thus, given two syllables /wa/ and /wad/ equated for overall duration, the former would be perceived as spoken at a slower rate of speech than the latter and thus the perceptual boundary for formant transition duration would be expected to occur at longer duration values for /wa/. Miller and Liberman (*8*) argued that a psychophysical explanation framed in terms of changes in the overall duration of the syllables could not account for their finding.

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11. The terms "relational" and "nonlinear fashion" are ones recently adopted by Eimas and Miller (*10*) to describe perceptual compensation for context-conditioned variation in the speech signal, that is, shifts in the perceptual boundary that occur with changes in speaking rate [compare (*8*)]. Although they do not state it explicitly, Eimas and Miller (*10*) seem to imply that infants are responding to changes in speaking rates.
12. Both studies assumed that Miller and Liberman's demonstration (*8*) that the internal structure of the syllable and not just its overall duration affected the perceptual boundary for formant transition duration was sufficient to rule out a psychophysical account. Neither study considered the possibility that nonspeech sounds displaying similar internal relationships might give the same result.
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15. This possibility seems unlikely since Carrell *et al.* (*14*) gave their subjects a questionnaire after the test, the results of which gave no indication that subjects perceived the stimuli as being speech or speechlike.
16. Information about the way infants discriminate these sounds is needed to test whether specialized speech processing capacities are responsible for context effects, because although the studies with adults have examined both discrimination and identification, Eimas and Miller (*10*), studying infants, tested only discrimination. As is the practice, the adult identification data provide a basis for designating which stimulus pairings involve between-category discriminations and which involve within-category ones. Hence, any adequate explanation for the underlying basis of context effects must account for the infant's performance along with that of the adult.
17. Each complex tone stimulus was composed of three sinusoids whose frequencies, amplitudes, and temporal characteristics matched those of a synthetic speech continuum between /ba/ and /wa/. Carrell *et al.* (*14*) provide a complete description.
18. Of the 100 infants who completed the experiment, approximately half were males and half females. A total of 262 infants were tested. Of the infants who failed to complete the experiment, 107 infants cried, 26 fell asleep, 24 rejected the nipple, and 6 were dismissed because of equipment failure or experimenter error. There was no statistically significant difference in dropout rate across any of the conditions.
19. In a recent replication of their earlier study J. L. Miller and P. D. Eimas [*Cognition* **13**, 135 (1983)] reported that subjects in the within-category conditions showed higher postshift rates of responding than control subjects did. Analysis of our data for the full 4-minute period after shift revealed a similar tendency in the performance of the within-category groups 35–55S and 15–35L. This indicates that the same underlying perceptual mechanisms are operating for both speech and nonspeech.
20. Indeed, R. Goldhor's recent model [*J. Acoust. Soc. Am.* **73**, S4 (1983)] of speech processing by the peripheral auditory system can account for the relational effects observed when syllable durations are increased. The same relational patterns are predicted without any assumptions about computation of speaking rate.
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Fast Extracellular Calcium Transients: Involvement in Epileptic Processes

Abstract. *Improved liquid ion-exchanger microelectrodes made possible the observation of large, rapid decreases in the concentration of extracellular calcium ions during single epileptic spikes. Moreover, in definite cortical layers the decreases regularly started shortly before the onset of each epileptic spike. In view of the prominent role played by extracellular calcium ions in neuronal processes, including transmitter release and membrane excitability, these alterations probably exert a profound influence on the cellular events underlying epileptiform activity.*

Periods of synchronous neuronal activity are associated with substantial alterations in extracellular ion concentrations. It has been thought that these changes are rather slow, with time scales of hundreds of milliseconds, and that the participation of large populations of neurons is required. Such slow changes have been shown to occur in a variety of situations (*1*); however, it is important to determine whether rapid changes in extracellular ion concentrations take place during synchronous activation of groups of neurons, as during single epileptic events; these changes could then contribute significantly to the mechanisms by which synchronization occurs and hyperexcitability spreads. Technical limitations of liquid ion-exchanger electrodes, such as the slow rise time of responses, have prevented recordings of any rapid variations in the concentration of extracellular ions, especially variations in Ca^{2+}. Since ion-selective electrodes with short response rise times could be manufactured in our laboratory, we attempted to determine whether fast, transient changes in Ca^{2+} occur in epileptiform penicillin foci in the rat.

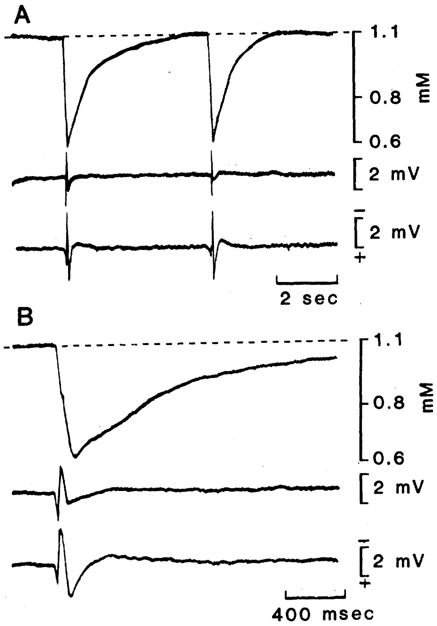

Fig. 1. (A and B) Alterations in the concentration of extracellular Ca^{2+} during spontaneous epileptic spikes in neocortical penicillin foci in rats. Upper traces, recordings of extracellular Ca^{2+}; middle traces, local field potentials (d-c–coupled) recorded through the reference side of the ion-sensitive microelectrode; bottom traces, electrocorticograms (a-c–coupled) from the neighboring cortical surface. The traces in (A) and (B) were obtained at two different sweep speeds. Recording depth was 600 μm below the cortical surface.

Ion-selective electrodes with a short response rise time were produced by the method of Ujec *et al.* (*2*). Conventional double-barreled ion-sensitive reference electrodes were siliconized and filled. A thinner, separately pulled micropipette was inserted into the ion-sensitive side until the longitudinal distance between the inner and outer tip was 5 to 10 μm, reducing considerably the longitudinal resistance of the ion-sensitive channel. The electrodes responded with an average of 26.93 ± 1.42 mV to a tenfold change in the Ca^{2+} concentration. The response rise time was measured in normal Ringer solution streaming in a thin tube. To eliminate electrical and mechanical artifacts, small amounts of a solution containing various Ca^{2+} concentrations were pressure-injected close to the tip of the electrode. Using a neutral ion exchanger (*3*), we measured the time to peak or trough of the responses at 2 to 4 msec. Recordings were performed in penicillin-induced cortical foci in rats under light halothane N_2O-O_2 anesthesia. Standard techniques were used for electrocardiographic recordings, for epicortical or forepaw stimulations, and for the creation of a restricted penicillin focus (20 IU of sodium penicillin G) in the forepaw area of the somatosensory cortex.

The average resting level of Ca^{2+} was 1.2 to 1.3 m*M*. After penicillin application, a progressive decrease of 0.1 to 0.2 m*M* could often be observed over a period of 2 to 4 minutes (*4*); then the resting level stabilized and remained constant throughout the experiments. During interictal discharges, extracellular Ca^{2+} levels decreased abruptly from baseline to minimum values of 0.45 to 0.55 m*M*, depending on the amount of time between penicillin application and