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Left Hemisphere Selectivity For Processing Duration In Normal Subjects

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The role of the left cerebral hemisphere for the discrimination of duration was examined in a group of normal subjects. Two tasks were presented: the first required a reaction-time response to the offset of monaural pulse sequences varying in interpulse duration, and the second required the discrimination of small differences in durations, within a delayed-comparison paradigm. In each task a right-ear advantage was obtained when the durations were 50 msec or less. No ear advantage was obtained for the larger durations of 67 to 120 msec. Since the perceptual distinctiveness of phonemes may be provided by durations approximating 50 msec, the nature of the relationship between the left hemisphere's role in temporal processing and speech processing may be elaborated.

The speech function in man is known to be organized primarily within the left cerebral hemisphere. To account for the lateralization of speech, some investigators have attempted to determine more elementary left hemisphere processes upon which the perception and production of speech may be based (Efron, 1963a,b; Kimura, 1976). The reductionist approach taken by Efron (1963a,b) suggests that the left hemisphere contains specialized timing mechanisms employed for speech and nonspeech events. Efron (1963b) demonstrated that aphasics were impaired in judging the order of occurrence of nonverbal stimuli and concluded that aphasia was primarily a temporal disorder. He further demonstrated with normal subjects (Efron, 1963a) that the left hemisphere was the locus for judgments of the successive order and simultaneity of nonverbal stimuli. Consequently, the "language" hemisphere was shown to be a "temporally specialized" hemisphere.

Subsequent investigations with brain-damaged and nonbrain-damaged subjects have identified the left hemisphere as the primary site for other

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forms of temporal analysis as well. At present, a left-hemisphere superiority has been shown for brain-damaged subjects in tasks requiring perception of the simultaneity of visual and auditory stimuli (Efron, 1963b), of sequential order (Nachshon & Carmon, 1971) and of differences in stimulus duration (Gordon, 1967; Needham & Black, 1970). For normal subjects, a left-hemisphere superiority has been reported for tasks requiring visual, tactile, and auditory perception of temporal order (Efron, 1963a; Mills, 1977) and perception of tonal sequences (Halperin, Nachshon, & Carmon 1973; Papcun, Krashen, Terbeek, Remington, & Harshman, 1974; Natale, 1977).

Since speech sounds are temporally structured, a relationship between temporal processing and speech processing appears plausible. However, previous data do not permit elaboration of this hypothesized relationship. One reason for the resulting lack of clarification may be due to the limited investigation that the hypothesis has received. For example, in the reported studies of brain-damaged and normal subjects, only three kinds of temporal discriminations have been investigated. Consequently, one purpose of the present investigation was to examine the generality of the left hemisphere–temporal processing hypothesis.

Hemispheric asymmetry for processing temporal characteristics of nonverbal auditory stimuli was examined within temporal tasks not previously employed with normal subjects. Two experiments examined possible hemispheric specialization for processing stimulus duration. The paradigm employed in Experiment I introduces a new methodology to investigate the discrimination of unfilled stimulus durations, whereas in Experiment II a delayed-comparison paradigm was employed to investigate the discrimination of small differences in duration.

A second purpose of the present research was to examine possible constraints on the generalization that temporal functions are subserved by the left hemisphere. If the left hemisphere's capacity to process speech is, in part, based upon a specialized ability to analyze temporal information, it is possible that the left hemisphere would be restricted to processing only that temporal information in the same time range as speech. The structure of speech may be described with reference to the temporal parameters associated with correct perception of phonemes, of syllables, and of larger units such as phrases and sentences. Hence, to conceptualize a relationship between speech processing and temporal processing, it becomes necessary to identify those temporal characteristics of speech which may be associated with left hemisphere lateralization.

The stimulus values for the duration tasks of the present study were based on the phoneme, permitting a comparison of nonverbal temporal discriminations with temporal discriminations underlying phonemic distinctions. The phoneme was the linguistic unit chosen for comparison because perceptual cues for phonemes and, in particular, consonants may be provided by stimulus durations or differences in duration of approximately 50 msec (Minifie, 1973). Moreover, the perception and identification of these consonant sounds has been shown to be consistently lateralized to the left hemisphere (Berlin, Lowe-Bell, Cullen, Thompson, & Loovis, 1973; Studdert-Kennedy & Shankweiler, 1970). This value provides an indication of the temporal characteristics which are functionally important at the phonemic level of speech, whereas temporal units at other levels of speech are not as readily identified.

The present experiments, then, reflect an attempt to specify the relationship between speech processing and temporal processing within the left hemisphere by identifying a critical range of nonverbal stimulus durations for which specialization of the left hemisphere would be demonstrated. The experiments employed auditory stimulation in order to provide a closer approximation to the natural sequence of speech than would be provided by visual or cutaneous stimulation. The exclusive use of the auditory modality seemed both reasonable and warranted since the specific experimental hypothesis is related to speech processing. However, the more general left hemisphere–temporal processing hypothesis would require further testing in the visual and cutaneous modalities to justify the conclusion that the left-hemisphere timing process is an elementary process upon which speech is possibly organized. Positive findings employing auditory stimulation may derive from the auditory nature of speech, suggesting that the timing mechanism may be a functional part of the linguistic system in the left hemisphere rather than a basic elementary process.

Hemispheric asymmetry for the discrimination of duration has not received prior investigation with normal subjects and studies with brain-damaged patients (Gordon, 1967; Needham & Black, 1970), for which there is a general impairment of functioning, do not permit an uncontaminated estimate of the range of stimulus durations for which the normal left hemisphere may be specialized. Hence, the relationship between left-hemispheric specialization for processing temporal cues of duration and for processing speech could not be accurately assessed from studies of brain-damaged patients.

If both hemispheres were involved in processing durations outside the critical range, then a constraint on the hypothesis concerning the left hemisphere's role in processing temporal information would be necessary. If the critical ranges do, in fact, compare to the values of the temporal units which provide perceptual cues for the identification of phonemes, then an elaboration of the relationship between the speech processing and temporal processing functions of the left hemisphere may be provided.

EXPERIMENT I

The first experiment investigated the left hemisphere's role in processing the temporal interval or unfilled duration between two pulses in a train. Previous studies of normal subjects have shown that perception of temporal order and tonal sequences yield a right-ear advantage (Halperin et al., 1973; Papcun et al., 1974). Although identification in these tasks involves perception of differences in duration, it is confounded with perception of temporal order.

In the present study the subject heard a pulse sequence in either the left or the right ear in the presence of contralateral stimulation (steady buzz). A reaction-time (RT) response was required when the observer detected the offset of the pulse sequences. These trains of pulses varied in presentation rate and, thus, in interpulse interval, such that the temporal separation between successive clicks was 40, 50, 67, or 100 msec. The rationale for the task suggests that the subject would have to process the interval between pulses (unfilled duration) in order to know the sequence had ended, prior to making the RT response. Thus, each pulse train required that durations of either 40, 50, 67, or 100 msec be processed.

It is assumed that an ear difference in RT reflects specialized processing of the duration information from the contralateral hemisphere. This assumption is based upon Kimura's (1967) model which suggests that during dichotic stimulation, information on the contralateral pathways has functional priority over information on the ipsilateral ones. Consequently, a right-ear advantage reflects a predominant sampling of left-hemisphere function. The converse holds given a left-ear advantage.[1] The present study used dichotic stimulation to strengthen confidence in the assumption that the contralateral pathways would be employed and thus increase the probability of demonstrating an ear difference. Hence, the rationale for the task suggests that if the processing of duration occurs in the left hemisphere, then information related to the time of occurrence of each pulse will be transferred from the right hemisphere to the left hemisphere following left-ear stimulation. The transfer will be reflected in a greater RT value for sequences delivered to the left ear. Since information related to the time of occurrence of right-side stimulation is transmitted directly to the left hemisphere, there will be no transfer time involved in the resulting RT value. If both hemispheres are equipped to process the temporal information, then no transfer is required and there should be no ear differences in the resulting RT values.

[1] It should be pointed out that dichotic stimulation is not the only condition which will reveal an ear difference since under some conditions, monaural stimulation is sufficient (Bakker, 1969; Morais & Darwin, 1974). However, the occurrence of an ear difference when employing monaural stimulation is tenuous, depending both upon the type of response measure and the complexity of the task (Bever & Chiarello, 1974; Catlin, VanderVeer, & Teicher, 1976; Zurif, 1974).

Given the present hypothesis, an ear difference was expected for discrimination of the nonverbal stimulus durations of 50 msec or less, since the order of magnitude is comparable to stimulus durations associated with phoneme discrimination.

Materials and Methods

Subjects. A total of seven subjects ranging in age from 18 to 25 years were paid for participation in the experiment. They reported normal hearing and were right-handed as indicated by a questionnaire of six items. The items reflect skills found by Annett (1970) to be consistently performed with the preferred hand.

Apparatus. The experimental pulse trains were produced by modules of the Haer digital stimulator system, while the contralateral competition pulses were produced by Tektronix waveform and pulse generators. A Hewlett–Packard oscilloscope was used to calibrate the pulses. The stimuli were directed to the left or right channel of stereophonic headphones (Sharpe HA-10-A). A Hewlett–Packard countertimer was used to measure RT; it started when the last pulse was generated and was stopped by the subject's response.

Procedure. Sequences of 1-msec square wave pulses were presented at four presentation rates to either the left or the right ear at an average intensity of 80 dB SL. At the same time, the contralateral ear was presented with a competing stimulus consisting of a recurrent 1-msec square wave pulse presented at 100 Hz with an average intensity of 55 dB SL. The presentation rate of 100 Hz was chosen for the competition stimulus so as to be distinguishable from the experimental sequence and its intensity was determined by the subject to be equal to the intensity of the pulse trial. On each trial, the recurrent competition pulse started before the experimental sequence and continued on slightly longer, so that RT would be uninfluenced by its offset.

The experimental trains were composed of nine different lengths (2, 3, 4, 5, 7, 8, 10, 12, or 15 pulses per sequence), each randomly presented twice within a block of 18 trials. The difference in length was introduced as a control measure to prevent the subject from anticipating sequence termination. For each interpulse duration, the experiment included 288 trials (16 blocks); one-half of these were delivered to each ear. The order of presentation of right- or left-ear trials was given in a prearranged sequence of randomized blocks such that the maximum number of blocks delivered successively to one ear was not greater than two. The left hand was used to respond to one-half of the trials to either ear and the right hand for the other half. The order of hand use was counterbalanced within subjects. The subject was informed prior to a sequence presentation, which ear would be stimulated and which hand was to be used in the response. The RT response was made with the thumb on the top of the hand-held switch and the fingers were curled around the handle to minimize their movement.

The four presentation rates employed provided interpulse durations of 40, 50, 67, and 100 msec. The presentation order of pulse trains differing in interpulse duration was counterbalanced across subjects.

Each subject was given 72 practice trials at the beginning of an experimental session and received a total of four experimental sessions. A session consisted of 288 trials at one interpulse duration: 72 for each ear-hand combination.

Results and Discussion

An analysis of variance was computed with repeated measures on the factors of ear (left and right) and interpulse duration (40, 50, 67, and 100 msec). The overall mean RT value for sequences presented to the left ear (mean of 291.9 msec) was not significantly different from the RT value for sequences presented to the right ear (mean of 289.2 msec). A significant difference in RT was observed for interpulse duration; smaller durations were responded to more quickly than larger durations [$F(3,18) = 18.69$, $p < .001$]. The data for RTs as a function of interpulse duration and ear presentation are presented in Table 1. An interaction of ear and duration was significant at a confidence level of .05 [$F(3,18) = 4.586$]. A Neumann–Keuls test on the means indicated RT was shorter for the right ear compared to the left for the 40- and 50-msec interpulse durations ($p < .01$). For the 67- and 100-msec interpulse durations, mean ear differences did not reach significance. In fact, the two ears showed almost identical RT for 67 msec and the left ear had a somewhat smaller mean value for 100 msec.

The results indicate that the left hemisphere is predominant in processing interpulse durations of 40 and 50 msec, whereas both hemispheres are apparently involved in processing interpulse durations of 67 and 100 msec. The difference in RT values between the left and the right ear at the faster rates (6.7 to 8.4 msec) may be assumed to reflect the interhemispheric transfer time of temporal information, the value of which is compatible with estimates obtained from other investigations (Catlin & Neville, 1976; Efron, 1963a; Jeeves & Dixon, 1970).

The use of the left and the right hand was a control measure to ensure that neither hemisphere gained an advantage from a more direct control of motor output, and therefore was not included in the main analysis. Nevertheless, an analysis of variance computed for hand and rate factors showed the right-hand response was significantly faster than the left-hand response at each rate of presentation [$F(1,6) = 13.007$, $p < .001$]. A right-hand advantage in RT is consistent with the present hypothesis, except for the condition in which pulse sequences having interpulse durations of 67 and 100 msec arrived at the left ear. In this condition, no hand difference was anticipated.

The increase in RT with increases in interpulse duration for 50, 67, and 100 msec, shown in Fig. 1, suggests that the subject was performing the task in a rational manner according to the hypothesis. The observation

TABLE 1
MEAN REACTION TIME FOR THE LEFT AND THE RIGHT EAR FOR EACH OF FOUR INTERPULSE DURATIONS

Interpulse duration (msec)	Left	Right	*p*
100	335.5	338.0	n.s.
67	290.5	291.6	n.s.
50	268.5	261.8	<.01
40	273.8	265.4	<.01

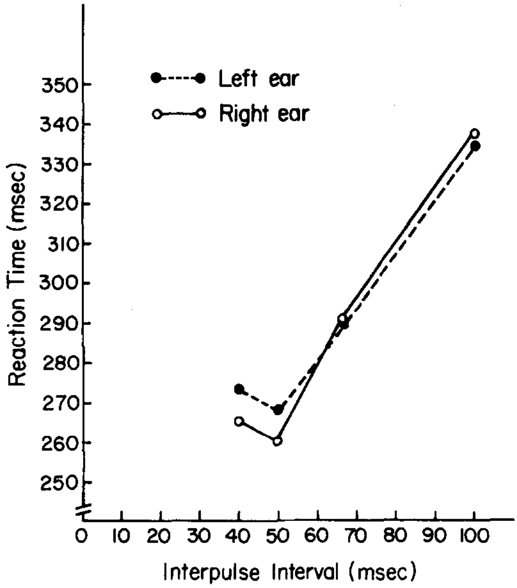

FIG. 1. Mean reaction time in milliseconds for the left and the right ear for each of four interpulse durations.

that the slope of this effect is not equivalent to 1.0, but rathers shows a 30-msec increase in RT for each 20-msec increase in interpulse duration indicates that memory or criterion factors cause the subjects to be less than ideal observers.

Reaction times to the offset of pulses separated by 40 and 50 msec were about the same. It seems likely that these values reflect a level below which RT does not further decrease.

EXPERIMENT II

The second experiment employed monaural presentation within a delayed comparison paradigm to investigate hemispheric specialization for processing small differences in duration. The delayed-comparison paradigm is comparable to that used with brain-damaged subjects (Gordon, 1967; Needham & Black, 1970) and the condition of monaural presentation is similar to that described by Morais and Darwin (1974) for presenting speech sounds. In the present task, the standard stimulus was presented binaurally, followed by a comparison stimulus presented monaurally to either the left or the right ear. It was assumed that the binaurally presented standard duration would be transmitted to both cerebral hemispheres whereas the monaurally presented comparison duration would be transmitted more strongly to the contralateral side. This assumption is based on the functional prepotence of the contralateral auditory pathways over the ipsilateral pathways; a difference found with monaural stimulation (Rosenzweig, 1951; Tunturi, 1946) and enhanced with dichotic stimulation (Hall & Goldstein, 1968). Consequently, the demonstration of a right-ear advantage is consistent with the assumption that processing occurred predominantly in the contralateral hemisphere. (For a more detailed description of possible information transmission in a monaural task, see Catlin, et al., 1976.)

It was anticipated that if the left hemisphere was primarily responsible for discrimination of small differences in duration, the accuracy of difference judgments would be greater for pairs in which the comparison durations were presented to the right ear than for pairs in which the comparison durations were presented to the left ear.

Materials and Methods

Subjects. A sample of 10 right-handed college students was tested and paid for participation. Each reported normal hearing and was given the previously described handedness questionnaire (Annett, 1970).

Apparatus. Output of the Haer stimulator system was used to produce the stimuli which were composed of 1-msec square wave pulses repeated every 20 msec. Differences in total train duration were controlled by preset gate values. All sequences were prerecorded on an audio tape and presented through Sharpe stereophonic headphones.

Procedure. A standard duration of 250 msec was played binaurally followed by a comparison duration of either 210, 230, 250, 270, or 290 msec randomly presented monaurally to the left or the right ear at an intensity level of 70 dB SL. The interval between the onset of the standard and the comparison duration was 2.5 sec. The subject was required to judge the relative duration of the two stimuli and orally report whether the comparison duration (always the second member of the pair) was the same, shorter, or longer than the standard duration. A total of 150 trials was given: 75 with comparison durations to the left ear and 75 to the right ear. The first 30 trials were considered as practice trials and not scored in the data analysis. The headphones were reversed for one-half of the subjects to control for any asymmetries in the audio channel.

Results and Discussion

An analysis of variance with repeated measures was computed on the data. The factors of classification were: ear (left and right) and duration (210, 230, 250, 270, and 290 msec). Comparison durations heard in the right ear were identified more accurately (an overall mean of correct judgments of 35.9) than were durations heard in the left ear (overall mean of 31.4). The ear effect was significant at the .01 level [$F(1,9) = 12.5$]. In addition, the shorter durations were more accurately identified than the longer durations for both the left and the right ear [$F(4,36) = 33.46, p < .01$], revealing a time order error. The psychometric function showing percentage correct responses for the left and the right ear at each comparison stimulus is shown in Fig. 2.

Inspection of these data indicates that the right-ear advantage occurred when comparison stimuli were the same duration or longer than the standard duration by 20 or 40 msec. No difference between pairs occurred

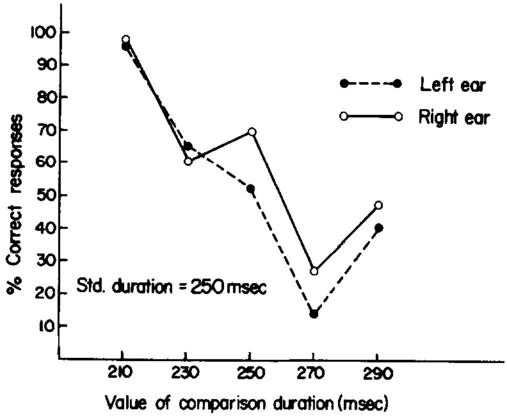

FIG. 2. Percentage correct responses for the left and the right ear at each value of the comparison duration.

when the comparison duration was 210 msec and a small difference favoring the left ear occurred when it was 230 msec.

The percentage correct responses for each ear as a function of type of judgment—shorter, same, or longer—are shown in Fig. 3. The nature of the errors made may be assessed from this figure. When the comparison duration was 250 msec, the most frequent error was to judge it as shorter than the standard when heard in either ear, although there were significantly more such errors when heard in the left ear [$t(9) = 2.011, p < .05$]. At the longer comparison durations of 270 and 290 msec, the majority of the errors for both ears consisted of making "same" judgments. Significantly more "same" judgments were shown for the left ear responses at the 270 msec value [$t(9) = 2.2298, p < .05$] but the difference did not reach significance for the 290 msec value [$t(9) = 1.0078, p > .05$]. As a consequence, a constant error was shown for the left ear but not for the right ear. The left ear point of subjective equality was at 270 msec, while that for the right ear was 250 msec (Woodworth & Schlosberg, 1954, p. 213).

In pairs in which the comparison stimulus was shorter than the standard stimulus, the majority of errors consisted of judging the comparison to be the same as the standard, but such errors were infrequent. Thus, performance was much improved in this condition over that in which the comparison stimulus was longer than the standard. The reason for this divergence in performance for duration differences of equal magnitude may be attributable to memory processes for duration. It is suggested that in this paradigm, the error in discrimination results from underestimation of the second stimulus (Mills, in progress). Consequently, errors in discrimination when the comparison stimulus was shorter than the standard stimulus would be undetected and a left-ear disadvantage would be masked.

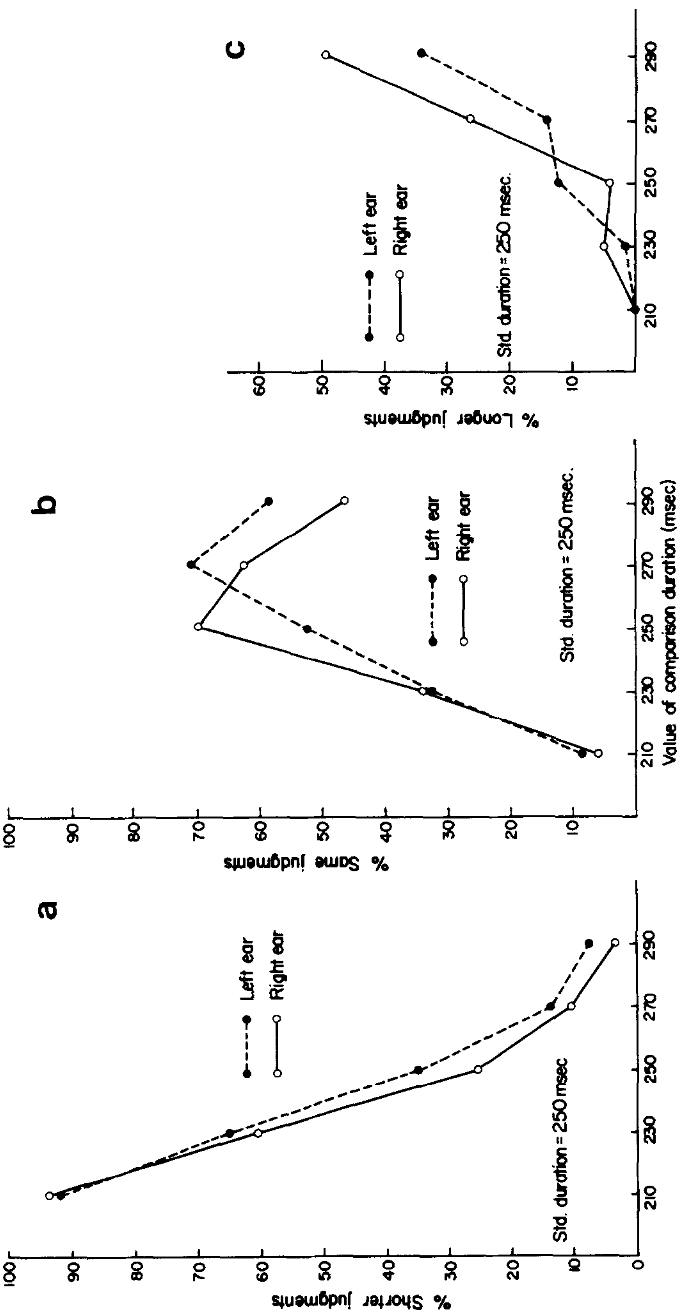

FIG. 3. Percentage correct responses for (a) shorter judgments, (b) same judgments, and (c) longer judgments at each value of comparison duration.

The right-ear advantage shown for differences in duration of 40 msec or less is in accord with the finding of Experiment I showing that the left hemisphere was superior to the right for processing durations of 50 msec or less. In the delayed comparison task the temporal discrimination is of a difference rather than an absolute duration, yet it is proposed that both tasks would require, among other things, a common mechanism in the left hemisphere which would process durations in the critical range. In Experiment II, the values of the duration differences were 20 and 40 msec. The difference could not be increased beyond the critical value of 50 msec and permit an evaluation of constraints on left-hemisphere processing, since larger duration differences (i.e., greater than 50 msec) would be easily discriminated, producing a ceiling effect which would obscure ear differences.

However, the paradigm would be useful for testing the hypothesis if the value of the standard duration was increased. According to Weber's Law, a larger stimulus difference will be required to produce a just noticeable difference when a larger standard stimulus is employed.

In the study just reported, the standard duration was 250 msec, but if it was increased to a value producing incorrect discrimination of comparison durations differing from the standard by more than 50 msec, an ear difference would not be predicted. A test of this prediction was made in a shorter version of Experiment II. Six subjects were employed and presented with a standard duration of 400 msec and comparison durations of 320, 360, 400, 440, 480, and 520 msec. A total of 84 pairs were presented: 42 with the comparison stimulus to the right ear and 42 with the comparison stimulus to the left ear. The percentage correct responses for each ear at each comparison duration are shown in Fig. 4, beside the comparable data from Experiment II.

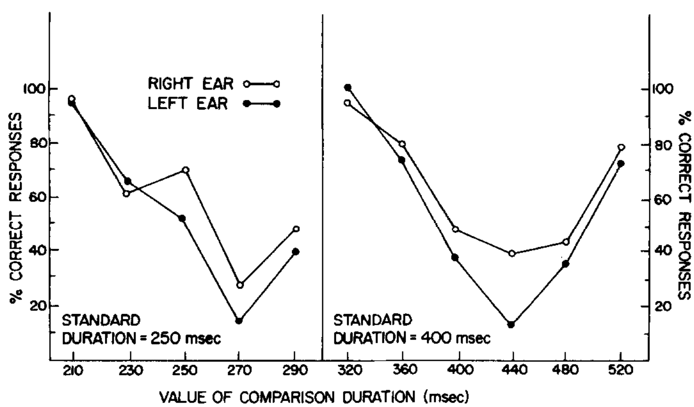

FIG. 4. Percentage correct responses for the left and right ear at each value of the comparison duration when the standard duration is 250 or 400 msec.

Observation of these data reveals that 75% correct discrimination for the condition employing the 250-msec standard required a stimulus difference of 30 msec whereas in the condition employing the 400-msec standard a stimulus difference of 50 msec was required. The function is consistent with Weber's Law and the Weber fraction is 0.12 for each condition.

Considering the between-ear performance in the 400-msec standard condition, a right ear advantage was shown [$t(5) = 2.82$, $p < .05$] and occurred when comparison stimuli were the same duration, or longer than the standard duration by 20 or 50 msec. The ear difference for the longer comparison stimuli was nonsignificant despite the difficulty in discrimination. This failure to observe a significant ear advantage for difference durations of 80 and 120 msec supports the hypothesis that the absolute value of the duration differences employed (i.e., approximately 50 msec) is critical to a demonstration of left hemisphere specialization.

GENERAL DISCUSSION

The results of the present investigation support previous findings indicating that the left hemisphere may be specialized for processing temporal information. Specifically, the discrimination of small durations and differences in duration of auditory stimuli appears to be dependent upon left-hemisphere processes, thus replicating with normal subjects the left-hemisphere superiority demonstrated in similar tasks with brain-damaged patients (Gordon, 1967; Needham & Black, 1970). However, on the basis of the present results the conclusion that the left hemisphere is specialized for auditory temporal discriminations needs to be qualified. The results obtained demonstrated left hemisphere specialization for processing stimulus durations only when those durations did not exceed 50 msec. This finding supports the hypothesis presented earlier, namely, that left-hemisphere specialization for processing duration information may be restricted to a defined range of stimulus durations. If stimulus durations in excess of 50 msec are employed, the left and right hemispheres appear equally capable of responding.

The notion that left-hemispheric specialization for duration may be restricted to a critical range is suggested by data obtained with brain-damaged subjects. These studies indicate that beyond certain interstimulus intervals, left and right brain-damaged groups perform similarly in tasks requiring identification of temporal order (Carmon & Nachshon, 1971; Efron, 1963b) or duration (Gordon, 1967; Needham & Black, 1970). However, the actual interstimulus interval required for equivalent performance between groups varied considerably from study to study. Unfortunately, due to the general impairment of functioning that accompanies brain damage, these estimates do not permit a meaningful assessment of the relationship between left-hemispheric specialization for processing temporal cues and for processing speech. The present study, employing normal subjects, obtained an uncontaminated estimate of the range of stimulus durations critical to left-hemispheric specialization and, therefore, provides a basis upon which the relationship between the left hemisphere's role in speech and its role in temporal duration tasks may be elaborated.

Left Hemisphere Specialization for Temporal Cues of a Critical Order of Magnitude

A specific hypothesis of this research suggested that the order of magnitude of temporal cues within a nonverbal temporal discrimination would be critical to the demonstration of left-hemisphere superiority. This hypothesis was based on the supposition that linguistic processing of phonemes necessarily requires the resolution of fine-grade temporal information conveyed in the acoustic waveform. The temporal information may be provided by small differences in the duration of otherwise identical formant transitions, differences in voice onset time for voiced and voiceless sounds, or differences in the overall duration of a sound. For each example the temporal dimension is one which conveys perceptually distinctive information facilitating the recognition of different speech sounds (Minifie, 1973; Sharf, 1971). The demonstration of hemispheric asymmetry for the discrimination of selected durations in a nonverbal context, as shown in the present study, is thought to be based on the same mechanism for temporal analysis as employed for the resolution of temporal information in a verbal context. Specifically, it is suggested that tasks requiring the perception of speech *qua* speech and tasks requiring the perception of nonverbal temporal stimuli are both dependent upon a specialized timing mechanism located in the left hemisphere. This conclusion identifies the temporal characteristics of phonemic stimuli as at least one critical feature for their lateralization in the left hemisphere.

This conclusion receives support from a study by Cutting (1974) who presented speech and nonspeech stimuli to subjects dichotically. The speech stimuli were synthetic consonant–vowel syllables and the nonspeech stimuli were like consonant–vowel syllables except that the first formant transition was inverted. As a consequence the stimuli could not have been produced in the vocal tract and were labeled "nonspeech." A right-ear advantage was obtained for both types of sounds. One explanation offered by Cutting is that the advantage reflected a superiority of the left hemisphere for auditory processing and that only auditory mechanisms were employed in the task. If discrimination of the speech sounds was based on auditory processing as seems likely, then discrimination of the nonspeech stimuli may have required similar processing since the identification was dependent upon comparable acoustic waveforms. Recently, Liberman, Shankweiler, and Syrdal (1974) have attempted to evaluate hemispheric asymmetry specifically for auditory processing and have presented isolated formant transitions dichotically. They report a slight left-ear advantage in recognition of these stimuli. This task does not necessarily require attention to the temporal dimension of the transition, i.e., its duration, and so left-hemisphere specialization would not be expected. If isolated formant transitions were presented in a paradigm which required attention to a temporal dimension, for example, a comparison of respective duration, then a right-ear advantage would be predicted.

Although durations less than 50 msec were critical to the observation of a right-ear advantage in the present study and are comparable to durations critical in cueing phoneme distinctions, left-hemisphere specialization has been shown for larger time units employing normal subjects. An attempt to account for this difference between the present study and previous studies of normal subjects follows from a consideration of the specific tasks employed. Halperin et al. (1973) reported a right-ear superiority for recall of dichotically presented tonal patterns containing one or two transitions in duration. The durations presented were 200 and 400 msec. In the Papcun et al. (1974) study, a right-ear advantage was obtained for dichotically presented Morse code patterns with units as long as 101.3 msec. In each of these studies a sequence of at least three stimuli was presented. The task, therefore, required the identification of a temporal pattern rather than a single duration, or difference in duration, as required within the tasks of the present investigation.

To draw an analogy with speech, the basic information unit within the structure of connected speech sequences is more likely the syllable rather than the phoneme, and the duration of a syllable approximates 200 msec (Lenneberg, 1967). Discrimination of a sequential pattern may require a different level of temporal processing than that required for a single duration. Consequently, the critical value associated with left hemisphere superiority when dealing with temporal patterns may be larger than that proposed here for single durations. It is suggested that the specific timing processes tapped in the left hemisphere are dependent upon the structure of the stimulus and the resultant task demands. If a temporal pattern can be discriminated on the basis of a larger time-unit than that critical for a single duration, then the syllable may be the relevant speech unit in the first instance, while the phoneme may be the unit in the second.

However, while it is considered that linguistic processing of phonemes invariably requires temporal analysis, other modes of perceptual analysis may be possible for syllables. It has been suggested that recognition of syllables may be based on identification of these stimuli as integrated wholes (Levy, 1974; Savin & Bever, 1970). Perception of a stimulus pattern as an integrated whole or gestalt would not involve a temporal analysis of that pattern. It therefore would not, according to the present account, depend upon a left-hemisphere timing mechanism. It is perhaps noteworthy that right hemisphere participation in speech, as demonstrated by studies of split-brain patients, occurs at the syllable level and beyond. Recognition of single phonemes, letters, or numbers is relatively poor (Levy, 1974; Zaidel, 1977). This finding, according to the present hypothesis, is accounted for by the supposition that phonemes necessarily require a fine-grade temporal analysis, the mechanism for which is lacking in the right hemisphere.

With respect to nonverbal tonal sequences, it has been also suggested that perception of these may occur in a gestalt manner. Papcun et al. (1974) obtained a significant left-ear advantage for one condition in their study and concluded the subject was attending to the tonal sequence in an holistic fashion. Spellacy (1970) presented tonal patterns similar to those of Papcun et al. (1974) and did not obtain any ear advantage. Consequently, extension of the present conclusions to the perception of syllables and nonverbal stimulus sequences would clearly be speculative. More data are required than are currently available in order to further an understanding of the processes underlying the lateralization of sequential stimuli and syllables.

Given these considerations, the type of timing mechanism located in the left hemisphere can, at the present time, be conceptualized as necessarily involved in temporal analysis of stimulus durations of the order of magnitude of phonemic durations.

REFERENCES

Aitken, P. 1976. The effects of contralateral noise on reaction time to monaural stimuli. *Perception and Psychophysics*, **19**(2), 206–210.

Annett, M. 1970. A classification of hand preferences by association analysis. *British Journal of Psychology*, **6**, 303–321.

Berlin, C., Lowe-Bell, S., Cullen, J., Thompson, C., & Loovis, C. 1973. Dichotic speech perception: An interpretation of right-ear advantage and temporal offset effects. *Journal of the Acoustical Society of America*, **53**(3), 699–709.

Carmon, A., & Nachshon, I. 1971. Effect of unilateral brain damage on perception of temporal order. *Cortex*, **7**(4), 410–418.

Catlin, J., VanderVeer, N., & Teicher, R. 1976. Monaural right-ear advantage in a target-identification task. *Brain and Language*, **4**, 471–481.

Cutting, J. 1974. Different speech processing mechanisms can be reflected in the results of discrimination and dichotic listening tasks. *Brain and Language*, **1**, 363–373.

Efron, R. 1963a. Effect of handedness on the perception of simultaneity and temporal order. *Brain*, **86**, 261–284.

Efron, R. 1963b. Temporal perception, aphasia and deja vu. *Brain*, **86**, 403–424.

Gordon, M. 1967. Reception and retention factors in tone duration discrimination in brain-damaged and control patients. *Cortex*, **3**, 233–249.

Hall, J., & Goldstein, M. 1968. Representation of binaural stimuli by single units in primary auditory cortex of anaesthetized cats. *Journal of the Acoustical Society of America*, **43**(3), 456–461.

Halperin, Y., Nachshon, I., & Carmon, A. 1973. Shift of ear superiority in dichotic listening to temporally patterned nonverbal stimuli. *Journal of the Acoustical Society of America*, **53**, 46–50.

Kimura, D. 1976. *Acquisition of a motor skill after left-hemisphere damage. Paper presented at the 21st International Congress of Psychology,* Paris.

Lennenberg, E. 1967. *Biological foundations of language.* New York: Wiley.

Levy, J. Psychobiological implications of bilateral asymmetry. In S. J. Dimond & J. G. Beaumont (Eds.) *Hemisphere function in the human brain.* London: Paul Elek (Scientific Books). Pp. 121–138.

Liberman, A., Shankweiler, & Syrdal 1974. The specialization of the language hemisphere. In *The neurosciences, third study program.* Cambridge, Ma: M.I.T.

Mills, L. Memory processes for auditory duration, in progress.

Minifie, F. 1973. Speech acoustics. In F. Minifie, T. Hixon, & F. Williams (Eds.) *Normal aspects of speech, hearing and language.* Englewood Cliffs, NJ: Prentice-Hall. P. 271.

Natale, M. 1977. Perception of nonlinguistic auditory rhythms by the speech hemisphere. *Brain and Language,* **4,** 32–44.

Needham, E., & Black, J. 1970. The relative ability of aphasic persons to judge the duration and intensity of pure tones. *Journal of Speech and Hearing Research,* **13,** 725–730.

Papcun, G., Krashen, S., Terbeek, D., Remington, R., & Harshman, R. 1974. Is the left hemisphere specialized for speech, language and/or something else? *Journal of the Acoustical Society of America,* **55**(2), 319–327.

Rosenzweig, M. 1951. Representation of the two ears at the auditory cortex. *American Journal of Physiology,* **167,** 147–158.

Savin, H., & Bever, T. 1970. The nonperceptual reality of the phoneme. *Journal of Verbal Learning and Verbal Behavior,* **9,** 295–302.

Sharf, D. 1971. Perceptual parameters of consonant sounds. *Language and Speech,* **14,** 169–177.

Spellacy, F. 1970. Lateral perference in the identification of patterned stimuli. *Journal of the Acoustical Society of America,* **47**(2), 574–578.

Studdert-Kennedy, M., & Shankweiler, D. 1970. Hemispheric specialization for speech perception. *Journal of the Acoustical Society of America,* **48,** 579–594.

Tunturi, A. 1946. A study on the pathway from the medial geniculate body to the acoustic cortex in the dog. *American Journal of Physiology,* **147,** 311–319.

Woodworth, R., & Schlosberg, H. 1954. *Experimental psychology* (revised). New York: Holt, Rinehart & Winston.

Zaidel, E. 1977. Auditory vocabulary of the right hemisphere following brain bisection or hemidecortication. *Cortex,* **12**(3), 191–211.

Zurif, E. 1974. Auditory lateralization: Prosodic and syntactic factors. *Brain and Language,* **1,** 391–404.