Rate of Acoustic Change May Underlie Hemispheric Specialization for Speech Perception

Abstract. *Phonemically similar syllables, differing only by temporal acoustic cues, were presented dichotically to investigate temporal processing mechanisms in hemispheric specialization for speech. Reducing the rate of acoustic change within syllables while keeping their phonemic characteristics constant significantly decreased the characteristic asymmetry in processing speech.*

One basic assumption related to hemispheric asymmetry is that the left cerebral hemisphere subserves language processing for most people and the right hemisphere plays a role in nonverbal acoustic processing. This study leads us to question the basis of this dichotomy.

Although the evidence for left-hemispheric dominance for language originally derived from observations of patients with acquired brain lesions (*1*), more recently evidence for this specialization in normal subjects has been demonstrated through the use of the dichotic listening test procedure (*2*): When two different stimuli are presented simultaneously, one to each ear, most right-handed listeners report more accurately verbal stimuli presented to the right ear. Kimura (*2*) interpreted the right ear advantage (REA) for dichotically presented verbal material as indicating that verbal information is processed in the left hemisphere.

Computerized techniques for synthesizing speech while selectively controlling acoustic variables have been used to investigate how speech is distinguished from nonspeech and why it is processed in the left hemisphere. When presented dichotically, not all classes of speech sounds produce equivalent REA's. Cutting (*3*) demonstrated that the largest REA is produced when stop consonants /b,d,g,p,t,k/ are presented in pairs dichotically; liquids (/l/ and /r/) produce a less strong REA, and steady-state vowels (/æ/ and /ɛ/) do not produce an REA. Cutting concluded that this different magnitude in the REA occurs systematically for different phonetic classes. In addition to phonetic differences, these classes of speech sounds also differ in the rate of change of acoustic cues that characterize their spectra. Thus, a critical factor underlying the REA may relate to acoustic rather than linguistic components. The results of several recent studies with normal and aphasic subjects suggest that, in fact, certain nonverbal acoustic processing occurs in the left rather than the right hemisphere (*4*). In each of these studies, signals to be processed were characterized by rapidly changing temporal cues. Thus, the REA for verbal material may reflect superiority of the left hemisphere for processing rapidly changing events, of which speech is only one example.

We suggest that psychoacoustic and speech processing studies, when viewed together, indicate that there may be a direct relationship between rapid temporal processing and speech processing. We proposed to investigate this hypothesis directly by dichotically presenting phonemically similar speech sounds, in which the rate of change of the formant transition was synthetically extended. We hypothesized that if the REA for verbal stimuli were related to rapidly changing temporal cues, altering the temporal component of the acoustic spectra within a phonetic class should result in a significant change in the magnitude of the REA.

Fifteen male and 15 female college students with normal hearing (*5*) were presented with two sets of synthetic speech stimuli, presented in pairs dichotically (*6*). Each set comprised six stop-consonant-vowel (CV) syllables, /ba,da,ga, pa,ta,ka/, presented randomly (*7*). In one set, 40-msec formant transitions, characteristic of these syllables, were used (*8*). In the other set, the duration of the formant transition was extended synthetically to 80 msec (*9*). The order of presentation of these two sets of stimuli was counter-balanced across subjects. A previous study demonstrated that, although the duration of the transition within these syllables was extended, the phonetic class perceived was not significantly altered (*10*).

For each set of stimuli two of the six syllables were paired and presented dichotically, one to each ear. For each set, 240 trials were presented. On a given trial, subjects indicated which two syllables they perceived; they were not asked to report the ear in which they were heard. Correctly identified syllables were scored according to the ear to which they had been presented. The absolute ear advantage was determined by subtracting the number of correct responses from syllables presented to the right ear (R) from those presented to the left ear (L).

Table 1. Correct responses to dichotically presented CV syllables incorporating 40- and 80-msec formant transitions, analyzed according to the ear of presentation.

Formant transition (msec)	Correct	Right ear	Left ear	R − L
40	7515	4136	3379	757
80	7482	3956	3526	430

There were no significant differences in the overall accuracy in reporting the CV syllables with 40-msec (52.4 percent correct) and 80-msec (52.0 percent correct) formant transitions, or in the order in which the two sets were presented [$F_{(1,28)} = 1.98$]. The interaction between order and transition duration was also nonsignificant [$F_{(1,28)} = .138$]. However, a significant main effect for transition duration was demonstrated [$F_{(1,28)} = 6.87$; $P < .014$]. The magnitude of the REA was significantly reduced when the duration of the formant transition was extended from 40 to 80 msec. The results with the characteristic 40-msec transition produced the expected REA, thus replicating the results of earlier studies (*11*). When the duration of the transition was extended from 40 to 80 msec, however, the magnitude of the REA significantly decreased. This decrease occurred because subjects produced fewer correct right-ear responses and more correct left-ear responses on the 80-msec transition set than they did on the 40-msec set (Table 1).

Traditionally, in studies of dichotic listening, the superior performance of the right ear has been explained as a reflection of the left cerebral hemisphere's subserving linguistic abilities. Although the basis of this linguistic superiority is not known, acoustic rather than purely linguistic mechanisms have been suggested (*4*). However, in previous studies in which direct attempts have been made to investigate the role of acoustic processing in hemispheric specialization for speech perception either (i) only nonverbal stimuli were used or (ii) verbal stimuli were used but both acoustic and linguistic cues were varied. In our study, however, stimuli were specifically developed to allow for acoustic variation within speech stimuli, in the absence of phonemic change. The results demonstrate that dichotically presented phonemically similar CV syllables, differing only in the rate of change of the formant transitions, are processed differently.

This finding, in conjunction with previous studies of other verbal and nonverbal stimuli (*4*), suggests that a strong REA (taken to reflect superiority of the left hemisphere) is obtained selectively for signals incorporating rapidly changing acoustic spectra, of which speech is one good example. We have shown that the rate of change of acoustic cues rather than the linguistic nature of the stimuli, per se, may underlie this effect. Analysis of rapidly changing acoustic features may, in fact, play a critical role in the accurate perception of fluent speech by binding together phonetic segments so that at rapid transmission rates the temporal order and segmentation of speech may be preserved (*12*). It is in the areas of perception and production of rapidly changing sequential information that patients with language disorders have been found to be specifically impaired (*13, 14*). Tallal and her colleagues (*14, 15*) have suggested that a basic deficit in perceiving and producing rapidly changing sequential information may contribute significantly to the speech and language disorders of some aphasic patients.

We are not suggesting that the REA does not reflect superiority of the left hemisphere for processing linguistic material. Rather, the superiority of the left hemisphere for linguistic processing may reflect, at least in part, left-hemispheric dominance in processing rapidly changing acoustic events, which is critical for the processing of fluent speech.

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References and Notes

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5. All subjects had normal hearing sensitivity as assessed by standard audiometry and no directional discrepancy between right and left ear thresholds of more than 5 dB across the frequencies between 500 and 4000 Hz.
6. The CV syllables, generated on the Haskins Laboratories parallel resonance synthesizer, formed a matched set differing from each other only in place of articulation, voicing, or both. Each stimulus was 250 msec long with an initial 5-msec broad-spectrum burst followed by a transitional formant period in which the formants moved toward the steady-state segment for the vowel /a/, which was identical for all stimuli. During the transitional segment, the frequencies changed linearly over time from the starting values to the steady-state values. For each of the six syllables there were two different fundamental frequencies: 114 and 110 Hz. Overall amplitude contours were identical for all stimuli.
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9. The first set had syllables incorporating a 40-msec formant transition, and the second set, 80-msec ones. The spectra values for the 80- and 40-msec transition syllables were identical; only the rate of change of the transition was extended by means of a parallel resonance synthesizer. These stimuli with formant transitions of extended duration were originally developed by P. Tallal and M. Piercy [*Neuropsychologia* **13**, 69 (1975)] to investigate the impairment of children with language disorders in discriminating speech sounds that incorporate rapidly changing acoustic spectra. These children's ability to discriminate these sounds improved significantly when the rate of acoustic change of the formant transitions was synthetically decreased.
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16. We thank J. Miller and P. Eimas for allowing us to use their synthetic speech stimuli; the Haskins Laboratory for allowing us to use their facilities; and G. Yeni-Komshian for technical advice and theoretical discussion.
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Microwaves Induce Peripheral Vasodilation in Squirrel Monkey

Abstract. *Vasomotor activity in cutaneous tail veins was indexed by changes in local skin temperature during exposure of the whole body to 12.3-centimeter continuous microwaves. At an ambient temperature (26°C) just below that at which tail vessels normally vasodilate, criterion dilation was initiated by 5-minute exposures to a microwave power density of 8 milliwatts per square centimeter. This intensity deposits energy equivalent to approximately 20 percent of the monkey's resting metabolic rate but produces no observable change in deep body temperature. Intensity increments of 3 to 4 milliwatts per square centimeter for 1°C reductions in ambient temperature below 26°C produced identical responses. That no vasodilation occurred during infrared exposures of equivalent power density suggests that noncutaneous thermosensitive structures may mediate microwave activation of thermoregulatory responses in the peripheral vasomotor system.*

In thermally neutral environments, the peripheral vasomotor response of warm-blooded (endothermic) species continuously provides fine control of body temperature. Physiological regulation of heat flow into or out of the body depends largely on autonomically controlled changes in the volume, rate, and distribution of blood supplied to the skin. The stimulus to constriction or dilation of cutaneous vessels is often peripheral as, for example, when localized or whole-body changes occur in the temperature of the skin (*1*). The stimulus can also originate centrally, in the absence of peripheral thermal events, when the deep body temperature rises (*2*). Rapid changes in peripheral vasomotor state have been produced in a variety of experimental animals by altering the temperature of the anterior hypothalamus with stereotaxically implanted thermode devices (*3*). In such experiments, dilation or constriction in highly vasoactive skin areas such as ears, tail, or extremities is often indexed by abrupt increases or decreases in local skin temperature.

Under specific exposure conditions and at relatively low intensities, electromagnetic energy of the microwave frequency range can produce body heating, often favoring deep tissues over the skin (*4, 5*). Exposure to intense microwaves raises the body temperature of animal subjects and interferes significantly with ongoing behavioral and physiological processes, thereby upsetting thermal homeostasis (*6*). On the other hand, investigations into the biological effects of low-intensity microwaves (often dubbed "nonthermal") have largely ignored the thermoregulatory consequences of such exposure, although subtle thermal effects caused by exposure to power densities of 1 to 10 mW/cm² have been suspected but not demonstrated (*7*). We now report that monkeys in a cool environment can be induced to vasodilate by brief whole-body exposures to microwaves at intensities that produce no ob-

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