

1968

## Sensitivity to and Temporal Resolution of Electrical Stimuli to the Tongue.

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SENSITIVITY TO AND TEMPORAL RESOLUTION OF  
ELECTRICAL STIMULI TO THE TONGUE

Louisiana State University and Agricultural and  
Mechanical College, Ph.D., 1968  
Speech Pathology

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1969

SENSITIVITY TO AND TEMPORAL RESOLUTION OF  
ELECTRICAL STIMULI TO THE TONGUE

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  
Anna Klein Pleasonton  
M.A., Northwestern University, 1959  
August 1968

## ACKNOWLEDGMENT

This research was made possible through the use of funds and equipment obtained through NIH Grants NB-07533-02 and NB-07005-02 to the Communication Sciences Laboratory, Louisiana State University School of Medicine, under the direction of Dr. Charles I. Berlin and Grant R01-NB06261 CMS to the Department of Pharmacology, Louisiana State University School of Medicine, under the direction of Dr. Ernest A. Daigneault.

The writer wishes to express her appreciation to Wendy Botnick, Natalie Herz, Nathalie Musson, Michael Patrick and Shepard Samuels for their cheerful cooperation during lengthy test sessions, and to the Department of Biometry, Louisiana State University School of Medicine for assistance in evaluating the data.

Special thanks and appreciation go to Deborah A. Majeau for her help with instrumentation, and in particular, for designing the electrodes used in this study. Deep gratitude is expressed to Dr. Charles I. Berlin for

his generous and excellent advice and for always being available in times of need. I am also most thankful to Dr. Gerald N. McCall for his encouragement and support over the years and for his most thorough and critical evaluation of the various stages in the writing of this dissertation.

A special expression of gratitude goes to my husband, Al, without whose patient and loving support this study would not have been completed.

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## ABSTRACT

The integrity of the sensory feedback mechanism has been shown to be a prerequisite for normal speech. However, only two aspects of sensation of the oral region have been investigated: sensitivity to intensity and spatial discrimination. A third crucial parameter, time, has been ignored.

It has been demonstrated that the tongue tip is more sensitive to touch-pressure and for two-point discrimination than the dorsum. The relative sensitivity of the various areas of the blade and of one side compared to the other have not previously been established. Likewise, there are no earlier studies of temporal discrimination on the tongue.

This study attempts to increase our knowledge of the basic processes underlying speech. Two areas of study are selected: (1) sensitivity patterns of various lingual areas to electrical stimulation; (2) the temporal resolution of electrical stimuli applied to several areas of the tip and dorsum on the right and left sides of the tongue.

The subjects were five normal adolescents, tested on five separate days. Six lingual areas (the tip, the midline area of the dorsum and the lateral margins of the dorsum, on the right and left sides) were investigated. Surface electrodes were used to administer single or paired DC square wave pulses of one millisecond duration generated by an S8 Grass Laboratory Stimulator.

Thresholds of sensitivity obtained were evaluated in volts and decibels. Results show the tongue tip to be markedly more sensitive than the tongue blade in all subjects, for all test sessions. Differences in sensitivity recorded among the areas of the dorsum were of smaller magnitude and were not consistent from day to day nor from subject to subject. Neither the right nor the left side, nor the side corresponding to the dominant or non-dominant hand, showed consistent evidences of greater sensitivity.

Thresholds for temporal resolution were defined as the smallest interstimulus interval at which the paired stimuli were still consistently perceived as successive. The stimuli were administered with decreasing interstimulus intervals to a single lingual

location, or to two homologous locations on the two sides of the tongue.

The results did not show any consistent differences in temporal acuity among the lingual areas investigated, or between the two sides of the tongue. This similarity in acuity contrasts with the pattern of decreasing sensitivity from tip to dorsum seen in intensity and two-point discrimination studies. A marked and consistent difference was, however, observed between the two modes of presentation: stimuli presented in pairs to each single lingual location were not perceived as successive 75 percent of the time until an interval of 140-170 msec was reached, with 200 to 240 msec intervals needed for a 100 percent response. In contrast, stimuli presented bilaterally to the same locations were perceived as successive 75 percent of the time at intervals of 55 to 65 msec, and 100 percent of the time at intervals of 100 to 125 msec. These results support the hypothesis that temporal analysis of successive stimuli presented to one single cortical location differs significantly from the analysis of stimuli presented at similar intervals to dissimilar cortical areas.

## CHAPTER I

### INTRODUCTION

#### Lingual Sensation

The tongue is generally reported to be the most sensitive organ of tactile discrimination. The importance of adequate sensory feedback for motor control has been demonstrated by numerous authors; by Chase (1965 a, b) and MacNeilage, Rootes and Chase (1967) in particular. Acute sensitivity appears to be a requirement for fine motor control.

Absolute tactile thresholds cannot be reported since the numerical values obtained depend upon the parameters of the experiment, such as type of stimulation, duration, rise and decay times of the stimulus, etc. Relative thresholds have been published for some specific receptors and specific body areas but the human tongue is not one of the areas for which such values have been given. In fact, it is surprising how little is actually known about lingual sensitivity. Recent studies have shown that the tongue tip is more sensitive than the posterior areas, for touch-pressure, (Grossman,

1967; Henkins & Banks, 1967) and for spatial discrimination (Olroyd, 1965). Of the parameters of sensation, only intensity and spatial appreciation have been investigated. Time, this most important parameter, has been ignored despite the fact that adequate temporal discrimination is imperative for the performance of the rapid overlapping and successive movements required for precise articulation. We therefore are interested in how the tongue processes information on intensity and temporal sequencing.

#### Coding of Sensory Information

Sensation has several dimensions. These are quality, intensity, locus, and time. The mechanisms by which these are coded and interpreted by the central nervous system are complex and not fully understood.

##### Quality.

Receptors and first order fibers have been shown to be differentially sensitive to specific types of energy. These findings are related to and based upon two traditional laws: the law of "adequate stimulus" which states that sense organs have a low threshold for one form of energy, although they may respond to other forms of energy if such stimuli are sufficiently intense; and the law of "specific nerve energies" which states that stimulation

of a sense organ or central stimulation of a sensory system give rise to a response of the same subjective quality regardless of the physical nature of the stimulus. Research is under way for further knowledge of the nature of the receptors for touch, their specific pathways and the relation of the stimulus used to the submodality under investigation.

Locus.

Specificity for place has been demonstrated not only with studies of single cortical and subcortical neurons, but also with studies of evoked potentials, and stimulation studies in animals and humans. Penfield (1950, 1959) in particular, has shown that stimulation of a specific cortical sensory area gives rise to sensations referred to the peripheral receptors which that sensory area subserves. Likewise, motion results from stimulation of specific motor areas. Penfield's work has permitted the elaboration of maps of the somatosensory cortex and its association areas. Specificity for place and modality has been demonstrated for the tongue in particular by Landgren (1957, 1960, 1961, 1965), Kruger, Siminoff and Witkowsky (1961), Cohen and others (1957), Appelberg and Landgren (1958), Eisenman and others (1964).

Studies of single neurons have lead to an awareness of the converging-diverging relationship between peripheral and central areas; each cortical unit subtends a number of peripheral units, while a stimulus to a restricted peripheral area activates a number of cortical neurones (Mountcastle, 1966). Landgren (1960) indicates that the evidence points to two systems of neurons for the tongue: one with point-to-point connections and a minimum of convergence, the other with an increasing degree of convergence at higher levels of the pathway.

A gradient of excitability demonstrated in peripheral receptive fields sharpens localization ability: a stimulus generates strong excitation in the center of the field, with short latencies and increased frequency of firing. In the periphery of the field, weak excitation and strong inhibition occur; frequency of firing is decreased and latency is increased. Surround inhibition of receptors adjacent to the area of stimulation has been demonstrated for peripheral receptors (Lindblom, 1958) and for cortical neurons (Brooks, Rudomin and Slayman, 1961). It has been subjectively confirmed in Békésy's experiments with trained human subjects (Békésy, 1967).

### Intensity.

Two types of receptors sensitive to mechanical deformation have been described: rapidly adapting, phasic receptors, with discharge to sustained touch lasting only 0.2 sec, and slowly adapting tonic receptors which adapt slightly at the beginning of stimulation and thereafter maintain a steady discharge for the duration of the stimulus (Ruch and Patton, 1965).

Information about intensity is coded through three major aspects: the latency of the action potentials, the frequency of firing of the individual units stimulated, and the number of units responding. This has been shown to hold true for the tongue, in particular, by Landgren (1957, 1960), and by Cohen and co-authors (1957). Phasic receptors, which may only respond to a stimulus with a single spike, respond to increases in intensity by a gradual recruitment of active units. Tonic receptors respond to an increase in intensity by an increase in firing rate (Ruch and Patton, 1965). Between threshold and that intensity at which response is maximal, a power function can be used to describe the relation between intensity and firing frequency. This function is similar in slope to the results obtained with psycho-



physical experiments by Stevens and others (Mountcastle, 1966).

Time.

Some information about the temporal aspects of stimulation is obtained from the peripheral receptors' responses: phasic receptors fire when stimulated, adapt rapidly, and generally fire again when the stimulus is removed, thus giving an "on" and an "off" response which signals the duration of the stimulus. Tonic receptors, which adapt only slowly with time, signal continuously while stimulated. As indicated previously, the duration of the phasic receptor's response to a stimulus, and the latency of response of both receptors, are an indication of stimulus intensity and apparently do not transmit temporal information.

The way in which sensory information is coded in terms of its temporal aspects has not been resolved. The means by which the central nervous system discriminates temporally is a matter all too often neglected when the coding and transmission of incoming information to conscious levels is discussed. For instance, no reference to time discrimination could be found in several major textbooks, or in articles reviewing the ways in

which sensory data is coded by the central nervous system.

### Research Objectives

In an attempt to increase our knowledge of normal processes underlying speech, two topics have been selected for the present study: the investigation of

- 1) sensitivity patterns across the tip and the dorsum of the right and left sides of the tongue, and
- 2) the temporal resolution of electrical stimuli applied to the tip and the dorsum of the right and left sides of the tongue.

## CHAPTER II

### REVIEW OF THE LITERATURE

#### Sensitivity Studies

##### Touch and Pressure.

Many investigators have used various approaches to assess tactile sensitivity quantitatively; the oldest and most commonly used method is the one in which stimuli are applied by short filaments of known diameter and force, until a "just noticeable bend" occurs. Such method is exemplified by Von Frey hairs and the Semmes-Weinstein aesthesiometer. The force corresponding to the thinnest filament perceived by the subject is recorded as threshold. There are limitations to this technique, and these, as well as its advantages, are discussed by Head (1920) and Semmes, Weinstein, Ghent, and Teuber (1960). The last named authors investigated somatosensory changes in a large number of veterans having suffered penetrating brain wounds. One interesting result of their study was the discovery of a hitherto-unsuspected greater sensitivity of the left hand, compar-

ed to the right hand, of their normal controls. This increased sensitivity was not accompanied by improved two-point discrimination or localization. Weinstein and Sersen (1961) confirmed the greater sensitivity of the left hand, irrespective of age or handedness. Ghent (1961) attempted a developmental study of sensitivity on the two sides of the body, but her results were inconclusive.

Several investigators have studied patterns of oral sensitivity: Henkins and Banks (1967) used a series of nine graduated filaments to derive mean detection thresholds for several oral and manual sites. They found the tongue tip and hard palate significantly more sensitive than any of the other areas tested, with the tongue blade not significantly different from the hand. No significant sex or age differences were found.

Grossman (1967) used six filaments to investigate several oral and perioral areas. His results are expressed in number of times a positive response to each filament was obtained at each site, making comparison with other studies difficult. He found the upper lip more sensitive than any other area tested. He also described another approach (1964, 1967) based upon the use

of force transducers, results of which are in keeping with his other findings.

#### Vibratory Stimuli.

Other researchers have used vibratory stimulation, which represents somewhat more accurately the complex, fast, repetitive stimuli dealt with by the organism. Ruch and Patton (1965) compare it to the flicker phenomenon in vision and indicate that it depends on the perception of temporal patterns of touch and pressure.

Threshold values for vibratory stimuli over parts of the body do not appear to have been published. Pollock (1937) reports, without including data, that he found the tongue extremely sensitive to vibration. Plumb and Meigs (1961) report that sensitivity to vibration decreases with age, and that threshold curves follow a U-shaped line, with maximum sensitivity between 200 and 400 cps. Verrillo (1962, 1963, 1965, 1966) carefully investigated the parameters such as contactor area, circumference, rate of vibration, number of pulses, and extent of protrusion into the skin, which affect threshold; he remarked that the effects of these variables could be obviated by the use of extremely small contactor sizes. Such studies of the factors affecting

threshold measurements have not been carried out for other types of stimulating devices.

#### Electrical Stimulation.

Stevens, Carton and Shickman (1958) demonstrated that the apparent intensity of an electric current grows in a prothetic continuum, with subjective intensity related to the 3.5 power of the current. This slope is very steep, when compared to the slopes of growth of subjective intensity for loudness and tactile vibration (Stevens, 1961).

Gilmer (1937) investigated thresholds of sensitivity to various stimulating frequencies, using the index or middle finger of four subjects. He found maximum sensitivity around 256 cps with sharply increasing thresholds above 2000 cps. He remarked on the similarity of the perception evoked by stimulation with alternating currents and with mechanical vibrators.

Korin and Fink (1957) measured thresholds on the mandibular area of the cheek and the dorsum of the hand of thirty-four psychiatric patients, to evaluate the importance of sensitivity differences in the face-dominance pattern observed in these patients. They recorded thresholds of 6.76 and 7.85 volts for the right and left cheek

respectively, 29.25 and 22.35 volts for the right and left hand. They attributed the predominance of responses referred to the face to differences in sensation level of the stimuli.

As part of a study of the perception of paired stimuli in normal and brain-injured patients, Green and others (1961) plotted an intensity-duration threshold curve for electric shocks applied to the right and left thumbs. They found a marked increase in voltage necessary to compensate for durations shorter than .1 msec, and a slight threshold difference in favor of the left thumb.

Information concerning electrical thresholds on the tongue is still lacking. Grossman (1967) reported on pilot studies carried out at the National Institute of Dental Research, and indicated that subjective responses of normal subjects showed greater sensitivity on the anterior part of the tongue than on the dorsum. No further information was available.

#### Taste Sensations.

It has been known since Volta's days that the passage of an electric current over the tongue would give rise to taste sensations, and this has been used for the clinical evaluation of the taste sense (Krarup, 1958;

Jauhiainen, 1967). Békésy (1964) investigated electrically produced taste sensations, found them dependent upon the specific papilla stimulated, the size of the electrode, and the frequency of stimulation. In his report, no mention of touch was made. Békésy concluded that accurate study of taste sensations requires extremely small electrodes of non-polarizable material, and pulse durations of less than one millisecond.

No discussion relating taste and touch on the tongue has been found. It is known that some receptors on the tongue and some cortical cells respond to both types of stimuli; however, the responses can always be differentiated by their latencies. (Landgren, 1957, 1960, 1961; Cohen and others, 1957; Emmes, 1966).

#### Studies of Temporal Discrimination

Studies of temporal discrimination are rare. Even rarer is any discussion of its underlying physiological processes. A careful and thorough review of the confusing literature relating, directly or indirectly, to temporal processing suggests only one possible conclusion: two different factors are involved, the first when temporally separated stimuli reach a single cortical area, the second when two different cortical areas are excited.



Published studies of temporal integration, to be reviewed here, deal primarily with the stimulation of adjacent but not overlapping, or bilateral cortical areas. Such is the case when two fingers, two ears, two visual quadrants are excited by one repeated stimulus, or when two dissimilar frequencies, auditory or visual, are used. On the other hand, the information about the temporal integration of repetitive stimuli by one single cortical area must be obtained from the numerous studies dealing with cortical scanning and cortical excitability cycles. Rarely, however, do students of temporal discrimination refer to this extensive literature.

#### Integration of Stimuli to One Single Cortical Area.

Physiological studies. Harter (1967) reviews the literature dealing with cortical excitability cycles and presents two major hypotheses. The first hypothesis proposes that these cycles serve as a gating or timing device for incoming sense data, the other proposes a central scanning mechanism which temporally groups sense data into "moments," such moments being discrete periods of psychological time containing no temporal information. The first model is based primarily on paired-stimuli experiments:

The cortex is assumed to vary rhythmically in threshold so that the effect of incoming sensory data on the cortex is a function of when it arrives at the cortex in reference to the excitability cycle. ... The variations in cortical threshold are assumed to serve as a gating mechanism of incoming sensory and outgoing motor pulses. ... The rhythmic nature of the excitability cycle is assumed to be the result of a large number of cortical neurons having synchronous membrane potentials, the time period of the cycle being a function of the electrochemical nature of the neurons involved. (1967, p. 55-56).

The second model is based primarily on theoretical grounds. According to Harter,

The model suggests that the sensory projection areas are scanned by some kind of central scanning mechanism, sensory information being sampled and coded in terms of psychological moments with each successive scan. ... Usually the hypothesized scanning mechanism was associated with the alpha rhythm of the cortex. ... Moments and cortical scanning mechanisms have been conceived in a number of different ways. Moments have been defined as the unit of time required between successive events for them to retain their temporal representation; and as a unit of information or percept. In the former case, moments are assumed to reflect an absolute time base on which the central nervous system functions, information falling in one moment or another. In the latter case, moments are not necessarily assumed to reflect an absolute time base and may overlap and interact with one another in time. The duration of psychological moments was proposed as being relatively constant at 100 milliseconds, and as being variable ranging from 50 to 200 milliseconds. (1967, p. 54, 55).

The two major approaches used for the study of cortical excitability are recording the activity of single cortical neurons investigated with implanted electrodes,

and the study of evoked potentials, usually from the surface of the brain.

Single neuron analysis reveals that the usual response of a somatosensory neuron at thalamic or cortical levels is a brief repetitive train, the latency and number of impulses being directly related to the intensity of the stimulus and its position within the peripheral field. Thalamic and cortical lemniscal neurons do not appear to have a refractory period and can follow stimuli up to frequencies of 100 per second; at higher frequencies the response equilibrates. This equilibration occurs only near the center of the receptive field, and the cells at the periphery cease to respond. (Mountcastle, 1961). It thus appears again that the temporal properties of the response are determined by the intensity and location of the stimulus.

Landgren (1960) investigated the response of thalamic and cortical "touch" cells. The cortical response was described as consisting of an initial group of spikes discharged with short latency, followed by a period of inhibition lasting approximately 80 msec, then by a long lasting series of after-discharges. Such after-discharges were rarely seen in thalamic "touch" cells.

Cohen and co-authors (1957) tested the response of cortical cells to consecutive touch stimuli applied to the tongue. Each individual cell tested was fired by both volleys from the receptors when the interval between stimuli was 2.5 to 5 msec, no second spike was recorded when the interval was between 7 and 50 msec, and the cell again responded to both stimuli when these were separated by time intervals greater than 50 msec.

Evoked potentials are usually recorded through macroelectrodes applied to the pial surface or to the scalp. Eccles (1951) discusses the nature of these potentials when elicited by direct stimulation of the cortex. First a superficial response, surface-positive, lasting approximately 10-30 msec, with a rapid spatial decrement, is observed; this wave is attributed to the synaptic excitatory action of the impulses on the dendrites of the cortical neurons. It is followed by a long lasting, surface-negative deep response, complex and variable, attributed to synaptic potentials and to impulses generated in cerebral neurons after one or more synaptic relays of the afferent volley in the cortex. The deep response is followed by a repetitive response, the after-discharge of a series of waves, lasting 10-14

seconds, occurring after cessation of the stimulation. This spontaneous activity is attributed to continuously circulating activity in complex neuronal chains (probably thalamo-cortical). This activity is inhibited by strong stimuli which excite all neurons so that no more excitable neurons are available to start the circulating activity.

When the potentials are evoked by afferent impulses from peripheral receptors instead of direct cortical stimulation, the initial surface-positive wave is sharply restricted to the area where the afferents terminate, and it is followed by a more prolonged negative wave. The initial surface-positive wave is also shortened by previous stimulation.

Bourassa and Swett (1967) and Swett and Bourassa (1967) have demonstrated that sensory thresholds and evoked potential thresholds occur at essentially the same intensity required for threshold activation of peripheral nerve. However, they also demonstrated (in cats) that the presence of a cortical response in the form of a primary evoked potential, is not necessarily associated with perception.

Uttal and Cook (1964) compared the peripheral nerve

response, the evoked potential, and the subjective response to electrical stimulation of the median nerve, in two selected subjects. They report a monotonic increase of estimated magnitude and of peripheral nerve response as the intensity is increased. The relationship between stimulus intensity and amplitude of response did not extend to cortical potentials, which reached half their maximum amplitude at threshold, and 100 percent of full amplitude long before full stimulus intensity was reached. This unusual growth of potential amplitude was labelled "saturation phenomenon" by the authors, who unfortunately, did not compare the amplitude of the response with the subjective magnitude of sensation.

Cortical excitability cycles were first described in 1933 for the visual system, and subsequently demonstrated for all other sensory modalities. In 1933 Bishop observed that electrical shocks administered at various intervals to the stump of the optic nerve evoked responses of varying amplitudes at cortical levels. This lead the author to conclude "There is a spontaneously rhythmic variation in excitability; that the time in this cycle at which the stimulus falls determines whether or not a response shall take place in the cortex." (1933, p. 216).

The rhythm in rabbits was found to vary between  $1/5$  and  $1/3$  of a second.

Bartley (1936) amplified on this research. At moderate intensities, no response to the second shock was elicited until an interval of 80-100 msec was reached. The response reached maximum amplitude when this interval was doubled, and waned to a minimum when it was tripled. A second and a third maximum and minimum of decreasing amplitude followed. Decreasing the intensity of the second shock increased the duration of the refractory interval, while increasing it shortened the interval. Stimulation with trains of repetitive stimuli elicited an early "period of reorganization" characterized by responses of unequal sizes and at uneven intervals, followed by a period characterized by responses of equal size, smaller than the larger responses seen during the early period. This steady state response was attributed to a distribution of neural elements so that a different group of fibers was available to respond to each stimulus. Both augmentation and inhibition were noted when the retina was stimulated with spatially separated flashes, presented at various interstimulus intervals.

Cigánek (1964) used light flashes and reported an absolute refractory period of approximately 40 msec, followed by two maxima of facilitation at 100 and 200 msec, and an incomplete subnormal period at 150 msec.

Gastaut (1951) attempted to quantify and describe the pattern of responsiveness. They used light flashes separated by intervals ranging from 5 to 500 msec, in 10 msec steps. They described R1, the response to the first stimulus, as a straight line parallel to the abscissa. R2, the response to the second stimulus, consisted of a curve with an absolute refractory period of 20 msec or less, followed by a relative refractory period lasting approximately 40 msec during which the R2 curve grew rapidly to the level of R1, indicating progressive recuperation of excitability. This was followed by a period of oscillations above and below the level of R1, the first oscillation occurring around 120 msec, the second at 220. Barbiturate anesthesia lowered the response line of R1 on the ordinate, and displaced the curve for R2 to the right. The authors mention that they obtained similar results in experiments with audition.

Jarcho (1949) stimulated the radial cutaneous nerve of cats with paired electrical stimuli separated by



varying time intervals and reported a progressive decrease in the response to the second stimulus as the time interval between stimuli was decreased. He reports an absolute refractory period ranging from 19 to 84 msec, and a relative unresponsive period lasting 80 to 300 msec. The longer durations corresponded to deeper levels of anesthesia. At these deeper levels, the line describing the response to the second stimulus remained flat once full excitability was reached. At lighter levels of anesthesia, changes in excitability were noticed and briefly mentioned.

Chang (1951) investigated the cortical responses to clicks presented to the ear and to electric shocks applied directly to the auditory cortex. These stimuli were preceded by a single conditioning shock to the cortex. He reported an absolute refractory period shorter than 20 msec, a relative refractory period of 40-55 msec, followed by a periodic waxing and waning of responses, with periods of 100 msec from peak to peak of excitability. He indicated that facilitation was more pronounced than inhibition, and that the peak of facilitation became greater with each succeeding cycle. Chang's finding of increased facilitation has not been reported by

any other author, previously or since.

Rosenzweig and Rosenblith (1950) briefly reported on a study undertaken to investigate the electrophysiological correlates of the perception of double clicks. They described a smooth recovery function at the round window, 75 percent complete at 7-8 msec, 100 percent complete at about 100 msec. At cortical levels a small response to the second stimulus could be seen at 7 msec, but it did not reach its peak until 90 msec. The curve describing the response showed a few dampened cycles of increasing and decreasing amplitude before reaching its steady level. The authors amplified on their report in 1953, described and plotted the responses to a first and second click, at the round window and at the auditory cortex. The recovery curves at the round window were monotonic, never became supernormal, and recovery was rapid for short time intervals. Their particular shape depended upon the intensities of the first and second stimulus. At cortical levels the amplitude of the response to the first stimulus remained relatively constant. The amplitude of the response to the second stimulus varied systematically as the interstimulus interval increased. The intervals at which enhanced and

depressed responses occurred varied, depending upon the intensity of the stimuli, the level of anesthesia, and the temperature of the animal. The cortical recovery function was described as composed of two components, one monotonic, the other cyclical. The monotonic component was related to the response to the first stimulus and represented the discharge of a population of cortical units. The cyclical component was obtained by subtracting the monotonic component from the cortical recovery function; it was considered to be an expression of fluctuations in cortical responsiveness following the first response. As the intensity of the first stimulus was increased, the cyclical component was emphasized, its period was shortened, and the interval required for complete recovery of the monotonic component was lengthened. The depression described occurred whether the stimulation was monotonic or dichotic.

The authors remark:

It is often asked how far apart in time two clicks must be spaced in order to be perceived as separate. An answer to this question depends on such factors as the intensities of the two clicks and the particular perceptual criteria used. The round-window recovery functions suggest a lower limit to the delta interval at which the second click can evoke a sizable response. The cortical recovery functions suggest that relatively long intervals are necessary

for the second response to appear... (1953, p. 23).

Finck and Ruben (1962) also studied the interaction of monaural double clicks at the round window, eighth nerve and inferior colliculus of cats. They showed a progressive decrease in the recovery rate, and increase in the effects of intensity as the higher levels of the auditory system were studied.

Cortical excitability cycles are generally attributed to thalamo-cortical reverberating circuits, and related to the alpha rhythm since their frequency is similar. Eccles (1951) indicates that their source is probably the same and states that:

The common alpha rhythm at about 10 per second is readily explained if it is due to circulation of impulses in closed self re-exciting chains. After the discharge of an impulse a neurone develops a positive after-potential and an associated phase of depressed excitability. ...Recovery from deep depression begins at about 15 msec, and is almost complete by 100 msec. ...Thus at low background levels of activity, the most probable rhythm of neuronal discharge is about 10 per second. ... Successive discharges from the same neurone would be evoked by those impulses that happened to bombard it at about 100 msec after a preceding discharge. In this context it is interesting to recall that cortical bombardment from the medial thalamus at frequencies from 8 to 12 per sec. rapidly built up a rhythmic response to the cortex which appeared to be identical with the spontaneous alpha rhythm. (1951, p. 462).

While this explains the source of the rhythm at rest, it did not satisfactorily explain why a first impulse was always effective in eliciting a response.

Schwartz and Shagass (1963) demonstrated that reticular formation stimulation at thalamic levels sharply augmented the second response at 25-50 msec. This augmentation was not demonstrable during EEG arousal. It indicates that the reticular formation must play a role in cyclic excitation.

Demetrescu (1967) investigated the inhibitory and facilitatory effects of the midbrain reticular formation on cortical responsiveness. He demonstrated that selective damage to the caudate nucleus and suprapontine reticular formation lead to a dramatic increase of the second response during the early part of unresponsiveness (7-20 msec for the visual system, 25-30 msec for the somesthetic system). After such damage, stimulation of the midbrain reticular formation no longer suppressed the response. Potentials during the late period of unresponsiveness were greatly increased by stimulation of the reticular formation and by behavioral activation, and were not affected by caudate or pontine lesions. This lead him to suggest that in the intact brain a tonic

inhibitory process limits a second response. This inhibitory influence depends on ascending circuits from the caudate nucleus and the caudal reticular formation, which are activated by the phenomena involved in the production of the first evoked potentials. He concluded:

Two main effects have been noticed during midbrain RF stimulation or behavioral activation. One is enhancement of inhibition of the second response in the early period (7-10 msec) as seen with arousal in the chronic cat or even in the intact acute cat. The other RF effect, observable when rostromedullary section is added to caudate lesion, is facilitation of all evoked responses, regardless of length of pairing interval. ...This facilitatory process is not time-locked to the first stimulus, because it also affects the first response itself. Thus, the fact that reticular facilitation of the second response increases with increasing pairing interval, suggests an interaction between an inhibition, time-locked and progressively fading with time, and a sustained constant facilitation. (1967, p. 42-43).

#### Psychophysical Studies. Rosner states

When two brief, equally intense shocks stimulate a single cutaneous locus, they must be separated by 15 to 40 msec before the subject feels two temporally discrete events. The exact separation necessary for temporal resolution varies considerably among different observers. When the two shocks are felt as separate, the second feels less intense than the first for separations well beyond 40 msec. A similar situation obtains in audition, where Rosenzweig and Rosenblith report that two successive monotic clicks fuse into a continuous event for separations below 10 msec. Beyond this separation, the second click may seem softer than the first. Comparison of somesthesia and audition indicates, therefore, that the skin is somewhat more sluggish

than the ear in its recovery from transient stimuli. In both systems, the time course of recovery depends partly on the intensity of the stimuli. (1961, p. 731)

A similar conclusion about the skin and the ear's ability to discriminate small temporal differences was reached by Gescheider (1966, 1967) who studied the resolution and apparent successiveness of clicks presented to the ear and the fingertip. Stimuli to one ear had to be separated by 1.6 msec, to be perceived as successive, while stimuli to the index finger required intervals of 10 msec. However, the author states that "The S was instructed to report 'two' ...when he perceived a rough rather than a smooth sensation in one ear or on one skin area." (1966, p. 379) This judgment, which Gescheider calls "temporal separation" and "apparent successiveness" does not correspond to the separation mentioned by Rosner, Rosenzweig and Rosenblith, or to be investigated in this study. Rather, it probably corresponds to the change in perception described as a "hump" by Rosenzweig and Rosenblith (1950), the change in shape and perceived intensity described by Békésy (1967). Such a change was also reported by the subjects used in the experiment described in this paper, at separations of a few milliseconds, while true "separation" did not occur until

much larger intervals were reached, as will be discussed.

Pieron and Segal (1939) reported finding evidences of forward and retroactive summation, when they stimulated the fingertip with shocks of chronaxy duration and threshold voltages. Rosner (1961) indicated that he was unable to duplicate their results. He was, however, able to demonstrate summation at subthreshold voltages and durations shorter than one millisecond. These stimuli were perceived as single events.

The only study found correlating perceptual and neurophysiological events during double stimulation was by Donchin and Lindsley (1965). They correlated the subjective impressions of their subjects with their evoked potentials in response to stimulation by a brief test flash followed by a second brighter flash. At small interflash intervals (90 msec or less) they found a phenomenon they called "perceptual masking" with the test flash masked by the brighter flash; the evoked potentials corresponded to the response to the brighter flash alone. At longer interflash intervals (100-150 msec) there was brightness enhancement of the first flash, and the evoked potentials resembled neither those of the first nor second flash seen alone, but showed linear summation.



Finally, at still larger interflash separations, the two flashes were perceived as separate and the evoked potentials were distinct and typical of the response to each flash alone. The masking effect of the second flash upon the first at the smaller intervals, which appears to contradict the results of other investigations cited, is undoubtedly due to the greater intensity of the second flash. With the decreased latency resulting from the much greater intensity, it is possible for the neural response to the second flash to overcome the first during transmission to the higher centers.

Temporal integration of stimuli to two distinct cortical areas.

Physiological studies. Rosenzweig and Rosenblith (1953) indicate that the cortical changes they described for monotic clicks can also be demonstrated when stimulation is dichotic. The relative amplitudes of the two responses varied depending upon the ear stimulated first and the cerebral hemisphere on which the electrode was placed. They state:

When the delta interval for dichotic stimuli is sufficiently brief, a single response occurs, and this response is often larger than the response to either one of the stimuli. The response tends to be larger at the hemisphere contralateral to the ear that receives the first stimulus. Thus, if we stimulate

the ears in the order left-right, the response at the right hemisphere tends to be larger than the response at the left hemisphere. Significant differences can be observed even when the delta interval is well under 1 msec. We have shown elsewhere that the data obtained with dichotic stimulation can be interpreted in the following way: The two ears are represented at each cerebral hemisphere by two partially overlapping populations of cortical units; at each hemisphere the population that represents the contralateral ear is larger than the population that represents the ipsilateral ear. (1953, p. 21)

Uttal and Cook (1964) investigated evoked potentials in human subjects and failed to find a significant interaction between responses produced by independent stimuli applied simultaneously to the two wrists.

Psychophysical studies. Békésy (1957, 1963, 1965, 1967) has investigated extensively the sensory inhibition of stimuli of all modalities, separated spatially and temporally. He indicates that two equally intense stimuli presented simultaneously fuse into a single event located between the two sites of stimulation. When a time difference is introduced between them, the sensation moves towards the stimulator receiving the earlier stimulus. At a critical time separation the sensation will be localized entirely under the first stimulator, with no sensation at all under the second. Beyond this time interval, the two

stimuli separate spatially. He named the phenomenon responsible for this disappearance of the second stimulus "lateral inhibition," and demonstrated it for touch, vibration, hearing, smell and taste. The critical time separations needed for complete localization to one side depended upon the spatial separation between the areas stimulated: it was 1 msec for vibrators placed 12 cm apart on the arm, 0.5 msec for odors, 2 msec for taste stimuli administered 2.6 cm apart on the tongue, 3 msec for hearing.

Békésy (1967) stresses the importance of controlling the sensory magnitudes of the stimuli, and their durations, since different time intervals are needed for stimuli in different modalities to reach maximum subjective intensity (0.2 sec for sound, over one second for taste, smell, and vibration). He relates his findings to the physiological investigations dealing with nerve responses, and concludes that the process of localization is determined by the very early responses to stimulation, and that sensory magnitude and quality are determined by the later responses.

Hirsh (1959) and Hirsh and Sherrick (1961) studied temporal resolving power (the ability to distinguish be-

tween successive versus simultaneous stimuli) and temporal order judgments. They report separation times of 2 msec for auditory clicks, of 15-20 msec for cutaneous stimulation of palm and finger. The visual system is reported as being more sluggish than the auditory or the somesthetic system. Subjects were required to differentiate between stimuli (left and right, upper or lower, for lights; left or right, low or high pitched, or a combination of both, for sounds), and to indicate which was presented first. Separation times of 20-40 msec were obtained for the 75 percent correct identification of order, for the three modalities investigated, leading the authors to conclude: "whereas the time between successive stimulations that is necessary for the stimuli to be perceived as successive rather than simultaneous may depend upon the particular sensory modality employed, the temporal separation that is required for the judgment of perceived temporal order is much longer and is independent of the sense modality employed." (1961, p. 432). In a later study, Sherrick (1964) remarked that when the temporal order of two subjectively equal stimuli of one modality was studied, the subjects occasionally failed to report stimulation at one of the sources. He stated

that this lead him to investigate further the effects of double simultaneous stimulation of the skin by changing relative intensities of the stimuli until the weaker one disappeared. He found that an intensity ratio of 1:2 or 1:8 would produce masking of the less intense signal. Altering the time of onset of masking and test signal produced a shift in the threshold curves, with the greatest effects occurring when the conditioning stimulus preceded the test signal by a few milliseconds.

Rosner (1961) quotes an unpublished doctoral dissertation by Matin, later published under her marital name of Schmid (1961). Schmid investigated the degree of masking of an electrical stimulus applied to a finger, by electrical stimuli of varying intensities applied to other fingers of the same hand; the time separation between stimuli was varied. Like Sherrick's, her results indicate that the inhibitory effect was maximal when the conditioning shock preceded the test shock by a short interval. Schmid also found that for a fixed interval, the amount of masking or "inhibition" was a monotonic function of the intensity of the conditioning shock, and was also related to the spatial separation between areas stimulated.

Gescheider (1966) compared the temporal resolution power of the ear and the skin, for unilateral and bilateral stimuli. Binaural clicks were perceived as temporally discrete at 1.8 msec separation, while cutaneous clicks had to be separated by 12.5 msec to be resolved. Changes in the relative intensities of the stimuli affected threshold, and the best resolution occurred when the first stimulus was 5 to 10 dB less intense than the delayed stimulus. He then (1967a) compared the "apparent successiveness" of stimuli to the ears and the fingertips. He reported that apparent auditory time is directly proportional to actual time over a wide range of time intervals from resolution (1.6 msec monaurally, 1.8 msec binaurally) to several seconds. On the skin, the same rate of growth of "successiveness" applies only for times greater than 30 msec. Altering the relative intensities of the signal (1967b) affected both in similar fashion. This lead him to infer that similar neural mechanisms are operative for both modalities, and that a prior stimulus may exert an inhibitory effect on activity produced by a second stimulus; this inhibition may be reduced or compensated for by making the second stimulus more intense than the

first.

Efron (1963a) attempted to obtain evidence for the theory that judgments of sequence are made in the hemisphere dominant for speech. He asked normal subjects, chosen and rewarded for internal consistency, to report on the order of shocks and visual stimuli administered in descending runs, from separations of 100 msec to the first report of simultaneity. His results deal only with the "center point of simultaneity" at the midrange of the limits of fusion, but his graphs suggest that there is a range of approximately 20 msec on either side of true simultaneity (0 msec interval) during which the subjects perceived the stimuli as simultaneous. It appeared that 50 or more msec were necessary for the 100 percent correct evaluation of the order of presentation; no significant differences between results of visual and cutaneous stimulation were noted. Significant differences in the statistically averaged "center point of simultaneity" were found between right-handers and "true sinistrals," giving support for the theory he proposes.

In a second article, Efron (1963b) deals with changes in order judgments generated by changes in the relative intensities of the stimuli, but does not report

any figures other than the changes in the "center point of simultaneity."

In a recent publication (1967) he indicates that inexperienced subjects required approximately 50 to 60 msec intervals before the correct order of stimuli could be identified. A similar figure is given by Hirsh and Fraisse (Eisenson, 1968).

Lowe and Campbell (1965) report that normal children, aged 7-14, required 15 to 30 msec to perceive sequence for two similar tones, 15 to 80 msec for a 75-percent correct order judgment of two tones of widely separated frequencies.

Malone (1967) compared the ability to identify speech presented at various rates with auditory temporal ordering abilities. He reports "a mean speech identification task score" of about 33 msec and a mean temporal ordering task score of about 71 msec. He concludes that his results "demonstrate no relationship between temporal ordering ability as measured by a two-signal procedure and speech comprehension of normals." (1967, p. 547) Effects of brain-injury on temporal discrimination.

The importance of small time differences for the perception of speech sounds has been demonstrated and



stressed by the experiments with synthetic speech reported by the staff of the Haskins Laboratories (Delattre, Liberman and Cooper, 1955; Lisker, 1957; Liberman and others, 1956, 1958, 1961). At the same time we are becoming aware of the effects that lesions of the central nervous system, of the temporal and parietal lobes in particular, have on the ability to judge sequence.

"Extinction" in particular, is an evidence of problems resulting from CNS lesions in general, from parietal lobe lesions in particular. It is characterized by the individual's inability to perceive and attend to two simultaneously applied stimuli, while being able to perceive and attend to each when they are presented separately. This phenomenon had originally been described in 1885 by Oppenheim, referred to by several neurologists over the years (Jones, 1907; Maas, 1910; Head and Holmes, 1911) but did not receive much attention until the 1940's and 1950's (Bender, 1945 and 1952; Bender and Furlow, 1945; Bender, Wortis and Cramer, 1948; Fink and Bender, 1953; Ross and Fountain, 1948; Swanson, 1957; Denny-Brown, 1952; Critchley, 1949). Denny-Brown and Critchley discussed it under other names and made references to the possibility of overcoming the perceptual loss by

changing the relative intensities of the two stimuli and by introducing a time interval between them. Schwartz and Eidelberg (1968) experimentally created a problem similar to extinction in monkeys by surgically removing parietal and frontal cortex.

Although extinction can sometimes be overcome by greatly increasing the intensity of the stimulus to the defective side (Critchley, 1949), it can most effectively be overcome by introducing an appreciable time delay between the stimuli (Denny-Brown, 1952; Critchley, 1949; Birch, Belmont and Karp, 1967). For this reason, it can properly be considered time-dependent. This confirms the importance of the integrity of time processing for adequate functioning of the individual.

Green (1961) first reported that "impaired discrimination between one and two brief cutaneous stimuli was the only type of sensory deficit specific to intracranial disease." (1961, p. 1010) He showed that a group of patients with intracranial disease could not distinguish between two high-intensity electrical stimuli presented in close succession as well as his normal controls. Unfortunately, he reported no figures to support his statement.

Efron (1963c) demonstrated defects in sequencing in patients with lesions in the dominant hemisphere. He compared the intervals needed for the correct identification of the sequence of lights and sounds for 12 patients with left-hemisphere damage, 11 of whom were aphasic, and 5 subjects with right-hemisphere lesions and no aphasia. The controls (brain-injured without aphasia) required 80 and 75 msec for the 75 percent correct identification of the order in which visual and auditory stimuli, respectively, were presented. The subjects with expressive aphasia required 100 and 400 msec for visual and auditory sequencing, while the receptive aphasics required 160 and 140 msec. He later (1967) commented that

We found that patients who had aphasia ... frequently require enormous intervals before they can separate and give a correct report of which sound occurred first. I have already given you the normal figure -- 60 msec. I have come across aphasics who have required as much as a second between two brief, 10 msec. sounds of very different frequencies before they could correctly identify the temporal order. (1967, p. 30)

Lowe and Campbell (1965) demonstrated evidences of disturbances in temporal ordering in aphasoid children. They reported no significant difference between their subjects and their controls in the identification

of sequence, but they did report a significant difference in temporal ordering. Their controls required 15 to 80 msec for the 75 percent correct identification of the order of presentation of sounds of widely differing frequencies, while their subjects required 55 to 700 msec (with a mean of 357 msec). As in most of the studies of sequence, a forced choice was required between the two alternatives, and judgments of simultaneity were not allowed.

Birch, Belmont and Karp (1967) suggested that the failure to respond to two stimuli presented in close succession is due to the increased latency of response and recovery time of the damaged nervous system. Their model proposes that simultaneous bilateral stimulation is associated with a slower rate of response by the affected side and that "what is externally simultaneous is probably physiologically successive in patients with unilateral cerebral damage." (1967, p. 124) "Extinction" is best regarded as the result of slowed afferent processing in the damaged hemisphere and greater vulnerability of this region to interference from the intact and more rapidly integrating undamaged portions of the system. To validate their hypothesis, they experi-

mentally demonstrated that extinction can be reduced or eliminated by the prior stimulation (by 300 and 600 msec) of the damaged side. With a further increase in interval, a shift of lateralization of response from the intact to the damaged side was seen; this was interpreted as inhibition of the sound hemisphere by the damaged one, which had been given time to fully integrate and organize. Prior stimulation of the intact side gave results similar to those obtained with simultaneous stimulation.

The subjects used were hospitalized chronic left hemiplegics. As extinction of the sound side by the damaged side has not been reported in normal subjects, it is questioned whether the reversal of extinction might not have been due to the presence of some impairment of the "intact" hemisphere. In any case, this study also shows the vulnerability of temporal discrimination skills to brain injury.

The importance of temporal sequencing skills to speech pathology can best be re-stated by two quotes:

We can thus consider it to be definitely established that aphasics as a group suffer from a profound defect of auditory sequencing. What is not clearly established is the relationship of this clearly defined defect of auditory function to the understanding of spoken language. We now know that there is an association between aphasia and this type of

sequencing defect. It has not been proved that the defect in temporal sequencing is the primary cause of the inability to understand speech. (Efron, 1967, p. 30)

Thus, we may characterize the child with developmental aphasia as one who has a basic impairment in the necessary capacity for the analysis of speech signals and for the sequencing of temporal events... (Eisenson, 1968, p. 12)

These two statements refer only to auditory temporal sequencing. The temporal sequencing of somesthetic stimuli by the aphasic or speech defective has never been investigated.

## CHAPTER III

### METHODOLOGY

#### The Questions

This study consists of two major parts: the first deals with sensitivity patterns of the tongue, the second with the temporal integration of electrical stimuli applied to the lingual surface.

#### Sensitivity of the lingual surface to electrical stimulation.

1. Are there differences in sensitivity among the areas of the tongue primarily involved in articulation, namely the tip, middle area of the dorsum, and lateral margins of the dorsum, on the right and left sides?
2. Is there any evidence of greater sensitivity of one side as opposed to the other?

#### Temporal discrimination of electrical stimuli.

#### Temporal separation thresholds for double stimuli applied to each of the specific areas of the tongue.

1. Are there differences in temporal acuity among the various areas of the tongue, similar to

those reported in studies of sensitivity and two-point discrimination?

2. Is there evidence of asymmetry in the temporal acuity of the two sides of the tongue?

Temporal separation thresholds for bilateral electrical stimuli presented to homologous pairs of locations on the lingual surface.

1. Are there differences in the temporal acuity for bilateral stimulation among the various areas of the tongue?
2. Are the temporal limits for separation of bilateral stimuli affected by the order in which the sides of the tongue are stimulated?
3. Is there evidence pointing towards a dominant sensory side for the tongue, as suggested by Efron, and demonstrated by a shift in the perceptual "center point of simultaneity" from true simultaneity (no interval between stimuli)?

Comparison of separation thresholds for double stimulation of single locations, and for bilateral stimulation of these same areas in homologous pairs.

Is there a consistent difference between the results obtained in these two experiments?



### Subjects

Two boys and three girls, aged 15-5 and 16-6 were used for the study. The two boys (subjects 4 and 5) and one girl (subject 1) were right-handed, the other two girls (subjects 2 and 3) were left-handed (with left-handed siblings but right-handed parents). The subjects were sophomores or juniors in two local high schools, and were informed of the project by classmates. All were non-smokers, of normal intelligence as evidenced by scholastic performance, and free from any health or speech problems. A fee of one dollar an hour was tendered for their services. A release form, included in the appendix, was signed by the subjects and by their parents.

Teen-agers were selected as preferred subjects for several reasons: availability for repeated testing within short periods of time, the fact that testing in various sensory modalities indicates that sensitivity is greatest at that age, and the hope that the testing technique developed may be made applicable to younger age groups as well as to older subjects. A single age group was decided upon to eliminate any variability which might be attributed to sensory changes due to

aging, preliminary testing having suggested the possibility of an elevation of thresholds with age.

### Equipment

#### Stimulator:

A Grass S8 two-channel laboratory stimulator was used. Square wave DC pulses of 1-msec duration, with rise and decay times of approximately 5 microsec, were administered to the subjects according to the protocol to be described later. A picture of the equipment is shown in Fig. 1.

The S8 stimulator is designed as a low-impedance, constant-voltage cathode follower type, and was used as such in this experiment. Conversion to a constant-current source, by the insertion of an extremely large resistor in series with the output, was considered and rejected because of the extremely large voltage outputs required to overcome the increased resistance. This conversion, or a truly parallel circuit, would have made the threshold readings independent of any fluctuations in the resistance of the subject. However, since the debate about perceived intensity and its controlling factor (voltage, current, or power) remains

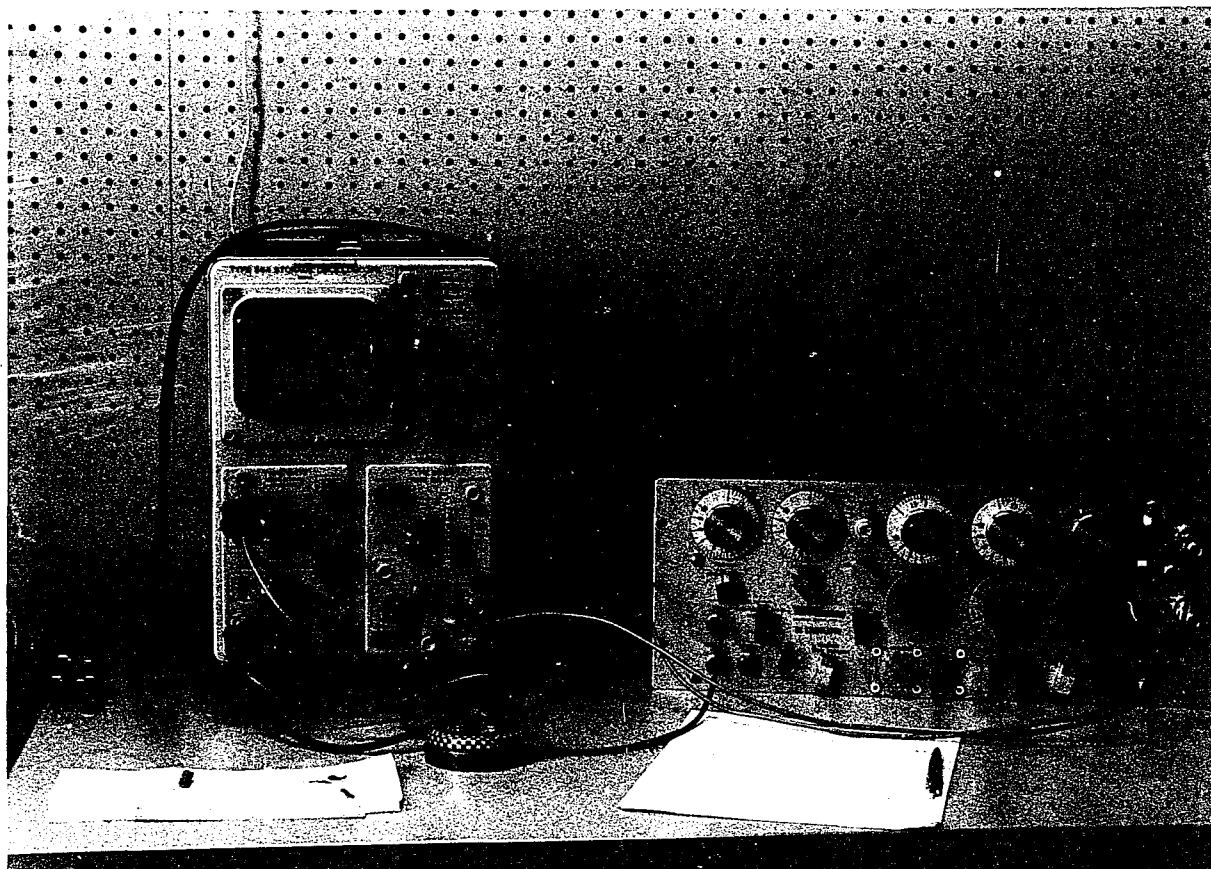


Fig. 1.-- Equipment used for electrical stimulation of the tongue

unresolved, it was decided to attempt to record both current and voltage across the subject's tongue.

There are strong indications from the literature dealing with electrodermal stimulation that stimulation of the skin alters its resistance and conductance. Wilcott and Hammond (1965) attributed it to increased voltage, and Tursky and Watson (1964-65) indicate it is a local phenomenon which occurs regardless of whether voltage, current or power are held constant. They recommend local treatment of the area to be stimulated (rubbing with electrode paste to reduce impedance) but neither their recommendations, nor those suggested by Montagu and Coles (1966) were found applicable to this study. Thus, threshold readings were not made independent of resistance changes, and local fluctuations could not be controlled. However, the output of the stimulator remained constant for any changes in load above 1000 ohms, and changes in the power output caused by changes in the load could be ruled out. It was also assumed that the short duration of the stimuli and their minimal intensity would preclude changes in resistance due to stimulation.

During testing, it was discovered that the stimu-

lator could put forth a high-voltage DC pulse lasting several seconds, then return to normal function. This unexpected and undesired signal was attributed to a transient malfunction in a transistor by one of the company's representatives, and was therefore considered unavoidable. To prevent a possible painful shock to the subjects, an AGX 1/500 fuse was installed in series with the electrodes. This fuse was tested and burned out at approximately 50 volts and 5.5 ma for stimuli lasting one millisecond, at 3.5 ma for stimuli of longer duration (5 msec). Due to the shortness of the stimuli, these intensities were not found painful.

To read the total voltage generated, a cathode ray oscilloscope was connected in parallel with the output of the stimulator and the electrodes. The diagram of the circuits is shown in Fig. 2. In this system the voltage drop across the channel of the oscilloscope was equal to the voltage drop across the electrodes and the subject's tongue. To obtain readings of the effective current, the stimulator output was also connected to the second channel of the oscilloscope, which was in parallel with a 1000 ohm resistor and in series with the electrode. Instantaneous current values to the subject

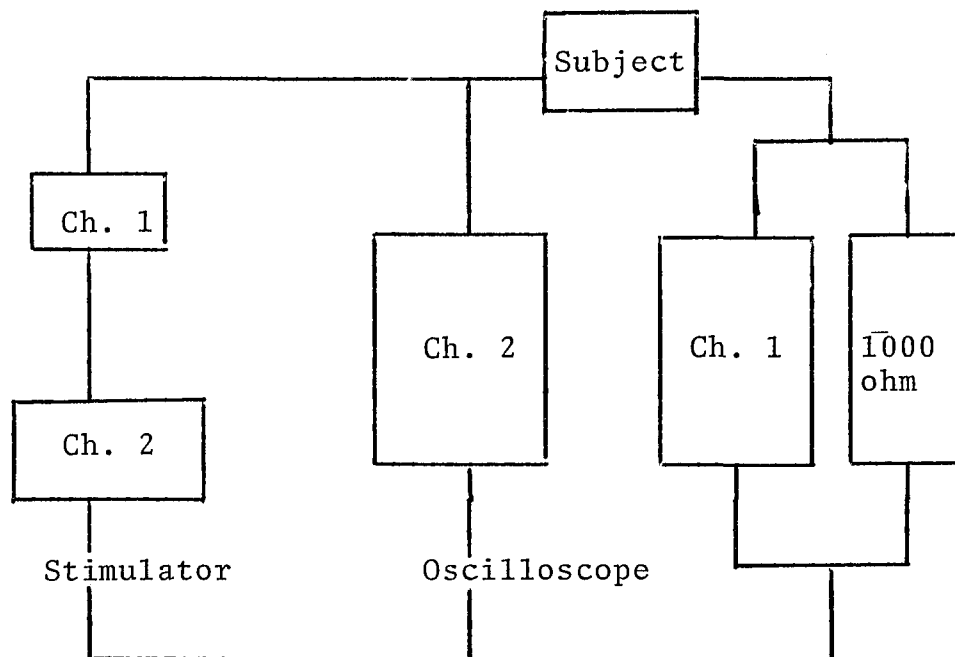


Fig. 2.-- Diagram of the equipment used for measurement of sensitivity of the tongue to electrical stimulation

were calculated by recording the voltage generated across this 1000 ohm resistor, and dividing it by the resistance, according to the formula  $I=E/R$ . This resistor was in series with the electrodes, and the current through the electrodes (and the tongue) was equal to the current through the resistor.

The 1000 ohm value of the resistor was selected after due experimentation: large enough to permit adequate voltage readings on the scope, small enough to eliminate the need for increased voltage output.

The voltage drop across the subject's tongue was calculated by subtracting the voltage drop across the 1000 ohm resistor from the total voltage output. Subject resistance was calculated by dividing subject voltage by subject current, in accordance with the formula  $R=E/I$ .

Direct measurement of resistance by placing the terminals of an ohmeter on the tongue was attempted. Comparison of the resistances obtained by this method with the ones obtained by the calculations described above revealed that the readings on the ohmeter were much larger than the calculated resistances, and were strongly affected by the degree of pressure exerted on

the leads.

### Electrodes.

Various types of electrodes and methods of positioning were considered and rejected. The electrodes decided upon were of the type designed by Majeau (1967) for electroretinography and are shown in Fig. 3. They were preferable to all others for the following reasons: (1) They can be placed and retained with a great degree of accuracy without immobilizing the tongue, and without the use of suction. Immobilizing the tongue increases subject tension and fatigue, and suction interferes with the sensitivity we were attempting to measure. (2) They need not be held in place by the subject, nor by the examiner or a helper. (3) They do not cause lingual deformation and the pressure they exert remains constant, minimizing the activation of deep pressure receptors. (4) The small stimulating area recommended by Verrillo (1963, 1965, 1966) and by Békésy, avoids excitation of taste buds, decreases counter-impedance, and permits a greater current density at the point of stimulation. (5) They are easy to make, inexpensive, can be replaced with a minimum expenditure of time and money, and can therefore, be used as disposable electrodes.



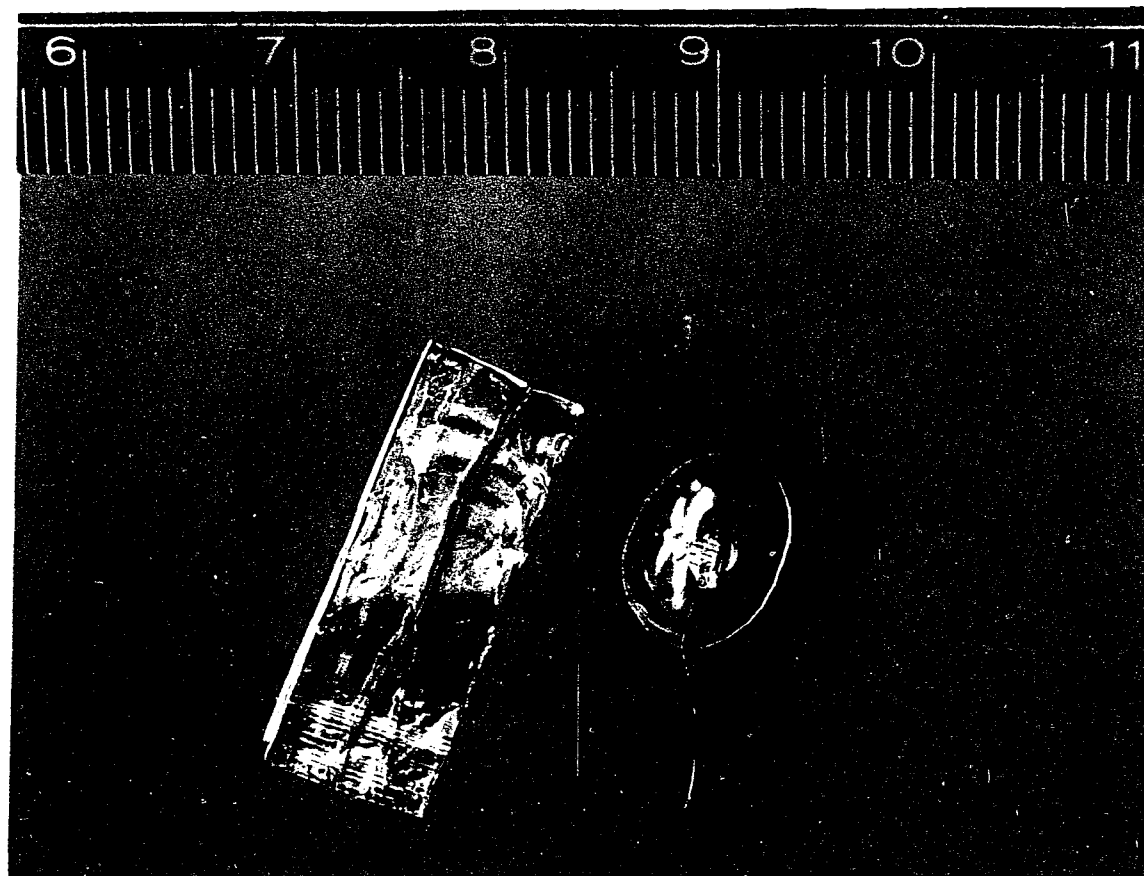


Fig. 3.-- Electrodes used for electrical stimulation of the tongue

These electrodes consisted of a silver foil point of approximately  $1 \text{ mm}^2$  surface area, embedded in a plastic disc, 0.075" in thickness, 3/8" in diameter, connected to the stimulator output by fine wire and adhering to the tongue through surface tension. The indifferent electrode consisted of a piece of foil .7 by 2 cm, placed under the tongue.

New electrodes were used for each test session. They were also replaced whenever warping was noticed, or whenever a break occurred at any point in the connections.

The possibility of the electrodes interacting with the saliva to form a battery was investigated. The maximum current generated, as measured with a string galvanometer, was in the range of 16 nanoamps. Electrolytic by-products were kept at a minimum by limiting pulse duration to 1 msec, and stimulating area to  $1 \text{ mm}^2$ . The effects of repeated stimulation were investigated by placing the electrodes in a beaker of saliva and stimulating several hours without interruption. No changes in the amplitude or the shape of the signal recorded on a Tektronix 564 storage oscilloscope could be detected.

Signal.

The stimuli consisted of square wave pulses of 1 msec duration with rise and decay times of approximately 5 microseconds. The duration was selected, as mentioned, to minimize counter-impedance and the build-up of electrolytic by-products, and to make for a highly tolerable stimulus, felt as a tap rather than as a shock.

The frequency of stimulation selected was one every 5 seconds, experimentation having shown that changes in threshold occurred with higher rates of stimulation. This interstimulus interval also gave sufficient time for accurate manipulation of dials and recording of data.

#### Recording technique.

All stimuli were monitored for frequency, duration, amplitude, and interstimulus interval by displaying the signal on the two channels of a Tektronix 564 storage oscilloscope, which was checked for calibration prior to each test session. The voltages displayed on the oscilloscope were recorded on forms attached in the appendix. Current and resistance were calculated from the raw data obtained and recorded on these same forms. The intervals between paired stimuli were also read on the scope, and recorded, as were the voltages corresponding to "comfort levels."

### Areas Investigated

Three general areas considered most involved in consonant articulation, were selected. These were the tip, the midline area of the dorsum, and the lateral margin of the dorsum, on the right and on the left sides of the tongue.

The following locations shown diagrammatically in Fig. 4 were selected, as representing these areas:

1. A point on the tongue tip on either side of midline, 5 mm from the anterior margin (arbitrarily designated as location A on the right, location B on the left).
2. On the blade on either side of midline, at the ending of the midline sulcus, or at 2 cm from points A and B for the one subject whose midline sulcus did not end in that area, (locations D on the right, E on the left).
3. On the blade, 5 mm from the lateral margin on an imaginary line crossing through D and E (location C on the right, F on the left).

The degree of protrusion and of tension of the tongue altered the exact margins to some extent; the 5 mm from the edge is only an approximate figure. All points

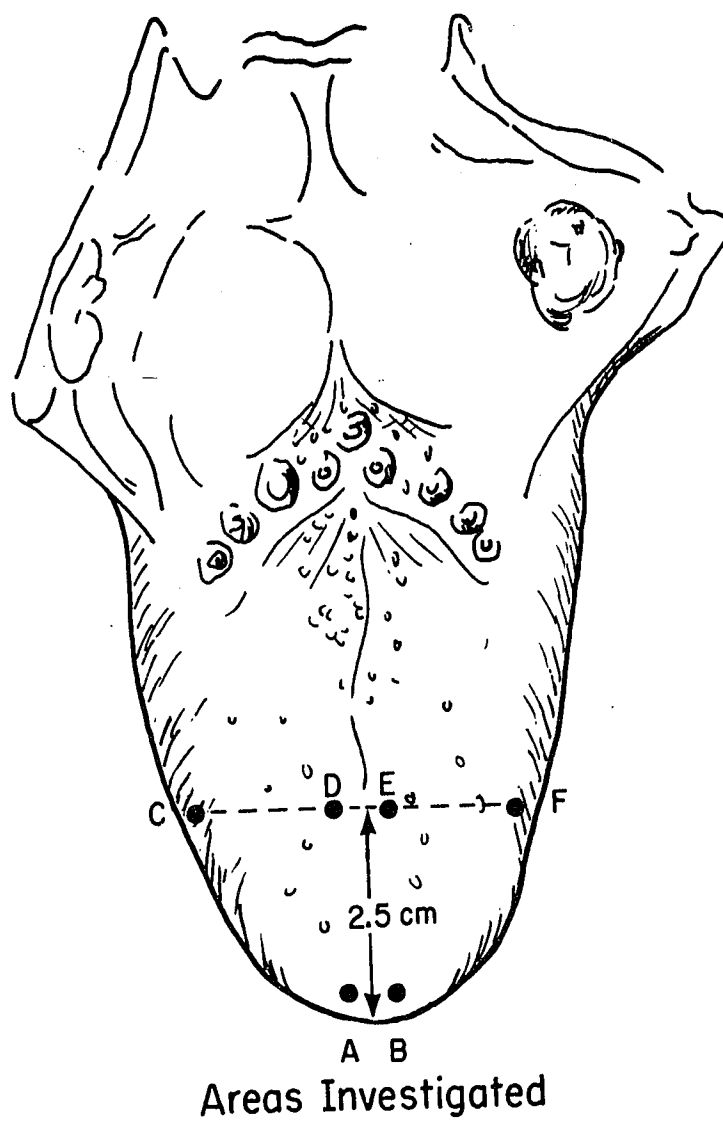


Fig. 4.-- Areas of the tongue investigated with electrical stimulation

were marked with Tincture of Gentian Violet which remained indelible for the duration of the test session.

### Test Sessions

Each subject was seen individually for five repeated test sessions lasting from approximately four hours for the first session, to two and a half to three and a half hours for subsequent sessions. These sessions were originally planned at regular five day intervals; due to malfunction of the equipment, however, it became impossible to keep to the planned schedule. All subjects were seen at intervals of no less than five days, no greater than 13, with an average of seven days. Conditions were maintained as constant as possible throughout the duration of the experiment. All tests were given after school hours or on the week-end; the time of day, activity prior to the test session, and time from last food or drink intake were not controlled.

Each test session was divided into three successive parts: first, the threshold determination for the six areas investigated, called Test I. Second, the determination of separation thresholds of double stimuli to each of the areas, called Test II. Third, the deter-

mination of separation thresholds for paired bilateral stimuli to homologous pairs of areas (pairs A-B, B-A, C-F, F-C, D-E and E-D), called Test III. These tests were separated by short rest periods.

### Procedure

The subject was seated in a comfortable reclining chair, placed alongside the equipment so that he could be watched by the examiner without being able to see the stimulator dials or the oscilloscope screen. He relaxed while calibration was checked, the electrodes cleaned in 95% alcohol and connected. He then extended his tongue for marking with a toothpick dipped in Gentian Violet. The indifferent electrode was placed under his tongue and the stimulating electrode was placed on the particular area to be tested.

Detailed instructions were given at the start of the first test session, followed by a practice period to allow the subject to familiarize himself or herself with the stimuli used and to alleviate fears of painful shocks. A long practice session was avoided to permit a comparison of the first and later test sessions, to evaluate learning effects. The instructions were repeated

in abbreviated form at the start of each test session and each test within each session.

Sensory threshold measurements. The equipment was connected, as described previously, with the subject in series with channel one of the scope (and a 1000 ohm resistor in parallel with channel 1) and in parallel with channel 2 of the oscilloscope. Outputs 1 and 2 of the stimulator were connected to the single electrode used; output 2 of the stimulator was not used, but was connected to keep circuits and loads constant. The electrode was placed on the area to be tested. The locations were tested in a randomly determined order.

The subject was instructed to raise a finger whenever he felt the stimulus, perceived as a single light tap at the point of contact with the stimulating electrode. The stimuli were administered at the rate of one every five seconds and the intensity increased in steps of one volt until a response was obtained. The intensity was then decreased by one volt, and increased again in steps of 0.1 volt until threshold, defined as the level at which three successive stimuli were perceived, was reached. This procedure was repeated until five thresholds for each location were recorded. At intensity



levels above 10 volts, it became impossible to control or monitor increases of 0.1 volt, and 0.5 volt increments were used instead. The test ended when five threshold determinations had been recorded for each of the six locations.

Separation thresholds for double stimulation of single spots.

The equipment remained connected as for Test I. The output of both channels of the stimulator was used to generate paired stimuli of equal voltages, separated by intervals controlled by the S2 DELAY setting of output 2. The locations were tested in randomly determined order.

The subject was instructed to respond by raising two fingers as long as two separate and successive stimuli were felt. A "one" response, consisting of raising one finger, was required when the stimuli were no longer successive and distinct, that is, when they became fused, or when the second stimulus disappeared. Special care was taken to caution the subjects against responding "two" when the signals were perceived as separate but no longer successive, since preliminary investigations had shown that after fusion of the

stimuli at given intervals, two stimuli could again be perceived at still smaller intervals as "two points on a long line," "two sharp points within an oval," or "a long line cut in two." The significant difference between these and previous perceptions was that the signals were appreciated as simultaneous in time, and separated spatially, in spite of being presented through one single electrode.

Stimulus intensity was set at twice threshold for the area under test, and adjusted as requested by the subject until it felt "comfortable." The output of the second channel of the stimulator was matched exactly to that of the first.

A 300 msec interval was selected as the starting point, previous investigations having disclosed that all subjects could appreciate two stimuli easily at that setting. An approximate separation threshold was obtained by rapidly decreasing the time interval until the subject reported a change from "two" to "one." The time separation was increased by 50-100 msec, decreased in 10 msec steps until threshold was reached. The stimuli were presented at least twice at each interval. Threshold was defined as the last time interval at which a

consistent "two" response was obtained. In case of uncertainty, the stimuli were repeated until the subject felt confident of his decision.

Five repeated thresholds were obtained at each location. Testing was concluded when five thresholds were recorded for each of the six locations. Decreasing intervals only were used to minimize variability.

It was noted that at certain intervals, the subjects would hesitate and sometimes change from "two" to "one," and then revert their decision at the next smaller interval. When this occurred, and the decision reverted to "two" at the next smaller interval, testing was continued until a consistent change to "one" occurred. On the other hand, if the "one" response was followed by another "one" at the succeeding interval, the interval at which the last "two" was given was recorded as threshold, in spite of the reoccurrence of "two" at still smaller intervals.

Separation thresholds for bilateral stimulation of paired homologous locations.

The output of each channel of the stimulator was connected to one of the channels of the scope and to an electrode. The electrodes were placed on the two areas to be tested. The order of testing for each pair was

randomly determined. The rate of presentation of stimuli (one every five seconds) was controlled by the `FREQ.` setting of the first output of the stimulator, the interval between paired stimuli by the `DELAY` setting of the second output of the stimulator.

The voltage to the electrode receiving the first stimulus was set at twice threshold voltage for that location, and adjusted to "comfort setting." The output to the second electrode was set to match the first, and the subject indicated the adjustments necessary for a perfect intensity match between the two sides. A minimal interval of five seconds between stimuli to be matched was carefully maintained to avoid interaction between the signals.

The subjects were instructed to respond by raising two fingers as long as the signals were perceived as successive, and as long as they were aware of one stimulus preceding the other. A "one" response, raising one finger, was to be given when the stimuli were perceived as simultaneous.

A 200 msec interval was selected as a starting point; this interval was decreased rapidly until an approximate threshold was established. The interval

was increased by approximately 50 msec, decreased in 5 msec steps, presented at least twice, until threshold was reached. Threshold was defined as the last time interval at which a consistent "two" response was obtained, and below which signals were reported to be simultaneous. Five thresholds were obtained for each pair, after which the electrodes were moved to their new locations, and the procedure repeated. Testing was completed when five separation thresholds were obtained for each of the six pairs tested.

The stress was placed on order of presentation because preliminary testing had shown that all subjects were aware of both stimuli at all time separations, including true simultaneity. It is thus comparable to the order judgments required by Hirsh and Sherrick (1961) or Lowe and Campbell (1965); it differs from these in not being a forced-choice experiment, and in requiring "one" responses when the subject became uncertain as to order of lead.

## CHAPTER IV

### RESULTS AND DISCUSSION

#### Test I. Study of Lingual Sensitivity

The means for the five threshold responses obtained for each subject, on each day and at each location, were computed and are shown in Tables 6-10 of the appendix.

An analysis of variance was performed on the values recorded; it is shown in Table 11. As may be seen, all main effects and interactions were highly statistically significant (0.01 level). Because of the significant interactions no conclusions should be drawn about the over-all main effect. Therefore, results for each subject, day, and location were studied in independent analyses of variance, the design of which is shown in Table 12 of the appendix.

#### Differences in sensitivity among the areas investigated.

The differences among the threshold voltages obtained for each subject, on each day, and at each location, were calculated and are displayed in Figures 5 to 9. The results of analyses of variance of the dif-

ferences among the various thresholds obtained for each subject on each day on which Figures 5-9 are based, were evaluated. A comparison between thresholds obtained on tip areas (areas A and B) and thresholds obtained on the dorsum (areas C, D, E, and F) showed that differences were highly significant (0.01 level) in all cases.

Figures 5-9 show the direction of these differences and indicate that the tongue tip is markedly more sensitive to electrical stimulation than the dorsum. A comparison of the differences between the margins (areas C and F) and the midline (areas D and E) of the dorsum indicated that they were significant (0.05 level) in 19 cases; of these, the midline was more sensitive in 12 cases, the margins in 6. There was no consistent trend to these significant differences, either within subjects, or for handedness or sex.

The extent of the voltage differences among areas and locations was calculated. The threshold voltages for the tongue tip were compared to the threshold voltages for the dorsum. The values of A or B were found equal to, or less than, half the mean values of the right and left side of the dorsum, respectively (half of  $\frac{C + D}{2}$  and  $\frac{E + F}{2}$ ) in 44 out of 50 cases. In the

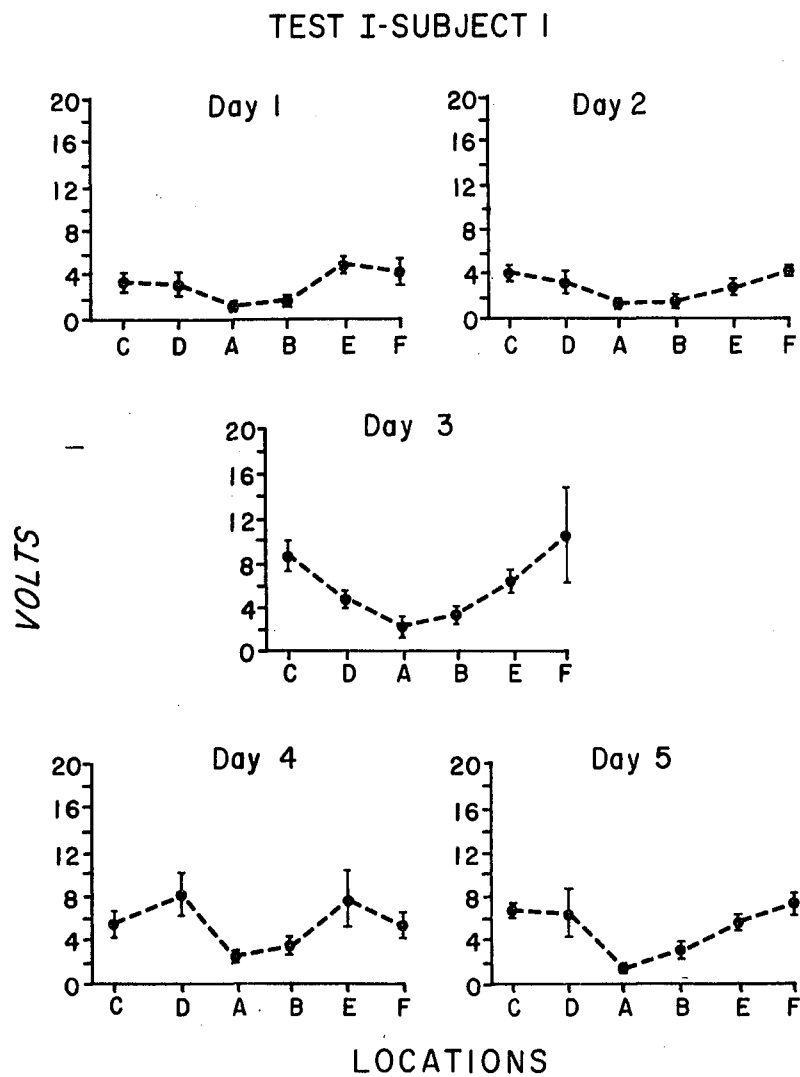


Fig. 5.-- Sensitivity threshold voltages for Subject 1; means and 2 standard deviations



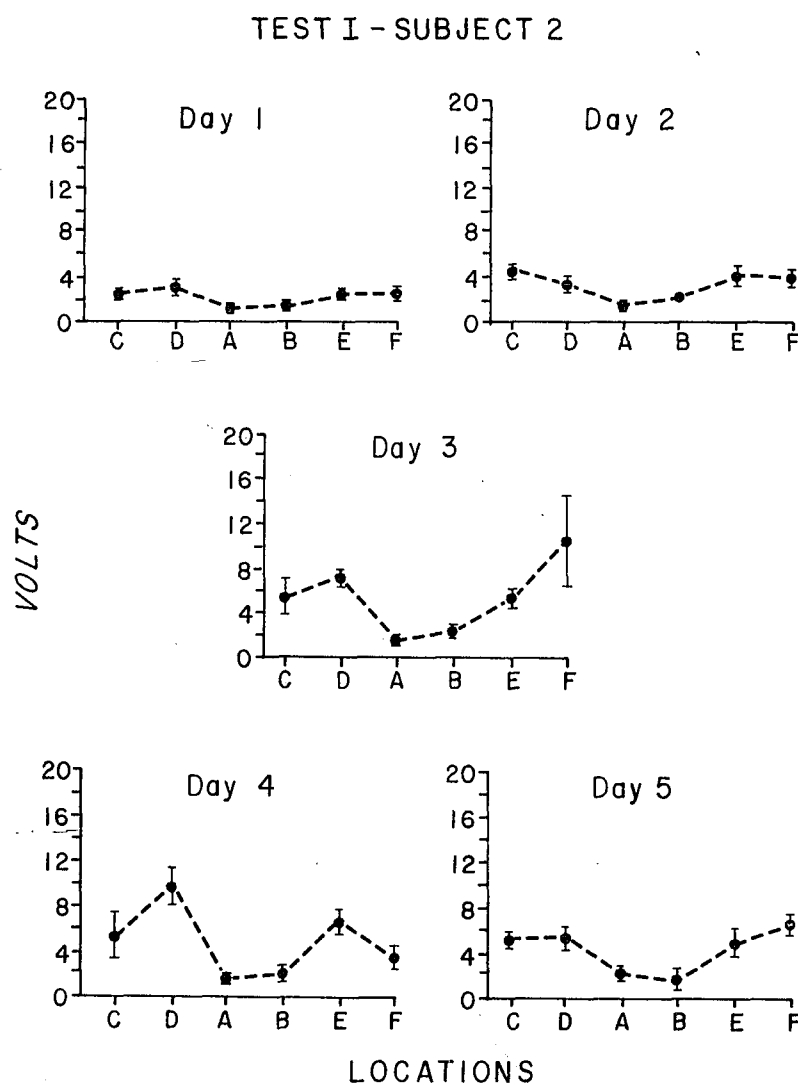


Fig. 6.-- Sensitivity threshold voltages for Subject 2; means and 2 standard deviations

## TEST I - SUBJECT 3

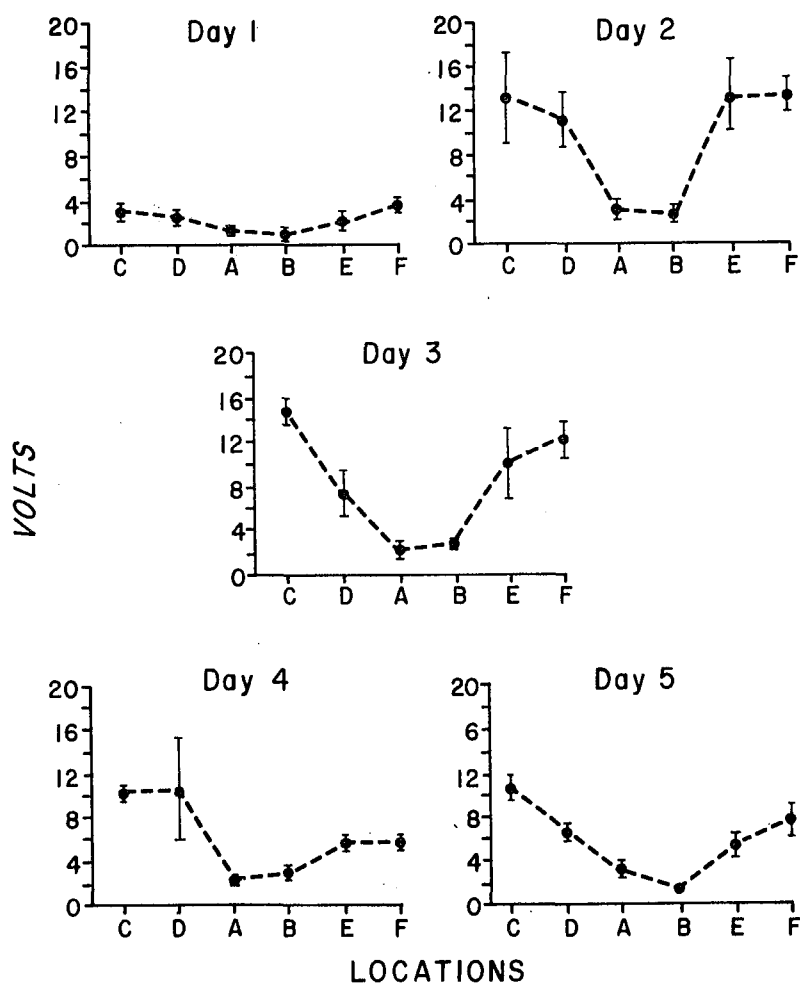


Fig. 7.-- Sensitivity threshold voltages for Subject 3; means and 2 standard deviations

## TEST I-SUBJECT 4

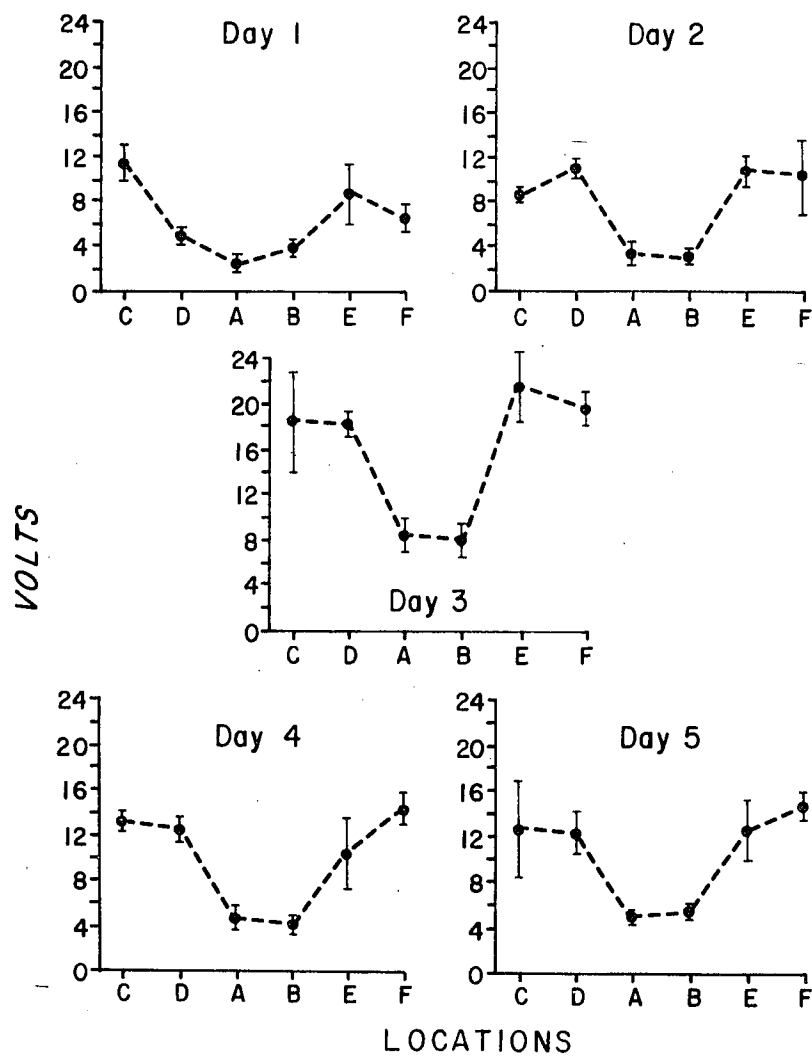


Fig. 8.-- Sensitivity threshold voltages for Subject 4; means and 2 standard deviations

## TEST I - SUBJECT 5

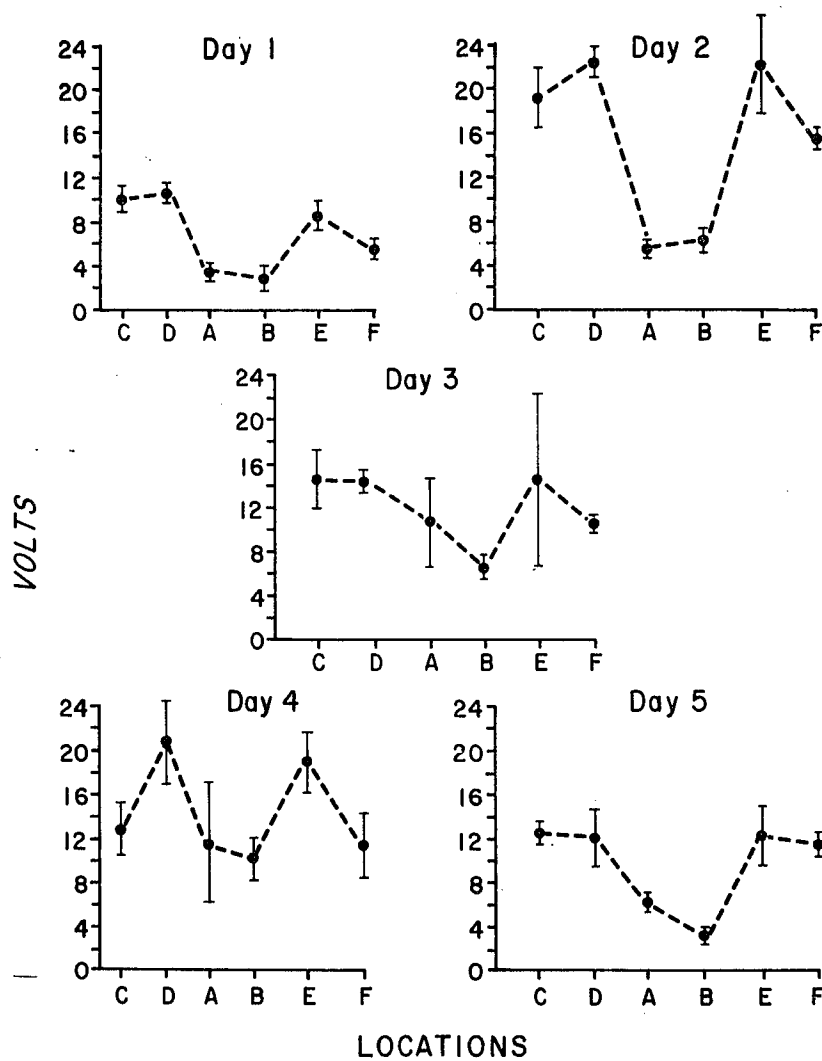


Fig. 9-- Sensitivity threshold voltages for Subject 5; means and 2 standard deviations

remaining six cases the values for A or for B were larger than half the mean values for the corresponding side of the dorsum.

A comparison of the threshold voltages obtained during each test session for pairs A-B, C-D, E-F, C-F, and D-E indicated that the smaller voltage of each pair was at least 0.7 the larger value in seventy-five percent of the pairs compared. Only 3 (out of 125 comparisons) had one value that was less than half the other (in the range of 44 to 50 percent). These small differences are in contrast with the larger differences observed between the threshold values for the tip and the dorsum, and suggest that the similarity among these pairs is more marked than their differences.

Differences in sensitivity between sides.

The results of the individual analyses of variance were examined for evidences of greater sensitivity of one side in contrast to the other. The results of the comparisons between the right and the left side (ACD versus BEF) are shown in Table 1. As can be seen, the right side was more sensitive six times, and the left side six times. These differences in sensitivity were not consistent from day to day for each individual.

TABLE 1.-- Frequency of statistically significant differences in sensitivity of the right and the left side of the tongue, as determined by an analysis of variance test

| Subjects     | More sensitive side |      |
|--------------|---------------------|------|
|              | Right               | Left |
| Right-handed | 4/15                | 3/15 |
| Left-handed  | 2/10                | 3/10 |
| Total        | 6/25                | 6/25 |

When the side corresponding to the dominant hand and the other side of the tongue were compared, no consistent differences were seen either.

A cumulative frequency distribution of threshold voltages by locations, for all subjects and all test sessions is seen in Figure 10. It confirms the marked difference in threshold sensitivity between the tongue tip and the dorsum, and the lack of meaningful differences among the various areas of the dorsum. The range of voltages for thresholds on the tip was 1 to 15 volts, with a fifty-percent level of response at 2-3 volts, while the range for the dorsum was 1.5 to 25 volts, with the fifty-percent level between 6.5 and 9.0 volts.

Conversion to a decibel scale was made, since it has been demonstrated by various investigators, Stevens in particular, that the way in which the central nervous system handles intensity is best described by a power function. For electric stimulation, this exponent corresponds to approximately 3.5 (Stevens, Carton and Shickman, 1958). It has become standard convention in psychophysics to express intensity in decibels. Results of this conversion to decibels according to the formula  $dB = 20 \log \frac{\text{volt obt.}}{1 \text{ volt}}$  are given in Tables 13-17, and the re-

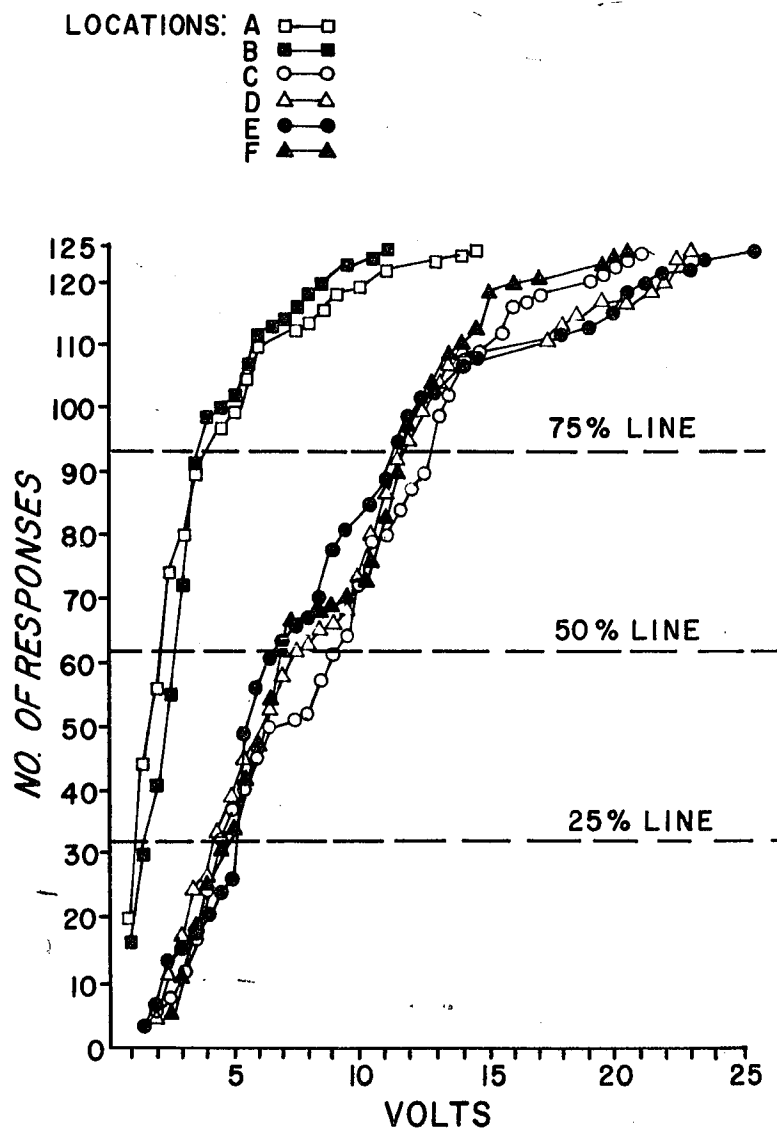


Fig. 10-- Cumulative frequency distribution of sensitivity thresholds



sults for each subject, at all locations and all days, are shown in Figures 11 and 12. As can be seen, the variability at each location and for each subject, from test to test, is well within the normal 10 dB range reported for psychophysical experiments. It does not, in any case, exceed 16 dB. The relationship of tip to dorsum, and the lack of marked differences among the areas of the dorsum are maintained.

#### Discussion.

Current and resistance values were calculated for each test session and each location. Current reflected the same differences in threshold between the tip and the dorsum, and the same lack of consistent differences among locations of the dorsum as were seen in the thresholds in volts. The changes in current within locations and from day to day were not entirely proportional to the changes in voltage, reflecting changes in the lingual resistance. Current was recorded to the nearest 100 microamps, a measurement which was not found sufficiently sensitive to accurately record thresholds for the tongue tip of the girls involved in the study. Currents for locations A and B for the girls were thus uniformly 100 microamps. Currents for the dorsum ranged

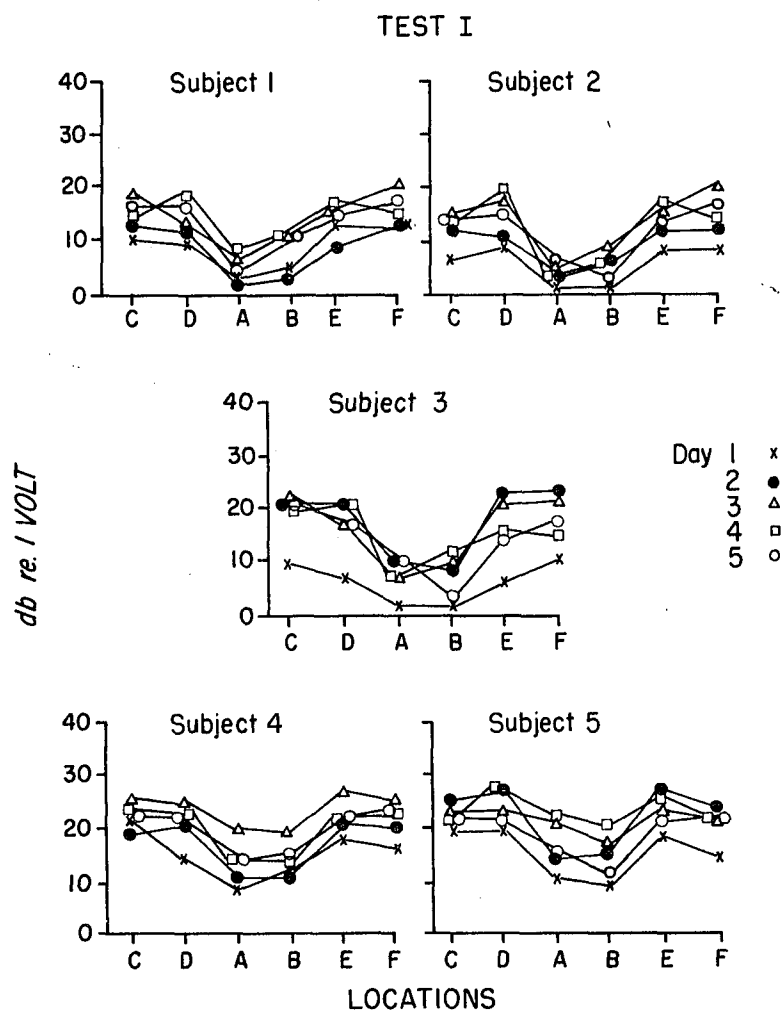


Fig. 11.-- Sensitivity thresholds in decibels, by subjects and locations

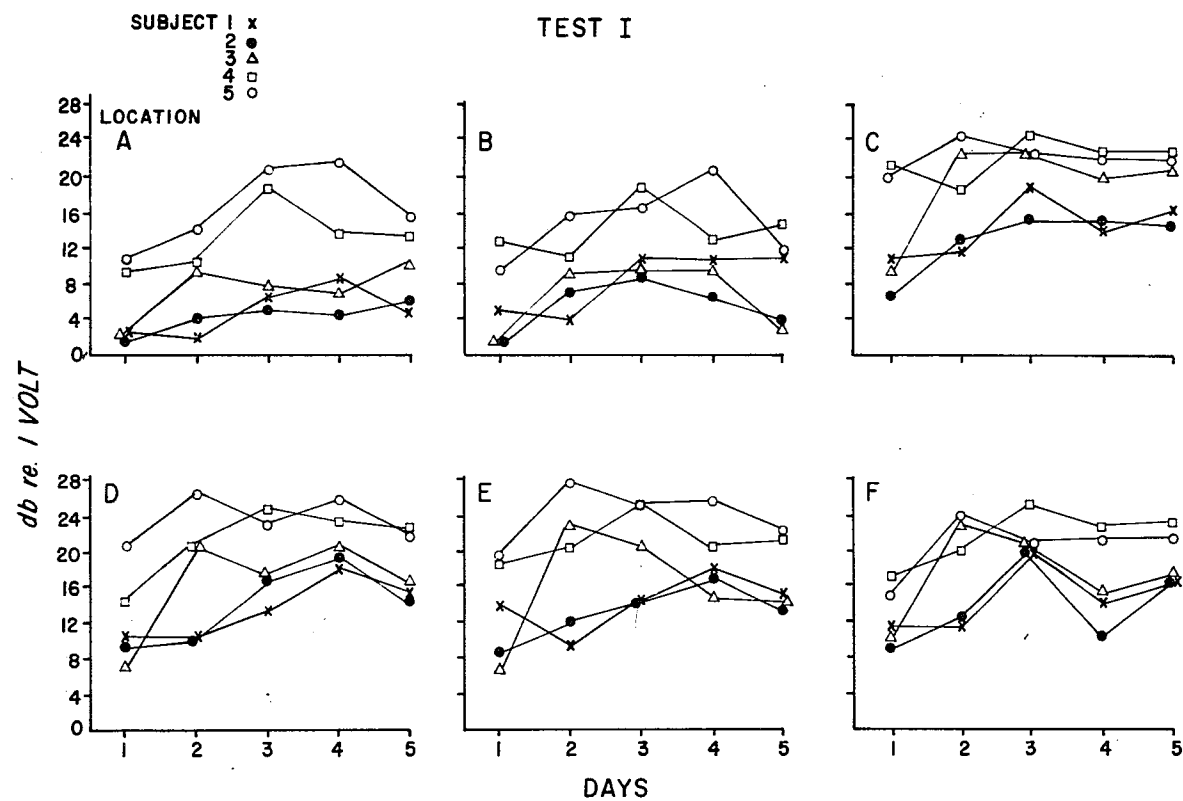


Fig. 12.-- Sensitivity thresholds, in decibels, by locations and days

from 100 to 700 microamps. Values for the boys were less uniform: Subject 4 ranged from 100 to 300 microamps for the tip and 700 to 1400 microamps for the dorsum, while Subject 5 had thresholds of 100 to 900 microamps on the tip, 400 to 2500 microamps on the dorsum of the tongue.

Power measurements reflected the patterns seen in voltage and current readings, and showed the same differences between tip and dorsum, and lack of meaningful differences among the other locations.

Resistance measurements were seen to fluctuate from day to day; the tongue tip generally averaged 20 to 40 thousand ohms, with decreased resistance for the dorsum.

Possible sources of error which might be responsible for the voltage and current fluctuations from day to day were considered. The calibration of the equipment was checked regularly and remained unchanged for the duration of the study. Among the technical factors were the displacement of the electrode, and a possible loss of contact at the tongue surface-electrode junction. These two factors can be dismissed, since small displacements of the electrode did not result in any threshold changes, while loss of contact produced such extensive change in

the relationship between voltage and current that it was immediately noticed and remedied. A third factor was a change of impedance at the electrode-tongue junction; this factor cannot be ruled out although care was taken to replace any electrode showing signs of wear. Changes in the resistance of the tongue were seen to occur; they were attributed to alterations in salivary make-up and to physiological and psychological fluctuations in the status of the subject.

The following suggestions are made, for improvement in the testing technique: first, a change in circuitry, converting the system to either constant-voltage, with the stimulator output in parallel with the subject and the oscilloscope, or to constant-current, by inserting an extremely large resistor in series with the stimulator output and the electrode. In either case, the changes in thresholds attributable to changes in resistance would be eliminated. The loss of information resulting from the change from two to one single measure of sensitivity should not be crucial since current and voltage reveal a similar pattern of sensitivity distribution. Second, controlling the amount of rest and of food and fluid intake prior to testing might prove

helpful.

In summary, a consistent pattern of sensitivity change from tip to back of the tongue has been observed. The ratio of sensitivity in volts of the areas investigated at the tip to those on the dorsum was 2:1 or greater. In contrast, the differences observed among similar locations on the dorsum were much smaller and inconsistent. The clinical implication of these results is that only differences in volts, among locations and sides, greater than 50 percent, and consistent over repeated test sessions, should be considered of significance.

Test II: Temporal separation limits for electrical stimuli presented in pairs to specific areas of the tongue.

Mean intervals in milliseconds were computed for the five separation thresholds obtained during each test session, for each subject and at each location. These are shown, with their standard deviations, in Tables 18 to 22 of the appendix.

An analysis of variance was performed on all the thresholds obtained. Its results are shown in Table 23. As can be seen, main effects for location were significant (0.05 level) and effects for subjects were highly sig-

nificant (0.01 level), as were the interactions of subjects with days and with locations, and of subjects, days, and locations. Because of the significant interactions, no conclusions about over-all main effects were drawn.

Differences in temporal acuity among the areas investigated.

Individual analyses of variance of the differences in separation thresholds obtained for each location, on each day, for each subject, between the tongue tip (areas A and B) and the dorsum (areas C, D, E, and F), and between the margins of the dorsum (areas C and F) and the midline of the dorsum (areas D and E) were computed; the model is shown in Table 12. The results obtained are shown in Table 2. They indicate that no meaningful differences between the tip and the blade, and between the margins and midline areas of the dorsum were found, among the subjects, during successive test sessions.

The mean separation thresholds and their standard deviations, obtained for each subject and each location, during five test sessions, were calculated. They are listed in Table 24 of the appendix, and displayed in Figure 13. They confirm the lack of consistent signifi-

TABLE 2.-- Frequency of statistically significant differences in temporal separation thresholds between successive stimuli, by subject. Tip compared to dorsum, margins compared to midline.

| Compari-<br>sons         | More sensi-<br>tive area | Subjects                   |   |   |   |   | Total<br>frequency |
|--------------------------|--------------------------|----------------------------|---|---|---|---|--------------------|
|                          |                          | 1                          | 2 | 3 | 4 | 5 |                    |
|                          |                          | No. of tests<br>(out of 5) |   |   |   |   | (out of 25)        |
| tip<br>vs<br>blade       | tip                      | 1                          | 4 | 0 | 0 | 0 | 5                  |
|                          | blade                    | 2                          | 0 | 4 | 4 | 5 | 15                 |
| margins<br>vs<br>midline | margins                  | 0                          | 0 | 2 | 1 | 0 | 3                  |
|                          | midline                  | 3                          | 5 | 0 | 2 | 1 | 11                 |



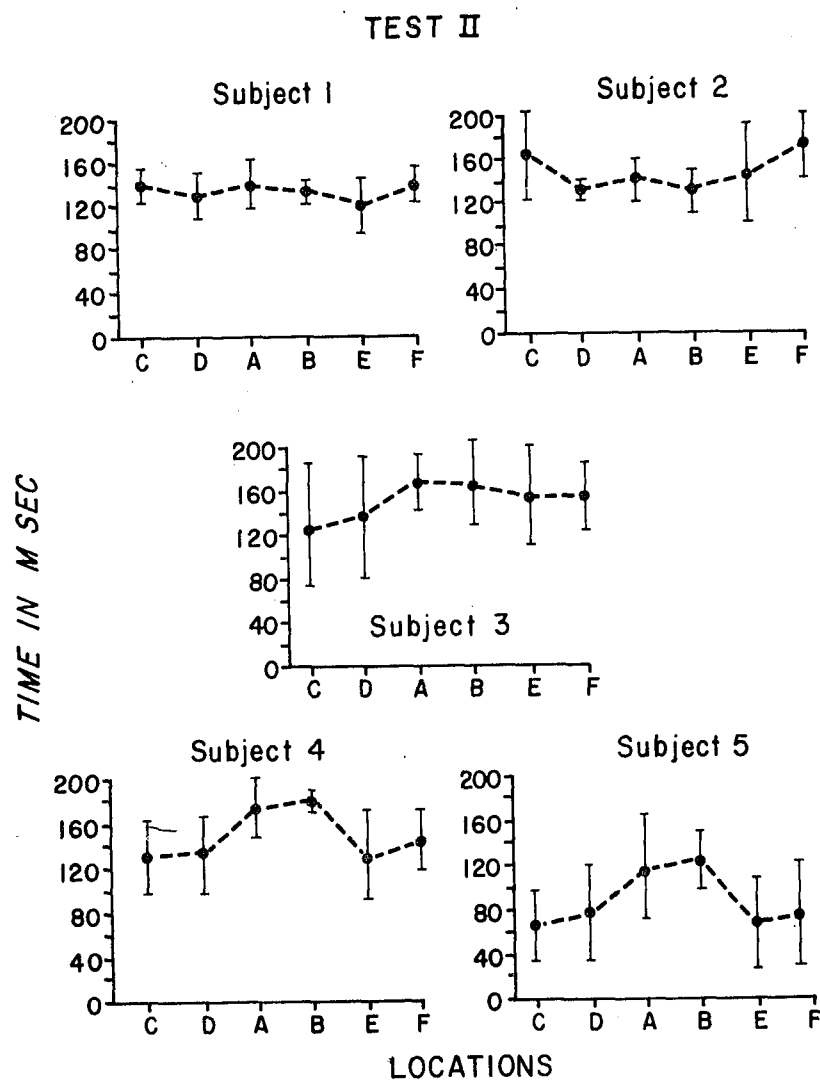


Fig. 13.-- Separation thresholds of successive stimuli to each location, by subjects

cant differences among areas of the tongue.

Differences in temporal separation between the two sides of the tongue.

There was no evidence of marked or consistent differences between the right and the left side of the tongue (areas CDA versus areas BEF) as seen from the comparisons of the thresholds obtained for these locations on all days, for all subjects. These results are seen in Table 3. Table 3 also indicates the lack of meaningful differences between the side corresponding to the dominant hand and the side of the tongue corresponding to the non-dominant hand.

A cumulative frequency distribution of these temporal separation thresholds is seen in Figure 14. The graph shows that the 50 percent response level for all subjects corresponds to intervals ranging from 120 to 140 msec, the 75 percent level of response to intervals ranging from 140 to 170 msec. All subjects were able to perceive two distinct and successive stimuli 100 percent of the time at intervals of 200 to 240 msec.

Conversion to a logarithmic scale was made, in keeping with the standard convention of expressing psychophysical data. The results of this conversion for all

TABLE 3.-- Frequency of significant differences in separation thresholds between successive stimuli, on the right and the left sides of the tongue

| Subjects     | More sensitive side |      |
|--------------|---------------------|------|
|              | Right               | Left |
| Right-handed | 3/15                | 2/15 |
| Left-handed  | 4/10                | 2/10 |
| Total        | 7/25                | 4/25 |

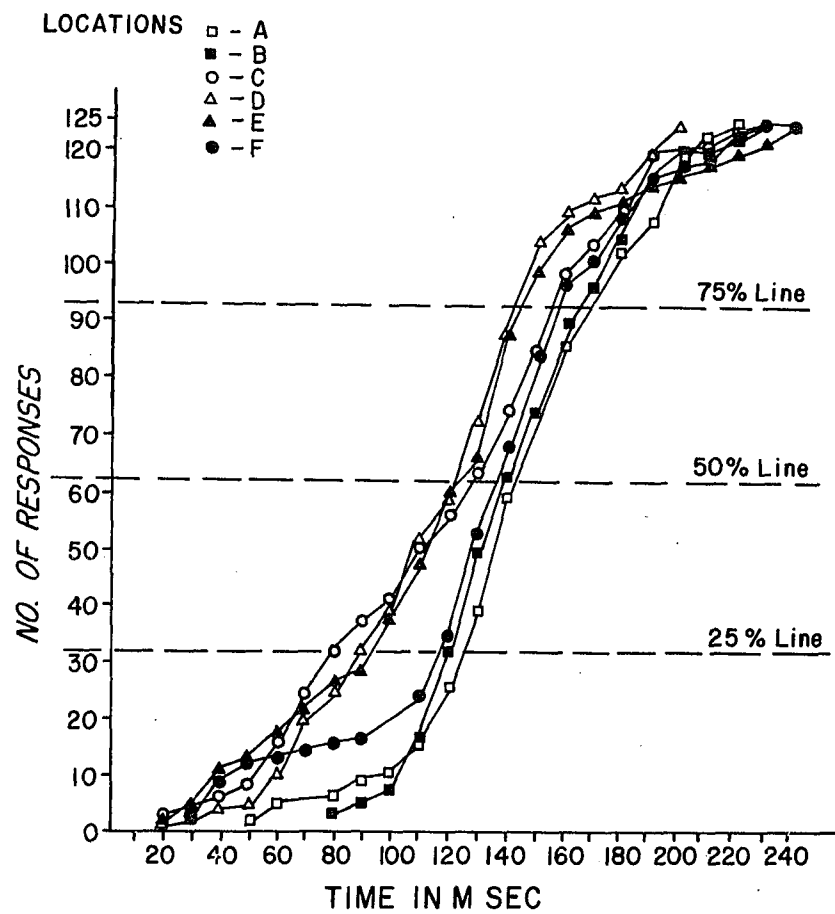


Fig. 14.-- Cumulative frequency distribution of separation thresholds of successive stimuli to each location

subjects, days, and locations, are given in Tables 25-29 and shown in Figure 15. They confirm the information obtained from the statistical analyses and the cumulative frequency distribution.

### Discussion.

The subjective feelings associated with the perception of variations in interstimulus intervals were described by the subjects as follows: as the interval is decreased, the second stimulus approximates the first. It then decreases in intensity and fades away. It may reappear at still smaller intervals and is perceived as two points, or two parts of a line, spatially separated but simultaneous in time. The task of judging sequence under these conditions is thus a particularly hard one, requiring judgments of order, intensity, and location. Some of the differences in thresholds over days may be due to the difficulty in grasping and retaining one same concept of sequence and intensity to respond to. The extent of the agreement between subjects, and from test session to test session is therefore gratifying.

The values obtained are in good agreement with results from physiological experiments, and with research findings in other modalities, such as, for instance, the

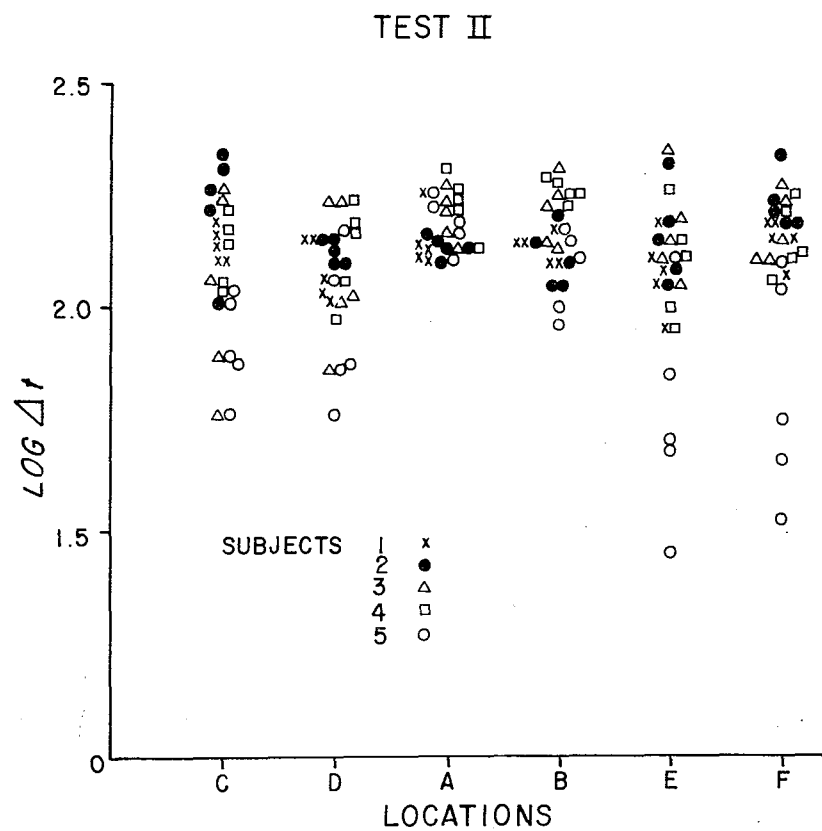


Fig. 15.-- Logarithmic display of separation thresholds of successive stimuli to each location

duration of auditory summation of loudness, and the "critical off-time" required between successive stimuli for Békésy audiometry (Wright, 1968). They also seem to agree well with reported diadochokinetic rates for normal speakers (Powers, 1957), suggesting a possible critical relation between temporal discrimination and sequencing of speech sounds.

The subjects sometimes gave evidences of confusion at intervals greater than their established thresholds. These periods of confusion seemed to occur at regular intervals, and were interpreted as evidences of cyclic fluctuations in perception, similar to those discovered by evoked potential studies. Since the fluctuations discussed in the literature on cortical potentials are intensity-sensitive, a study of these apparent perceptual fluctuations, and their sensitivity to alterations in intensity, is indicated.

A possible source of error was the failure to control intensity more rigourously. It had been speculated that, due to the very steep line of growth of intensity of electrical stimuli reported by Stevens, Carton and Shickman (1958), the range corresponding to "comfort level" would be small; in fact, the "comfort levels"

were found to vary between twice and three times threshold intensity in volts for the location investigated, and for the day of testing. These corresponded to 6-10 dB sensation level (with a range of 2.5 to 16 dB SL). The effects of intensity changes on separation thresholds need investigating, as does the question of whether the important parameter is physical intensity or sensation level.

In summary, no consistent significant differences in temporal discrimination of stimuli applied in pairs to different areas of the tongue were seen, between sides, among locations, and for right- and left-handers. All subjects perceived all stimuli as successive, at all locations and all days, at intervals of 200 to 240 milliseconds.

Test III: Temporal separation limits for successive bilateral electrical stimuli applied to specific pairs of locations on the tongue

The following pairs of locations on the tongue were investigated: A-B (A leading), B-A (B leading), C-F (C leading), F-C (F leading), D-E (D leading), and E-D (E leading).

Mean intervals in milliseconds were computed for the five threshold determinations obtained during each



test session, for each subject, at each location pair. They are shown, with their standard deviations, in Tables 30 to 34 in the appendix.

An analysis of variance was performed on all the thresholds obtained on each day, at each pair of locations, for each subject. The results of this analysis of variance are shown in Table 35. As can be seen, the main effects for subjects were highly significant (0.01 level) as were the interactions for subjects and locations, subjects and days, and subjects, days, and locations. Because of these significant interactions, no conclusions regarding the over-all main effects were drawn. The results were evaluated for each subject and each pair of locations. The means and standard deviations of the twenty-five intervals obtained for each pair of locations and each subject are listed in Table 36 of the appendix, and are displayed in Figure 16.

Differences in temporal separation thresholds to bilateral stimulation among the various tongue areas.

Analyses of variance of the results obtained for each subject, at each pair of locations, and on each day, were computed to determine whether significant differences between pairs on the tongue tip (pairs A-B and

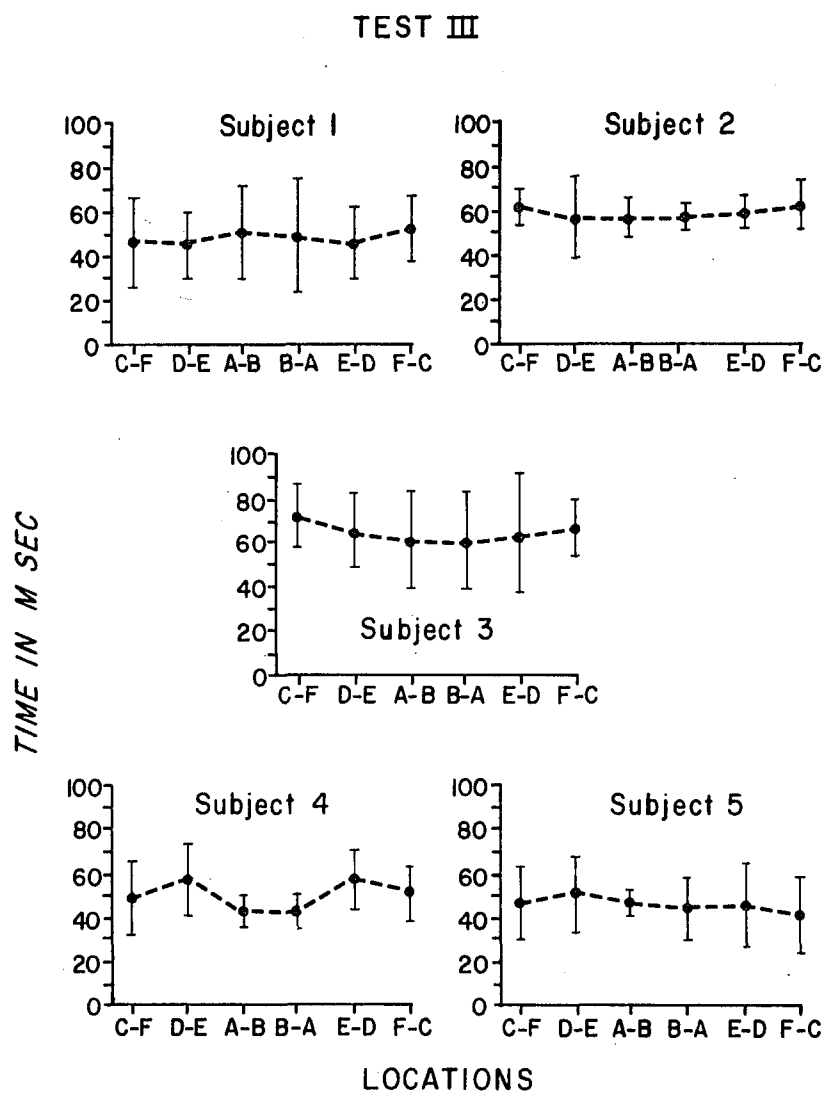


Fig. 16.-- Separation thresholds of bilateral stimuli to pairs of locations

B-A) and pairs on the dorsum (pairs C-F, F-C, D-E and E-D) and between pairs on the margins (C-F and F-C) and in the midline area of the dorsum (D-E and E-D) could be found. The model for these comparisons is shown in Table 12, in the appendix. The results are seen in Table 4. As can be seen from Figure 16, these differences are small; Table 4 indicates they do not follow any consistent pattern.

Effects of side of lead on separation thresholds of bilateral stimuli.

The comparisons, for each subject and each test session, were evaluated for differences between sides when the right side or the left side was stimulated first. The significant differences found by this analysis of variance are shown in Table 5. They indicate that no consistent difference between the side of lead and the side stimulated second was found. Even when the side stimulated first corresponded to the dominant hand, as opposed to the non-dominant hand, no difference could be demonstrated either.

A cumulative frequency distribution of the  
temporal separation thresholds of bilateral stimuli to the various pairs of locations, for all subjects and all

TABLE 4.-- Frequency of statistically significant differences in temporal separation thresholds of successive bilateral stimuli, by subject. Tip compared to dorsum, margins compared to midline

| Compari-<br>sons         | More sensi-<br>tive area | Subjects                   |        |        |        |        | Total<br>frequency |
|--------------------------|--------------------------|----------------------------|--------|--------|--------|--------|--------------------|
|                          |                          | 1                          | 2      | 3      | 4      | 5      |                    |
|                          |                          | No. of tests<br>(out of 5) |        |        |        |        | (out of 25)        |
| tip<br>vs<br>dorsum      | tip<br><br>dorsum        | 3<br>2                     | 4<br>1 | 4<br>1 | 4<br>0 | 3<br>1 | 18<br>5            |
| margins<br>vs<br>midline | margins<br><br>midline   | 0<br>1                     | 2<br>3 | 1<br>2 | 3<br>1 | 3<br>2 | 9<br>9             |

TABLE 5.-- Frequency of significant differences in separation thresholds between successive bilateral stimuli, with the right side and the left side leading

| Subjects     | More sensitive leading side |      |
|--------------|-----------------------------|------|
|              | Right                       | Left |
| Right-handed | 3/15                        | 4/15 |
| Left-handed  | 4/10                        | 3/10 |
| Total        | 7/25                        | 7/25 |

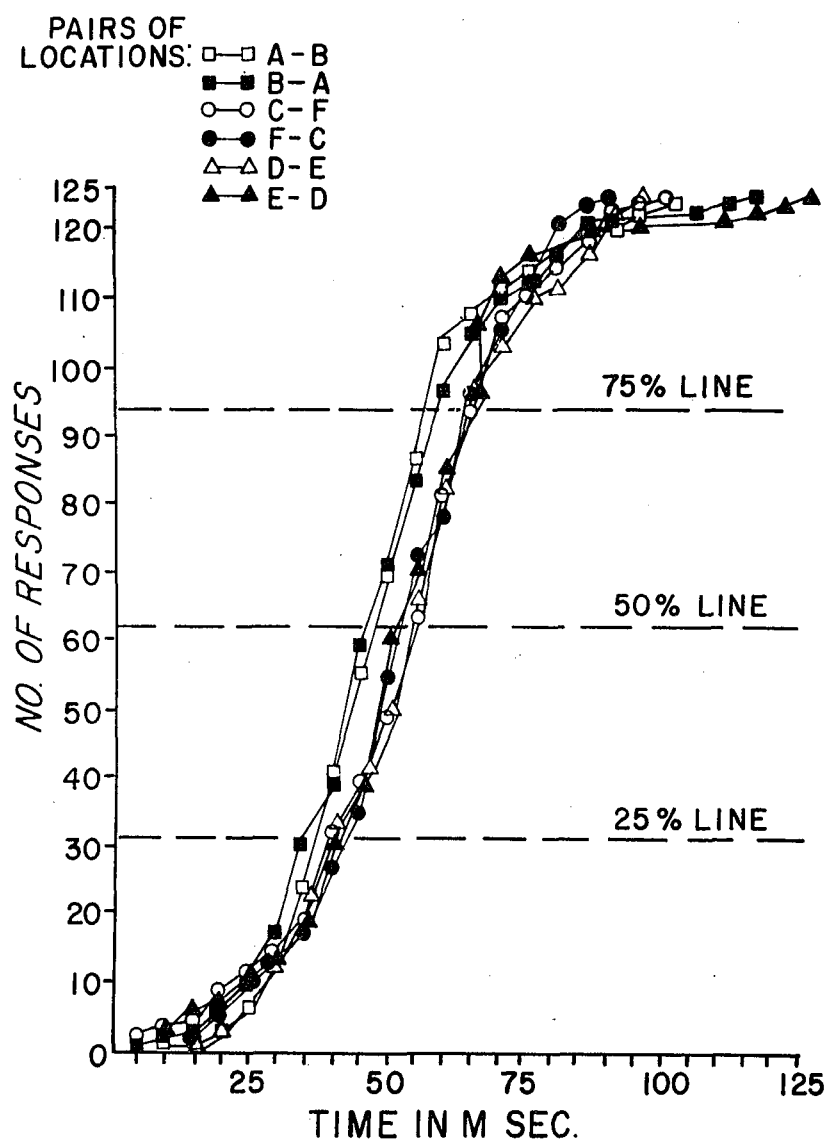


Fig. 17.-- Cumulative frequency distribution of separation thresholds of bilateral stimuli to pairs of locations

test sessions, is shown in Figure 17. As can be seen, the 75 percent level of response corresponds to intervals ranging from 55 to 65 msec, and the 100 percent level of response was reached by all subjects at intervals of 100 to 125 msec. Figure 17 also confirms the lack of differences among pairs of locations and between sides of lead.

Conversion to a logarithmic scale was done, in keeping with the standard convention. The results are given in Tables 37-41, and shown in Figure 18. They confirm the information given by the statistical analyses and the cumulative frequency distribution.

A "center point of simultaneity" was calculated in the manner suggested by Efron (1963a):  $(R+L)/2$ , R being the interval when the right side leads, expressed in negative values, L the interval when the left side leads, expressed in positive values. No consistent deviation from simultaneity was observed for any of the subjects, and no evidence was found to support Efron's theory that judgments of temporal order are performed by the hemisphere dominant for speech.

#### Discussion.

The task for Test III differed from the task for

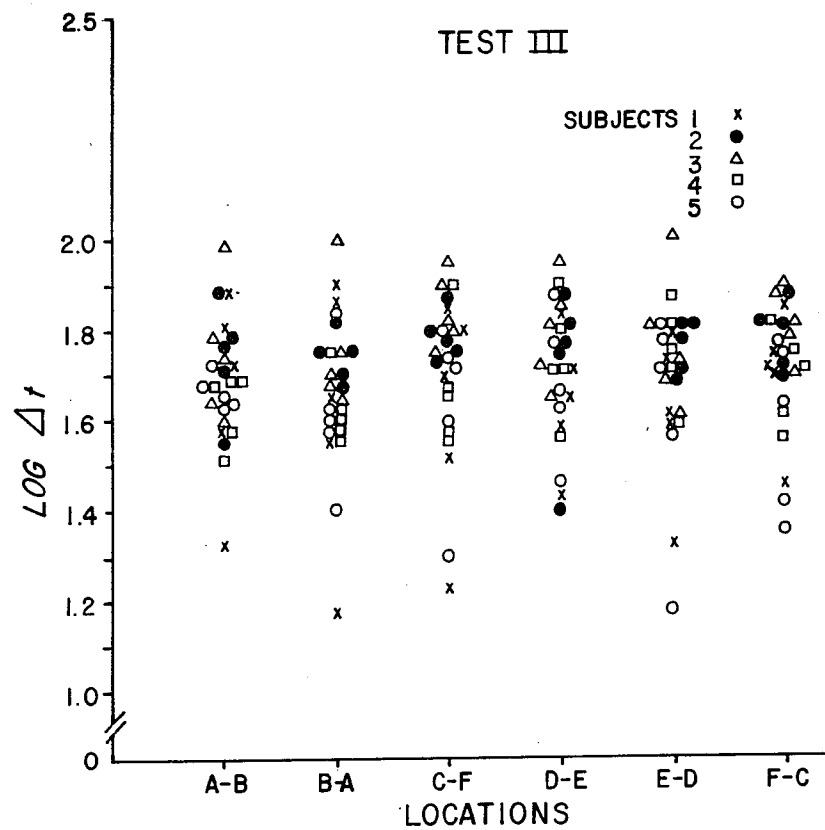


Fig. 18.-- Logarithmic display of separation thresholds of bilateral stimuli to pairs of locations



Test II in that the subjects were aware of the presence of both stimuli at all times, including at intervals of 1 msec and at true simultaneity. The judgments required from the subjects, called "separation" in this study, resemble the "temporal order" judgments required by Hirsh and Sherrick (1961), by Efron (1963a, b, c) and by Lowe and Campbell (1965) since the subjects were instructed to respond "two" only when they were aware of a temporal lead of one of the stimuli, that is, when they were able to identify the leading side. The "temporal resolution" studied by Gescheider (1966, 1967) could then correspond to an awareness of stimulation on both sides. It does appear that the terminology and definitions used require clarification.

The data obtained are in good agreement with the temporal order values reported by Hirsh (1967) and by Efron (1967), (a 75 percent correct response at approximately 60 msec), for naive listeners. They reinforce these authors' suggestion that similar temporal limitations for judgments of order apply to the somesthetic and auditory systems.

The lack of meaningful differences among pairs C-F and F-C with locations separated by less than 1 cm,

and pairs D-E and E-D, separated by approximately 3 cm, suggests that the type of temporal discrimination required for Test III may be independent of spatial factors. This requires investigation.

Finally, neither "extinction" nor midline fusion were reported by any of the subjects involved in this study, for intervals as small as 1 msec. They were not systematically looked for, but all subjects were tested, at least once, at these small intervals and questioned about their perception of the stimuli.

In summary, no consistent significant differences in temporal separation of successive bilateral stimuli to homologous pairs of locations on the tongue were found, for areas, side of lead, right- and left-handed subjects. All subjects perceived two successive stimuli at all locations and under all conditions, at intervals of 100-125 msec.

Comparison of temporal separation thresholds for double stimulation of single areas of the tongue, and for bilateral stimulation of these areas in homologous pairs.

A comparison between the cumulative frequency distribution of thresholds obtained through double stimulation of single areas and through the bilateral stimulation of these same areas is shown in Figures 19 to 21.

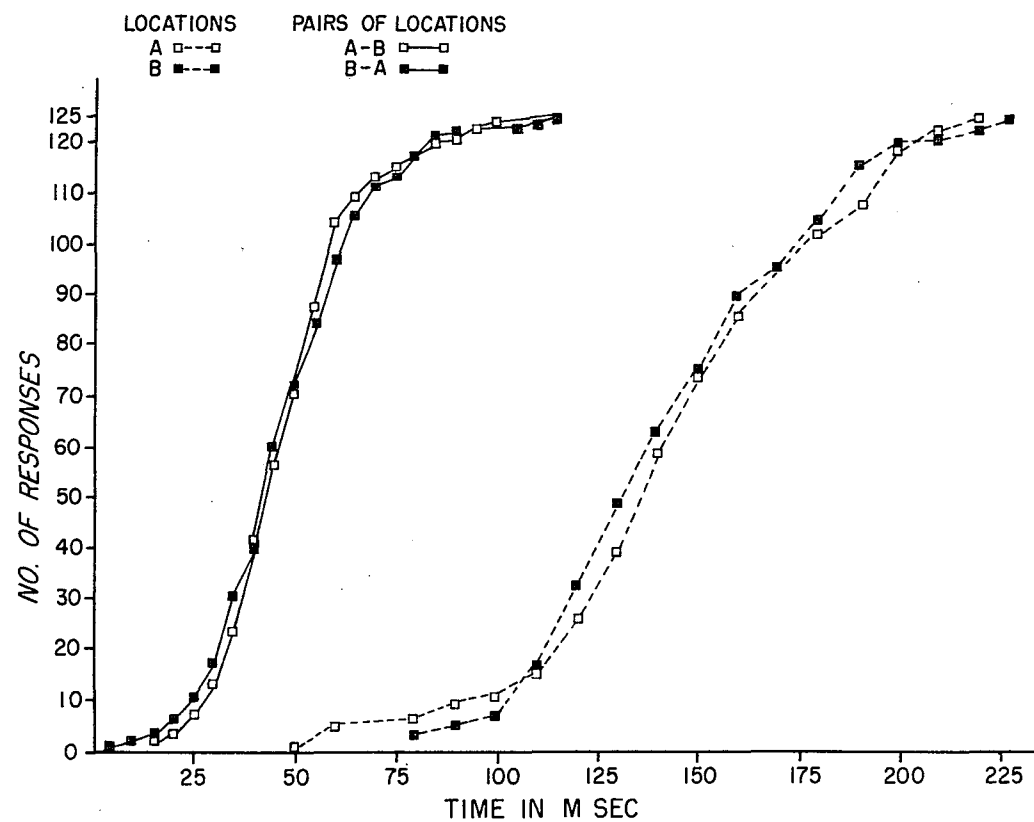


Fig. 19.-- Comparison of separation thresholds of successive stimuli to locations A and B, and to pairs of locations A-B and B-A

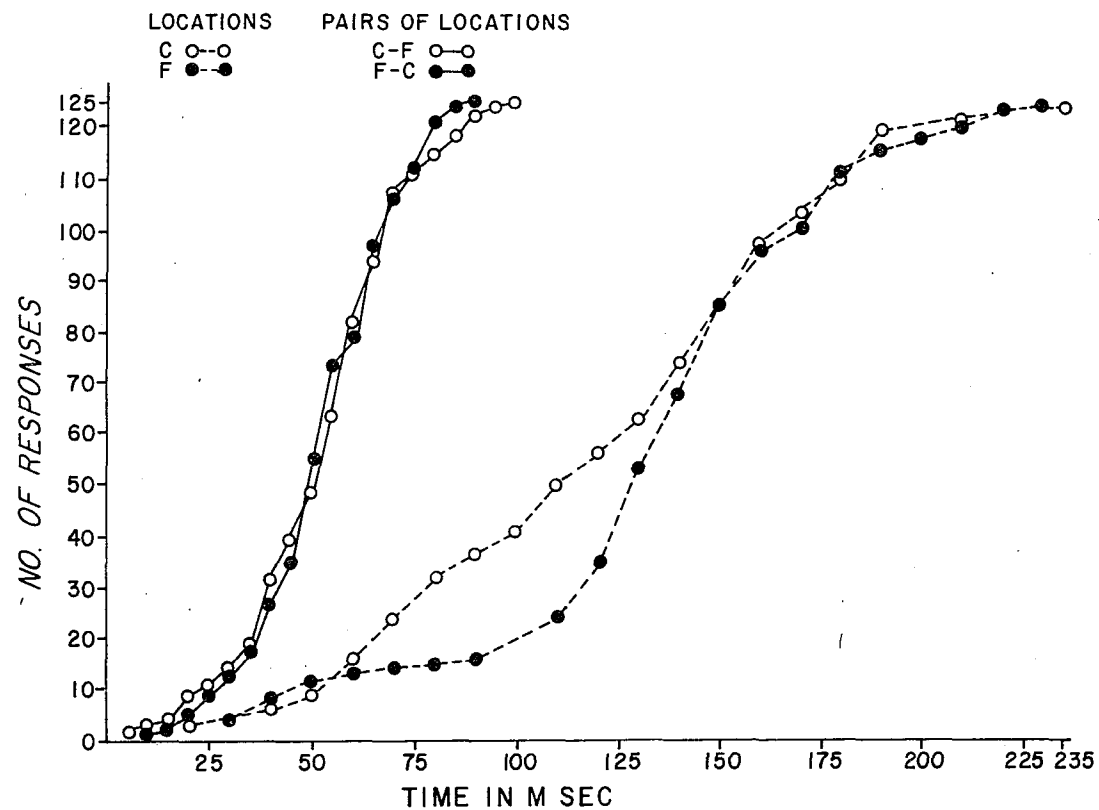


Fig. 20.-- Comparison of separation thresholds of successive stimuli to locations C and F and to pairs of locations C-F and F-C

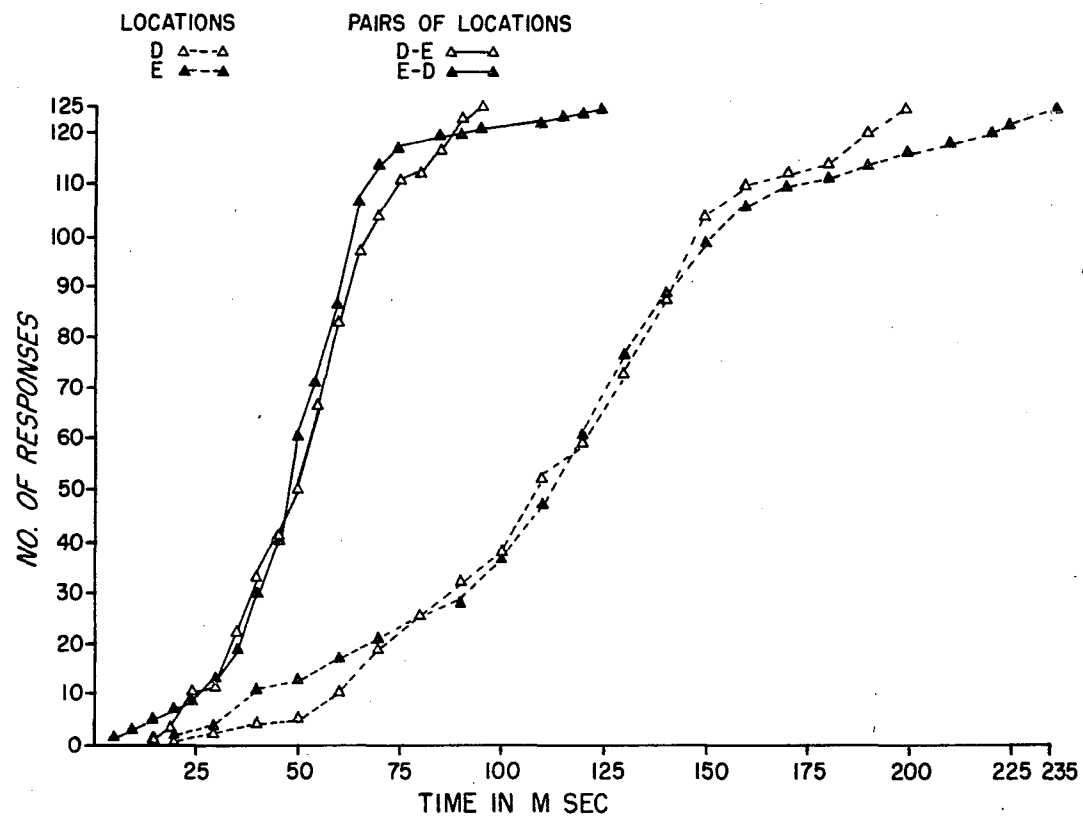


Fig. 21.-- Comparison of separation thresholds of successive stimuli to locations D and E and to pairs of locations D-E and E-D

Each of these figures shows the thresholds obtained for homologous locations on the two sides of the tongue, when they are stimulated singly, and in pairs. The differences in the ranges and in the 50 and 75 percent levels of response are so obvious as to preclude the need for statistical analysis. They confirm the distinction suggested in the review of the literature: the temporal analysis of stimuli presented to one single cortical area differs significantly from the analysis of stimuli presented at similar intervals to dissimilar cortical areas. The greater interval needed for the perception of sequence for stimuli administered to one single location indicates the presence of an occlusive or inhibitory phenomenon for temporal perception.

## CHAPTER V

## SUMMARY AND CONCLUSIONS

The temporal integration of sensory stimuli is an area in which our knowledge remains limited, but its importance is undeniable. The disruptive effects of alteration in the normal pattern of feedback has been demonstrated. An association of defects in temporal ordering of auditory and visual stimuli with communication has been reported.

Review of the literature suggested that the perception of sequence varies with sensory modality involved while temporal ordering remains consistent from modality to modality. The studies of temporal order compared visual and auditory stimuli of differing frequencies, colors, and locations, while studies of sequencing abilities or "successiveness" used identical stimuli to one or more areas. The concept of "successiveness" was not well defined, but appeared to be based upon the awareness of "more than one"; it may depend upon spatial and intensity determinations, as well as upon time differences. The perception of auditory order was seen to

be disturbed in some subjects with communication disorders. The perception of "successiveness" was only investigated once in a clinical population and appeared unimpaired. The temporal ordering of somesthetic stimuli by a clinical population has not been investigated.

The tongue is recognized as one of the most sensitive body areas, for touch and pressure and for two-point discrimination. Its acute sensitivity is assumed to be a requirement for the monitoring and sequencing of the rapid and precise movements required for speech. A similar acuteness in the discrimination of temporal differences can be hypothesized.

The present study was undertaken to attempt to validate or disprove the latter hypothesis, and to provide some basic information about the temporal integration of stimuli to the tongue. It consisted of two parts: a study of the patterns of sensitivity to electrical stimulation across the lingual areas most involved in consonant articulation, and a study of the temporal discrimination ability of these areas.

For the study of lingual sensitivity to electrical stimulation, the following questions were asked:



1. Are there consistent differences in sensitivity among the areas of the tongue primarily involved in articulation?
2. Is there evidence of greater sensitivity of one side as opposed to the other?

The investigation of temporal discrimination on the tongue was divided into two substudies. The first dealt with separation thresholds for double stimuli applied to each of the individual lingual areas tested in this research. The following questions were asked:

1. Are there differences in temporal acuity among the areas of the tongue?
2. Is there evidence of asymmetry in temporal acuity of the two sides of the tongue?

The second substudy dealt with separation thresholds for bilateral stimulation of homologous pairs of locations on the right and left sides of the tongue. The questions asked were:

1. Are there differences in temporal acuity for bilateral stimulation among the various areas of the tongue?
2. Are the temporal thresholds of separation of bilateral stimuli affected by the order in

which the sides of the tongue are stimulated?

The last question about temporal integration was:

Is there a consistent difference between the results obtained from these two experiments?

Five teen-age subjects were used for the experiment, and were seen for five test sessions. Each test session consisted of a determination of the threshold of sensitivity on six locations of the tongue, then the separation thresholds for successive stimuli applied twice to each location, and bilaterally to pairs of matched locations on the right and left sides of the tongue. The areas investigated were the tongue tip, the margins of the tongue blade, and locations on each side of the midline of the blade, on the right and left sides.

Results of the first test indicated that a definite and consistent difference in sensitivity to electrical stimuli exists between the tip and the dorsum of the tongue. In 88 percent of the comparisons between the tip and the dorsum, the voltages eliciting a threshold response on the tip were about one-half the intensity of the threshold voltages for the dorsum. Differences of lesser magnitude were found among the different locations on the dorsum. In contrast to the difference

between tip and dorsum, which was demonstrable, and in the same direction, in all cases, the differences among locations on the dorsum varied among and within subjects. No meaningful differences between the right and left sides, or between the side corresponding to the dominant hand and the other side, were found.

Large apparent differences in over-all sensitivity were found between test and retest sessions. Conversion into a dB scale showed that these were well within the  $\pm 7$  dB units usual in experiments in the area of sensory physiology.

The results of Test I, the determination of sensitivity patterns on the tongue, indicate that the method used can give adequate results, consistent with those obtained by other authors, and that it can be used for further investigations of sensitivity of the tongue.

The results for Test II and Test III, the investigation of separation thresholds of paired electrical stimuli, to single areas and to these same areas in pairs, indicate that no consistent significant difference among the areas investigated or between the two sides of the tongue could be demonstrated. The hypothesis of an increased sensitivity of the tongue tip, for temporal

factors, similar to its increased sensitivity to touch-pressure and for two-point discrimination, is thus rejected. It was seen that the values obtained for temporal separation of two stimuli applied to a single area corresponded with the intervals reported in physiological experiments involving evoked potentials. These values differed markedly from the separation values obtained for bilaterally stimulated areas, which in turn were consistent with the values reported for temporal order judgments obtained with psychophysical experiments. These results suggest that there is some justification for the concepts and assumptions on which the review of the literature was based. These assumptions propose that two different mechanisms are involved in temporal perception and judgment. The perception of successive stimuli to one single cortical area is sharply limited by an occlusive (or inhibitory) effect, which decreases with time and distance, and which appears to be effective within intervals ranging from 100 to 200 msec. A second mechanism is involved in the perception of stimuli to separate areas of the cortex and acts to group events into discrete temporal units and set a limit to the number of successive events which can

be perceived within a given time interval. These temporally discrete units would appear to range from 30 to 100 msec. Within each such unit, successive events appear to be perceived as spatially differentiated.

Several areas of future study are indicated. A collection of normative data, including developmental information and the effects of aging, seems essential for a better understanding of sensory mechanisms, and for a better understanding of normal and defective articulation processes. Specific studies are also suggested for the investigation of the causes of the variations in over-all sensitivity, the effects of smoking, and a comparison between males and females. The effects of such variables as rate of presentation, duration of the signal, and size of the stimulating electrode also need to be investigated.

For a better understanding of the factors involved in temporal discrimination, further research is indicated, to confirm or disprove the theory advanced here. Particularly valuable would be studies of systems capable of unilateral and bilateral cortical excitation (such as the visual system). The presence or absence of cycles in the perceptual evaluation of stimuli presented in

pairs with varying interstimulus intervals, needs to be established. It will be necessary to evaluate the effects of changes in intensity upon temporal discrimination, and upon such cycles, if they are demonstrated.

A correlation needs to be made between what is seen on recordings of evoked potentials and reports of awareness. The physiological changes associated with alterations in perception need to be established.

Normative and developmental studies are essential, not only for the perception of paired stimuli, but for the perception of series of dissimilar events occurring in close succession.

The compilation of normal data for sensitivity and for temporal perception in the oral region, would permit a comparative evaluation of patients with known neurological disorders, and later, of individuals showing speech and communication difficulties. The results of such studies, applied to people with "functional speech problems" could signify a breakthrough in our understanding and treatment of such "functional" problems.

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## APPENDIX

TABLE 6.-- Means and standard deviations for five threshold determinations, in volts, obtained for Subject 1, on each day, and at each location

| Day |      | A     | B     | Location |        | E      | F      |
|-----|------|-------|-------|----------|--------|--------|--------|
|     |      |       |       | C        | D      |        |        |
| 1   | Mean | 1.38  | 1.78  | 3.72     | 3.24   | 5.00   | 4.32   |
|     | S.D. | (.11) | (.22) | (.33)    | (.48)  | (.25)  | (.74)  |
| 2   | Mean | 1.26  | 1.54  | 4.08     | 3.32   | 2.92   | 4.24   |
|     | S.D. | (.13) | (.23) | (.24)    | (.56)  | (.30)  | (.15)  |
| 3   | Mean | 2.18  | 3.32  | 8.58     | 4.90   | 6.02   | 10.38  |
|     | S.D. | (.41) | (.29) | (.66)    | (.26)  | (.41)  | (2.04) |
| 4   | Mean | 2.92  | 3.46  | 5.44     | 8.08   | 7.94   | 5.20   |
|     | S.D. | (.18) | (.26) | (.62)    | (.94)  | (1.39) | (.56)  |
| 5   | Mean | 1.72  | 3.30  | 6.56     | 6.38   | 5.48   | 7.24   |
|     | S.D. | (.08) | (.28) | (.26)    | (1.08) | (.23)  | (.43)  |

TABLE 7.-- Means and standard deviations for five threshold determinations, in volts, obtained for Subject 2, on each day, and at each location

| Day |      | Location |       |        |       |       |        |
|-----|------|----------|-------|--------|-------|-------|--------|
|     |      | A        | B     | C      | D     | E     | F      |
| 1   | Mean | 1.16     | 1.20  | 2.26   | 3.04  | 2.58  | 2.70   |
|     | S.D. | (.11)    | (.12) | (.13)  | (.38) | (.18) | (.14)  |
| 2   | Mean | 1.62     | 2.20  | 4.26   | 3.56  | 4.26  | 4.16   |
|     | S.D. | (.22)    | (.00) | (.41)  | (.36) | (.33) | (.33)  |
| 3   | Mean | 1.94     | 2.74  | 5.86   | 7.30  | 5.84  | 10.60  |
|     | S.D. | (.09)    | (.09) | (.88)  | (.31) | (.27) | (1.93) |
| 4   | Mean | 1.70     | 2.00  | 5.18   | 9.98  | 6.70  | 3.66   |
|     | S.D. | (.10)    | (.19) | (1.01) | (.89) | (.51) | (.67)  |
| 5   | Mean | 2.00     | 1.56  | 5.26   | 5.26  | 4.92  | 6.78   |
|     | S.D. | (.19)    | (.36) | (.26)  | (.50) | (.61) | (.30)  |

TABLE 8.-- Means and standard deviations for five threshold determinations, in volts, obtained for Subject 3, on each day, and at each location

| Day |      | Location |       |        |        |        |       |
|-----|------|----------|-------|--------|--------|--------|-------|
|     |      | A        | B     | C      | D      | E      | F     |
| 1   | Mean | 1.32     | 0.96  | 3.08   | 2.38   | 2.00   | 3.50  |
|     | S.D. | (.11)    | (.09) | (.23)  | (.25)  | (.42)  | (.14) |
| 2   | Mean | 3.18     | 2.80  | 13.28  | 11.36  | 13.22  | 13.16 |
|     | S.D. | (.26)    | (.20) | (2.17) | (1.41) | (1.57) | (.72) |
| 3   | Mean | 2.46     | 2.98  | 14.94  | 7.30   | 10.06  | 12.14 |
|     | S.D. | (.43)    | (.09) | (1.12) | (2.04) | (1.54) | (.78) |
| 4   | Mean | 2.42     | 3.18  | 10.24  | 10.42  | 5.70   | 5.70  |
|     | S.D. | (.11)    | (.19) | (.18)  | (2.36) | (.22)  | (.23) |
| 5   | Mean | 3.24     | 1.52  | 10.68  | 6.74   | 5.38   | 7.78  |
|     | S.D. | (.28)    | (.13) | (.64)  | (.26)  | (.50)  | (.75) |

TABLE 9.-- Means and standard deviations of five threshold determinations, in volts, obtained for Subject 4, on each day, and at each location

| Day |      | A     | B     | Location |       | E      | F      |
|-----|------|-------|-------|----------|-------|--------|--------|
|     |      |       |       | C        | D     |        |        |
| 1   | Mean | 2.62  | 4.00  | 11.46    | 5.08  | 8.62   | 6.58   |
|     | S.D. | (.20) | (.25) | (.77)    | (.23) | (1.42) | (.40)  |
| 2   | Mean | 3.20  | 3.82  | 8.78     | 11.08 | 10.76  | 10.22  |
|     | S.D. | (.55) | (.16) | (.04)    | (.44) | (1.15) | (1.61) |
| 3   | Mean | 8.36  | 8.04  | 18.76    | 18.34 | 21.84  | 19.52  |
|     | S.D. | (.76) | (.86) | (2.21)   | (.51) | (1.56) | (1.46) |
| 4   | Mean | 4.92  | 4.24  | 13.30    | 12.52 | 10.46  | 14.22  |
|     | S.D. | (.46) | (.35) | (.35)    | (.43) | (1.55) | (.70)  |
| 5   | Mean | 4.96  | 5.44  | 12.84    | 12.40 | 12.42  | 14.40  |
|     | S.D. | (.15) | (.29) | (2.10)   | (.73) | (1.31) | (.50)  |



TABLE 10.-- Means and standard deviations of five threshold determinations, in volts, obtained for Subject 5, on each day, and at each location

| Day |      | A      | B      | Location |        | E      | F      |
|-----|------|--------|--------|----------|--------|--------|--------|
|     |      |        |        | C        | D      |        |        |
| 1   | Mean | 3.78   | 3.02   | 10.00    | 10.24  | 8.70   | 5.62   |
|     | S.D. | ( .08) | ( .64) | ( .59)   | ( .35) | ( .84) | ( .33) |
| 2   | Mean | 5.88   | 6.28   | 19.16    | 22.54  | 22.50  | 15.36  |
|     | S.D. | ( .23) | ( .59) | (1.37)   | ( .64) | (2.31) | ( .41) |
| 3   | Mean | 10.72  | 6.76   | 14.62    | 14.30  | 14.66  | 11.34  |
|     | S.D. | (1.95) | ( .94) | (1.27)   | ( .90) | (3.68) | ( .23) |
| 4   | Mean | 11.94  | 10.24  | 12.90    | 20.96  | 19.08  | 11.64  |
|     | S.D. | (2.35) | ( .75) | (1.03)   | (1.74) | (1.35) | (1.59) |
| 5   | Mean | 6.08   | 3.40   | 12.78    | 12.26  | 12.42  | 11.68  |
|     | S.D. | ( .26) | ( .23) | ( .43)   | (1.28) | (1.42) | ( .56) |

TABLE 11.-- Analysis of variance of all voltages corresponding to thresholds of sensitivity, for all subjects, on all days, and at all locations

| Source             | df  | MS      | F          |
|--------------------|-----|---------|------------|
| Subject            | 4   | 1,724.4 | 2,067.63** |
| Day                | 4   | 598.1   | 4.92**     |
| Location           | 5   | 1,040.4 | 17.57**    |
| Subj. x Day        | 16  | 121.6   | 145.80**   |
| Subj. x Loc.       | 20  | 59.2    | 70.98**    |
| Day x Loc.         | 20  | 37.1    | 2.56**     |
| Subj. x Day x Loc. | 80  | 14.5    | 17.39**    |
| Error              | 600 | .834    |            |
| Total              | 749 |         |            |

\*\* Significant at 0.01 level

TABLE 12.-- Model of planned comparisons of thresholds obtained at the various tongue locations for each subject during each test session

| Source     | df | MS | F |
|------------|----|----|---|
| Location   | 5  |    |   |
| AB vs CDEF | 1  |    |   |
| ADS vs CEF | 1  |    |   |
| DE vs CF   | 1  |    |   |
| Remainder  | 2  |    |   |
| Error      | 24 |    |   |
| Total      | 29 |    |   |

TABLE 13.-- Means, in decibels, re. 1 volt, of five sensitivity threshold determinations, obtained for Subject 1 on each day and at each location

| Day | Locations |       |       |       |       |       |
|-----|-----------|-------|-------|-------|-------|-------|
|     | A         | B     | C     | D     | E     | F     |
| 1   | 2.80      | 5.00  | 11.40 | 10.20 | 13.98 | 12.72 |
| 2   | 2.00      | 3.76  | 12.20 | 10.42 | 9.30  | 12.54 |
| 3   | 6.76      | 10.42 | 18.68 | 13.80 | 15.60 | 20.32 |
| 4   | 9.30      | 10.78 | 14.72 | 18.14 | 18.00 | 14.32 |
| 5   | 4.70      | 10.36 | 16.34 | 16.10 | 14.78 | 17.20 |

TABLE 14.-- Means, in decibels, re. 1 volt, of five sensitivity threshold determinations, obtained for Subject 2 on each day and at each location

| Day | A    | B    | Locations |       | E     | F     |
|-----|------|------|-----------|-------|-------|-------|
|     |      |      | C         | D     |       |       |
| 1   | 1.28 | 1.58 | 7.08      | 9.66  | 8.24  | 8.62  |
| 2   | 4.20 | 6.84 | 12.58     | 11.02 | 12.58 | 12.38 |
| 3   | 5.76 | 8.76 | 15.36     | 17.26 | 15.32 | 20.50 |
| 4   | 4.60 | 6.02 | 14.28     | 19.98 | 16.52 | 11.28 |
| 5   | 6.02 | 3.86 | 14.42     | 14.42 | 13.84 | 16.62 |

TABLE 15.-- Means, in decibels, re. 1 volt, of five sensitivity threshold determinations, obtained for Subject 3 on each day and at each location

| Day | A     | B     | Locations |       | E     | F     |
|-----|-------|-------|-----------|-------|-------|-------|
|     |       |       | C         | D     |       |       |
| 1   | 2.42  | 1.96  | 9.78      | 7.54  | 6.02  | 10.88 |
| 2   | 10.04 | 8.94  | 22.46     | 21.12 | 22.42 | 22.38 |
| 3   | 7.82  | 9.42  | 23.52     | 17.26 | 20.04 | 21.68 |
| 4   | 7.68  | 10.04 | 20.20     | 20.36 | 15.12 | 15.12 |
| 5   | 10.20 | 3.84  | 20.58     | 16.58 | 14.62 | 17.82 |

TABLE 16.-- Means, in decibels, re. 1 volt, of five sensitivity threshold determinations, obtained for Subject 4 on each day and at each location

| Day | Locations |       |       |       |       |       |
|-----|-----------|-------|-------|-------|-------|-------|
|     | A         | B     | C     | D     | E     | F     |
| 1   | 8.36      | 12.04 | 21.18 | 14.12 | 18.72 | 16.36 |
| 2   | 10.10     | 11.64 | 18.88 | 20.88 | 20.64 | 20.18 |
| 3   | 18.44     | 18.10 | 25.46 | 25.26 | 26.78 | 23.80 |
| 4   | 13.84     | 12.54 | 22.48 | 21.96 | 20.40 | 23.06 |
| 5   | 13.92     | 14.72 | 22.18 | 21.86 | 21.88 | 23.16 |

TABLE 17.-- Means, in decibels, re. 1 volt, of five sensitivity threshold determinations, obtained for Subject 5 on each day and at each location

| Day | A     | B     | Locations |       | E     | F     |
|-----|-------|-------|-----------|-------|-------|-------|
|     |       |       | C         | D     |       |       |
| 1   | 11.56 | 9.60  | 20.00     | 20.20 | 18.80 | 15.00 |
| 2   | 15.38 | 15.98 | 25.64     | 27.06 | 27.04 | 23.72 |
| 3   | 20.60 | 16.60 | 23.30     | 23.10 | 23.32 | 21.10 |
| 4   | 21.52 | 20.20 | 22.22     | 26.42 | 25.62 | 21.32 |
| 5   | 15.68 | 10.64 | 22.14     | 21.78 | 21.88 | 21.36 |



TABLE 18.-- Means and standard deviations of intervals, in milliseconds, corresponding to separation thresholds of paired stimuli administered to Subject 1, at each of six locations, during five test sessions

| Day |      | A    | B    | Location |      | E    | F    |
|-----|------|------|------|----------|------|------|------|
|     |      |      |      | C        | D    |      |      |
| 1   | Mean | 178  | 136  | 134      | 144  | 88   | 138  |
|     | S.D. | (13) | (15) | (11)     | (11) | (8)  | (8)  |
| 2   | Mean | 130  | 126  | 130      | 106  | 118  | 120  |
|     | S.D. | (10) | (11) | (10)     | (15) | (11) | (10) |
| 3   | Mean | 128  | 126  | 152      | 148  | 128  | 148  |
|     | S.D. | (13) | (9)  | (8)      | (11) | (8)  | (4)  |
| 4   | Mean | 130  | 140  | 130      | 108  | 112  | 158  |
|     | S.D. | (10) | (7)  | (0)      | (13) | (4)  | (11) |
| 5   | Mean | 136  | 154  | 166      | 144  | 156  | 140  |
|     | S.D. | (5)  | (5)  | (15)     | (5)  | (5)  | (0)  |

TABLE 19.-- Means and standard deviations of intervals, in milliseconds, corresponding to separation thresholds of paired stimuli administered to Subject 2, at each of six locations, during five test sessions

| Day |      | Location |      |      |      |      |      |
|-----|------|----------|------|------|------|------|------|
|     |      | A        | B    | C    | D    | E    | F    |
| 1   | Mean | 126      | 116  | 102  | 136  | 104  | 164  |
|     | S.D. | (11)     | ( 5) | ( 8) | (11) | ( 5) | (11) |
| 2   | Mean | 146      | 116  | 170  | 126  | 122  | 150  |
|     | S.D. | ( 5)     | (15) | ( 7) | ( 9) | ( 8) | (10) |
| 3   | Mean | 174      | 164  | 212  | 146  | 218  | 220  |
|     | S.D. | (11)     | (13) | (15) | (11) | (15) | ( 7) |
| 4   | Mean | 132      | 138  | 172  | 126  | 148  | 172  |
|     | S.D. | (13)     | (13) | ( 8) | (11) | (15) | (11) |
| 5   | Mean | 138      | 132  | 168  | 142  | 146  | 156  |
|     | S.D. | (13)     | (11) | (11) | (11) | ( 9) | (13) |

TABLE 20.-- Means and standard deviations of intervals, in milliseconds, corresponding to separation thresholds of paired stimuli administered to Subject 3, at each of six locations, during five test sessions

| Day |      | Location |      |      |      |      |      |
|-----|------|----------|------|------|------|------|------|
|     |      | A        | B    | C    | D    | E    | F    |
| 1   | Mean | 176      | 214  | 187  | 194  | 230  | 198  |
|     | S.D. | (13)     | ( 9) | (15) | ( 5) | (12) | (15) |
| 2   | Mean | 198      | 186  | 180  | 192  | 156  | 168  |
|     | S.D. | (11)     | ( 9) | (12) | ( 8) | ( 5) | (11) |
| 3   | Mean | 186      | 174  | 122  | 108  | 116  | 130  |
|     | S.D. | ( 5)     | ( 5) | ( 8) | (11) | (13) | ( 7) |
| 4   | Mean | 138      | 130  | 78   | 78   | 146  | 142  |
|     | S.D. | ( 8)     | ( 0) | ( 8) | ( 8) | ( 5) | (11) |
| 5   | Mean | 144      | 132  | 60   | 108  | 134  | 130  |
|     | S.D. | (11)     | (11) | ( 0) | ( 8) | (13) | (14) |

TABLE 21.-- Means and standard deviations of intervals, in milliseconds, corresponding to separation thresholds of paired stimuli administered to Subject 4, at each of six locations, during five test sessions

| Day |      | Location |      |      |      |      |      |
|-----|------|----------|------|------|------|------|------|
|     |      | A        | B    | C    | D    | E    | F    |
| 1   | Mean | 168      | 168  | 92   | 142  | 136  | 130  |
|     | S.D. | ( 4)     | ( 8) | (13) | (11) | (11) | (12) |
| 2   | Mean | 212      | 186  | 148  | 120  | 134  | 164  |
|     | S.D. | ( 8)     | (13) | ( 8) | ( 7) | (13) | (11) |
| 3   | Mean | 184      | 192  | 174  | 176  | 188  | 182  |
|     | S.D. | (15)     | ( 8) | (15) | ( 5) | (11) | (15) |
| 4   | Mean | 136      | 180  | 116  | 136  | 90   | 130  |
|     | S.D. | ( 5)     | (14) | ( 9) | (15) | (10) | (12) |
| 5   | Mean | 170      | 174  | 124  | 86   | 100  | 120  |
|     | S.D. | (12)     | (11) | ( 9) | (11) | (14) | (12) |

TABLE 22.-- Means and standard deviations of intervals, in milliseconds, corresponding to separation thresholds of paired stimuli administered to Subject 5, at each of six locations, during five test sessions

| Day |      | Location |      |      |      |      |      |
|-----|------|----------|------|------|------|------|------|
|     |      | A        | B    | C    | D    | E    | F    |
| 1   | Mean | 150      | 154  | 38   | 46   | 30   | 116  |
|     | S.D. | (12)     | ( 9) | (11) | (11) | ( 7) | ( 9) |
| 2   | Mean | 128      | 142  | 63   | 65   | 50   | 57   |
|     | S.D. | ( 8)     | (11) | (14) | ( 4) | (13) | (10) |
| 3   | Mean | 92       | 96   | 46   | 54   | 48   | 34   |
|     | S.D. | (11)     | (15) | ( 9) | (13) | ( 8) | ( 5) |
| 4   | Mean | 58       | 100  | 78   | 76   | 70   | 48   |
|     | S.D. | ( 4)     | (10) | ( 8) | (15) | (10) | ( 8) |
| 5   | Mean | 170      | 136  | 114  | 148  | 132  | 132  |
|     | S.D. | (12)     | ( 9) | ( 9) | ( 4) | ( 4) | ( 8) |

TABLE 23.-- Analysis of variance of intervals, in milliseconds, corresponding to separation thresholds between successive stimuli applied to various lingual areas, for all subjects, on all days, and at all locations

| Source             | df  | MS      | F        |
|--------------------|-----|---------|----------|
| Subject            | 4   | 103,726 | 434.00** |
| Day                | 4   | 11,029  | .48      |
| Location           | 5   | 18,756  | 2.74*    |
| Subj. x Day        | 16  | 23,198  | 97.06**  |
| Subj. x Loc.       | 20  | 6,838   | 28.61**  |
| Day x Loc.         | 20  | 2,106   | .93      |
| Subj. x Day x Loc. | 80  | 2,266   | 9.48**   |
| Error              | 600 | 239     |          |
| Total              | 749 |         |          |

\* Significant at 0.05 level

\*\* Significant at 0.01 level

TABLE 24.-- Means and standard deviations of intervals, in milliseconds, corresponding to separation thresholds of paired stimuli administered to each of six locations, during five test sessions. By subject and location

| Subject |      | Location |      |      |      |      |                  |
|---------|------|----------|------|------|------|------|------------------|
|         |      | A        | B    | C    | D    | E    | F                |
| 1       | Mean | 140      | 136  | 142  | 130  | 120  | 141              |
|         | S.D. | (21)     | (12) | (16) | (21) | (25) | (14)             |
| 2       | Mean | 143      | 133  | 165  | 135  | 148  | 172              |
|         | S.D. | (19)     | (20) | (40) | ( 9) | (43) | (28)             |
| 3       | Mean | 168      | 167  | 125  | 136  | 156  | 154              |
|         | S.D. | (26)     | (36) | (58) | (53) | (44) | (29)             |
| 4       | Mean | 174      | 180  | 131  | 132  | 130  | 145 <sup>x</sup> |
|         | S.D. | (28)     | ( 9) | (31) | (33) | (38) | (26)             |
| 5       | Mean | 120      | 126  | 68   | 78   | 66   | 77               |
|         | S.D. | (45)     | (26) | (30) | (41) | (40) | (44)             |

TABLE 25.-- Mean intervals, in log, corresponding to separation thresholds of paired stimuli administered to Subject 1, at each of six locations, during five test sessions

| Day | Locations |      |      |      |      |      |
|-----|-----------|------|------|------|------|------|
|     | A         | B    | C    | D    | E    | F    |
| 1   | 2.25      | 2.13 | 2.13 | 2.16 | 1.94 | 2.14 |
| 2   | 2.11      | 2.10 | 2.11 | 2.03 | 2.07 | 2.08 |
| 3   | 2.11      | 2.10 | 2.18 | 2.17 | 2.11 | 2.17 |
| 4   | 2.11      | 2.15 | 2.11 | 2.03 | 2.05 | 2.20 |
| 5   | 2.13      | 2.19 | 2.22 | 2.16 | 2.19 | 2.15 |



TABLE 26.-- Mean intervals, in log, corresponding to separation thresholds of paired stimuli administered to Subject 2, at each of six locations, during five test sessions

| Day | Locations |      |      |      |      |      |
|-----|-----------|------|------|------|------|------|
|     | A         | B    | C    | D    | E    | F    |
| 1   | 2.10      | 2.06 | 2.01 | 2.13 | 2.02 | 2.21 |
| 2   | 2.16      | 2.06 | 2.23 | 2.10 | 2.09 | 2.18 |
| 3   | 2.24      | 2.21 | 2.32 | 2.16 | 2.34 | 2.34 |
| 4   | 2.12      | 2.14 | 2.23 | 2.10 | 2.17 | 2.24 |
| 5   | 2.14      | 2.12 | 2.22 | 2.16 | 2.16 | 2.19 |

TABLE 27.-- Mean intervals, in log, corresponding to separation thresholds of paired stimuli administered to Subject 3, at each of six locations, during five test sessions

| Day | A    | B    | Locations |      | E    | F    |
|-----|------|------|-----------|------|------|------|
|     |      |      | C         | D    |      |      |
| 1   | 2.25 | 2.33 | 2.27      | 2.29 | 2.36 | 2.30 |
| 2   | 2.30 | 2.27 | 2.26      | 2.28 | 2.19 | 2.23 |
| 3   | 2.27 | 2.24 | 2.09      | 2.03 | 2.06 | 2.11 |
| 4   | 2.14 | 2.11 | 1.89      | 1.89 | 2.16 | 2.15 |
| 5   | 2.16 | 2.12 | 1.78      | 2.03 | 2.13 | 2.11 |

TABLE 28.-- Mean intervals, in log, corresponding to separation thresholds of paired stimuli administered to Subject 4, at each of six locations, during five test sessions

| Day | Locations |      |      |      |      |      |
|-----|-----------|------|------|------|------|------|
|     | A         | B    | C    | D    | E    | F    |
| 1   | 2.23      | 2.23 | 1.96 | 2.15 | 2.13 | 2.11 |
| 2   | 2.34      | 2.28 | 2.17 | 2.08 | 2.13 | 2.21 |
| 3   | 2.26      | 2.29 | 2.24 | 2.24 | 2.27 | 2.26 |
| 4   | 2.13      | 2.25 | 2.06 | 2.13 | 1.95 | 2.11 |
| 5   | 2.23      | 2.24 | 2.09 | 1.93 | 2.00 | 2.08 |

TABLE 29.-- Mean intervals, in log, corresponding to separation thresholds of  
paired stimuli administered to Subject 5, at each of six locations,  
during five test sessions

| Day | A    | B    | Locations |      | E    | F    |
|-----|------|------|-----------|------|------|------|
|     |      |      | C         | D    |      |      |
| 1   | 2.18 | 2.19 | 1.58      | 1.66 | 1.48 | 2.06 |
| 2   | 2.11 | 2.15 | 1.80      | 1.81 | 1.70 | 1.76 |
| 3   | 1.96 | 1.98 | 1.66      | 1.73 | 1.68 | 1.53 |
| 4   | 1.76 | 2.00 | 1.89      | 1.88 | 1.85 | 1.68 |
| 5   | 2.23 | 2.13 | 2.06      | 2.17 | 2.12 | 2.12 |

TABLE 30.-- Means and standard deviations of intervals, in milliseconds, corresponding to separation thresholds of bilateral stimuli administered to Subject 1 at six pairs of homologous locations, during five test sessions

| Day |      | Pairs of locations |      |      |      |      |      |
|-----|------|--------------------|------|------|------|------|------|
|     |      | A-B                | B-A  | C-F  | D-E  | E-D  | F-C  |
| 1   | Mean | 76                 | 82   | 67   | 67   | 69   | 72   |
|     | S.D. | ( 7)               | ( 3) | (10) | ( 9) | ( 4) | ( 7) |
| 2   | Mean | 21                 | 15   | 17   | 26   | 21   | 29   |
|     | S.D. | ( 7)               | ( 7) | ( 4) | ( 7) | ( 4) | ( 7) |
| 3   | Mean | 64                 | 69   | 65   | 45   | 40   | 54   |
|     | S.D. | (14)               | ( 8) | ( 5) | ( 4) | ( 5) | ( 2) |
| 4   | Mean | 52                 | 46   | 50   | 50   | 54   | 56   |
|     | S.D. | ( 8)               | ( 2) | ( 6) | ( 8) | ( 6) | ( 7) |
| 5   | Mean | 38                 | 36   | 33   | 37   | 42   | 50   |
|     | S.D. | ( 6)               | ( 5) | (10) | ( 3) | ( 3) | ( 4) |

TABLE 31.-- Means and standard deviations of intervals, in milliseconds, corresponding to separation thresholds of bilateral stimuli administered to Subject 2 at six pairs of homologous locations, during five test sessions

| Day |      | A-B  | B-A  | Pairs of locations |      | E-D  | F-C  |
|-----|------|------|------|--------------------|------|------|------|
|     |      |      |      | C-F                | D-E  |      |      |
| 1   | Mean | 61   | 68   | 53                 | 62   | 67   | 64   |
|     | S.D. | ( 2) | ( 3) | ( 9)               | ( 4) | ( 8) | ( 9) |
| 2   | Mean | 75   | 58   | 75                 | 76   | 65   | 77   |
|     | S.D. | (11) | ( 9) | ( 5)               | (10) | ( 4) | ( 7) |
| 3   | Mean | 57   | 58   | 61                 | 57   | 61   | 68   |
|     | S.D. | ( 6) | ( 4) | ( 4)               | ( 6) | ( 5) | ( 8) |
| 4   | Mean | 35   | 47   | 66                 | 25   | 48   | 50   |
|     | S.D. | ( 4) | ( 3) | ( 4)               | ( 4) | ( 6) | ( 6) |
| 5   | Mean | 52   | 54   | 57                 | 63   | 54   | 53   |
|     | S.D. | ( 6) | (11) | ( 3)               | ( 6) | ( 5) | ( 3) |

TABLE 32.-- Means and standard deviations of intervals, in milliseconds, corresponding to separation thresholds of bilateral stimuli administered to Subject 3 at six pairs of homologous locations, during five test sessions

| Day |      | A-B  | B-A  | Pairs of locations |      | E-D  | F-C  |
|-----|------|------|------|--------------------|------|------|------|
|     |      |      |      | C-F                | D-E  |      |      |
| 1   | Mean | 99   | 101  | 92                 | 91   | 111  | 80   |
|     | S.D. | (10) | (13) | ( 6)               | ( 4) | (16) | ( 7) |
| 2   | Mean | 56   | 50   | 63                 | 65   | 54   | 50   |
|     | S.D. | ( 5) | ( 9) | ( 8)               | ( 6) | ( 4) | ( 4) |
| 3   | Mean | 61   | 58   | 64                 | 71   | 65   | 66   |
|     | S.D. | ( 5) | ( 6) | ( 5)               | ( 4) | ( 4) | ( 7) |
| 4   | Mean | 40   | 47   | 81                 | 45   | 43   | 78   |
|     | S.D. | ( 6) | ( 6) | (10)               | ( 4) | ( 9) | ( 5) |
| 5   | Mean | 44   | 46   | 58                 | 53   | 48   | 59   |
|     | S.D. | (10) | (12) | ( 3)               | ( 7) | ( 8) | ( 7) |

TABLE 33.-- Means and standard deviations of intervals, in milliseconds, corresponding to separation thresholds of bilateral stimuli administered to Subject 4 at six pairs of homologous locations, during five test sessions

| Day |      | Pairs of locations |      |      |      |      |      |
|-----|------|--------------------|------|------|------|------|------|
|     |      | A-B                | B-A  | C-F  | D-E  | E-D  | F-C  |
| 1   | Mean | 49                 | 38   | 48   | 51   | 58   | 57   |
|     | S.D. | ( 8)               | ( 6) | ( 3) | ( 7) | ( 8) | (10) |
| 2   | Mean | 39                 | 41   | 38   | 37   | 39   | 53   |
|     | S.D. | ( 6)               | ( 4) | ( 8) | ( 3) | ( 7) | (12) |
| 3   | Mean | 32                 | 35   | 37   | 65   | 53   | 36   |
|     | S.D. | ( 8)               | ( 7) | ( 7) | (14) | ( 4) | ( 4) |
| 4   | Mean | 47                 | 58   | 79   | 82   | 77   | 67   |
|     | S.D. | ( 7)               | ( 3) | (10) | (15) | (10) | (10) |
| 5   | Mean | 49                 | 42   | 44   | 52   | 60   | 42   |
|     | S.D. | ( 4)               | (11) | ( 5) | (10) | ( 7) | ( 3) |



TABLE 34.-- Means and standard deviations of intervals, in milliseconds, corresponding to separation thresholds of bilateral stimuli administered to Subject 5 at six pairs of homologous locations, during five test sessions

| Day |      | Pairs of locations |      |      |      |      |      |
|-----|------|--------------------|------|------|------|------|------|
|     |      | A-B                | B-A  | C-F  | D-E  | E-D  | F-C  |
| 1   | Mean | 41                 | 39   | 19   | 76   | 38   | 22   |
|     | S.D. | ( 7)               | (13) | (13) | (13) | ( 3) | ( 8) |
| 2   | Mean | 47                 | 69   | 40   | 31   | 15   | 26   |
|     | S.D. | ( 3)               | (12) | ( 6) | (11) | (12) | (10) |
| 3   | Mean | 54                 | 31   | 54   | 60   | 59   | 56   |
|     | S.D. | ( 5)               | (11) | ( 5) | ( 4) | ( 8) | ( 7) |
| 4   | Mean | 49                 | 43   | 53   | 48   | 64   | 44   |
|     | S.D. | ( 7)               | (12) | (13) | (13) | ( 5) | ( 5) |
| 5   | Mean | 42                 | 40   | 64   | 44   | 52   | 61   |
|     | S.D. | ( 5)               | (13) | ( 7) | (10) | (15) | ( 7) |

TABLE 35.-- Analysis of variance of intervals in milliseconds, corresponding to separation thresholds between successive bilateral stimuli applied to various pairs of lingual areas, for each subject, on each day, and at each pair of locations

| Source                 | df  | MS    | F        |
|------------------------|-----|-------|----------|
| Subject                | 4   | 9,342 | 150.68** |
| Day                    | 4   | 7,316 | 1.41     |
| Location               | 5   | 500   | 1.17     |
| Subj. x Day            | 16  | 5,193 | 83.76**  |
| Subj. x Location       | 20  | 427   | 6.89**   |
| Day x Location         | 20  | 669   | 1.27     |
| Subj. x Day x Location | 80  | 528   | 8.52**   |
| Error                  | 600 | 62    |          |
| Total                  | 749 |       |          |

\*\* Significant at 0.01 level

TABLE 36.-- Means and standard deviations of intervals, in milliseconds, corresponding to separation thresholds for bilateral stimuli administered to homologous pairs of locations during five test sessions. By subject and location

| Subject |      | Pairs of locations |      |      |      |      |      |
|---------|------|--------------------|------|------|------|------|------|
|         |      | A-B                | B-A  | C-F  | D-E  | E-D  | F-C  |
| 1       | Mean | 50                 | 50   | 46   | 45   | 45   | 52   |
|         | S.D. | (22)               | (27) | (21) | (15) | (18) | (15) |
| 2       | Mean | 56                 | 57   | 62   | 57   | 59   | 62   |
|         | S.D. | (15)               | ( 8) | ( 8) | (19) | ( 8) | (11) |
| 3       | Mean | 60                 | 60   | 72   | 65   | 64   | 67   |
|         | S.D. | (23)               | (23) | (14) | (18) | (27) | (13) |
| 4       | Mean | 43                 | 43   | 49   | 57   | 57   | 51   |
|         | S.D. | ( 7)               | ( 9) | (17) | (17) | (14) | (12) |
| 5       | Mean | 47                 | 44   | 46   | 52   | 46   | 42   |
|         | S.D. | ( 5)               | (14) | (17) | (17) | (20) | (17) |

TABLE 37.-- Mean of intervals, in log, corresponding to separation thresholds of bilateral stimuli administered to Subject 1, at six pairs of homologous locations, during five test sessions

| Day | Pairs of locations |      |      |      |      |      |
|-----|--------------------|------|------|------|------|------|
|     | A-B                | B-A  | C-F  | D-E  | E-D  | F-C  |
| 1   | 1.88               | 1.91 | 1.83 | 1.83 | 1.84 | 1.86 |
| 2   | 1.32               | 1.18 | 1.23 | 1.41 | 1.32 | 1.46 |
| 3   | 1.81               | 1.84 | 1.81 | 1.65 | 1.60 | 1.73 |
| 4   | 1.72               | 1.66 | 1.70 | 1.70 | 1.73 | 1.75 |
| 5   | 1.58               | 1.56 | 1.52 | 1.57 | 1.62 | 1.70 |

TABLE 38.-- Mean of intervals, in log, corresponding to separation thresholds of bilateral stimuli administered to Subject 2, at six pairs of homologous locations, during five test sessions

| Day | Pairs of locations |      |      |      |      |      |
|-----|--------------------|------|------|------|------|------|
|     | A-B                | B-A  | C-F  | D-E  | E-D  | F-C  |
| 1   | 1.79               | 1.83 | 1.72 | 1.79 | 1.83 | 1.81 |
| 2   | 1.88               | 1.76 | 1.87 | 1.88 | 1.81 | 1.89 |
| 3   | 1.76               | 1.76 | 1.79 | 1.76 | 1.78 | 1.83 |
| 4   | 1.54               | 1.67 | 1.82 | 1.40 | 1.68 | 1.70 |
| 5   | 1.72               | 1.73 | 1.76 | 1.80 | 1.73 | 1.72 |

TABLE 39.-- Mean of intervals, in log, corresponding to separation thresholds of bilateral stimuli administered to Subject 3, at six pairs of homologous locations, during five test sessions

| Day | A-B  | B-A  | Pairs of locations |      |      |      |
|-----|------|------|--------------------|------|------|------|
|     |      |      | C-F                | D-E  | E-D  | F-C  |
| 1   | 2.00 | 2.00 | 1.96               | 1.96 | 2.05 | 1.90 |
| 2   | 1.75 | 1.70 | 1.80               | 1.81 | 1.73 | 1.70 |
| 3   | 1.79 | 1.76 | 1.81               | 1.85 | 1.81 | 1.82 |
| 4   | 1.60 | 1.67 | 1.91               | 1.65 | 1.63 | 1.89 |
| 5   | 1.64 | 1.66 | 1.76               | 1.72 | 1.68 | 1.77 |

TABLE 40.-- Mean of intervals, in log, corresponding to separation thresholds of bilateral stimuli administered to Subject 4, at six pairs of homologous locations, during five test sessions

| Day | A-B  | B-A  | Pairs of locations |      |      |      |
|-----|------|------|--------------------|------|------|------|
|     |      |      | C-F                | D-E  | E-D  | F-C  |
| 1   | 1.69 | 1.58 | 1.68               | 1.71 | 1.76 | 1.76 |
| 2   | 1.59 | 1.61 | 1.58               | 1.57 | 1.59 | 1.72 |
| 3   | 1.51 | 1.54 | 1.57               | 1.81 | 1.72 | 1.56 |
| 4   | 1.67 | 1.76 | 1.90               | 1.91 | 1.89 | 1.83 |
| 5   | 1.69 | 1.62 | 1.64               | 1.72 | 1.78 | 1.62 |

TABLE 41.-- Mean of intervals, in log, corresponding to separation thresholds of bilateral stimuli administered to Subject 5, at six pairs of homologous locations, during five test sessions

| Day | A-B  | B-A  | Pairs of locations |      |      |      |
|-----|------|------|--------------------|------|------|------|
|     |      |      | C-F                | D-E  | E-D  | F-C  |
| 1   | 1.61 | 1.59 | 1.28               | 1.88 | 1.58 | 1.34 |
| 2   | 1.67 | 1.84 | 1.60               | 1.49 | 1.18 | 1.41 |
| 3   | 1.73 | 1.49 | 1.73               | 1.78 | 1.77 | 1.75 |
| 4   | 1.69 | 1.63 | 1.72               | 1.68 | 1.81 | 1.64 |
| 5   | 1.62 | 1.60 | 1.81               | 1.64 | 1.72 | 1.79 |



## VITA

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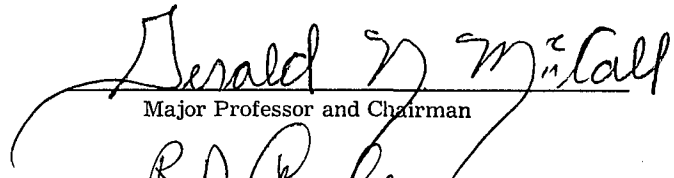
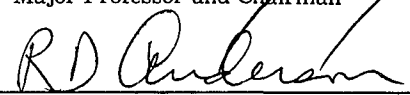
## EXAMINATION AND THESIS REPORT

Candidate: Anna Klein Pleasonton

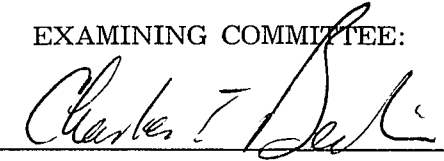
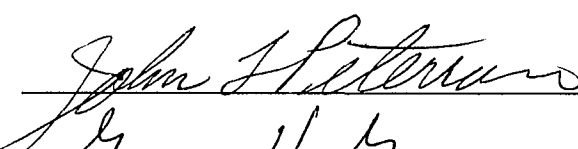
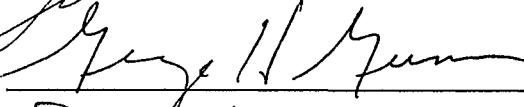
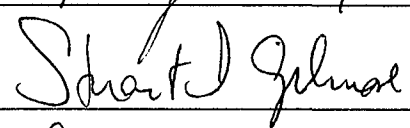
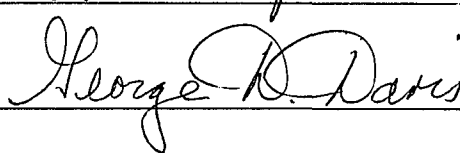
Major Field: Speech

Title of Thesis: Sensitivity to and Temporal Resolution of Electrical  
Stimuli to the Tongue

Approved:

  
Major Professor and Chairman  
  
Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

July 9, 1968