1972

Monotic and Dichotic Perception of (0-500 Msecs) Time-Staggered Cv-Monosyllables.

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73-2968

LOOVIS, Carl Francis, 1942-
MONOTIC AND DICHOTIC PERCEPTION OF (0-500 MSECS) TIME-STAGGERED CV MONOSYLLABLES.

The Louisiana State University and Agricultural and Mechanical College, Ph.D., 1972
Speech Pathology

University Microfilms, A XEROX Company, Ann Arbor, Michigan

MONOTIC AND DICHOTIC PERCEPTION OF (0-500 MSECS) TIME-STAGGERED CV MONOSYLLABLES

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Speech

by
Carl Francis Loovis
M.S., University of Wisconsin, 1966
August 1972

ACKNOWLEDGMENT

This research was made possible through the use of funds and equipment supplied by USPHS Grant No. NS-07005 to the Louisiana State University School of Medicine and the Kresge Hearing Research Laboratory of the South, under the direction of Dr. Charles I. Berlin. Personal support was obtained through a Neurological and Sensory Diseases Traineeship from the United States Office of Public Health, under the direction of Dr. Stuart I. Gilmore, Louisiana State University, Department of Speech, Baton Rouge, Louisiana.

The author wishes to express his appreciation to his wife, Mary, for her encouragement and endurance. Special thanks to Dr. Berlin and the staff of the Kresge Laboratory, whose vision, patience, and friendship made the effort a worthwhile experience. Thank you to Jack Cullen of the Kresge Laboratory and to Dr. Franklin S. Cooper and the staff of the Haskins Laboratories for their effort and cooperation in preparing the tapes. The author also appreciates Mrs. Gae Decker's part in preparing the manuscript, Dr. Sena Lowe-Bell's assistance in data collection, Dr. Carl Thompson's editorial diligence, and Dr. Prentiss Schilling and the Experimental Statistics Department, Louisiana State University, for their statistical support.

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ABSTRACT

Twelve female subjects were used to study the effects of time-staggered, paired CV nonsense syllables on dichotic and monotic listening. The naturally produced syllables were /pa/, /ba/, /ta/, /da/, /ka/, and /ga/, whose onsets were aligned to be simultaneous, then 90, 180, 250, and 500 msecs apart. A special condition designated as "boundary" (alignment of CV monosyllables at the beginning point of large amplitude periodicity) was also used.

The study addressed itself to two basic questions:

1. What happens to lead-lag functions by ear when stimuli are time-staggered to 500 msecs?
2. When stimuli are aligned at their boundaries instead of their onsets:
    a. What happens to the right ear laterality effect?
    b. What happens to voiced-unvoiced differences?

Results showed:

1. Dichotic Condition
    a. At simultaneity, a right ear superiority was seen.

b. At 90 msecs, the right ear in the lag position did better than the left ear, but when the left ear was put in the lag position, it performed as well as the right ear.

c. Beyond 90 msecs, differences attenuated and no lag effect could be seen.

d. Leading and lagging CV's were equally intelligible at 500 msecs.

e. Introduction of the boundary condition enhanced laterality effect and markedly attenuated the preponderance of unvoiced over voiced CV identification seen in the simultaneous condition.

2. Monotic Condition

a. No ear superiority at simultaneity.

b. Ear symmetry was maintained at all time conditions.

c. Lead stimulus was reported at virtually 100 percent accuracy for all time conditions from 90-500 msecs.

d. Leading and lagging syllables were both perceived almost 100 percent of the time when separated by 500 msecs.

e. The boundary condition introduced no laterality effect, and reversed the preponderance of voiced over unvoiced CV identification.

CHAPTER I

INTRODUCTION

Evidence for Primacy of a Crossed Auditory Pathway and Left Hemisphere Dominance for Speech and Language

At the beginning of the nineteenth century, Gall and Spurzheim of Vienna set the stage for what was soon to become an intensive interest in cerebral localization of speech and language function. Modern trends in experimental and clinical neurology are decidedly against any rigid doctrine of cortical specification of psychological function. However, mounting evidence does suggest that major central components of linguistic activity involve roughly circumscribed regions of the cortex and their connections. Such evidence has been based on: (a) anatomical, (b) physiological, (c) pharmacological, and (d) psycho-physical observations.

Dichotic Message Testing--an Important New Vehicle in Assessing Hemispheric Dominance for Speech Perception

Simultaneous dichotic stimulus presentation[1] can indicate which hemisphere is dominant for speech perception. Supporting this argument is the prediction of dichotic results by the Wada-Rasmussen test (1949). This is a test of intra-carotid injection of sodium amytal. By temporarily interfering with the functioning of one cerebral hemisphere, it is possible to determine the dominant hemisphere with respect to its participation in speech. From the standpoint of qualitative appraisal of language, this method has the drawback that the time of action of the drug is too short to permit any extensive testing of the different aspects of language; nevertheless, there is ample neurosurgical confirmation that the test is a valid indicator of cerebral dominance for speech (Milner, Branch, and Rasmussen, 1964).

There is also evidence that certain acoustic stimuli presented dichotically are recalled better in one ear than the other, depending on the nature of the stimulus. Better right ear performance has been reported for verbal

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[1]Dichotic--two different stimuli presented, one to each ear.

acoustic stimuli, e.g., digits (Broadbent, 1954; Kimura, 1961a), words (Borkowski, Spreen, and Stutz, 1965), and nonsense syllables (Lowe, Cullen, Berlin, Thompson, and Willett, 1970; Studdert-Kennedy and Shankweiler, 1970), whereas better left ear performance has been reported for non-verbal acoustic stimuli, e.g., sonar signals (Chaney and Webster, 1966), music (Kimura, 1964), and environmental sounds (Curry, 1967).

Lowe et al. (1970) also found that when voiced and unvoiced nonsense syllables were paired in simultaneous dichotic presentation, the unvoiced predominated over voiced identification significantly. This was observed for both natural and synthetic speech[2]. When dichotic materials were delayed in one channel during dichotic presentation of nonsense syllables, the lagging syllable scores improved as the stimuli were further separated in time (Lowe, 1970; Studdert-Kennedy, Shankweiler, and Schulman, 1970).

Simultaneous monotic[3] stimulus presentation of nonsense syllables to the respective ears has failed to reveal a similar ear effect in normals (Lowe et al., 1970).

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[2]Natural speech--produced by a human subject; as opposed to synthetic speech which is produced by an electro-acoustical analog system.

[3]Monotic--two different stimuli presented to the same ear.

The present study sought to explore the following two factors in greater depth by:

1. Using additional time delays beyond the 90 msec limits of previous studies (Lowe, 1970), in order to assess when "closure"[4] would be elicited.
2. Studying the effects of voiced vs. unvoiced pairings and the effects of ear superiority as a function of different criterion for stimulus alignment. Previous simultaneous dichotic experiments in this series usually used "onset of the signal" as the alignment criterion. A "boundary alignment"[5] investigated what happened to voiced predominance and ear superiority when this criterion of alignment was used.

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[4]Closure--the 100 percent identification of both the leading and lagging stimulus; otherwise stated, that temporal separation where dichotic scores (elicited by a different message to each ear) do not differ from monaural scores (one message alone to either ear separately or individually).

[5]Boundary alignment--alignment of CV monosyllables at the beginning point of large amplitude periodicity.

CHAPTER II

LITERATURE AND HISTORY

Anatomical and Physiological Findings in Animals

The role of dual representation of the auditory systems in mammals is unclear; however, it is well known that this condition is the basis for interaction in localization. Anatomical findings in animals below man in the phylogenetic scale show a symmetry of the auditory cortices.

Among lower forms of mammals, physiological asymmetry of the auditory cortices has only been established in the dog (Tunturi, 1946). Various methods have been used for delimiting auditory areas of the cortex, including comparative cytoarchitecture, thalamocortical relations, and evoked potential methods (Whitfield, 1967). Roughly circumscribed areas of the auditory cortex have been defined in the cat by numerous investigators (Rose, 1949; Hind, in Rasmussen and Windle, 1960; Woolsey, in Rasmussen and Windle, 1960; Woolsey, in Rosenblith, 1961). Among these are the central field (the primary auditory area), and three surrounding bands of tissue termed the suprasylvian, posterior ectosylvian, and anterior

ectosylvian/gyri. The central field receives projections from the medial geniculate body whereas the input to surrounding auditory cortical areas seems indirect. Differential representation of the apical and basilar turns of the cochlea are found in all four auditory sections. Similar organization has been observed in the dog, but precise tonotopic organization varies with species.

In animal studies (involving the cat and dog), using micro-electrode placement to measure cortical response to acoustical stimulation of the respective ears, greater amplitudes of response were measured for the crossed pathways (Tunturi, 1946; Rosenzweig, 1951, 1954). They found that if a click was presented to the ear and recordings were taken from the ipsilateral and contralateral auditory cortices, the greatest difference between responses was in amplitude. This finding was thought to be related not to latency of cortical response but to the number of fibers fired.

In a series of experiments with cats (Diamond and Neff, 1957; Goldberg and Neff, 1961b; Neff, in Rosenblith, 1961; Diamond, Goldberg, and Neff, 1962), there was little or no loss of the response to the appearance of sound at thresholds after removal of all auditory areas of the cerebral cortex. When the lesion included the bilateral

ablation of the inferior colliculus, the thresholds were increased by 7-10 dB (Goldberg and Neff, 1961a). After removal of all tonotopically organized auditory cortical areas in the cat and monkey, a previously learned pitch discrimination was eliminated; however, if one cortex was preserved, rapid post-operative relearning occurred. With bilateral destruction, the animal could be reconditioned to appreciate changes in pitch but could no longer identify an absolute pitch (Goldberg and Neff, 1961b). Diamond and Neff (1957) trained cats to respond to a temporal sequence of acoustical events. When the auditory cortex was ablated, this ability was lost and could not be recovered even with extensive retraining. Cortical areas were then ablated selectively, showing that the central field was essential to this performance, but not in itself sufficient, as severe compromises in performance were noted when cortical auditory areas peripheral to the central field were removed. The results of these experiments suggest functional differentiation of the cortical areas. It appears that the central field is all that is required for pitch discrimination. However, tasks requiring information about temporal patterning of acoustical signals require functioning of areas surrounding the central field.

Summarizing, anatomical findings in mammals below man in the phylogenetic scale, show symmetry of the auditory cortices with primacy of the crossed auditory pathways. Physiological asymmetry of the auditory cortices has been demonstrated only in man and the dog. In all mammals studied, cortical areas are tonotopically organized; however, as demonstrated in man, thresholds and pitch discrimination seem to be only partially contingent upon cortical integrity (Jerger, Weikers, Sharbrough, and Jerger, 1969). Animal performance requiring temporal discrimination and absolute pitch information is compromised by interference with cortical function. The evidence for tonotopic localization (cochlear representation) on the cortex is unclear and varies with species.

In man, there is clear-cut evidence that speech perception and related functions are, to a great extent, controlled by the left hemisphere. The evidence for the primacy of crossed auditory pathways in man is less direct than in animals, but still convincing. However, direct cortical experimentation in vivo is limited to pathological subjects. A ten-year study of the neurophysiology of language, conducted by Penfield and Roberts (1959), differentiated between the motor and ideational aspects of speech. They found that the motor mechanism for speech

depends upon the well-being of the pre-Rolandic motor strip of the two hemispheres. If either of these motor areas is destroyed, the other will eventually take over for both. The ideational mechanism of speech seems to function in one hemisphere only. Three areas, namely Broca's Area, the supplemental motor area of the superior longitudinal gyrus, and the posterior or parieto-temporal area, were identified as important for language. Of these, the only one considered indispensable was the posterior area. In the nineteenth century, Broca correlated left frontal lobe damage with contralateral hemiparesis and dysfunction of articulated speech. Later, Wernicke made similar correlations between temporal lobe damage and inability to understand speech.

Wada and Rasmussen (1949) developed a pharmacological technique for determining hemispheric dominance in pre-operative seizure patients, where doubt existed as to which hemisphere was dominant for language. In a series of 20 patients, determination of cerebral dominance for speech was made by means of a sodium amytal injection. Subsequent craniotomy and cortical excision in 17 of the 20 patients provided direct and indirect evidence of cerebral dominance as determined by the amytal test.

In a study of 123 patients tested for cerebral dominance by the amytal test, Milner et al. (1964) found

that sinistral and ambidextrous individuals showed less clear-cut unilateral hemispheric specialization for language than right-handed persons. In addition, they found that when left-handedness was secondary to early damage to the left hemisphere, right-sided speech representation was more common; but in one/fifth of the cases, the left hemisphere still proved to be dominant.

Geschwind and Levitsky (1968) found marked right-left asymmetries of the human temporal lobes in postmortem examination of 100 healthy brains. The auditory association area (Wernicke's area) just posterior to Heschl's gyrus was observed to be larger on the left in 65 percent of the brains, larger on the right in only 11 percent. These modern developments have lent credence to years of clinical observation and autopsy findings of pathological cases, pointing to the left hemisphere's dominance in linguistic functions.

Psychophysical Experiments

For many years, hemispheric specificity of language could not be readily demonstrated in normal subjects. Recent results of experiments have been postulated as evidence for hemispheric specialization. Cherry (1953) showed that when different contextual material was presented simultaneously through stereo earphones (dichotically), the subjects reported virtually no

information conveyed by the "rejected message" side, other than the language and sex of the speaker. However, when these dichotically presented messages were short-term as in Broadbent's experiments (1954, 1956) using digit series, the subject could usually retain both messages presented, though with a decided edge to the right ear. Similar experimental findings using various speech stimuli have been reported, notably by Kimura (1961a), Borkowski et al. (1965), Staz, Achenbach, Pattishall, and Fennell (1965), Bryden (1969), Darwin (1969), Lowe (1970), Studdert-Kennedy and Shankweiler (1970), among others.

Milner, in Mountcastle (1962) has raised the question of whether the right hemisphere plays a more important role than the left in processing certain acoustic messages. Using the Seashore Measures of Musical Talents, pre- and post-operative testing of 38 patients undergoing temporal lobectomy revealed functional differences of the hemispheres. On all subtests, right temporal lobectomy patients scored a significantly greater number of errors post-operatively than pre-operatively. For left temporal lobectomy patients, only minor differences in post- vs. pre-operative scores were observed.

Kimura (1964) found that when presenting brief melodies dichotically, normal subjects identified more melodies arriving at the left ear than at the right.

Chaney and Webster (1966) have achieved similar results as part of a study involving the dichotic presentation of sonar signals. Using 12 sonar trained listeners and 12 listeners with no sonar training, the experimenters showed that when the subjects were asked to identify five physically similar dimensions of speech and sonar, there was a preference of the right ear for attending to speech sounds, and the left ear for sonar sounds. In a study of 20 left- and 20 right-handed subjects, Curry (1967) found dichotically presented non-verbal stimuli (environmental sounds) were better perceived by the left ear. In presenting strings of digits dichotically to the same subjects, a "right ear effect" was shown.

These differences in the efficiency of handling various types of acoustic stimuli suggest the existence of crossed and specialized hemispheric mechanism.

Therefore: Is Speech Special?

Results of dichotic experiments are often used to support the idea that speech may be a specially processed acoustic signal.

Research at the Haskins Laboratories (Liberman, Cooper, Shankweiler, and Studdert-Kennedy, 1967) and elsewhere (House, Stevens, Sandel, and Arnold, 1962; Kozhevnikov and Chistovich, 1965) suggests that vowels and consonants engage different perceptual processes. In

one such experiment (Liberman et al., 1967), subjects were required to listen to synthetic CV combinations where the consonant was varied in relatively small, acoustically equal steps through a sufficient range to produce three stops: /b/, /d/, and /g/. It was found that for certain consonant distinctions, the mode of perception was nearly categorical; that is, listeners could discriminate only slightly better than they could identify absolutely. The perception of steady-state vowels was quite different from the perception of stop consonants. When the experimenters adjusted the acoustic components of the synthetic vowels in small steps through a range sufficient to produce three different vowels--for instance, /i/, /I/, and /ɛ/--the subjects heard many other vowel-like sounds between the three basic vowels.

The corollary to this observation is to question whether a difference can be found in performance when listening to these two different types of speech, i.e., consonantal stops and steady-state vowels in the dichotic mode. Shankweiler and Studdert-Kennedy (1967) studied this question using synthetic syllables that contrasted by just one phoneme. The results showed a significant right ear advantage for stops but not for steady-state vowels. In another investigation, Studdert-Kennedy and Shankweiler (1970) studied the lateralization of competing

"natural" speech vowels in dynamic contexts (CVC nonsense syllables). Again, only a minimal tendency toward a right ear advantage was observed.

Interest in lateralization has spread to study phonemic distinctions. Studdert-Kennedy and Shankweiler (1970) analyzed the errors made in identifying initial stop consonants of simultaneously presented dichotic messages; the features of voicing and place appeared to be processed separately. The stress of the dichotic testing situation generated a superiority of voicing identification over place of articulation. In addition, there appeared to be a larger percentage of correctly identified features for the right ear than for the left. Analysis showed that a large proportion of the errors arose from the inappropriate combination of correctly abstracted features. Confusions resembled the effects seen in low-pass filtering and noise in the monaural experiments of Miller and Nicely (1955).

This latter finding prompted Darwin (1969) to question whether speech is lateralized with phonemic or acoustic information. In an experiment using synthetic (initial) fricatives followed by /ɛp/, Darwin found that the presence of a formant transition was necessary in order to obtain a right ear advantage. Additional fricatives of high intelligibility were fashioned

without a formant transition but with an abrupt change from friction to continuous vowel. Results showed that these latter syllables did not display a right ear advantage.

In another experiment, Darwin (1969) contrasted the laterality effects of phonemes produced by one synthetic vocal tract system and two different synthetic vocal tract systems. He failed to show a laterality effect using a single vocal tract source; however, a large laterality effect could be produced when the competing vowel messages came from two different vocal tracts. He concluded that lateralization for vowels may depend on the complexity of the perceptual discrimination.

On the basis of mounting evidence, it is suggested that a distinction be made between the extraction of acoustic features and their linguistic interpretation. It seems reasonable to assign the role of extraction of acoustic features to both hemispheres, while reserving the specialized processing of interpretation to the dominant hemisphere.

Findings with Patients

Studies of persons with left- and right-sided epileptogenic lesions and lobectomies have provided corroborative evidence of functional differences between the hemispheres in auditory perception (Jerger, 1960;

Kimura, 1961b; Milner, 1962; and Shankweiler, 1966). Milner, Taylor, and Sperry (1968) have reported striking evidence of dominance of the left over the right hemisphere during the reception of competing verbal stimuli. Their study showed that seven right-handed patients who had undergone commissurectomies (severing of the corpus callosum), were unable to report the left ear portion of a dichotically presented pair. This same group reported the right ear portion of the dichotic message with the same accuracy as a normal group. Monotically, the patients heard as many digits at one ear as the other. Sparks and Geschwind (1968) showed dichotic findings similar to Milner et al. (1968) in their experiments with commissurectomized patients. Retest, with the patient instructed to attend to the left ear, showed a 35 percent gain in correct report[6]. This improvement suggested that messages entering via the weaker ipsilateral pathway in dichotic listening are being processed by the left temporal lobe. It appears that corpus callosum fibers between the left and right auditory cortices (with left hemisphere dominant) are more important than the ipsilateral fibers in the perception of material presented to the left ear.

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[6]The patient's report for the right ear upon retest was not specified.

Berlin, Lowe, Thompson, Berlin, and Schumacher (1971) used time-delayed dichotic material to test three patients with circumscribed temporal lobe lesions. Whereas normals perceived the lagging stimulus better than the leading stimulus, temporal lobe patients showed no such effect. The ear contralateral to the lesion scored more poorly when stimuli were staggered, as well as when stimuli began simultaneously. Finally, as recovery from the effects of the lesion took place, further asymmetry developed between the hemispheres. These findings suggest that ipsilateral pathways to the dominant hemisphere might be adequate under non-competing conditions but become strongly inhibited in competition with contralateral pathways.

Other Interpretations for the Dichotic Right Ear Effect

Broadbent (1956) first used the dichotic message paradigm to test his hypothesis of short-term memory for the auditory system. Using simultaneously presented strings of digits to each ear, one pair/½ sec, he showed that individuals tended to report all the numbers presented to one ear before reporting any presented to the other. He also showed that the ear of first report was more accurate in identifying the material than the ear reported second. At less rapid rates of presentation,

subjects tended to report the digits in the order they were presented, irrespective of the ear. From these observations, Broadbent hypothesized that the presentation rate was a critical variable determining retrieval strategy. He explained an "ear effect" during rapid stimulus presentation on the basis of the designations "P-system" (perception) and "S-system" (storage). The "P-system" could only pass information in one channel, whereas the "S-system" stored excess information from the other channel, not momentarily handled by the "P-system." Broadbent explained that this arrangement accounted for "trace-decay" in which information in the S-system" was lost in a short period of time.

Using a free recall method of response, Bryden (1966) found that information from one ear tended to be reported before the information from the other. In addition, accuracy on two-number series in one channel decreased as a function of the amount of time material was held in storage.

Several studies have suggested that ear responses grouped by order can be shifted to temporal responses grouped by order by establishing meaningful associations between stimuli. Emmerich (1965) showed that temporal switching could be accomplished at rapid presentation rates by using meaningfully associated words instead of

digits. Though this study was repudiated by Bartz, Satz, Fennell, and Lally (1967) on the grounds of an experimental artifact, Borkowski et al. (1965) have replicated its results in a carefully controlled study employing abstract and concrete words. When abstract and concrete word tests were constructed in parallel fashion with respect to channels, ear order effects were maintained. If concrete and abstract words were crisscrossed with the stimulus rate remaining constant, ear order effects diminished and the tendency toward temporal order of report increased.

Inglis (1962) maintained that individuals in dichotic listening demonstrated a right ear effect, simply because they responded to right ear messages before left ear messages; therefore, the right ear's superiority was seen because information to the left ear was subject to greater trace decay.

Wilson, Dirks, and Carterette (1968) designed a study testing the effects of ear order of report on laterality. The subjects were tested under three conditions:

1. No bias (subject requested to write response in any order he wished).
2. Right bias (subject requested to respond to right ear presentations first).

3. Left bias (subject requested to respond to left ear presentations first).

In the no-bias condition (under dichotic stimulation), the right ear performed better than the left, despite the fact that the material presented to the left ear was sometimes responded to first. This seems to contradict the "trace decay" principle in that one would expect the right ear stimulus to be less efficiently handled, since it was required to be held in storage. In addition, although results always favored the ear of instructed bias, the right ear vs. left ear difference in the right bias condition was at least double the right ear vs. left ear difference in the left bias condition. These results implied that the Inglis hypothesis cannot account solely for the right ear effect.

Carr (1969) also explored the possibility that dichotically stimulated subjects would respond to stimuli with one ear before the other. However, he found no systematic order of report preference. Carr attributed report preferences to the same factors which contribute to the right ear effect, viz., hemispheric dominance. Bryden (1963) and Borkowski et al. (1965) have shown superiority of right over left for both immediate and delayed orders of report, thus supporting Carr's conclusion.

Berlin and Lowe (1972) and Studdert-Kennedy and Shankweiler (1970) pointed toward the minor role of trace decay with their demonstration of the lag effect where the second stimulus is reported with greater accuracy than the first stimlus in the 30-90 msec range. The results of the present study in delays from 90-500 msecs will also add to the mounting evidence questioning trace decay as a major source of ear effect.

In a study dealing specifically with the question of order of report, Satz et al. (1965) re-explained Kimura's hemispheric dominance theory within the framework of Broadbent's model. They found that a right ear effect was still observed even if the right ear report was held in delay. No similar effect was noted when the left ear report was held in delay. Thus, if a trace decay mechanism were in effect, material could still be more efficiently held for the right ear report than for the left.

Bryden (1969) attempted to show that the laterality effect during dichotic test stimulation was not a function of competition, but of division of attention required to listen to two signals simultaneously. He based his idea on observations of a right visual field superiority when subjects were required to identify tachistoscopic materials being presented randomly to either side of the subject's

visual fixation point. He concluded that because laterality effects were seen no matter which ear the subject attended to, competition alone was both necessary and sufficient for producing laterality effects.

Summary of Previous Research at Kresge Research Laboratory

Berlin, Lowe, Thompson, and Cullen (1968) constructed a dichotic test which made words simultaneous within ±2.5 msecs. Using this instrument, a total of 70 normal adult subjects were tested in phonetically-controlled listening experiments using competing messages.

Employing nonsense syllables, both real and synthetic (Lowe et al., 1970), a significant right ear laterality effect was observed using simultaneous competing messages in the dichotic mode. No such effect was noted when competing messages were presented monotically.

Lowe (1970) reported that when competing real speech messages were time-staggered in the dichotic mode, the ear with the lagging stimulus achieved higher scores. Ear differences were greatest when the right ear information lagged behind the left ear message by 30-90 msecs. In contrast, when the same time-staggered stimuli were presented monotically, the lead ear achieved approximately 70 percent higher scores when the stimuli were staggered by 15, 30, 60, and 90 msecs.

Lowe et al. (1970) found that in the dichotic mode, for both real and synthetic speech, when voiced CV's were placed in simultaneous competition with voiceless CV's, the voiceless onset syllables were reported more accurately than voiced syllables. In the monotic mode, for both real and synthetic speech samples under similar simultaneous competing conditions, the voiced syllables were identified more accurately than the voiceless syllables.

CHAPTER III

SPECIFIC STATEMENT OF PROBLEM

Main Questions

Monotic and Dichotic Listening Conditions.

1. Does the right ear out-perform the left ear either dichotically or monotically when competing messages are simultaneous?
2. Are there differences in the number of unvoiced CV's correctly identified as opposed to voiced CV's for the simultaneous condition?
3. Are there differences between leading and lagging CV intelligibility when word onsets are aligned at 90, 180, 250, and 500 msecs?
4. When boundaries between large amplitude periodic and aperiodic energy are aligned in monotic and dichotic presentation:
   a. Is there an enhancement or suppression of ear effect?
   b. Is there a difference in the number of voiceless CV's correctly identified as opposed to voiced CV's?

Subsidiary Questions

Dichotic and Monotic Modes.

1. Are there differences in the number of correct responses for each ear as a function of confidence?
2. Are there differences between leading and lagging CV intelligibility as a function of confidence when CV onsets are aligned at 0, 90, 180, 250, and 500 msecs?
3. In the dichotic mode, are there channel differences when CV onsets are aligned at 0, 90, 180, 250, and 500 msecs?

CHAPTER IV

METHODOLOGY

Test Construction

Test tapes consisted of 30 pairs of nonsense syllables based on all possible combinations of six CV syllables. Each of the six CV syllables was aligned with every other syllable except itself. This was done because the experimental design required that each stimulus pair be made up of two different consonants. For the first 15 pairs on the master tapes, a set of 15 individual CV's was recorded on Channel I and another on Channel II. For the succeeding 15 pairs, the CV's were routed to opposite channels. Thus, for delayed stimuli, the 30 pairings allowed each CV to lead and lag the same number of times.

Six tests were constructed, the first requiring simultaneous alignment of the CV pairs, subsequent tests using the recorded delays of 90, 180, 250, and 500 msecs. One additional tape aligned the boundaries between the aperiodic and large amplitude periodic portions of the test stimuli. To facilitate speed and accuracy of tape construction, a computer-controlled pulse code modulated system (see Chapter V) was used through the courtesy of

Haskins Laboratories, New York City. The completed tests were dubbed from a Tandberg Model 1221 X tape recorder to an Ampex Type AG-440 tape recorder.

For the boundary condition, alignments were prepared using a delay line fabricated by Audio Instrument Company. Simultaneously aligned CV pairs were dubbed onto the two-channel loop recording system in which the reproduce heads could be moved with respect to each other. A Tektronix Model 564 storage oscilloscope was used to monitor alignments as the distance between the reproduce heads was adjusted. Once suitable alignment was accomplished, the CV pairs were dubbed onto an Ampex Model PR-10 tape recorder.

In order to minimize learning effect, five randomizations of each of the test conditions were prepared (see Appendix A). Dubbings from the master tape were marked, cut, spliced, and assembled into the appropriate random orders.

Equipment for Test Administration

Subjects were seated in an IAC (Industrial Acoustics Company) Model 1204 sound suite. The stimulus material was presented by means of matched sets (confirmed by frequency response curves) of Telephonics Type TDH 49 earphones which were checked for calibration

(±1 dB at 1 kHz) prior to and after each test session. The phones were driven by a Dynaco Solid State power amplifier, Model 120-A, through a distribution and matching network. Input to the power amplifier came from an Ampex Type AG-440 tape recorder, through an audio mixing network, which provided both monotic and dichotic switching. Attenuation was controlled separately, and monitoring of signal amplitude was accomplished by means of a Brüel and Kjaer Model 2604 microphone amplifier used as a voltmeter.

Subjects

Subjects consisted of 12 female students ranging in age from 18-29 who were paid for their work. They were:

1. Without formal training in phonetics.
2. Native speakers of English and essentially monolingual.
3. Right-handed.
4. Without history of hearing loss.
5. Without history of head trauma or brain injury.

Prior to testing, each subject was screened by means of pulsed sweep frequency Békésy audiometry in the frequency range from 300 to 3 kHz. Criterion for acceptable hearing was 10 dB ISO or better within the

frequency range tested and less than 10 dB difference between ears. In addition, each subject was given a PB-50 discrimination test presented at 40 dB SL, with 1/2 lists delivered to each ear. Criterion for acceptable discrimination was a score of 96 percent or better.

Test Procedure

The entire test battery was performed in two sessions lasting approximately 2 hrs.and 15 min., and 1 hr. and 30 min., respectively. The Békésy tracings, discrimination testing, and the dichotic tests were performed on the first day; monotic testing was completed on the second day. The test order was justified because familiarization with competing message testing was felt to be easier using dichotic material. In addition, test order was not felt to be biasing in light of previous experimental findings at the Kresge Laboratory (Lowe, 1970).

Twelve subjects were divided into six groups of two subjects each and then run in yoked pairs for control of possible inequalities between electronic channels. For the dichotic test run, Subject 1 received the Channel I signal through the red phone on the left ear and Subject 2 received the Channel I signal through the red phone on the right ear. For the monotic test run,

Subject 1 received Channels I and II through the red phone on the left ear. Subject 2 received Channels I and II through the red phone on the right ear (see Appendix B for detailed test protocol).

Prior to the test runs, subjects heard 15 monaural CV's for practice from a list which was not used for the simultaneous test condition. Six dichotic practice items from the unused simultaneous test randomization were also presented prior to the actual test runs.

Subjects were instructed to record the numbers "1" and "2" in the appropriate blanks on a previously prepared answer sheet; "1" denoted that item of which the subject was more sure, "2" denoted that item of which the subject was less sure (see Appendix C for specific test instruction). This order of confidence will henceforth be known as "choice," or "confidence."

CHAPTER V

SPECIAL PROBLEMS

Criteria for Stimulus Selection

Stimulus material consisted of simultaneous and time-staggered CV nonsense syllables. The nonsense syllables consisted of one of six stop consonants combined with a common nucleus vowel, /a/. The consonants, /p/, /t/, /k/, /b/, /d/, and /g/ are specifiable on two counts: the first being voiced vs. voiceless (/p/, /t/, and /k/ are voiceless and /b/, /d/, and /g/ are voiced) and the second being place of articulation (/p/ and /b/ are labial; /t/ and /d/ are alveolar; and /k/ and /g/ are velar).

Justification for use of stop consonants was based on:

1. Considerable literature on the critical acoustic features which make them intelligible (Liberman et al., 1967).
2. The clear definition of their onset on oscillographic tracings.

Nonsense syllables were used because they minimized the influence of non-acoustic cues (the semantic aspects of recognition), which could have a biasing effect.

The natural speech for this experiment satisfied three basic requirements:

1. Its fundamental frequency as measured from striations of a broad band spectrogram was uniform among stimuli ($\bar{x}$ = 97.5 Hz ±2.5 Hz).
2. The formant structure as shown by spectrographic analysis was well defined and compatible with known standards of speech synthesis.
3. The vowel energies of the CV's as measured by graphic level recordings were within 1 1/2 dB of one another.

To obtain uniform length of the test stimuli, all stimuli were edited to 460 msecs duration by means of the PCM system described in the next section. Offset times were carefully controlled to prevent clicks.

Pulse Code Modulation System

Before using this system, the experimenter recorded the six CV syllables in an IAC Model 1204 sound suite with a 1 inch Brüel and Kjaer condenser microphone. He recorded the six CV inventory on one track of a Tandberg Model 1221 X tape recorder, with a 10 kHz tone on the other track. The latter tone served to activate a sensing device to facilitate read-in of the test stimuli into the computer memory.

The hardware for this system consisted of a Honeywell DDP-224 computer, connected to a disc file, an analog-to-digital converter, two digital-to-analog converters, a Tektronix Model 564 storage oscilloscope, and an Ampex Type AG-500 tape recorder (see Appendix D).

To initiate test construction, the pre-recorded test stimuli were read into the computer memory by means of an analog-to-digital converter. This was followed by editing of the offset times to insure uniform length of the stimuli. Editing was accomplished when the digitized data were converted back to analog with the resulting wave form displayed on a storage oscilloscope. Criteria for onset were specified as the point at which background noise changed to either an aperiodic fast-rise burst for the voiceless consonant, or a periodic voiced portion for the voiced consonant. The peak vowel-to-noise ratio was in excess of 44 dB. By setting values in the index registers of the computer console, the appropriate durations were obtained and stored on one cylinder of the disc file. Using the same procedure, subsequent stimuli were converted, edited, and entered into the disc file.

Data regarding specification of stimulus pairs, inter-stimulus interval, delays, and the test order, were read into memory by means of a tape reader and master

tapes compiled. During the inter-stimulus interval, the samples for the two stimuli which form the next pair were retrieved from the disc file. At the termination of the interval, the paired samples were transmitted to the two digital-to-analog converters. After 4 kHz low-pass filtering, the outputs of the two converters were recorded onto the two tracks of the Ampex Type AG-500 tape recorder. As soon as each stimulus pair was converted, the next pair was retrieved from the disc file and the output procedure repeated.

CHAPTER VI

RESULTS AND DISCUSSION

Reconfirmed Observations

As shown in Tables 1 and 2 and Figures 1 and 2, this study reconfirms previous findings of right ear superiority for simultaneous dichotic listening and ear symmetry for monotic listening in normals (e.g., Lowe, 1970; Studdert-Kennedy et al., 1970). In addition, the preponderance of unvoiced over voiced identification was observed in the dichotic mode, whereas voiced over unvoiced preponderance was shown in the monotic mode (see Tables 3 and 4). Finally, at the 90 msec delay condition in the dichotic mode, the right ear in the lagging position did far better than the leading right ear. However, when the left ear was put in the lagging position, it performed as well as the leading right ear (see Table 5 and Figure 1). For monotic presentation at the 90 msec delay condition, the leading stimulus was heard more often than the lagging stimulus, regardless of ear (see Table 6 and Figure 2).

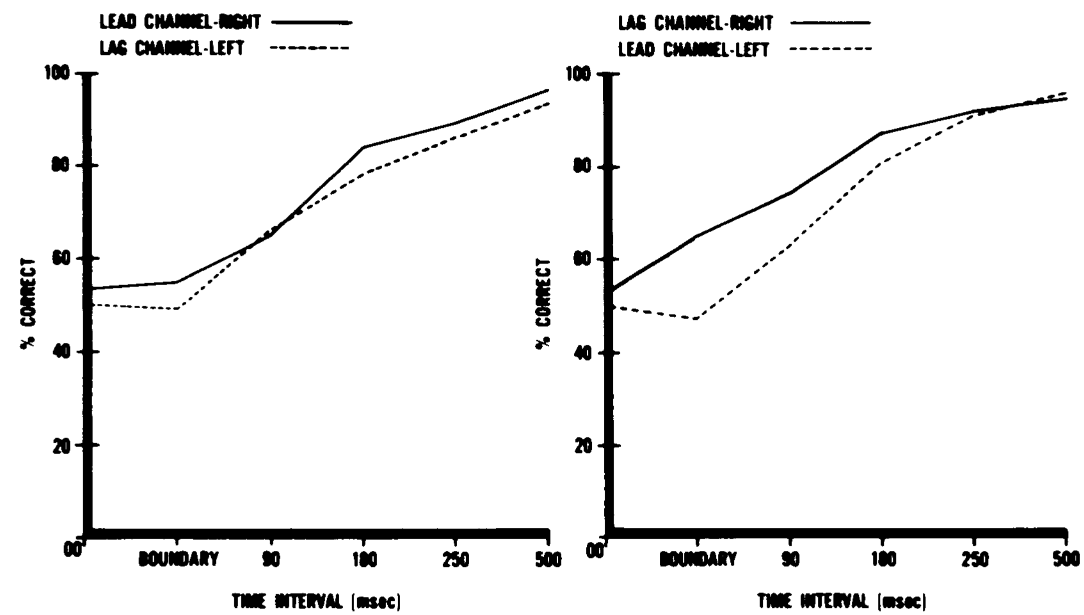
An analysis of variance for simultaneous dichotic data revealed a significant right ear superiority,

TABLE 1.--Dichotic Tests: Summary of raw scores and percent correct at each time condition by ear

Time Conditions	Raw Scores		Percent Correct n = 720/ear	
	Left	Right	Left	Right
Simultaneous	357	390	49.5	54.1
90 msecs	461	498	64.0	69.2
180 msecs	574	616	79.7	85.6
250 msecs	638	650	88.6	90.3
500 msecs	685	688	95.1	95.5
Boundary	349	433	48.5	60.1
Total	3,064	3,275	70.9	75.8

TABLE 2.--Monotic Tests: Summary of raw scores and percent correct at each time condition by ear

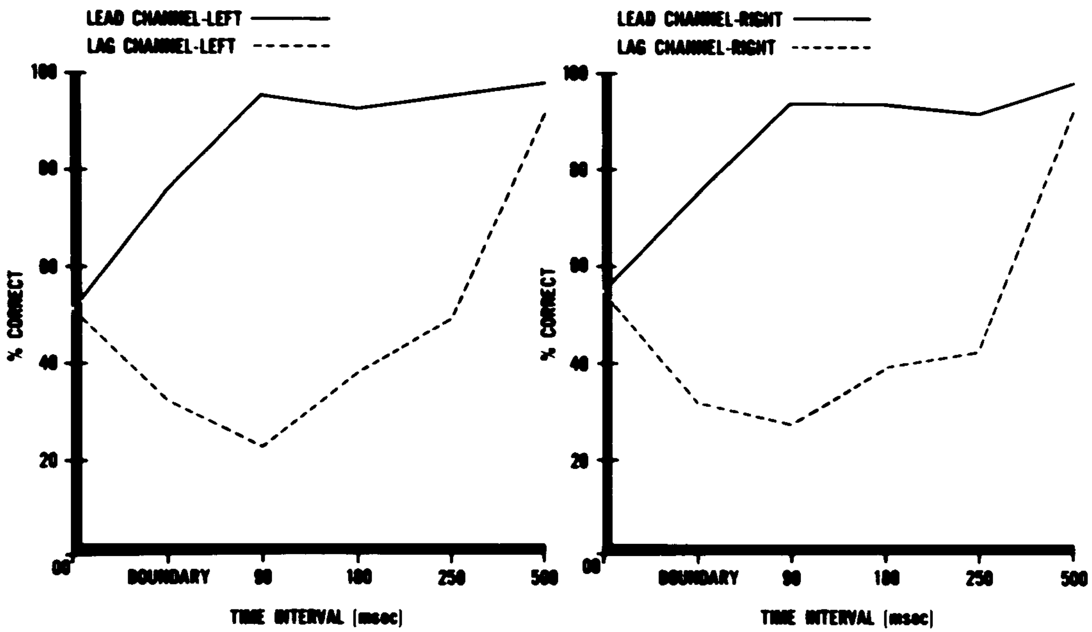
Time Conditions	Raw Scores		Percent Correct n = 720/ear	
	Left	Right	Left	Right
Simultaneous	376	398	52.2	55.3
90 msecs	435	424	60.4	58.9
180 msecs	472	478	65.6	66.4
250 msecs	522	490	72.5	68.0
500 msecs	680	678	94.4	94.2
Boundary	395	381	54.9	52.9
Total	2,880	2,849	66.7	65.9



TIME-STAGGERED DICHOTIC LISTENING TESTING

% CORRECT BY EAR AND CHANNEL 12 SUBJECTS

FIGURE 1



TIME-STAGGERED MONOTIC LISTENING TESTING

% CORRECT BY EAR AND CHANNEL 12 SUBJECTS

FIGURE 2

TABLE 3.--Dichotic--Simultaneous and boundary: comparison of raw scores and percent correct according to manner and place of articulation

Manner	Place	CV	SIMULTANEOUS Correct Responses n = 240/ class	SIMULTANEOUS Percent Correct	BOUNDARY Correct Responses n = 240/ class	BOUNDARY Percent Correct
Unvoiced	Bilabial	pa	148	61.7	139	57.9
	Apical	ta	202	84.5	176	74.2
	Velar	ka	65	27.1	87	36.2
	Sub-total		415	57.6	402	56.1
Voiced	Bilabial	ba	71	29.6	105	48.7
	Apical	da	192	80.0	181	75.4
	Velar	ga	69	28.8	94	39.2
	Sub-total		332	46.1	380	52.8
	Total		747	51.9	782	54.3

TABLE 4.--Monotic--Simultaneous and boundary: comparison of raw scores and percent correct according to manner and place of articulation

Manner	Place	CV	SIMULTANEOUS Correct Responses n = 240/class	SIMULTANEOUS Percent Correct	BOUNDARY Correct Responses n = 240/class	BOUNDARY Percent Correct
Unvoiced	Bilabial	pa	90	37.5	90	37.5
	Apical	ta	149	62.1	191	79.6
	Velar	ka	90	37.5	179	74.6
	Sub-total		329	45.7	460	63.9
Voiced	Bilabial	ba	133	55.4	62	25.8
	Apical	da	220	91.6	112	46.6
	Velar	ga	92	38.3	142	59.2
	Sub-total		445	61.8	316	43.9
	Total		774	53.7	776	53.9

TABLE 5.--Dichotic--Raw scores and percent correct as a function of ear and channel

Time Conditions	Left n = 720		Right n = 720	
Simultaneous	357 (49.6)		390 (54.2)	
	Lead n = 360	Lag n = 360	Lead n = 360	Lag n = 360
90 msecs	225 (62.5)	236 (65.6)	233 (64.7)	265 (73.6)
180 msecs	293 (81.4)	281 (78.1)	304 (84.4)	312 (86.7)
250 msecs	324 (90.0)	314 (87.2)	320 (88.9)	330 (91.7)
500 msecs	346 (96.1)	339 (94.2)	346 (96.1)	342 (95.0)
Boundary*	170 (47.2)	179 (49.7)	199 (55.3)	234 (65.0)

*Note--Lead or lag in the boundary condition refers to position of the onsets of the syllables.

TABLE 6.--Monotic--Raw scores and percent correct as a function of ear and channel

Time Conditions	Left n = 720		Right n = 720	
Simultaneous	376 (52.2)		398 (55.2)	
	Lead n = 360	Lag n = 360	Lead n = 360	Lag n = 360
90 msecs	347 (96.4)	88 (24.4)	334 (92.8)	90 (25.0)
180 msecs	336 (93.3)	136 (37.7)	340 (94.4)	138 (38.3)
250 msecs	346 (96.1)	176 (48.8)	337 (93.6)	153 (42.5)
500 msecs	348 (96.6)	332 (92.2)	348 (96.7)	330 (91.7)
Boundary*	273 (75.8)	120 (33.3)	269 (74.7)	120 (33.3)

*Note--Lead or lag in the boundary condition refers to position of the onsets of the syllables.

right ear superiority, great subject variability and no difference between electronic or acoustic channels of presentation. (For complete analysis, see Appendix.)

ANOV 1.-Dichotic Simultaneous*

Source	df	SS	MS	F
Ear[a]	1	.85	.85	5.32
Subject[b]	11	5.21	.47	2.96
Channel[c]	1	.01	.01	<1
Error	1309	209.04	.16	

a - Significant ear difference, right better than left ($p=<.05$).
b - Significant subject difference ($p=<.01$).
c - No channel difference.

*No lead-lag effect in simultaneous time condition.

An analysis of variance for simultaneous monotic data revealed no ear superiority and great subject variability. (For complete analysis, see Appendix.)

ANOV 2.-Monotic Simultaneous*

Source	df	SS	MS	F
Ear[a]	1	.23	.23	1.52
Subject[b]	11	4.55	.41	2.79
Error	1309	194.29	.15	

a - No ear difference.
b - Significant subject difference ($p=<.01$).

*No lead-lag effect in simultaneous time condition.

Theoretical Implications of Reconfirmed Observations

The Right Ear Effect.

Zero and 90 msec conditions replicated both Lowe's (1970) method and results. Confirmation of her findings lends support to the accuracy of both her data collection and data obtained in other portions of the present study. Right ear superiority for simultaneous dichotic verbal listening has been reconfirmed for the fifth consecutive experiment in this series, thus lending support to the stability of the data collection procedure (Lowe, 1970; Willett, 1969; Lowe et al., 1970; Hannah, 1971). The conclusion drawn here is the same: the right ear and left hemisphere are more efficient processors of dichotic speech material than the left ear and right hemisphere.

The Phonetic Effect.

Unvoiced dichotic preponderance.--Oscillographic tracings of unvoiced-voiced simultaneous CV pairings show that the beginning point of large amplitude periodicity occurs later for the unvoiced CV (see Appendix E). If this beginning point contains critical information for the identification of the lag message, dichotic unvoiced preponderance may be based on the same mechanisms as the dichotic lag effect. The effect, as described by Lowe (1970)

and Studdert-Kennedy et al. (1970), is a subject's tendency to more readily identify the lagging stimulus of a time-staggered CV pair. The theoretical aspects of the lag effect are discussed in the next section.

Voiced monotic preponderance.--By contrast, the simultaneous monotic results show that the voiced CV is more often identified than the unvoiced CV. In time-staggered monotic experiments (Studdert-Kennedy et al., 1970), lead CV predominance has been interpreted as a peripheral masking phenomenon. In aligning monotic voiced with unvoiced CV's at onset, we may simulate a monotic time-staggered paradigm by forcing critical information of voiced CV's to occur earlier, without interference from the voiceless syllable. We will see later how an alternative to "simple masking" is possible.

The Lag Effect at 90 msecs.

Dichotic.--At 90 msecs, there were more lagging than leading stimulus identifications. Thus, it appears that interference by the lag stimulus can occur even after the first 30-60 msecs of the CV, where the information critical for consonantal identification is located. Just what influences the lagging stimuli have on the lead element is unclear. However, reduction of the right ear effect by an appropriate lag to the left ear suggests that

we are probably looking at two independent phenomena. In the dichotic paradigm, it has been hypothesized (Berlin, Lowe-Bell, Cullen, Thompson, and Loovis, 1972) that the paired signals compete for linguistic analysis in the left posterior temporal-parietal lobe, having undergone preliminary independent acoustic analysis in the right and left anterior temporal lobes, respectively. The introduction of a lagging stimulus may be causing an interruption of analysis of the first-in stimulus before it is completely analyzed for its critical information elements. Lowe (1970) saw this lag effect reach its largest values at 15-30 msecs; in her study the effect began to attenuate by 90 msecs. Studdert-Kennedy et al. (1970) also found the lag effect to be largest at around 50 msecs. Here, then we may be seeing the waning effects of competition as time separation increases.

Monotic.--At the 90 msec delay, we witness what has been interpreted as a peripheral masking phenomenon (Studdert-Kennedy et al., 1970). The pooled data indicate at least 95 percent identification of CV's for the leading ear and 24 percent for the lagging ear. Later discussion of other monotic time delays will challenge a straight masking interpretation.

New Observations--At Time Staggers from 180-500 msecs

Dichotic.

Increasing the delay past 90 msecs generated four new observations (see Figure 1 and Table 5):

1. Ear differences disappeared past 180 msecs.
2. Lag effect was minimized as the time delay increased.
3. Percentage of items correct increased for both ears.
4. Closure was obtained at 500 msecs delay.

An analysis of variance for pooled time delayed dichotic data revealed a significant right ear superiority, enhanced perception of the lag syllable, great subject variability, differences in intelligibility as a function of time condition, and no differences between electronic or acoustic channels of presentation. (For complete analysis, see Appendix.)

ANOV 3.-Dichotic Time Delayed

Source	df	SS	MS	F
Ear[a]	1	1.67	1.67	15.29
Lead-lag[b]	1	.71	.71	6.52
Subject[c]	11	18.27	1.66	15.24
Time Condition[d]	3	66.97	22.32	204.82
Channel[e]	1	.10	.10	<1
Time x lead-lag x ear[f]	3	2.11	.70	6.44
Error	5269	571.90	.11	

a - Significant ear difference, right better than left (p=<.01).
b - Significant lead-lag difference, lag better than lead (p=<.05).
c - Significant subject difference (p=<.01).
d - Significant difference between time conditions (90 msec - 500 msec) (p=<.01).
e - No channel difference.
f - Significant time x lead-lag x ear interaction (i.e., differences between ears as a function of extent of lag effect and time delay) (p=<.01).

At 500 msecs separation, when the syllables no longer overlapped in time, closure was observed. Combining the Lowe (1970) findings with the present study, the right ear effect was balanced out when the left ear lagged by 30-90 msecs.

Monotic.

Increasing the delay past 90 msecs generated four results (see Figure 2 and Table 6):

1. Ear symmetry was maintained at all time conditions.
2. Lead stimuli were reported with the same accuracy for all time conditions at 90-500 msecs.
3. Percentage of items correct increased gradually for the lag stimulus from 90 out to 500 msecs.
4. Closure was obtained at 500 msecs delay.

An analysis of variance for pooled time delayed monotic data revealed no ear superiority, enhanced perception of the lead syllable, great subject variability, and differences in intelligibility as a function of time condition. (For complete analysis, see Appendix.)

ANOV 4.- Monotic Time Delayed

Source	df	SS	MS	F
Ear[a]	1	.04	.04	<1
Lead-lag[b]	1	293.40	293.40	3761.58
Subject[c]	11	6.22	.57	7.25
Time Condition[d]	1	102	34	435.92
Time x lead-lag x ear[e]	3	.10	.03	<1
Error	5269	410.45	.08	

a - No ear difference.
b - Significant lead-lag difference, lead better than lag ($p=<.01$).
c - Significant subject difference ($p=<.01$).

d - Significant difference between time conditions (90 msec - 500 msec) (p=<.01).
e - No time x lead-lag x ear interaction (i.e., no differences between ears as a function of extent of lag effect and time delay).

Inspection of Figure 2 and Table 6 shows gradual increase of the lag stimulus intelligibility at the 90, 180, and 250 msec time delays. If we were looking at simple masking, we would expect that the vowel portion of the leading CV would serve as the masker; therefore, as long as there is 60 msecs or more overlap between the vowel of the leading CV and the onset of the trailing CV, masking should be uniform. At the 90 msec time condition, masking effectiveness is considerably greater than at the 250 msec time condition, where acoustic competition of vowel with consonant is relatively unchanged. Although the vowel may drop a dB or two before its termination, note that masking effectiveness progressively lessens from 90 to 250 msecs, despite the fact that the consonantal portion of the lagging CV is in competition with the vowel during each delay condition. This is not entirely consistent with the idea that the leading syllable is masking the lagging syllable.

In this regard, Speaks, Wiggington, and Germono (1970) attempted to study the influence of two different competing messages of the same temporal envelope on a

primary speech message. One competing signal was a speech message, the other was a specially prepared speech-like noise which was devoid of intelligibility. They found that the speech signal was significantly more effective than the noise in masking out the primary speech message. Since both forms of competition generated identical temporal envelopes and frequency content, the experimenters attributed the differences in masking effectiveness to some unique distraction characteristics of the speech signal. The lead speech signal in the monotic mode seems to preempt the lagging CV's attempt to capture a hypothetical speech processor.

The mode of preemption may be related to the distraction device Speaks et al. (1970) consider in their study. In the dichotic paradigm, there was hypothetical competition of the two CV's for phonemic analysis in the left posterior temporal lobe. Lag effect was postulated on the failure of the left posterior temporal lobe to analyze the lead message completely due to a preemption by the lagging CV. The lead speech signal in the monotic mode seems to preempt the lagging CV's to capture a hypothetical analyzer. It must be recognized that in the monotic paradigm the two CV's ascend the same contralateral pathway prior to entry into the temporal-parietal area of the dominant hemisphere. The mode of preemption may be

based on competition for acoustic analysis in the anterior temporal lobes rather than phonemic analysis in the posterior temporal lobe as in the dichotic paradigm. As we move to longer time delays, the acoustic analyzer is presumably less taxed because acoustic information-bearing elements of the lagging CV are occurring at more opportune times for analysis. Conversely, when acoustic information-bearing elements are in closer proximity to the lead CV, detectors will more likely be occupied by information processing involving the lead CV.

Possible effects of middle ear muscle reflexes.--
It is well known that at high intensity levels, the stapedial reflex attenuates signals reaching the cochlea. It was thought that gradual recovery of the second syllable in the monotic condition may have been caused by middle ear muscle contraction following introduction of a relatively high intensity (78 dB SPL) speech signal.

Despite the provocative nature of this hypothesis, an independent study indicated that the monosyllabic materials could not elicit the acoustic reflex at the standard presentation level of the test (78 dB SPL) in normal subjects.

Boundary Condition

As seen in the photographs, Appendix G, when the boundaries are aligned, the onset times of the competing CV's are no longer aligned. Thus, in the simultaneous onset condition, the CV boundaries are offset with respect to each other, while in the boundary condition, it is the onsets which are no longer synchronous. The OBT[7] of the six CV's are all different. Since /ka/ had the longest OBT (approximately 66 msecs), it always led the CV with which it was paired, whereas the briefest OBT was /ba/ (approximately 30 msecs), forcing it to trail its paired CV. The other syllable OBT's sometimes lagged and sometimes led in this special composite condition.

Boundary--Dichotic.

Right vs. left preponderance.--This alignment materially enhanced the right ear effect. With simultaneous alignment the right ear (at 54.1 percent) was 4.6 percent better than the left ear; however, the boundary alignment raised the right ear score to 60.1 percent and the total ear difference increased to 11.6 percent in favor of the right.

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[7]OBT--onset-to-boundary-time: time of onset of boundary of each CV.

Analysis of variance for boundary dichotic data revealed a significant right ear superiority, enhanced perception of the lag syllable, great subject variability, and no differences between electronic or acoustic channels of presentation. (For complete analysis, see Appendix.)

ANOV 5.-Dichotic Boundary

Source	df	SS	MS	F
Ear[a]	1	5.50	5.50	28.07
Lead-lag[b]	1	1.28	1.28	6.55
Subject[c]	11	4.40	.40	2.04
Channel[d]	1	.31	.31	1.56
Error	1309	256.18	.20	

a - Significant ear difference, right better than left (p=<.01).
b - Significant lead-lag difference, lag better than lead (p=<.01).
c - Significant subject difference (p=<.05).
d - No channel difference.

In a study of the effects of alignment on dichotic listening, Hannah (1971) reported that the magnitude of right ear superiority was greatest (16.3 percent) when the alignment condition was simultaneous. His condition designated as boundary generated a right ear superiority far less than the simultaneous alignment (7.6 percent), thus conflicting with the present findings. The present results can be reconciled with Hannah's findings when one compares the nature of the boundary condition in the two

studies. Hannah used synthetic speech in order to more precisely control micro-structure alignment. The intervals of onset, transition, VOT, OBT, and their combinations were all carefully distinguished. Therefore, Hannah's "boundary" aligned only large amplitude periodicity; all other intervals were out of alignment. Because the present study used natural speech, there was no assurance that other intervals were not also aligned along with the boundary, thus artificially enhancing the laterality effect.

Phonetic effects.--The superiority of voiceless consonants, when paired with voiced consonants, observed in the simultaneous condition decreased in the boundary condition. In the simultaneous condition, unvoiced consonants were identified 57.6 percent of the time, while voiced were perceived correctly 46.1 percent of the time. In the boundary condition, however, voiced consonants became more intelligible (53.0 percent) while unvoiced consonants remained essentially unchanged.

Interaction of phonetic effects with the lag effect.--Inspection of the oscillographic tracings of /ba/ versus /ka/ (see Appendix F) reveals that, when the syllables are aligned by their boundaries, /ba/ starts about 36 msecs after /ka/. This tends to put voiced

syllables in the advantageous "lag position" and attenuates the voiceless preponderance seen in ordinary simultaneous dichotic conditions. Figure 3 shows how the scores varied depending upon whether the syllables led or lagged in the left or right ears.

For unvoiced-unvoiced CV combinations, there was a decided lag effect, whereas the lag effect disappeared for both unvoiced-voiced and voiced-voiced CV combinations. This issue was discussed by Hannah (1971), who found that both the boundary and VOT alignment conditions of voiced-unvoiced pairs yielded superior voiced item identification. When CV's of the same class competed, i.e., unvoiced-with-unvoiced or voiced-with-voiced, the same lag advantage occurred. Hannah's findings show that when boundary and VOT are aligned, a lag effect is a function of which onset occurs later.

The present results are not in agreement. When boundaries (as operationally defined in the present study) were aligned and one onset was forced to trail with respect to the other, a lag effect occurred only for unvoiced-unvoiced combinations. Confounding these results was the fact that differences between onsets of the unvoiced CV's were as little as 2 msecs (for /ka-ta/ pairing). Inspection of intelligibility results for the unvoiced CV's in the boundary and simultaneous conditions (see Table 3)

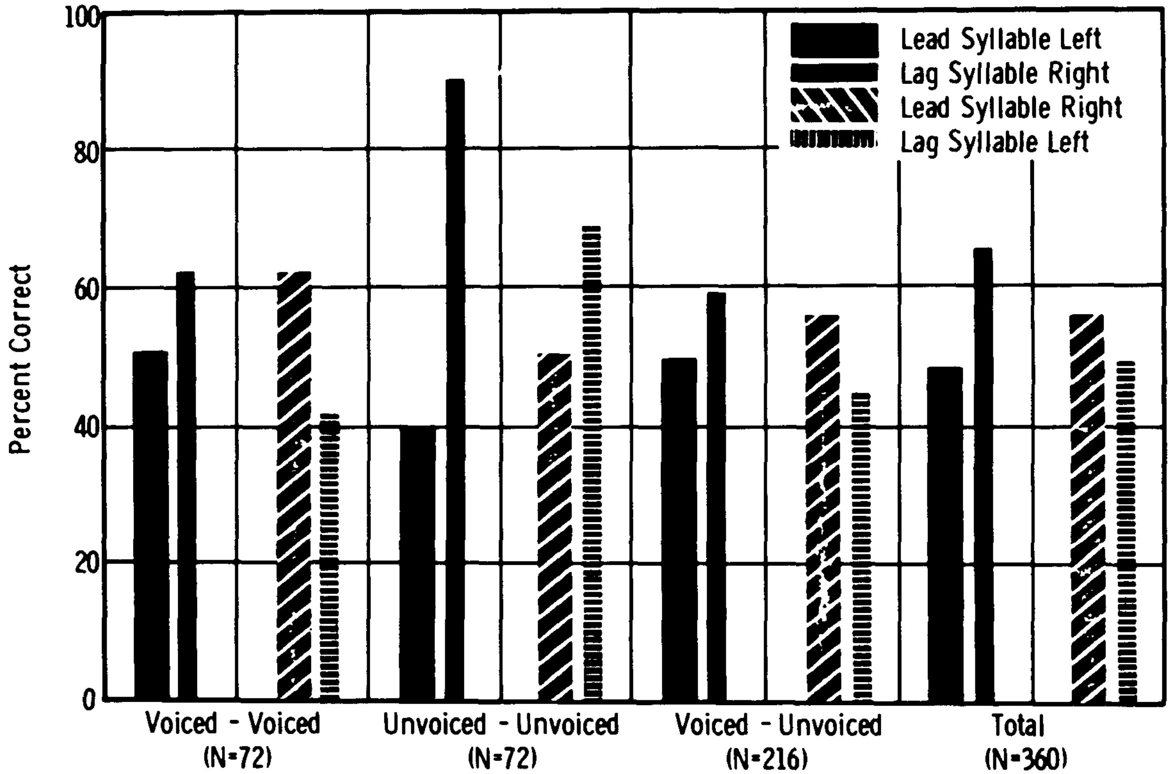

Figure 3. Percent correct for lagging vs. leading syllables in dichotic listening, boundary alignment.

revealed a comparatively low percentage correct for /ka/, a CV used in two of the three unvoiced pairings. Since the CV /ka/ was always in the lead, it was concluded that the lag effect was attributed to the superior intelligibility of the companion CV.

Boundary--Monotic.

Right vs. left preponderance.--This alignment resulted in no ear effect. With simultaneous alignment, the right ear was 3.0 percent better than the left; however, the boundary alignment showed a 1.3 percent ear difference in favor of the left ear.

An analysis of variance for boundary monotic data revealed no ear superiority, enhanced perception of the lead syllable, and great subject variability. (For complete analysis, see Appendix.)

ANOV 6.-Monotic Boundary

Source	df	SS	MS	F
Ear[a]	1	.03	.03	<1
Lead-lag[b]	1	65.03	65.03	427.80
Subject[c]	11	3.70	.34	2.21
Error	1309	198.63	.15	

a - No ear difference.
b - Significant lead-lag difference, lead better than lag ($p=<.01$).
c - Significant subject difference ($p=<.01$).

Phonetic effect.--The superiority of voiced consonants over unvoiced CV's observed in the simultaneous condition reversed for the boundary alignment. In the simultaneous mode, voiced consonants were identified 61.9 percent of the time while unvoiced were perceived correctly 46.1 percent of the time. In the boundary condition, however, unvoiced consonants became more intelligible (64.1 percent) while voiced consonants dropped to 44.1 percent intelligibility.

Interaction of phonetic effects with the lead advantage for monotic presentation.--Oscillographic tracings reveal that when syllables are aligned by their boundaries, the unvoiced CV starts before the voiced CV (see Appendix F). In the monotic mode, this tends to put unvoiced CV's in the advantageous "lead position," thus reversing the voiced preponderance seen in monotic simultaneous presentation. Since OBT's differ for each syllable, a lead advantage is also seen when syllables of like manner are paired. This lead advantage is in favor of the syllable with the longest OBT. Figure 4 shows percentage correct of the syllable pairs for the lead and lag positions in a given ear.

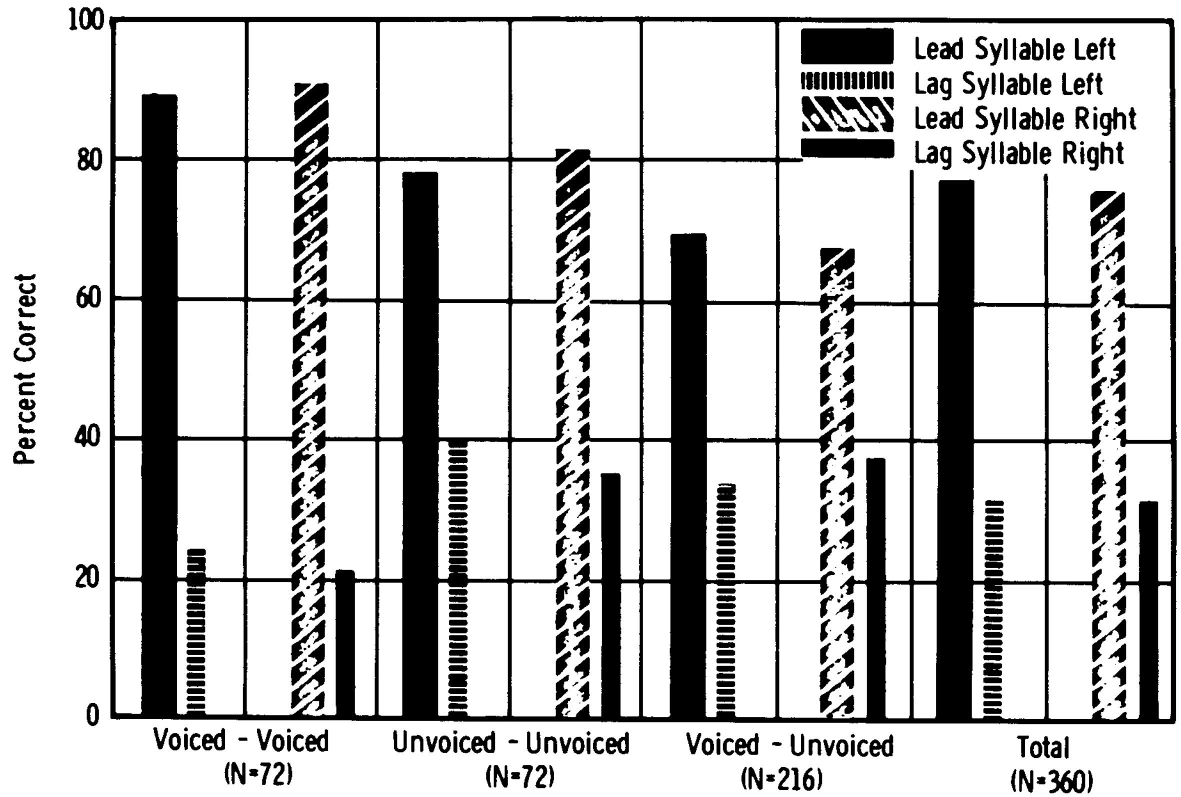

Figure 4. Percent correct for lagging vs. leading syllables in monotic listening, boundary alignment.

Dichotic and Monotic Confidence Measures

Dichotic.

The analysis of first vs. second choice responses for dichotic testing (see Table 7) showed that:

1. The right ear effect could be seen by analyzing first choice responses alone.
2. First choices at simultaneous and 90 msecs were more frequently correct than second choices. Subject confidence was related to subject accuracy.
3. Beyond 90 msecs, subjects began to answer serially--that is, they answered first choice for the lead syllable, and second choice for the lag syllable. The accuracy of both first and second choices tended to increase as time separation increased (see Tables 7 and 8).

When serial response occurred, the lagging CV approached the reported accuracy of the lead CV. This indicated that as time delays were increased, first choice did not necessarily account for loss of confidence in reporting the second choice.

Beyond 90 msecs, the lagging syllable was also the second choice syllable. Because the last to arrive should

TABLE 7.--Dichotic Percentage Correct for First and Second Preferences by Ear and Channel (Lead-Lag)

	SIMULTANEOUS				90 MSECS			
	Left		Right		Left		Right	
	Ch I	Ch II	Ch I	Ch II	Lead	Lag	Lead	Lag
First	32.5	31.3	35.2	39.4	37.0	37.0	44.4	43.6
Second	17.7	17.5	17.5	16.1	25.5	28.6	20.3	30.0
Total	50.2	48.8	52.7	55.5	62.5	65.6	64.7	73.6

	180 MSECS				250 MSECS			
	Left		Right		Left		Right	
	Lead	Lag	Lead	Lag	Lead	Lag	Lead	Lag
First	61.4	16.7	71.4	27.0	80.8	8.1	83.1	12.2
Second	20.0	61.3	13.0	59.7	9.2	79.2	5.8	79.4
Total	81.4	78.0	84.4	86.7	90.0	87.3	88.9	91.6

TABLE 7.--Continued

	500 MSECS			
	Left		Right	
	Lead	Lag	Lead	Lag
First	92.8	4.7	92.0	3.6
Second	3.3	89.5	4.1	91.4
Total	96.1	94.2	96.1	95.0

TABLE 8.--Dichotic-Percentage Correct for First and Second Preferences

	SIMULTANEOUS		90 MSECS		180 MSECS	
	Left	Right	Left	Right	Left	Right
First	31.9	37.3	37.0	44.1	39.0	49.2
Second	17.6	16.8	27.0	25.1	40.7	36.4
Total	49.5	54.1	64.0	69.2	79.7	85.6

	250 MSECS		500 MSECS	
	Left	Right	Left	Right
First	44.4	47.6	48.7	47.8
Second	44.2	42.6	46.4	47.6
Total	88.6	90.2	95.1	95.4

also be the last to "decay," these data question the validity of the "trace decay" theory. If "trace decay" were in effect, the subjects should have more easily recalled (and thus been more sure of) the lagging syllable at 180, 250, and 500 msecs. However, both lead and lag CV's were recalled with roughly equal accuracy at these time delays.

Monotic.

The analysis of first vs. second choice responses for monotic testing showed that (see Tables 9 and 10):

1. Ear symmetry could be seen whether one analyzed all responses or the first choice responses alone.
2. First choices at simultaneous, 90, 180, and 250 msecs were more frequently correct than second choices, thus reflecting the lead CV's preponderance in the monotic mode.
3. At 90 msecs and beyond, the accuracy of both first and second preferences tended to increase as time separation increased.
4. At 90-500 msecs, subjects answered serially--that is, they answered first choice for the lead syllable, and second choice for the lag syllable.

TABLE 9.--Monotic-Percentage Correct for First and Second Preferences by Ear and Channel (Lead-Lag)

	SIMULTANEOUS				90 MSECS			
	Left		Right		Left		Right	
	Ch I	Ch II	Ch I	Ch II	Lead	Lag	Lead	Lag
First	43.9	31.1	45.0	33.9	89.2	3.9	86.4	21.1
Second	15.5	13.9	16.4	15.3	7.2	20.5	6.4	3.9
Total	59.4	45.0	61.4	49.2	96.4	24.4	92.8	25.0

	180 MSECS				250 MSECS			
	Left		Right		Left		Right	
	Lead	Lag	Lead	Lag	Lead	Lag	Lead	Lag
First	88.1	2.0	90.0	1.4	93.3	2.0	90.6	2.0
Second	5.3	35.8	4.4	36.9	2.8	47.0	3.0	40.5
Total	93.4	37.8	94.4	38.3	96.1	49.0	93.6	42.5

TABLE 9.--Continued

	500 MSECS			
	Left		Right	
	Lead	Lag	Lead	Lag
First	96.1	.6	96.7	.6
Second	.6	91.6	0	91.7
Total	96.7	92.2	96.7	92.3

TABLE 10.--Monotic-Percentage Correct for First and Second Preferences

	SIMULTANEOUS		90 MSECS		180 MSECS		250 MSECS		500 MSECS	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
First	37.5	39.4	46.5	45.4	45.0	45.7	47.6	46.3	48.3	48.6
Second	14.7	15.8	13.9	13.5	20.5	20.7	24.9	21.8	46.1	45.6
Total	52.2	55.2	60.4	58.9	65.5	66.4	72.5	68.1	94.4	94.2

At 500 msecs, lead and lag syllables yielded similar intelligibilities but with a slight advantage to the leading syllable. If "trace decay" were occurring here, again the lead syllable should have been more poorly retained than the lag syllable, since it had to be held in storage for roughly 500 msecs.

Channel Equality for the Dichotic Mode

There were no differences between channels as a function of whether they were directed to the right or left ears, thus assuring that there were no appreciable electronic or acoustic artifacts that would affect data validity. Analysis of monotic channel difference was not necessary, because only one channel of the power amplifier was employed to present the test material.

A Comment on Subject Variability

Specific subject differences are of little consequence. Inter-subject variability simply reflects the discrepancy of subjects in attaining a uniform number of correct responses.

The significance of subject data lies in the determination of the extent of laterality and phonetic effect and in recognizing that real differences exist between subjects.

Implication of this Work for Understanding Brain Function in Speech

It was observed that most normals show a slight right ear advantage when responding to dichotically presented messages. By contrast, patients with superficial, anterior temporal lobe lesions show a severe depression of scores in the ear contralateral to the lesion. It will also be recalled that in normals there is a lag effect when CV's are delayed with respect to each other by time separations of 30-90 msecs; whereas, Berlin and Lowe (1972) have shown no lag effect in patients with superficial anterior temporal lobe lesions.

Berlin et al. (1972) have proposed a model which predicts both normal and patient performance:

1. The left posterior temporal-parietal lobe is more likely dominant for speech and language functions.
2. The left and right anterior temporal lobes are recognized as acoustic analyzers involved in the pre-processing of the speech signal. This is based on decreased dichotic performance in the ear contralateral to the lesion observed in post-operative temporal lobe patients.

3. The right ear effect may be seen in normals because of the closer proximity of the left anterior temporal lobe to the left primary (posterior temporal-parietal) area. By comparison, left ear information travels up the contralateral pathways to the right hemisphere where it undergoes preliminary processing in the anterior temporal lobe. Following transmission to the dominant hemisphere by means of commissural tracts, it undergoes final analysis in the left posterior temporal lobe.

Information going to the left posterior temporal lobe from the right side need not pass through the left anterior temporal lobe first. Indeed, if it did, we would expect to find profound effects on language function in patients after left anterior temporal lobe lesions. In fact, it is only damage to the left posterior temporal lobe which causes these disabling effects.

Results of dichotic testing following commissurectomy show a complete suppression of dichotic information going to the left ear. This suggests there are one-way pathways for routing speech information from the right hemisphere to the left. There appears to be no analogous pathway from the left to right hemisphere.

As further support for the one-way nature of this data, Sparks, Goodglass, and Nickel (1970) have shown how a deep left hemisphere lesion can cause a left ear disruption: The deep lesion interrupts the commissural pathway so that left ear information crossing from the right hemisphere is prevented from reaching the primary speech center of the left hemisphere. Thus, for <u>deep</u> lesions of the left hemisphere one may see a decrease in ear performance <u>on the same side</u>. By contrast, deep lesions in the right hemisphere cause contralateral left ear suppression under dichotic listening conditions; in this case, material traveling from the left ear via crossed pathways to the right hemisphere is again blocked from crossing over to the left hemisphere by way of commissural pathways.

The work of Sussman (1971) has lent strong support to this postulated unilateral speech analyzer by revealing a laterality effect without dichotic speech stimulation. By having subjects track an externally controlled target sound in the right and left ears, using either the tongue or the right hand, a significant right ear effect was found only when the source of motor control over the acoustic signal was the speech-related movements of the tongue. It is felt that this asymmetry was because of the special ability of the "speech detector"

to interact with movements and acoustic transitions related to the vocal tract. Sussman's work suggests that any acoustic signal can be lateralized to the left hemisphere if it can be tied to complex vocal tract movements.

Why is There a Lag Effect?--If speech messages from the left ear have to be transmitted across commissural fibers before they arrive at the left posterior temporal lobe, one would expect that they would be slightly delayed with respect to messages from the right ear. It is, therefore, paradoxical that there is no left ear superiority due to a "lag effect" during simultaneous presentations. In fact, there is no lag effect observed when time delays are as great as 15 msecs, according to Lowe (1970) and Studdert-Kennedy and Shankweiler (1970).

These differences have been reconciled by hypothesizing that a single left hemisphere speech processor is being entered from two partially interactive channels. This hypothetical processor would require a finite time (probably 30 to 60 msecs) to handle a CV accurately, provided it were not interrupted by different information arriving from the other channel. This last concept is important because, in the real world, we

listen diotically, and dichotic competition is a rare and "unnatural" condition.

The presumption is that the lag effect may be related to an interruption of the analysis of one syllable by the intrusion of the second syllable. When "interruption," or in our case intrusion of the second syllable, took place at 90, 180, 250, or 500 msecs, perception of both lead and lag syllables gradually improved over that seen when the syllables over-lapped in the 30-60 msec range.

Furthermore, it was noted that when CV's were delayed by more than 90 msecs, subjects tended to respond to them in the order in which they were given, presumably because the signals were now being analyzed sequentially.

If the lag advantage were given to either ear, after anterior temporal lobectomy, it could not be used by the speech analyzer, since the preliminary acoustic analysis would be poor and insufficient information would be available to bring about switching or intrusion.

The preceding argument suggests two separate brain mechanisms for the processing of speech; one an acoustic analyzer and the other, a phonologic and/or linguistic analyzer. The left posterior temporal lobe is probably prepotent in linguistic interpretation rather than being superior in acoustic analysis. The latter

capacity is assigned to the anterior temporal lobes of <u>both</u> hemispheres.

The conclusions reached within the framework of this postulated model have not only enriched our understanding of the role of the dominant hemisphere in speech processing, but provided promise as a valuable diagnostic tool for temporal lobe dysfunction.

Geschwind, in Darley and Millikan (1967) and others, have reaffirmed the importance of the connections between different functional regions of the brain which deal with primary motor and sensory activities.

Disruption of such connections moderating speech activity is manifested in various dichotic results:

1. Disconnection of right from left hemispheres by corpus callosum section reveals an almost complete suppression of dichotic speech information going into the left ear.
2. An anterior temporal lobe lesion results in depressed contralateral ear scores. However, deep temporal lobe lesions of the left hemisphere may result in decreased performance on the same side, whereas deep temporal lobe lesions of the right hemisphere cause contralateral ear suppression.

3. In connection with superficial anterior temporal lobe lesions, Berlin et al. (1971) have found that by gradually increasing the intensity of a speech signal in the ear ipsilateral to the lesion in such patients, the contralateral ear scores decrease. By contrast, if noise is substituted for the speech signal in the ipsilateral ear, much less of a decrease is seen in ear performance. Such an experiment points to the temporal lobe's capacity as a speech identifier and is suggested as a possible biological assessment for differentiating speech from non-speech elements.
4. With further experiments we hope to reveal functional differences between normals and patients manifesting various temporal lobe lesions by means of phonetic analysis.

CHAPTER VII

SUMMARY

Alignment of paired nonsense syllables (CV's) at the simultaneous, 90, 180, 250, 500 msec, and "boundary" conditions for the dichotic and monotic modes yielded the following results:

Dichotic Condition.

1. Three findings from the Lowe (1970) study were replicated:
    a. Right ear superiority at simultaneity.
    b. Unvoiced over voiced preponderance at simultaneity.
    c. At 90 msecs, the right ear in the lag position out-performed the left ear, but when the left ear lagged by 90 msecs, both ears performed similarly.
2. Increasing the delay past 90 msecs elicited four changes:
    a. Ear differences disappeared.
    b. Lag effect minimized.
    c. Overall performance (percent of items correct) increased for both ears.

d. Closure was obtained at 500 msecs.

3. The boundary condition introduced three major effects:
   a. A right ear enhancement was observed when compared with the simultaneous condition; right ear performance improved appreciably, whereas left ear performance remained comparable.
   b. When unvoiced CV's were paired with voiced CV's, the unvoiced preponderance was vastly attenuated.
   c. When unvoiced CV's competed, there was a decided lag effect, whereas the lag effect disappeared for both unvoiced-voiced and voiced-voiced CV combinations.
4. The analysis of first and second choice responses showed that:
   a. Right ear effect was observed and expressed by analyzing first choices alone.
   b. First choices at simultaneous and 90 msecs were frequently more correct than second choices.
   c. Beyond 90 msecs, subjects began to answer serially--that is, they answered

first choice for the lead syllable and second choice for the lag syllable.

d. When serial responses occurred, first and second choices were recalled with roughly the same accuracy.

Monotic Condition.

1. Three findings from the Lowe (1970) study were replicated:
   a. No ear superiority at simultaneity.
   b. Voiced over unvoiced preponderance at simultaneity.
   c. The CV in the lead position out-performed the CV in the lag position, irrespective of ear.
2. Increasing the delay past 90 msecs generated four basic conclusions:
   a. Ear symmetry was maintained at all time conditions.
   b. Lead stimuli were reported with the same accuracy for all time conditions from 90-500 msecs.
   c. Overall performance for the lag stimuli increased as the delay moved from 90 out to 500 msecs.
   d. Closure was obtained at 500 msecs.

3. Results of the boundary condition in monotic listening revealed three major observations:
   a. There was no right ear effect.
   b. When unvoiced CV's were paired with voiced CV's, the former predominated; in dichotic listening, the pattern was reversed.
   c. When data were analyzed by ear as a function of lead-lag of onset, the ears were symmetrical. Lead CV's were identified at a 2:1 ratio over lag CV's.
4. The analysis of first vs. second choice responses showed that:
   a. Ear symmetry was seen in the first choice.
   b. First preferences at simultaneous, boundary, 90, 180, and 250 msecs were more frequently correct than second choices.
   c. At 90-500 msecs, subjects answered serially--that is, first choice was used for the lead syllable; second choice for the lag syllable.

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Appendix A.--Scripts of the Five Test Randomizations

RANDOMIZATIONS

A						B					
	Ch. I	Ch. II		Ch. I	Ch. II		Ch. I	Ch. II		Ch. I	Ch. II
1)	ba	pa	16)	pa	ba	1)	da	ba	16)	ba	da
2)	ka	ta	17)	ta	ka	2)	ba	ka	17)	ka	ba
3)	pa	da	18)	da	pa	3)	pa	ka	18)	ka	pa
4)	da	ba	19)	ba	da	4)	ka	da	19)	da	ka
5)	ba	ka	20)	ka	ba	5)	ba	ga	20)	ga	ba
6)	pa	ka	21)	ka	pa	6)	ga	pa	21)	pa	ga
7)	ka	da	22)	da	ka	7)	ta	pa	22)	pa	ta
8)	ba	ga	23)	ga	ba	8)	da	ta	23)	ta	da
9)	ga	pa	24)	pa	ga	9)	ga	da	24)	da	ga
10)	ta	pa	25)	pa	ta	10)	ta	ga	25)	ga	ta
11)	da	ta	26)	ta	da	11)	ta	ba	26)	ba	ta
12)	ga	da	27)	da	ga	12)	ga	ka	27)	ka	ga
13)	ta	ga	28)	ga	ta	13)	ba	pa	28)	pa	ba
14)	ta	ba	29)	ba	ta	14)	ka	ta	29)	ta	ka
15)	ga	ka	30)	ka	ga	15)	pa	da	30)	da	pa

RANDOMIZATIONS

C						D					
	Ch. I	Ch. II		Ch. I	Ch. II		Ch. I	Ch. II		Ch. I	Ch. II
1)	ka	da	16)	da	ka	1)	ta	pa	16)	pa	ta
2)	ba	ga	17)	ga	ba	2)	da	ta	17)	ta	da
3)	ga	pa	18)	pa	ga	3)	ga	da	18)	da	ga
4)	ta	pa	19)	pa	ta	4)	ta	ga	19)	ga	ta
5)	da	ta	20)	ta	da	5)	ta	ba	20)	ba	ta
6)	ga	da	21)	da	ga	6)	ga	ka	21)	ka	ga
7)	ta	ga	22)	ga	ta	7)	ba	pa	22)	pa	ba
8)	ta	ba	23)	ba	ta	8)	ka	ta	23)	ta	ka
9)	ga	ka	24)	ka	ga	9)	pa	da	24)	da	pa
10)	ba	pa	25)	pa	ba	10)	da	ba	25)	ba	da
11)	ka	ta	26)	ta	ka	11)	ba	ka	26)	ka	ba
12)	pa	da	27)	da	pa	12)	pa	ka	27)	ka	pa
13)	da	ba	28)	ba	da	13)	ka	da	28)	da	ka
14)	ba	ka	29)	ka	ba	14)	ba	ga	29)	ga	ba
15)	pa	ka	30)	ka	pa	15)	ga	pa	30)	pa	ga

RANDOMIZATION
E

	Ch. I	Ch. II		Ch. I	Ch. II
1)	ta	ga	16)	ga	ta
2)	ta	ba	17)	ba	ta
3)	ga	ka	18)	ka	ga
4)	ba	pa	19)	pa	ba
5)	ka	ta	20)	ta	ka
6)	pa	da	21)	da	pa
7)	da	ba	22)	ba	da
8)	ba	ka	23)	ka	ba
9)	pa	ka	24)	ka	pa
10)	ka	da	25)	da	ka
11)	ba	ga	26)	ga	ba
12)	ga	pa	27)	pa	ga
13)	ta	pa	28)	pa	ta
14)	da	ta	29)	ta	da
15)	ga	da	30)	da	ga

Appendix B.--Encoding for Dichotic and Monotic Presentation and Summary of Test Protocol

ENCODING DICHOTIC PRESENTATION

The dichotic modes of presentation were assigned four code numbers:

1-1 - Channel I to left ear (left lead); Channel II to right ear (right lag).

1-2 - Channel I to right ear (right lead); Channel II to left ear (left lag).

1-3 - Same as mode 1-1 above but with lists reversed in Channels I and II.

1-4 - Same as mode 1-2 above but with lists reversed in Channels I and II.

Summary of Dichotic Test Protocol

Since subjects were run in yoked pairs, Subject 1 received the Channel I signal through the red phone on the left ear, and Subject 2 received the Channel I signal through the red phone on the right ear.

The randomizations for all time conditions consisted of 30 CV pairs. The first 15 pairs were presented by mode 1-1 to Subject 1, mode 1-2 to Subject 2. The second 15 pairs were presented by mode 1-3 to Subject 1, mode 1-4 to Subject 2. At a given time condition then, Subject 1 received modes 1-1 and 1-3 while Subject 2 received modes 1-2 and 1-4 for each 30-pair randomization. The phones on the respective subjects were then reversed and a new randomization was put on the tape deck. Subject

1 then received modes 1-2 and 1-4, while Subject 2 received modes 1-1 and 1-3.

ENCODING MONOTIC PRESENTATION

The monotic modes of presentation were assigned four code numbers:

2-1 - Channel I and Channel II to right ear.

2-2 - Channel I and Channel II to left ear.

2-3 - Same as mode 2-1 above but with lists reversed in Channels I and II.

2-4 - Same as mode 2-2 above but with lists reversed in Channels I and II.

Summary of Monotic Test Protocol

Subjects were run in yoked pairs with Subject 1 receiving Channels I and II in the right ear, Subject 2 receiving Channels I and II in the left ear.

The randomizations were the same 30-item tapes as presented during dichotic testing. The first 15 pairs were presented by mode 2-1 to Subject 1 and mode 2-2 to Subject 2. The second 15 pairs were presented by mode 2-3 to Subject 1 and mode 2-4 to Subject 2. At a given time condition then, Subject 1 received modes 2-1 and 2-3 while Subject 2 received modes 2-2 and 2-4 for each 30-pair randomization. Then the phones on the respective subjects were reversed, a new randomization was put on the tape deck and Subject 1 received modes 2-2 and 2-4 while Subject 2 received modes 2-1 and 2-3.

Appendix C.--Instructions to Subjects for Dichotic and Monotic Tests

DICHOTIC INSTRUCTIONS

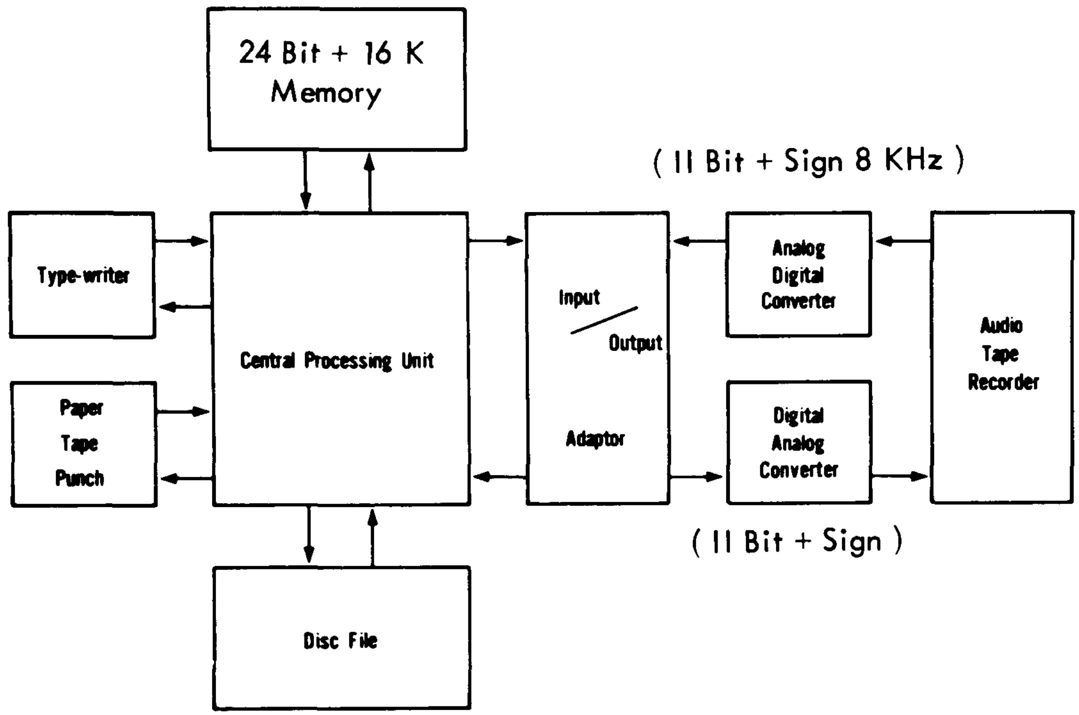
You are about to hear a test of nonsense syllables. The following are examples: (Presentation of 15 monaural stimuli employing the randomization not in use).

You will now hear two of these nonsense syllables at the same time, one to the right ear and a different one to the left ear. Write the number 1 on your answer sheet for that response which you're surest of. Write the number 2 on your answer sheet for the other response. For example, if you hear /ba/ and /ta/ and you're surest of /ba/, write the number 1 next to /ba/ and number 2 next to /ta/. If you are aware of, or only remember one nonsense syllable, write only the number 1 next to that syllable on your answer sheet. Do not be concerned about which ear got the syllable. If there are any questions, please raise your hand. Now we will begin. Are you ready?

MONOTIC INSTRUCTIONS

You are about to hear a test of nonsense syllables, such as you heard in the first testing session. This test will be different only in that you will hear both of the syllables in one ear at a time. Write the number 1 on your answer sheet for that response which you're surest of and the number 2 on your answer sheet for the other response. For example, if you hear /ba/ and /ta/ and you're surest of /ba/, write the number 1 next to /ba/ and the number 2 next to /ta/. If you are aware of, or only remember one nonsense syllable, write only the number 1 next to that syllable on your answer sheet. Do not be concerned about which ear got the syllable. If there are any questions, please raise your hand. Now we will begin. Are you ready?

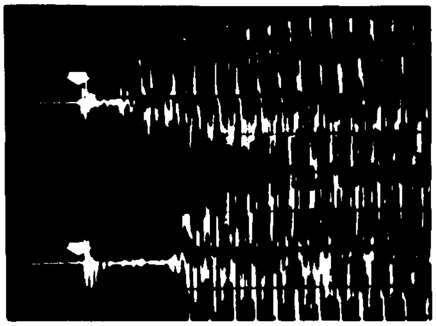
Appendix D.--Schematic of Computer-Controlled PCM System



COMPUTER-CONTROLLED PCM SYSTEM

Appendix E.--Oscillographic Tracings of all Simultaneous Alignments (all tracings were taken at a 20 msec/div. sweep time)

Note: Small differences in oscillographic gain and phosphor sensitivity generate apparent differences between representations of the same syllable. These differences are only artifactual.

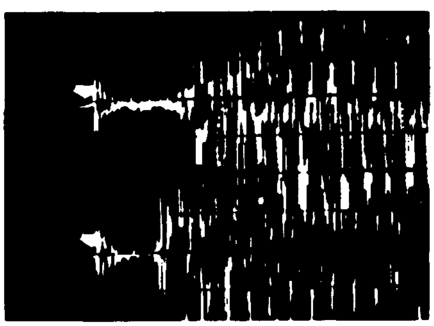


CH 1/ba
1 VOLT/PER DIV.

CH 2/pa
1 VOLT/PER DIV.

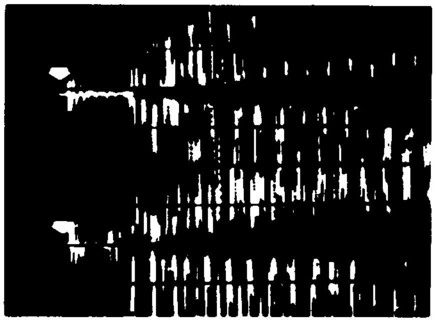
CH 1/ka
1 VOLT/PER DIV.

CH 2/ta
.5 VOLT/PER DIV.

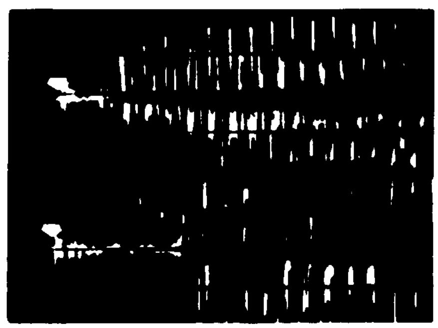


CH 1/pa
1 VOLT/PER DIV.

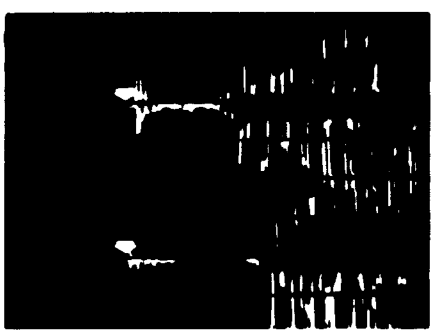
CH 2/da
.5 VOLT/PER DIV.



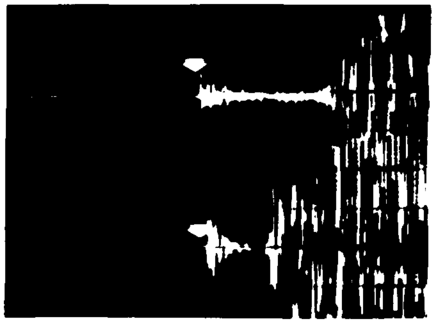
CH 1/da .5 VOLT/PER DIV. CH 2/ba 1 VOLT/PER DIV.



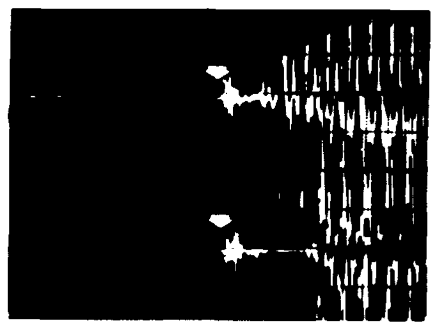
CH 1/ba 1 VOLT/PER DIV. CH 2/ka .5 VOLT/PER DIV.



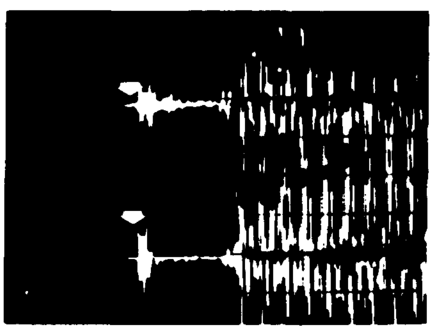
CH 1/pa 1 VOLT/PER DIV. CH 2/ka 1 VOLT/PER DIV.



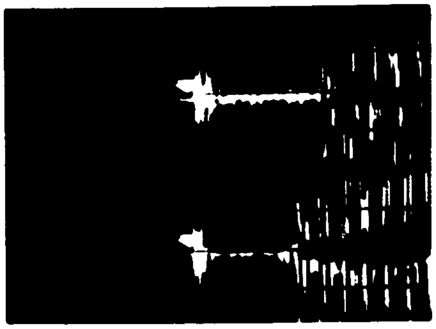
CH 1/ka 1 VOLT/PER DIV. CH 2/da .5 VOLT/PER DIV.



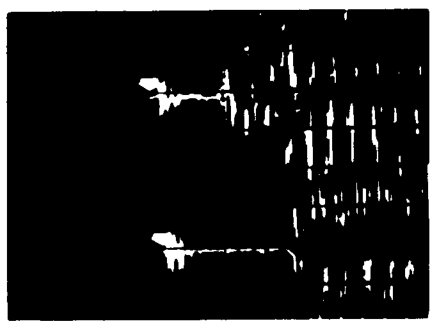
CH 1/ba 1 VOLT/PER DIV. CH 2/ga 1 VOLT/PER DIV.



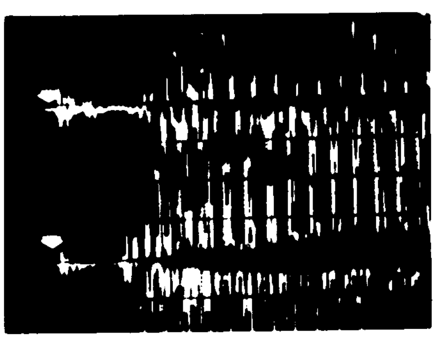
CH 1/ga 1 VOLT/PER DIV. CH 2/pa 1 VOLT/PER DIV.



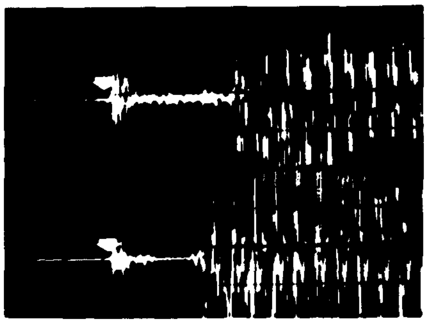
CH 1/ta 1 VOLT/PER DIV.
CH 2/pa 1 VOLT/PER DIV.



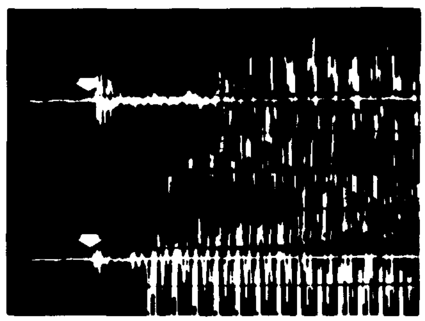
CH 1/da 1 VOLT/PER DIV.
CH 2/ta 1 VOLT/PER DIV.



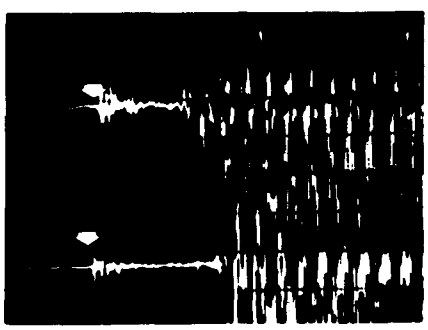
CH 1/ga 1 VOLT/PER DIV.
CH 2/da 1 VOLT/PER DIV.



CH 1/ta 1 VOLT/PER DIV. CH 2/ga 1 VOLT/PER DIV.

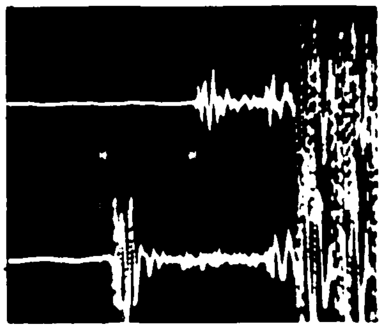


CH 1/ta 1 VOLT/PER DIV. CH 2/ba 1 VOLT/PER DIV.



CH 1/ga 1 VOLT/PER DIV. CH 2/ka 1 VOLT/PER DIV.

Appendix F.--Oscillographic Tracings of all Boundary Alignments (all tracings were taken at .5 volts/div. and a 10 msec/div. sweep time)

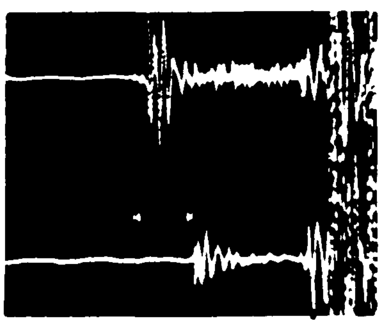


CH 1/ba CH 2/pa

23 msec

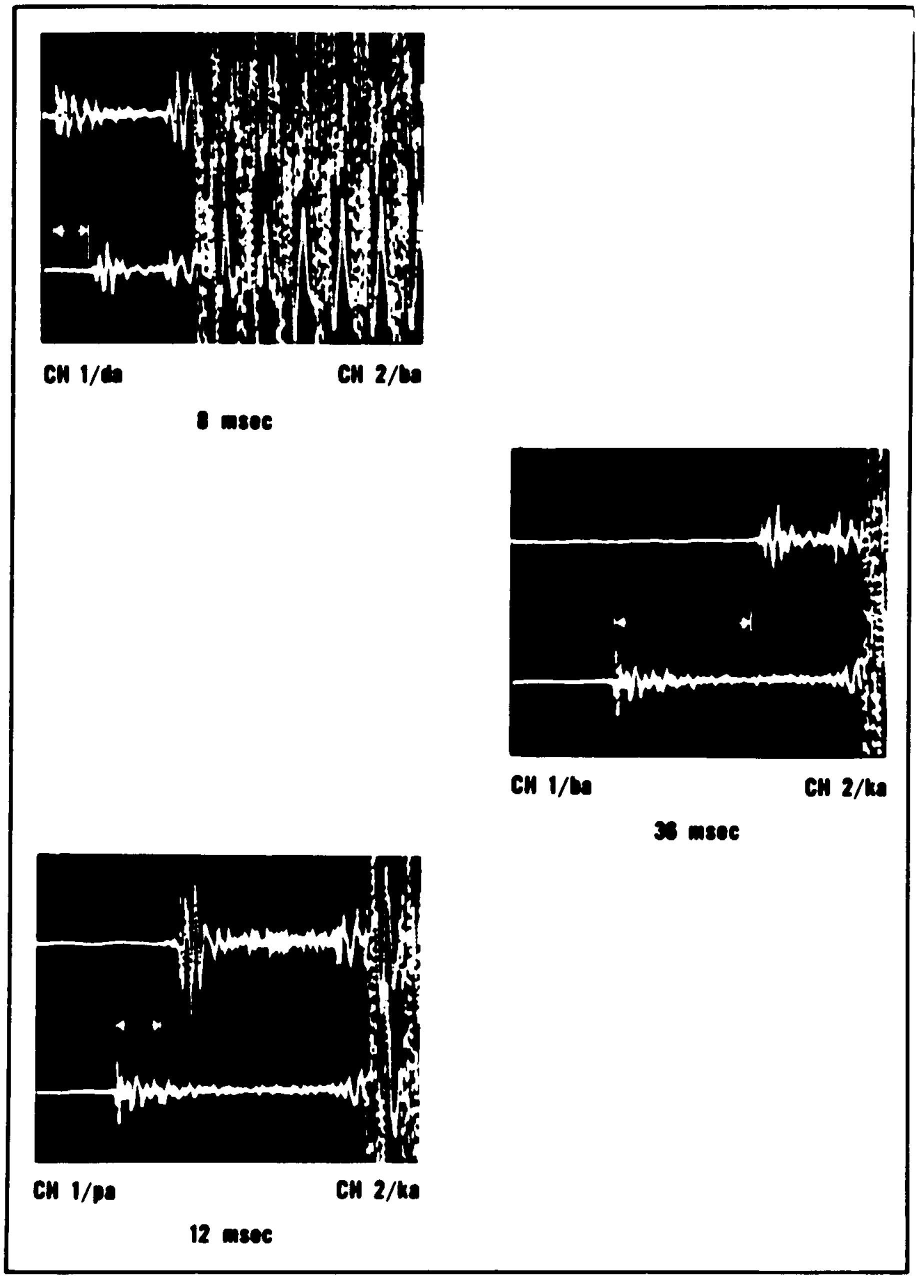
CH 1/ka CH 2/ta

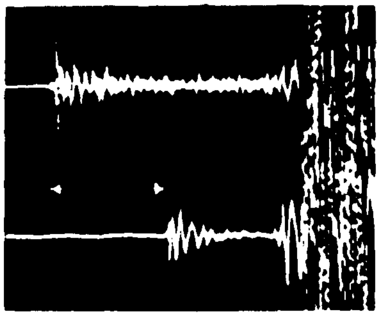
2 msec



CH 1/pa CH 2/da

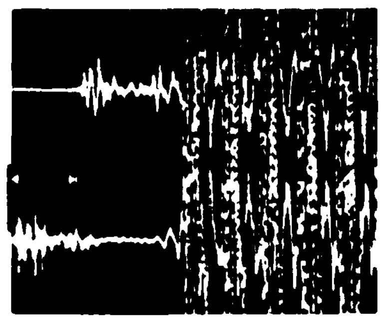
15 msec


CH 1/da
CH 2/ba
8 msec
CH 1/ba
CH 2/ka
36 msec
CH 1/pa
CH 2/ka
12 msec



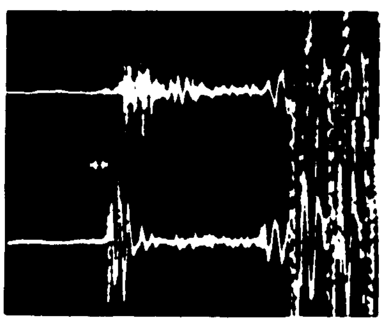
CH 1/ka CH 2/da

28 msec



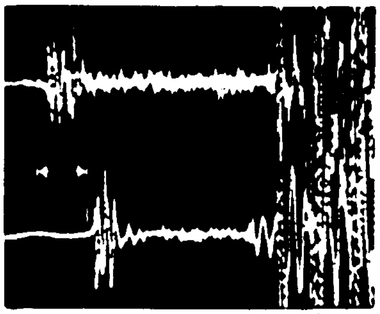
CH 1/ba CH 2/ga

15 msec



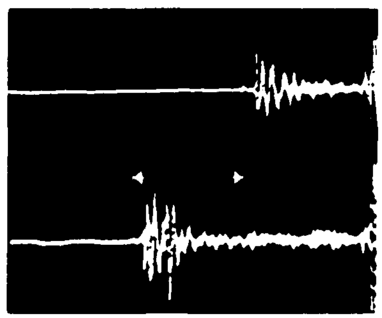
CH 1/ga CH 2/pa

5 msec



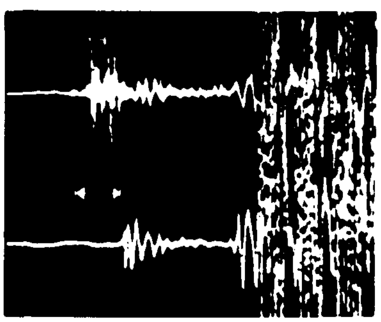
CH 1/ta CH 2/pa

12 msec



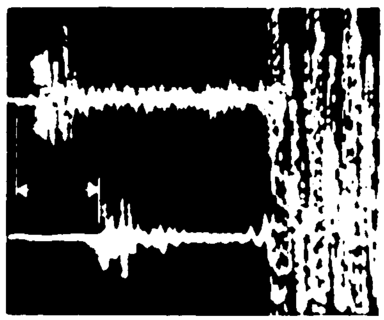
CH 1/da CH 2/ta

30 msec



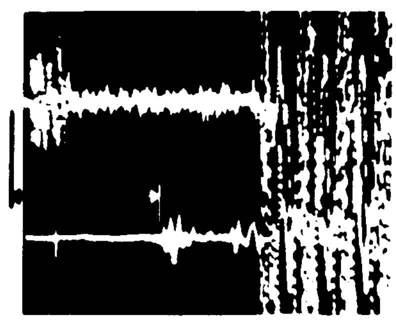
CH 1/ga CH 2/da

10 msec



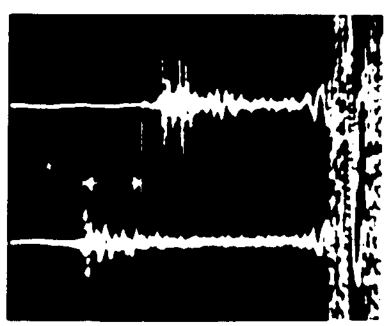
CH 1/ta CH 2/ga

20 msec



CH 1/ta CH 2/ba

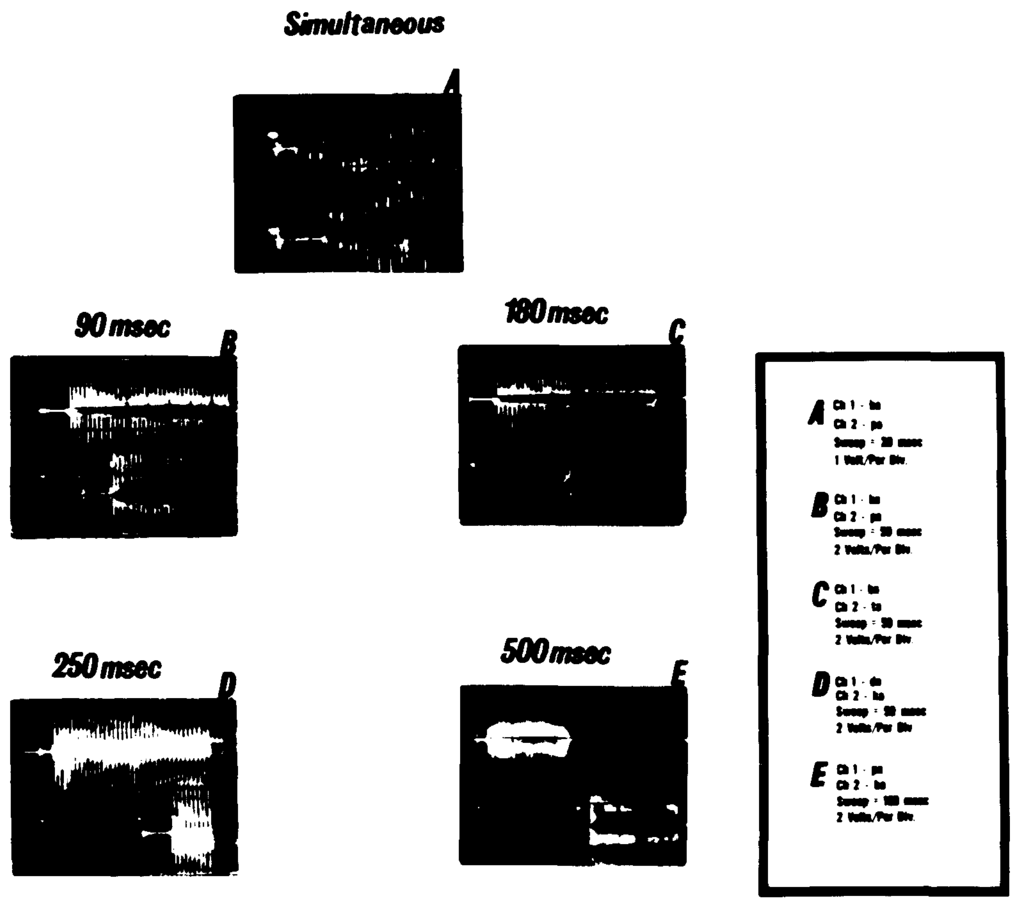
35 msec



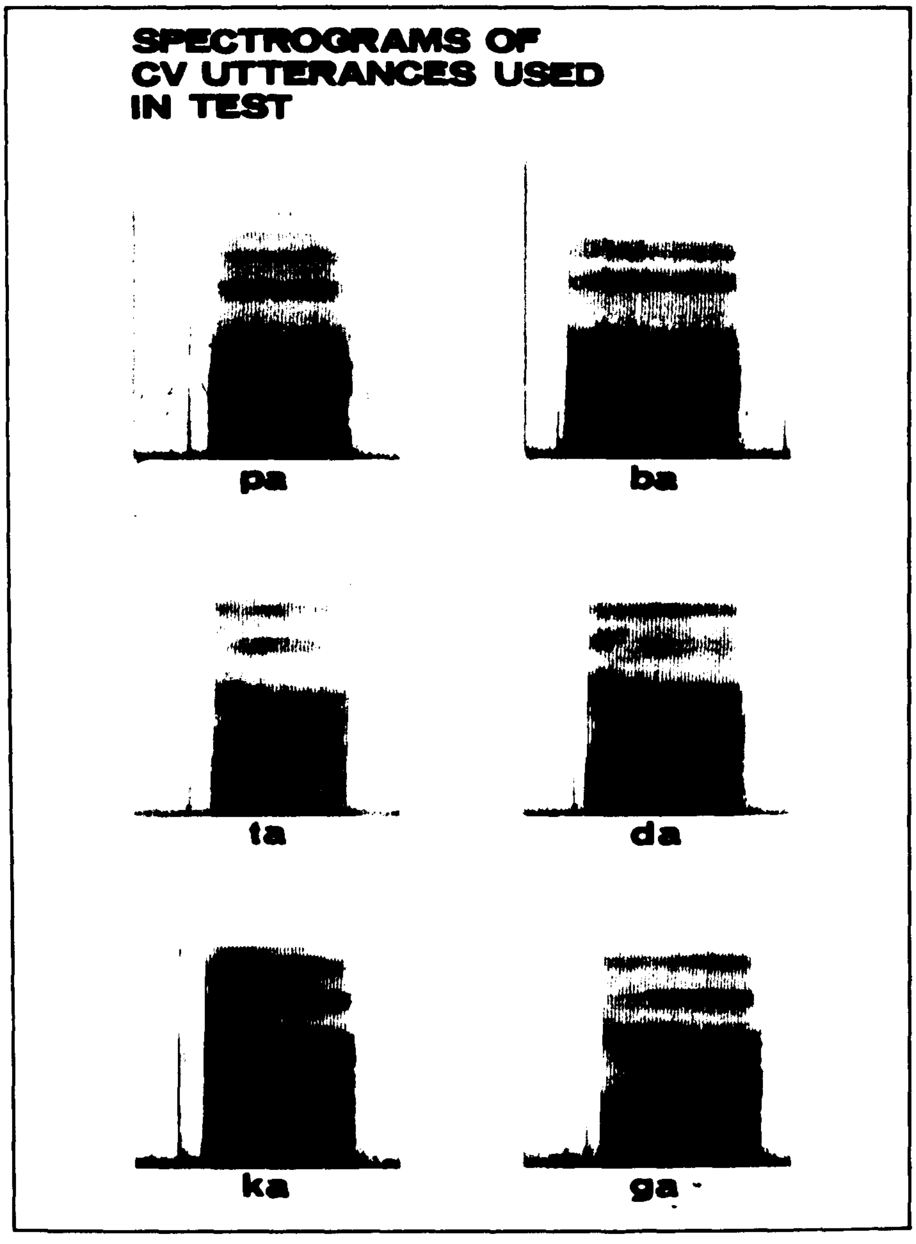
CH 1/ga CH 2/ka

17 msec

Appendix G.--Representative Oscillographic Tracings of all Time Delays


Simultaneous
A
90 msec
B
180 msec
C
250 msec
D
500 msec
E
A
B
C
D
E

Appendix H.--Spectrographs of Individual CV Utterances (Unedited)


SPECTROGRAMS OF
CV UTTERANCES USED
IN TEST
pa
ba
ta
da
ka
ga

Appendix I.--Subject Information Form

SUBJECT INFORMATION FORM

Code Number:_____

NAME: ________________________________ DATE: ____________

ADDRESS: ____

AGE: ________________ DATE OF BIRTH: __________ PHONE: ________

DO YOU WRITE WITH YOUR RIGHT OR LEFT HAND? ________________

HAVE YOU HAD BRAIN DAMAGE OR HEAD TRAUMA AT ANY TIME?
(If so, please explain) ______________________________________

____

HAVE YOU HAD ANY PREVIOUS HISTORY OF A HEARING LOSS? _______

____

HAVE YOU HAD ANY PREVIOUS TRAINING IN PHONETICS? (If so, please explain) ______________________________________

HAVE YOU HAD ANY PREVIOUS EXPERIENCE IN LISTENING TO SIMULTANEOUS MESSAGE TASKS? (If so, please explain) _______

____

PLEASE X IN HOURS WHEN YOU HAVE CLASSES OR WORK ELSEWHERE.
WRITE H IN BLOCKS WHEN YOU HAVE CLASSES HERE.

Hours	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.
8-9							
9-10							
10-11							
11-12							
12-1							
1-2							
2-3							
3-4							
4-5							

Appendix J.--Instructional Procedures Checklist

INSTRUCTIONAL PROCEDURES

___ PLACE EARPHONES ON SUBJECTS' HEAD.

___1. Put on introductory section of tape. ("ba as in bot...........ga as in got")

___2. Remove tape.

___3. Put Channel II of recorder on INPUT setting. Put on monaural list.

___4. After warning phrase, inform subject that monaural stimuli are coming. Tell them they'll only be hearing stimuli in one ear. No cover sheet will be used at this time so that observer can see subject errors.

___5. Present the 15 monaural stimuli using randomization not in use in first four simultaneous tests.

___6. After initial run, if there are subject errors, go back and repeat error stimuli to subjects. Don't forget to be diplomatic in telling subjects of errors.

___7. Run through error stimuli. Go for one error or less/15 stimuli.

___8. Set Channel II of recorder back to REPRO.

___9. Now start instruction tape from place where interrupted.

___10. Rewind and remove instruction tape.

___11. Put on randomization used for monaural listening and re-present as dichotic task. Go through eight items. DON'T FORGET TO USE COVER SHEETS.

___12. Take off "practice" run and put on "real" run.

___13. Advise subjects to turn page.

SUBJECT NO. ______________

DATE ______________________

Appendix K.--Multiple Choice Answer Form

MULTIPLE CHOICE ANSWER FORM

1.	Pa ___	Ta ___	Ka ___	Ba ___	Da ___	Ga ___
2.	Pa ___	Ta ___	Ka ___	Ba ___	Da ___	Ga ___
3.	Pa ___	Ta ___	Ka ___	Ba ___	Da ___	Ga ___
4.	Pa ___	Ta ___	Ka ___	Ba ___	Da ___	Ga ___
5.	Pa ___	Ta ___	Ka ___	Ba ___	Da ___	Ga ___
6.	Pa ___	Ta ___	Ka ___	Ba ___	Da ___	Ga ___
7.	Pa ___	Ta ___	Ka ___	Ba ___	Da ___	Ga ___
8.	Pa ___	Ta ___	Ka ___	Ba ___	Da ___	Ga ___
9.	Pa ___	Ta ___	Ka ___	Ba ___	Da ___	Ga ___
10.	Pa ___	Ta ___	Ka ___	Ba ___	Da ___	Ga ___
11.	Pa ___	Ta ___	Ka ___	Ba ___	Da ___	Ga ___
12.	Pa ___	Ta ___	Ka ___	Ba ___	Da ___	Ga ___
13.	Pa ___	Ta ___	Ka ___	Ba ___	Da ___	Ga ___
14.	Pa ___	Ta ___	Ka ___	Ba ___	Da ___	Ga ___
15.	Pa ___	Ta ___	Ka ___	Ba ___	Da ___	Ga ___

Appendix L.--Dichotic Raw Scores as a Function of Ear

DICHOTIC

Raw Scores as a Function of Ear

Simultaneous

Subject	Left	(R-L)	Right
1.	29	6	35
2.	26	12	38
3.	33	5	38
4.	33	3	36
5.	41	-2	39
6.	26	2	28
7.	26	1	27
8.	27	3	30
9.	36	0	36
10.	31	-5	26
11.	25	3	28
12.	24	5	29
	357	33	390
	$\bar{x}$ = 29.75	$\bar{x}$ = 2.75	$\bar{x}$ = 32.5

Boundary

Subject	Left	(R-L)	Right
1.	22	18	40
2.	22	16	38
3.	24	25	49
4.	35	6	41
5.	35	-8	27
6.	36	-5	31
7.	22	9	31
8.	23	8	31
9.	39	-3	36
10.	32	2	34
11.	28	11	39
12.	31	5	36
	349	84	433
	$\bar{x}$ = 29.08	$\bar{x}$ = 7.00	$\bar{x}$ = 36.08

DICHOTIC

Raw Scores as a Function of Ear (Continued)

90 msecs

Subject	Left	(R-L)	Right
1.	27	12	39
2.	30	12	42
3.	40	8	48
4.	45	-2	43
5.	39	10	49
6.	50	-12	38
7.	37	9	46
8.	30	6	36
9.	47	-2	45
10.	33	0	33
11.	35	-2	33
12.	48	-2	46
	461	37	498
	$\bar{x}$ = 38.42	$\bar{x}$ = 3.08	$\bar{x}$ = 41.5

180 msecs

Subject	Left	(R-L)	Right
1.	48	-7	41
2.	43	10	53
3.	46	14	60
4.	52	1	53
5.	51	1	52
6.	51	-3	48
7.	45	9	54
8.	50	-2	48
9.	53	5	58
10.	36	11	47
11.	46	-2	44
12.	53	5	58
	574	42	616
	$\bar{x}$ = 47.83	$\bar{x}$ = 3.5	$\bar{x}$ = 51.33

DICHOTIC

Raw Scores as a Function of Ear (Continued)

250 msecs

Subject	Left	(R-L)	Right
1.	49	1	50
2.	47	1	48
3.	55	3	58
4.	56	-2	54
5.	56	1	57
6.	58	-1	57
7.	52	6	58
8.	51	2	53
9.	56	2	58
10.	48	0	48
11.	53	-2	51
12.	57	1	58
	638	12	650
	$\bar{x}$ = 53.16	$\bar{x}$ = 1	$\bar{x}$ = 54.16

500 msecs

Subject	Left	(R-L)	Right
1.	55	-1	54
2.	57	-1	56
3.	59	-1	58
4.	60	0	60
5.	57	2	59
6.	57	0	57
7.	57	1	58
8.	58	1	59
9.	56	1	57
10.	53	0	53
11.	58	0	58
12.	58	1	59
	685	3	688
	$\bar{x}$ = 57.08	$\bar{x}$ = .25	$\bar{x}$ = 57.33

Appendix M.--Dichotic Raw Scores as a Function of Ear and Channel (Lead-Lag)

DICHOTIC

Raw Scores as a Function of Ear and Channel

Simultaneous

Subject	Channel I L	Channel I R	Channel II L	Channel II R
1.	11	19	18	16
2.	14	19	12	19
3.	18	19	15	19
4.	18	16	15	20
5.	25	18	16	21
6.	13	11	13	17
7.	13	15	13	12
8.	15	14	12	16
9.	17	17	19	19
10.	15	14	16	12
11.	10	15	15	13
12.	12	13	12	16
	181	190	176	200

Total - 371 Total - 376

DICHOTIC

Raw Scores as a Function of Ear and Channel (Continued)

90 msecs

Subject	Channel I L lead	Channel I R lead	Channel II L lag	Channel II R lag
1.	11	18	16	21
2.	14	23	16	19
3.	23	24	17	24
4.	23	21	22	22
5.	18	20	21	29
6.	22	15	28	23
7.	18	22	19	24
8.	13	13	17	23
9.	25	20	22	25
10.	16	15	17	18
11.	16	17	19	16
12.	26	25	22	21
	225	233	236	265

Total - 458 Total - 501

180 msecs

Subject	Channel I L lead	Channel I R lead	Channel II L lag	Channel II R lag
1.	25	21	23	20
2.	23	27	20	26
3.	24	30	22	30
4.	25	29	27	24
5.	25	23	26	29
6.	26	22	25	26
7.	23	28	22	26
8.	27	24	23	24
9.	27	29	26	29
10.	21	22	15	25
11.	24	22	22	22
12.	23	27	30	31
	293	304	281	312

Total - 597 Total - 593

DICHOTIC

Raw Scores as a Function of Ear and Channel (Continued)

250 msecs

Subject	Channel I L lead	Channel I R lead	Channel II L lag	Channel II R lag
1.	24	24	25	26
2.	23	24	24	24
3.	28	28	27	30
4.	27	26	29	28
5.	29	28	27	29
6.	28	28	30	29
7.	27	28	25	30
8.	27	28	24	25
9.	29	29	27	29
10.	25	24	23	24
11.	28	25	25	26
12.	29	28	28	30
	324	320	314	330

Total - 644 Total - 644

500 msecs

Subject	Channel I L lead	Channel I R lead	Channel II L lag	Channel II R lag
1.	27	27	28	27
2.	30	26	27	30
3.	30	30	29	28
4.	30	30	30	30
5.	30	29	27	30
6.	28	28	29	29
7.	27	29	30	29
8.	28	29	30	30
9.	29	30	27	27
10.	29	28	24	25
11.	28	30	30	28
12.	30	30	28	29
	346	346	339	342

Total - 692 Total - 681

Appendix N.--Dichotic Boundary--Raw Scores as a Function of Ear and Lead-Lag

DICHOTIC

Raw Scores as a Function of Ear and Lead-Lag*

Boundary

Subject	L lead	R lead	L lag	R lag
1.	10	19	13	20
2.	14	20	12	19
3.	8	22	14	27
4.	17	11	18	27
5.	13	13	21	16
6.	15	13	21	19
7.	12	13	10	18
8.	12	19	12	13
9.	21	16	17	21
10.	18	16	12	18
11.	14	21	14	17
12.	16	16	15	19
	170	199	179	234

*Note - Lead or lag in the boundary condition refers to relative position of the onsets of the syllables.

Appendix O.--Dichotic--Raw Scores and Summaries by Order of Confidence

DICHOTIC

Raw Scores by Order of Confidence

Simultaneous

Subject	1st Preference Ch I L	1st Preference Ch I R	1st Preference Ch II L	1st Preference Ch II R	2nd Preference Ch I L	2nd Preference Ch I R	2nd Preference Ch II L	2nd Preference Ch II R
1	10	10	11	11	1	9	7	5
2	8	12	8	12	6	7	4	7
3	13	12	11	12	5	7	4	7
4	12	9	12	12	6	7	3	8
5	11	12	8	16	14	6	8	5
6	9	8	8	12	4	3	5	5
7	8	12	7	9	5	3	6	3
8	10	11	10	14	5	3	2	2
9	10	7	13	10	7	10	6	9
10	11	13	8	9	4	1	8	3
11	7	10	10	12	3	5	5	1
12	8	11	7	13	4	2	5	3
Total	117	127	113	142	64	63	63	58

DICHOTIC (Continued)

Summary of Raw Scores by Order of Confidence

Simultaneous

	Total		1st Preference		2nd Preference	
	raw scores	% correct	raw scores	% correct	raw scores	% correct
L - Ch. I	181	50.2	117	32.5	64	17.7
R - Ch. I	190	52.7	127	35.2	63	17.5
L - Ch. II	176	48.8	113	31.3	63	17.5
R - Ch. II	200	55.5	142	39.4	58	16.1
		$\bar{x}$ = 51.8		$\bar{x}$ = 34.6		$\bar{x}$ = 17.2
L - (pooled)	357	49.5	230	31.9	127	17.6
R - (pooled)	390	54.1	269	37.3	121	16.8

DICHOTIC (Continued)

Raw Scores by Order of Confidence

90 msecs

	1st Preference				2nd Preference			
Subject	Ch I L lead	Ch I R lead	Ch II L lag	Ch II R lag	Ch I L lead	Ch I R lead	Ch II L lag	Ch II R lag
1	9	11	11	15	2	7	5	6
2	7	17	7	13	7	6	9	6
3	13	23	1	13	10	1	16	11
4	18	17	9	7	5	4	13	15
5	10	8	16	16	8	12	5	13
6	15	4	22	14	7	11	6	9
7	7	16	12	21	11	6	7	3
8	8	8	13	14	5	5	4	9
9	12	14	12	12	13	6	10	13
10	12	12	11	13	4	3	6	5
11	8	12	9	8	8	5	10	8
12	14	18	10	11	12	7	12	10
Total	133	160	133	157	92	73	103	108

DICHOTIC (Continued)

Summary of Raw Scores by Order of Confidence

90 msecs

	Total		1st Preference		2nd Preference	
	raw scores	% correct	raw scores	% correct	raw scores	% correct
L - lead	225	62.5	133	37.0	92	25.5
R - lead	233	64.7	160	44.4	73	20.3
L - lag	236	65.6	133	37.0	103	28.6
R - lag	265	73.6	157	43.6	108	30.0
		$\bar{x}$ = 66.6		$\bar{x}$ = 40.5		$\bar{x}$ = 26.1
L - (pooled)	461	64.0	266	37.0	195	27.0
R - (pooled)	498	69.2	317	44.1	181	25.1

DICHOTIC (Continued)

Raw Scores by Order of Confidence

180 msecs

Subject	1st Preference: Ch I L lead	1st Preference: Ch I R lead	1st Preference: Ch II L lag	1st Preference: Ch II R lag	2nd Preference: Ch I L lead	2nd Preference: Ch I R lead	2nd Preference: Ch II L lag	2nd Preference: Ch II R lag
1	21	17	5	6	4	4	18	14
2	19	24	2	7	4	3	18	19
3	18	30	0	8	6	0	22	22
4	23	27	2	3	2	2	25	21
5	14	10	18	15	11	13	8	14
6	18	12	13	9	8	10	12	17
7	13	25	5	13	10	3	17	13
8	21	21	4	5	6	3	19	19
9	23	23	6	6	4	6	20	23
10	9	20	5	16	12	2	10	9
11	22	21	0	0	2	1	22	22
12	20	27	0	9	3	0	30	22
Total	221	251	60	97	72	47	221	215

DICHOTIC (Continued)

Summary of Raw Scores by Order of Confidence

180 msecs

	Total		1st Preference		2nd Preference	
	raw scores	% correct	raw scores	% correct	raw scores	% correct
L - lead	293	81.4	221	61.4	72	20.0
R - lead	304	84.4	257	71.4	47	13.0
L - lag	281	78.0	60	16.7	221	61.3
R - lag	312	86.7	97	27.0	215	59.7
		$\bar{x}$ = 82.6		$\bar{x}$ = 44.12		$\bar{x}$ = 38.5
L - (pooled)	574	79.7	281	39.0	293	40.7
R - (pooled)	616	85.6	354	49.2	262	36.4

DICHOTIC (Continued)

Raw Scores by Order of Confidence

250 msecs

	1st Preference				2nd Preference			
Subject	Ch I L lead	Ch I R lead	Ch II L lag	Ch II R lag	Ch I L lead	Ch I R lead	Ch II L lag	Ch II R lag
1	23	24	1	3	1	0	24	23
2	19	20	3	6	4	4	21	18
3	27	27	2	2	1	1	25	28
4	26	26	0	1	1	0	29	27
5	21	21	9	8	8	7	18	21
6	26	23	6	3	2	5	24	26
7	18	27	2	12	9	1	23	18
8	27	28	0	1	0	0	24	24
9	29	28	1	1	0	1	26	28
10	21	23	3	6	4	1	20	18
11	26	24	1	0	2	1	24	26
12	28	28	1	1	1	0	27	29
Total	291	299	29	44	33	21	285	286

DICHOTIC (Continued)

Summary of Raw Scores by Order of Confidence

250 msecs

	Total		1st Preference		2nd Preference	
	raw scores	% correct	raw scores	% correct	raw scores	% correct
L - lead	324	90.0	291	80.8	33	9.2
R - lead	320	88.9	299	83.1	21	5.8
L - lag	314	87.2	29	8.1	285	79.2
R - lag	330	91.6	44	12.2	286	79.4
		$\bar{x}$ = 89.5		$\bar{x}$ = 46.1		$\bar{x}$ = 43.4
L - (pooled)	638	88.6	320	44.4	318	44.2
R - (pooled)	650	90.3	343	47.6	307	42.6

DICHOTIC (Continued)

Raw Scores by Order of Confidence

500 msecs

	1st Preference				2nd Preference			
Subject	Ch I L lead	Ch I R lead	Ch II L lag	Ch II R lag	Ch I L lead	Ch I R lead	Ch II L lag	Ch II R lag
1	27	27	0	0	0	0	28	27
2	30	24	2	0	0	2	25	30
3	30	30	0	0	0	0	29	28
4	30	30	0	0	0	0	30	30
5	27	25	4	3	3	4	23	27
6	26	21	8	3	2	7	21	26
7	25	29	0	2	2	0	30	27
8	28	29	0	0	0	0	30	30
9	29	30	0	1	0	0	27	26
10	25	28	1	4	4	0	23	21
11	27	30	0	0	1	0	30	28
12	30	28	2	0	0	2	26	29
Total	334	331	17	13	12	15	322	329

DICHOTIC (Continued)

Summary of Raw Scores by Order of Confidence

500 msecs

	Total		1st Preference		2nd Preference	
	raw score	% correct	raw score	% correct	raw score	% correct
L - lead	346	96.1	334	92.8	12	3.3
R - lead	346	96.1	331	92.0	15	4.1
L - lag	339	94.2	17	4.7	322	89.5
R - lag	342	95.0	13	3.6	329	91.4
		$\bar{x}$ = 95.4		$\bar{x}$ = 48.3		$\bar{x}$ = 47.0
L - (pooled)	685	95.1	351	48.7	334	46.4
R - (pooled)	688	95.6	344	47.8	344	47.6

Appendix P.--Monotic Raw Scores as a Function of Ear and Channel

MONOTIC

Raw Scores as a Function of Ear and Channel

Simultaneous

Subject	LEFT			RIGHT		
	Ch I	Ch II	Total	Ch I	Ch II	Total
1	19	14	33	19	10	29
2	18	15	33	21	18	39
3	17	11	28	16	10	26
4	18	15	33	21	13	34
5	17	14	31	17	17	34
6	18	21	39	18	16	34
7	17	12	29	19	16	35
8	18	11	29	19	16	35
9	21	15	36	22	18	40
10	19	10	29	16	13	29
11	17	11	28	15	15	30
12	15	13	28	18	15	33
Total	214	162	376	221	177	398

$$\frac{(R-L)}{n} = 1.8\%$$

MONOTIC (Continued)

Raw Scores as a Function of Ear and Channel

90 msecs

Subject	LEFT Ch I Lead	LEFT Ch II Lag	LEFT Total	RIGHT Ch I Lead	RIGHT Ch II Lag	RIGHT Total
1	30	11	41	30	10	40
2	28	8	36	24	7	31
3	30	2	32	29	4	33
4	30	8	38	30	4	34
5	28	9	37	28	9	37
6	29	6	35	29	10	39
7	29	8	37	29	4	33
8	28	8	36	29	10	39
9	30	11	41	28	9	37
10	27	3	30	24	4	28
11	29	6	35	24	11	35
12	29	8	37	30	8	38
Total	347	88	435	334	90	424

$$\frac{(R-L)}{n} = -.92\%$$

MONOTIC (Continued)

Raw Scores as a Function of Ear and Channel

180 msecs

Subject	LEFT			RIGHT		
	Ch I Lead	Ch II Lag	Total	Ch I Lead	Ch II Lag	Total
1	28	13	41	29	14	43
2	30	10	40	30	13	43
3	30	14	44	29	8	37
4	29	12	41	30	14	44
5	29	10	39	28	8	36
6	30	12	42	29	10	39
7	27	12	39	30	12	42
8	25	11	36	28	10	38
9	29	11	40	27	13	40
10	24	10	34	25	8	33
11	27	7	34	27	13	40
12	28	14	42	28	15	43
Total	336	136	472	340	138	478

$$\frac{(R-L)}{n} = .5\%$$

MONOTIC (Continued)

Raw Scores as a Function of Ear and Channel

250 msecs

Subject	LEFT Ch I Lead	LEFT Ch II Lag	LEFT Total	RIGHT Ch I Lead	RIGHT Ch II Lag	RIGHT Total
1	30	19	49	29	14	43
2	30	13	43	29	11	40
3	30	15	45	29	13	42
4	27	17	44	29	15	44
5	27	16	43	26	11	37
6	30	12	42	30	12	42
7	29	9	38	27	12	39
8	29	18	47	28	16	44
9	30	17	47	29	14	43
10	26	13	39	26	11	37
11	30	11	41	24	10	34
12	28	16	44	30	15	45
Total	346	176	522	336	154	490

$$\frac{(R-L)}{n} = -2.8\%$$

MONOTIC (Continued)

Raw Scores as a Function of Ear and Channel

500 msecs

Subject	LEFT Ch I Lead	LEFT Ch II Lag	LEFT Total	RIGHT Ch I Lead	RIGHT Ch II Lag	RIGHT Total
1	30	29	59	30	29	59
2	29	21	50	29	26	55
3	29	25	54	29	28	57
4	30	29	59	30	30	60
5	29	30	59	28	27	55
6	28	27	55	26	30	56
7	29	28	57	29	26	55
8	27	26	53	30	29	59
9	30	29	59	30	28	58
10	28	30	58	28	30	58
11	29	29	58	29	17	46
12	30	29	59	30	30	60
Total	348	332	680	348	330	678

$$\frac{(R-L)}{n} = -.16\%$$

Appendix Q.--Monotic Boundary--Raw Scores as a Function of Ear and Lead-Lag

MONOTIC

Raw Scores as a Function of Ear and Lead-Lag

<u>Boundary</u>*

	LEFT			RIGHT		
Subject	Ch I Lead	Ch II Lag	Total	Ch I Lead	Ch II Lag	Total
1	22	14	36	25	14	39
2	25	10	35	16	11	27
3	22	7	29	21	10	31
4	22	11	33	24	8	32
5	21	14	35	19	14	33
6	26	9	35	22	11	33
7	21	9	30	25	5	30
8	25	7	32	26	10	36
9	21	15	36	25	11	36
10	21	6	27	22	3	25
11	22	12	34	20	12	32
12	25	6	31	24	11	35
Total	273	120	393	269	120	389

$$\frac{(R-L)}{n} = -.25$$

*Note - Lead or lag in the boundary condition refers to relative position of the onsets of the syllables.

Appendix R.--Monotic Raw Scores and Summaries by Order of Confidence

MONOTIC

Raw Scores by Order of Confidence

Simultaneous

	1st Preference				2nd Preference			
Subject	Ch I L	Ch II L	Ch I R	Ch II R	Ch I L	Ch II L	Ch I R	Ch II R
1	12	10	14	9	7	4	5	1
2	14	11	13	12	4	4	8	6
3	17	7	15	9	0	4	1	1
4	13	14	16	12	5	1	5	1
5	12	10	14	10	5	4	3	7
6	14	10	14	9	4	11	4	7
7	14	10	15	13	3	2	4	3
8	14	7	11	8	4	4	8	8
9	13	10	14	9	8	5	8	9
10	10	6	10	10	9	4	6	3
11	16	7	13	9	1	4	2	6
12	9	10	13	12	6	3	5	3
Total	158	112	162	122	56	50	59	55

MONOTIC (Continued)

Summary of Raw Scores by Order of Confidence

Simultaneous

	Total raw scores	Total % correct	1st Preference raw scores	1st Preference % correct	2nd Preference raw scores	2nd Preference % correct
L - Ch I	214	59.4	158	43.9	56	15.5
L - Ch II	162	45.0	112	31.1	50	13.9
R - Ch I	221	61.4	162	45.0	59	16.4
R - Ch II	177	49.2	122	33.9	55	15.3
		$\bar{x}$ = 53.8		$\bar{x}$ = 38.5		$\bar{x}$ = 15.3
L - (pooled)	376	52.2	270	37.5	106	14.7
R - (pooled)	398	55.3	284	39.4	114	15.8

MONOTIC (Continued)

Raw Scores by Order of Confidence

90 msecs

	1st Preference				2nd Preference			
Subject	Ch I L lead	Ch II L lag	Ch I R lead	Ch II R lag	Ch I L lead	Ch II L lag	Ch I R lead	Ch II R lag
1	26	2	28	1	4	9	1	9
2	27	0	27	1	1	8	2	6
3	30	0	27	1	0	2	0	4
4	30	0	28	1	0	8	2	3
5	26	0	22	2	2	9	5	7
6	26	3	24	2	3	3	5	8
7	28	2	29	0	1	6	0	4
8	25	2	28	2	3	6	1	8
9	30	0	26	2	0	11	1	8
10	24	2	23	2	3	1	1	2
11	21	2	19	3	8	4	5	7
12	28	1	30	0	1	7	0	8
Total	321	14	311	16	26	74	23	14

MONOTIC (Continued)

Summary of Raw Scores by Order of Confidence

90 msecs

	Total		1st Preference		2nd Preference	
	raw scores	% correct	raw scores	% correct	raw scores	% correct
L - Ch I	347	96.4	321	89.2	26	7.2
L - Ch II	88	24.4	14	3.9	74	20.5
R - Ch I	334	92.8	311	86.4	23	6.4
R - Ch II	90	25.0	76	21.1	14	3.9
		$\bar{x}$ = 59.6		$\bar{x}$ = 50.1		$\bar{x}$ = 9.5
L - (pooled)	435	60.4	335	46.5	100	13.9
R - (pooled)	424	58.9	327	45.4	97	13.5

MONOTIC (Continued)

Raw Scores by Order of Confidence

180 msecs

	1st Preference				2nd Preference			
Subject	Ch I L lead	Ch II L lag	Ch I R lead	Ch II R lag	Ch I L lead	Ch II L lag	Ch I R lead	Ch II R lag
1	26	0	29	0	2	13	0	14
2	30	0	29	1	0	10	1	12
3	29	1	28	0	1	12	1	9
4	28	0	30	0	1	12	0	14
5	26	1	22	1	3	9	6	7
6	27	0	28	0	3	12	1	10
7	25	0	30	0	2	12	0	12
8	24	1	26	0	1	10	2	10
9	29	0	27	0	0	11	0	13
10	24	1	25	1	0	9	0	7
11	23	1	22	2	4	7	5	10
12	26	2	28	0	2	12	0	15
Total	317	7	324	5	19	129	16	133

MONOTIC (Continued)

Summary of Raw Scores by Order of Confidence

180 msecs

	Total raw scores	Total % correct	1st Preference raw scores	1st Preference % correct	2nd Preference raw scores	2nd Preference % correct
L - Ch I	336	93.3	317	88.1	19	5.3
L - Ch II	136	37.8	7	2.0	129	35.8
R - Ch I	340	94.4	324	90.0	16	4.4
R - Ch II	138	38.3	5	1.4	133	36.9
		$\overline{x}$ = 66.0		$\overline{x}$ = 45.4		$\overline{x}$ = 20.6
L - (pooled)	472	65.5	324	45.0	148	20.5
R - (pooled)	478	66.4	329	45.7	149	20.7

MONOTIC (Continued)

Raw Scores by Order of Confidence

250 msecs

Subject	1st Preference Ch I L lead	Ch II L lag	Ch I R lead	Ch II R lag	2nd Preference Ch I L lead	Ch II L lag	Ch I R lead	Ch II R lag
1	29	0	28	0	1	19	1	14
2	29	1	29	0	1	12	0	11
3	30	0	28	0	0	15	1	13
4	27	1	29	1	0	16	1	14
5	25	1	24	4	2	15	3	7
6	30	0	30	0	0	12	0	12
7	27	0	25	0	2	9	2	12
8	26	2	26	1	3	16	2	15
9	30	0	29	0	0	17	0	14
10	26	1	25	1	0	12	1	10
11	29	1	23	0	1	10	0	9
12	28	0	30	0	0	16	0	15
Total	336	7	326	7	10	169	11	146

MONOTIC (Continued)

Summary of Raw Scores by Order of Confidence

250 msecs

	Total		1st Preference		2nd Preference	
	raw score	% correct	raw score	% correct	raw scores	% correct
L - Ch I	346	96.1	336	93.3	10	2.8
L - Ch II	176	48.9	7	2.0	169	47.0
R - Ch I	337	93.6	326	90.6	11	3.0
R - Ch II	153	42.5	7	2.0	146	40.5
		$\bar{x}$ = 70.3		$\bar{x}$ = 47.0		$\bar{x}$ = 23.3
L - (pooled)	522	72.5	343	47.6	179	24.9
R - (pooled)	490	68.1	333	46.3	157	21.8

MONOTIC (Continued)

Raw Scores by Order of Confidence

500 msecs

	1st Preference				2nd Preference			
Subject	Ch I L lead	Ch II L lag	Ch I R lead	Ch II R lag	Ch I L lead	Ch II L lag	Ch I R lead	Ch II R lag
1	30	0	30	0	0	29	0	29
2	29	0	29	0	0	21	0	26
3	29	0	29	0	0	25	0	28
4	30	0	30	0	0	29	0	30
5	28	1	28	0	1	29	0	27
6	28	0	26	2	0	27	0	28
7	29	0	29	0	0	28	0	26
8	27	0	30	0	0	26	0	29
9	30	0	30	0	0	29	0	28
10	28	1	28	0	0	29	0	30
11	29	0	29	0	0	29	0	17
12	29	0	30	0	1	29	0	30
Total	346	2	348	2	2	330	0	328

MONOTIC (Continued)

Summary of Raw Scores by Order of Confidence

500 msecs

	Total		1st Preference		2nd Preference	
	raw scores	% correct	raw scores	% correct	raw scores	% correct
L - Ch I	348	96.7	346	96.1	2	.6
L - Ch II	332	92.2	2	.6	330	91.6
R - Ch I	348	96.7	348	96.7	0	0
R - Ch II	330	91.7	2	.6	328	91.7
		$\bar{x}$ = 94.3		$\bar{x}$ = 48.5		$\bar{x}$ = 46.0
L - (pooled)	680	94.4	348	48.3	332	46.1
R - (pooled)	678	94.2	350	48.6	328	45.6

Appendix S.--Complete Analyses of Variance for Simultaneous Dichotic and Monotic Conditions

1.--Analysis of Variance - Simultaneous Dichotic

Source	df	SS	MS	F
Ear	1	.85	.85	5.32*
Subject	11	5.21	.47	2.96**
Channel	1	.01	.01	<1
Order†	1	.31	.31	1.91
Pair	14	40.52	2.89	18.09**
Channel x Ear	1	.06	.06	<1
Channel x Order	1	.01	.01	<1
Channel x Pair	14	1.59	.11	<1
Ear x Order	1	.12	.12	<1
Ear x Pair	14	2.03	.15	<1
Order x Pair	14	1.83	.13	<1
Channel x Ear x Order	1	.25	.25	1.57
Channel x Ear x Pair	14	4.20	.30	1.88*
Channel x Order x Pair	14	1.75	.13	<1
Ear x Order x Pair	14	3.18	.23	1.42
Channel x Ear x Order x Pair	14	88.84	6.35	39.66**
Error	1309	209.04	.16	
Total	1439	359.80		

(Continued)

1.--Analysis of Variance - Simultaneous Dichotic
(Continued)

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†Order - For the first 15 pairs of a given randomization, a set of 15 individual CV's was recorded on Channel I and another on Channel II. For the succeeding 15 pairs, the CV's were routed to opposite channels. This analysis sought to find differences in intelligibility of the first vs. second 15 stimulus pairs.

*(p=<.05).

**(p=<.01).

2.--Analysis of Variance - Simultaneous Monotic

Source	df	SS	MS	F
Ear	1	.23	.23	1.52
Subject	11	4.55	.41	2.79**
Channel	1	5.88	5.88	39.72**
Order†	1	.10	.10	<1
Pair	14	25.37	1.81	12.24**
Channel x Ear	1	.01	.01	<1
Ear x Order	1	.01	.01	<1
Ear x Pair	14	1.94	.14	<1
Channel x Order	1	3.40	3.40	22.99**
Channel x Pair	14	4.54	.32	2.19**
Order x Pair	14	2.19	.16	1.06
Channel x Ear x Order	1	.07	.07	<1
Channel x Ear x Pair	14	1.20	.09	<1
Ear x Order x Pair	14	1.41	.10	<1
Channel x Order x Pair	14	110.76	7.91	53.46**
Channel x Ear x Order x Pair	14	1.72	.12	<1
Error	1309	194.29	.15	
Total	1439	357.66		

(Continued)

2.--Analysis of Variance - Simultaneous Monotic (Continued)

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†Order - For the first 15 pairs of a given randomization, a set of 15 individual CV's was recorded on Channel I and another on Channel II. For the succeeding 15 pairs, the CV's were routed to opposite channels. This analysis sought to find differences in intelligibility of the first vs. second 15 stimulus pairs.

*(p=<.05).

**(p=<.01).

Appendix T.--Complete Analyses of Variance for Time-Staggered Dichotic and Monotic Conditions

3.--Analysis of Variance - Time-Staggered - Dichotic

Source	df	SS	MS	F
Ear	1	1.67	1.67	15.29**
Lead-Lag	1	.71	.71	6.52*
Subject	11	18.27	1.66	15.24**
Time Condition	3	66.97	22.32	204.82**
Channel	1	.10	.10	<1
Pair	14	23.54	1.68	15.42**
Time x Lead-Lag	3	.25	.08	<1
Time x Ear	3	.63	.21	1.94
Time x Channel	3	.05	.02	<1
Time x Pair	42	15.27	.36	3.34**
Lead-Lag x Ear	1	.16	.16	1.43
Lead-Lag x Channel	1	0	0	<1
Lead-Lag x Pair	14	.47	.03	<1
Ear x Channel	1	0	0	<1
Ear x Pair	14	1.10	.08	<1
Channel x Pair	14	3.11	.22	2.04*
Time x Lead-Lag x Ear	3	2.11	.70	6.44**
Time x Lead-Lag x Channel	3	.03	.01	<1
Time x Lead-Lag x Pair	42	4.53	.11	<1
Time x Ear x Channel	3	.31	.10	<1

(Continued)

3.--Analysis of Variance - Time-Staggered - Dichotic (Continued)

Source	df	SS	MS	F
Time x Ear x Pair	42	4.56	.11	1
Time x Channel x Pair	42	4.45	.11	<1
Lead-Lag x Ear x Channel	1	.25	.25	2.30
Lead-Lag x Ear x Pair	14	2.77	.20	1.82*
Lead-Lag x Channel x Pair	14	.62	.04	<1
Ear x Channel x Pair	14	.85	.06	<1
Time x Lead-Lag x Ear x Channel	3	.06	.02	<1
Time x Lead-Lag x Ear x Pair	42	5.18	.12	1.13
Time x Lead-Lag x Channel x Pair	42	3.73	.09	<1
Time x Ear x Channel x Pair	42	4.55	.11	<1
Lead-Lag x Ear x Channel x Pair	14	35.86	2.56	23.50**
Time x Lead-Lag x Ear x Channel x Pair	42	20.62	.49	4.50
Error	5269	571.90	.11	
Total	5759	794.66		

*(p=<.05).

**(p=<.01).

4.--Analysis of Variance - Time-Staggered - Monotic

Source	df	SS	MS	F
Ear	1	.04	.04	<1
Lead-Lag	1	293.40	293.40	3761.58**
Subject	11	6.22	.57	7.25**
Time Condition	3	102	34	435.92**
Channel	1	.43	.43	5.56*
Pair	14	28.76	2.05	26.33**
Time x Ear	3	.65	.22	2.77*
Time x Lead-Lag	3	87.64	29.21	374.53**
Time x Channel	3	.68	.23	2.90*
Time x Pair	42	15.24	.36	4.65**
Lead-Lag x Ear	1	0	0	<1
Ear x Channel	1	.06	.06	<1
Ear x Pair	14	.27	.02	<1
Lead-Lag x Channel	1	.16	.16	2
Lead-Lag x Pair	14	37.37	2.67	34.22**
Channel x Pair	14	35.95	2.57	32.92**
Time x Lead-Lag x Ear	3	.10	.03	<1
Time x Ear x Channel	3	.48	.16	2.04
Time x Ear x Pair	42	3.33	.08	1.01
Time x Lead-Lag x Channel	3	.60	.20	2.54

(Continued)

4.--Analysis of Variance - Time-Staggered - Monotic (Continued)

Source	df	SS	MS	F
Time x Lead-Lag x Pair	42	20.26	.48	6.18**
Time x Channel x Pair	42	20.89	.50	6.38**
Lead-Lag x Ear x Channel	1	0	0	<1
Lead-Lag x Ear x Pair	14	.47	.03	<1
Ear x Channel x Pair	14	.55	.04	<1
Lead-Lag x Channel x Pair	14	38.51	2.75	35.27**
Time x Lead-Lag x Ear x Channel	3	.07	.02	<1
Time x Lead-Lag x Ear x Pair	42	1.55	.04	<1
Time x Ear x Channel x Pair	42	2.50	.06	<1
Time x Lead-Lag x Channel x Pair	42	23.95	.57	7.31**
Lead-Lag x Ear x Channel x Pair	14	.91	.06	<1
Time x Lead-Lag x Ear x Channel x Pair	42	4.03	.10	1.23
Error	5269	410.45	.08	
Total	5759	1137.50		

*(p=<.05).

**(p=<.01).

Appendix U.--Complete Analyses of Variance for Boundary Dichotic and Monotic Conditions

5.--Analysis of Variance - Boundary - Dichotic

Source	df	SS	MS	F
Ear	1	5.50	5.50	28.07**
Lead-Lag	1	1.28	1.28	6.55*
Subject	11	4.40	.40	2.04*
Channel	1	.31	.31	1.56
Pair	14	33.50	2.39	12.21**
Channel x Ear	1	.02	.02	<1
Channel x Lead-Lag	1	.01	.01	<1
Channel x Pair	14	1.08	.08	<1
Ear x Lead-Lag	1	.31	.31	1.56
Ear x Pair	14	2.55	.18	<1
Lead-Lag x Pair	14	44.39	3.17	16.18**
Channel x Ear x Lead-Lag	1	.08	.08	<1
Channel x Ear x Pair	14	1.66	.12	<1
Channel x Lead-Lag x Pair	14	2.46	.18	<1
Ear x Lead-Lag x Pair	14	1.58	.11	<1
Channel x Ear x Lead-Lag x Pair	14	1.93	.14	<1
Error	1309	256.18	.20	
Total	1439	357.24		

*(p=<.05).
**(p=<.01).

6.--Analysis of Variance - Boundary - Monotic

Source	df	SS	MS	F
Ear	1	.03	.03	<1
Lead-Lag	1	65.03	65.03	427.80**
Subject	11	3.70	.34	2.21*
Channel	1	.04	.04	<1
Pair	14	33.63	2.40	15.80**
Channel x Ear	1	.07	.07	<1
Channel x Lead-Lag	1	.07	.07	<1
Channel x Pair	14	.58	.04	<1
Ear x Lead-Lag	1	0	0	<1
Ear x Pair	14	.85	.06	<1
Lead-Lag x Pair	14	49.52	3.54	23.27**
Channel x Ear x Lead-Lag	1	0	0	<1
Channel x Ear x Pair	14	1.31	.09	<1
Channel x Lead-Lag x Pair	14	1.64	.12	<1
Ear x Lead-Lag x Pair	14	1.63	.12	<1
Channel x Ear x Lead-Lag x Pair	14	.79	.06	<1
Error	1309	198.63	.15	
Total	1439	357.50		

*(p=<.05).
**(p=<.01).

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Title of Thesis: Monotic and Dichotic Perception of (0-500 msecs) Time-Staggered CV Monosyllables

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July 16, 1971