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Left-ear advantage for sounds characterized by a rapidly varying resonance frequency

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Nonspeech stimuli were synthesized that could constitute second-formant transitions in consonant-vowel (CV) syllables, with either ascending or descending resonance frequencies. These were presented monaurally with contralateral noise, and reaction times for stimulus identification were measured. Reaction times were 12.8 msec faster when the stimulus was presented to the left ear than to the right ear, suggesting right-hemisphere involvement in the processing of these stimuli. This result suggests that rapid temporal variation is not a sufficient stimulus property to invoke left-hemisphere processing. The roles of acoustic structure of the stimulus and coding strategies of the subject are considered as factors that may determine lateralized hemispheric processing.

Accounts of the division of labor between the cerebral hemispheres have changed in recent years. In auditory perception, verbal processes have been attributed to the left hemisphere and nonverbal processes to the right hemisphere (Kimura, 1967). This view, however, has not accounted for subsequent data. For example, right-ear advantages, which are presumed to reflect left-hemisphere processes, have been found using nonverbal stimuli, such as sawtooth waves differing in rise time, which are musically codable as plucked or bowed violin strings (Blechner, in press), and rapidly changing tonal sequences (Halperin, Nachshon, & Carmon, 1973). These results, considered along with several studies using visual stimuli (e.g., Carmon & Nachshon, 1971; Goldman, Lodge, Hammer, Semmes, & Mishkin, 1968), suggest that rapid temporal variation is a sufficient (although perhaps not necessary) stimulus dimension for invoking the superiority of left-hemisphere processing mechanisms.

According to this view, left-hemisphere processes might also be summoned by tasks involving nonlinguistic sounds in which the resonance frequency is rapidly varied. Aside from their rapid temporal variation, such sounds are interesting from another perspective. In a speech context, as part of synthetic two-formant consonant-vowel (CV) syllables, they can constitute second-formant transitions that cue the phonemic distinction between voiced stop consonants (Liberman, Delattre, & Cooper, 1952). Yet, when isolated from a speech context, the formant transitions resemble the sound of birdsong, and have been called "chirps."

In a variety of experimental paradigms, the chirps yield distinctively different patterns of results than do speech sounds. For example, in identification and discrimination experiments, stop consonants in CV syllables demonstrate categorical perception, but their isolated second-formant transitions are not perceived categorically (Mattingly, Liberman, Syrdal, & Halwes, 1971). In addition, speeded classification tasks with CV syllables varying in consonant and fundamental frequency have revealed that irrelevant variation in pitch interferes with identification of stop consonants, whereas irrelevant variation in stop consonants does not interfere with pitch identification (Day & Wood, 1972; Wood, 1974, 1975). In contrast to this asymmetric interference, second-formant transitions varying in slope and fundamental frequency produce symmetric interference in the speeded classification task (Wood, 1975, Experiment 3).

These results, along with others, have been interpreted as reflecting a dichotomy between auditory and phonetic processes. However, recent experiments with nonspeech stimuli differing in rise time have yielded the same data patterns as speech stimuli in the above-mentioned paradigms, casting doubt on whether the results obtained with speech in these paradigms do in fact reflect a unique *phonetic* level of processing (Blechner, in press; Blechner, Day, & Cutting, 1976; Cutting & Rosner, 1974). Nevertheless, comparable results with speech and certain nonspeech sounds leave open the possibility that these paradigms do converge on a levels-of-processing distinction, but that the levels themselves are best characterized by a dimension other than the linguistic-nonlinguistic distinction, such as levels of acoustic complexity or degree of codability. Therefore, it still seems necessary to obtain a complete set of experimental results using a single set of stimuli such as the chirps.

Ear advantage data, which have been considered

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another experimental operation converging on the auditory-phonetic distinction (Studdert-Kennedy, Shankweiler, & Pisoni, 1972), have not been reported for chirps. Unpublished studies attempting to use a dichotic identification paradigm with randomly selected subjects have yielded inconclusive results, largely because of poor identifiability of the chirps (Liberman, Note 1).

The present experiment observes whether chirps yield a significant ear advantage by presenting them monaurally with contralateral noise to right-handed subjects and by measuring reaction time (RT) for stimulus identification. This procedure has yielded a right-ear advantage for CV syllables (Springer, 1973). More importantly, Springer's procedure has also yielded a statistically significant right-ear advantage with musical stimuli differing in rise time (Blechner, in press), whereas previous dichotic experiments with the same stimuli had yielded null results (Cutting, Rosner, & Foard, 1975).

METHOD

Stimuli

The stimuli were generated on the parallel resonance synthesizer at Haskins Laboratories. They consisted of a frequency-varying pulse-excited resonance. Specified bandwidth was 90 Hz. One stimulus, the rising chirp, varied linearly in frequency from 1,232 to 1,620 Hz. The other, the falling chirp, varied from 1,920 to 1,620 Hz. Both chirps had a duration of 50 msec. In a speech context, these two stimuli could cue the distinction between /bae/ and /dae/. However, when presented in isolation, they sound like nonspeech chirps.

These particular resonance frequencies were chosen for another reason. It was decided that the rising and falling chirps should end on the same resonance frequency, since Brady, House, and Stevens (1961) have shown in frequency matching experiments that subjects tend to assign most weight to the final portion of such stimuli, rather than integrating values over the entire stimulus. It was hoped that, with the final frequencies equivalent, listeners would be forced to attend to the entire stimulus and its contour in order to distinguish the stimuli accurately.

Noise, presented contralaterally to the stimuli, was also generated by the parallel resonance synthesizer. The noise was 550 msec in duration and its bandpass frequencies were 1,232 and 1,920 Hz. The noise and both kinds of stimuli were digitized and stored on disk file using the Pulse Code Modulation (PCM) system at Haskins Laboratories. They were reconverted to analog form at the time of tape recording. The absolute levels of the noise and target stimuli, as presented to listeners, were 75 and 68 dB SPL, respectively.

Tapes

All tapes were prepared using the PCM system. A *display tape* was prepared to introduce the subjects to the stimuli. The two kinds of stimuli (rising and falling chirps) were played in the same order several times, beginning with three tokens of each item, then two of each, and finally one of each. Two *binaural identification tapes* were prepared, each with 32 tokens of the chirp stimuli (16 of each) in random order. Four *dichotic test tapes* were recorded. On one channel of each test tape, 60 tokens of the chirp stimuli were recorded, in random order with the constraint that every 10 stimuli contained equal numbers of rising and falling chirps. Thus, long runs of any one kind of stimulus were prevented. Sixty tokens of the noise were recorded on the second channel of the tape, with noise onset preceding stimulus onset by 250 msec. The interstimulus interval was 2 sec, measured between offset and onset of the noise. Four *dichotic practice tapes* were also prepared. These were identical in design with the test tapes but contained only 20 stimuli each.

Subjects and Apparatus

The 16 subjects included 6 males and 10 females, ranging in age from 18 to 25 years. All were strongly right-handed, as indicated by the five most reliable criteria found by Annett (1970). All were native speakers of English, and all reported no history of hearing trouble.

The tapes were played on an Ampex AG-500 tape recorder, and the stimuli were presented through matched Telephonics headphones (Model TDH-300Z). Subjects sat in a sound-insulated room and responded with their index finger on either of two telegraph keys mounted on a wooden board. Throughout the experiment, the left key was used for "Sound 1" responses (rising chirp) and the right key was used for "Sound 2" responses (falling chirp).

The on-line RT system employed GT-40 and PDP-11/45 computers in tandem. RT measurement was initiated by the onset of the noise, but the 250-msec lead time between the noise and stimulus was automatically subtracted from each RT by the computer program.

Procedure

The procedure was nearly identical to that used by Blechner (in press) with different stimuli. Listeners participated in the experiment in groups of two. For preliminary training, they listened to the display sequence after being told that the first kind of sound was to be called "Sound 1" and the second kind "Sound 2." Subjects were not told until after the experiment that the stimuli typically formed part of speech sounds.

After listening once to the display sequence, subjects were instructed on the mode of response. They then listened to the display sequence twice more, responding first with the left hand and then with the right. This was to insure that they could identify the stimuli correctly. Next, they listened to the binaural identification tapes. Eight of the subjects responded to the first tape with the left hand and the second with the right. For the other eight subjects, the order of responding hands was reversed.

For each individual listener, the chirp stimuli were always presented through the same headphone. Ear of presentation was alternated by having the listener reverse the headset. For eight of the participants the stimulus was presented through one of the headphones, while for the other eight it was presented through the opposite headphone.

There were four possible hand-ear configurations. The order of these conditions was determined by a balanced Latin square design, yielding four possible orderings that were administered to four subjects each. The four practice and test tapes, however, were always played in the same order, to prevent any possible confusion between the effects of the random orders and the hand-ear configurations.

Subjects were instructed to respond as quickly and accurately as possible. In the final data analysis, only the last 50 test trials in each block were considered, the first 10 functioning as warm-up trials to stabilize performance. The listener, however, was not told that the first 10 trials would not count.

RESULTS AND DISCUSSION

Left-Ear Advantage

All of the subjects were able to identify the chirp stimuli accurately. In the binaural identification trials, no listener made more than 4.7% errors.

For the RT data of the task with contralateral noise, median RT was calculated for each block of test trials for each subject. An analysis of variance was performed on the medians, with order of conditions considered as a between-subjects factor and hand and ear of presentation as within-subjects factors. The mean across subjects of individual medians for left- and right-ear presentation of the stimuli were 686.8 and 699.6 msec, respectively. The 12.8-msec advantage for left-ear presentation was statistically significant [$F(1,12) = 10.02$, $p < .01$]. No other main effects or interaction terms were significant.

Listeners were very accurate in the stimulus-plus-noise identification task, with the mean error rate only 2.6%. An analysis of variance of the accuracy data, identical in design to the analysis of the RT data, showed no significant main effects or interactions.

Hemispheric Processes

The present finding of a left-ear advantage for identification of nonspeech sounds that vary rapidly in resonance frequency implicates the right cerebral hemisphere in the processing of these sounds. This result would seem to contradict the hypothesis that processing of rapid temporal variation may be specialized in the left hemisphere. However, in several important respects, the chirps used in this experiment differ from other temporally varying sounds for which laterality data have been obtained. For example, unlike the CV syllables used by Springer (1973) and the plucked and bowed sounds used by Blechner (in press), the chirps are not readily codable or even familiar to most listeners. It is possible that left-hemisphere processing mechanisms are invoked only by an interaction between temporal variation and codability, regardless of whether or not the coding of sounds is linguistic.

Two other factors should be considered. First, even though the present stimuli were characterized by rapid temporal variation, subjects could conceivably have distinguished between them without processing the rapid variation. They might, for instance, have attended to the initial frequency of the chirps. The study of Brady, House, and Stevens (1961) suggests that this is probably not the case, but it is not conclusive.

Second, certain purely acoustic characteristics distinguish the present stimuli from other nonlinguistic sounds that have yielded a right-ear advantage, and these acoustic characteristics alone may be responsible for the determination of hemispheric specialization. As an analogy, consider the plucked and bowed sounds used by Cutting et al. (1975). In a series of identification and discrimination experiments, they found that plucked and bowed sounds yielded the data pattern indicative of categorical perception when the stimulus amplitude decayed gradually over a period of approximately 750 msec. However, when the stimuli were truncated, so that only 250 msec of sound followed the attainment of peak amplitude, the data no longer reflected categorical perception. Unfortunately, no laterality data have yet been reported with such truncated plucked and bowed sounds. Nevertheless, the data of Cutting et al. stress the importance of the entire acoustic gestalt as a factor affecting perceptual processes. It is possible that, if the chirps were placed in an extended nonspeech context, they might still sound as unfamiliar and uncodable to subjects, but they might nevertheless yield rather different laterality data.

In summary, it appears that rapid temporal variation is not a sufficient stimulus characteristic to yield a right-ear advantage, but currently it is not clear which other factors, such as duration, codability, or listening strategy, may be significant.

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