72-22,323

BORDEN, Gloria Jones, 1930-
SOME EFFECTS OF ORAL ANESTHESIA ON SPEECH:
A PERCEPTUAL AND ELECTROMYOGRAPHIC ANALYSIS.

The City University of New York, Ph.D., 1972
Speech Pathology

University Microfilms, A XEROX Company, Ann Arbor, Michigan

SOME EFFECTS OF ORAL ANESTHESIA ON SPEECH:

A PERCEPTUAL AND ELECTROMYOGRAPHIC ANALYSIS

by

GLORIA JONES BORDEN

under the direction of

PROFESSOR KATHERINE S. HARRIS

A dissertation submitted to the Graduate
Faculty in Speech in partial fulfill-
ment of the requirements for the
degree of Doctor of Philosophy,
The City University of
New York

1971

This manuscript has been read and accepted for the Graduate Faculty in Speech in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

1/25/72 — Katherine S. Harris
Date — Chairman of Committee

1/25/72 — for Harry Levitt
Date — Executive Officer

Joel Stark

Oliver Bloodstein

A. S. House

Examining Committee

The City University of New York

ACKNOWLEDGEMENTS

This dissertation was conducted under the direction of Katherine S. Harris, Professor of Speech Science at City University of New York and Research Psychologist at Haskins Laboratories of New York and New Haven. The author wishes to thank Drs. Oliver Bloodstein and Joel Stark who kindly served as members of her advisory committee and Dr. Arthur Bronstein who was the executive officer of the Ph.D. program in speech. Thanks are due to Dr. Harry Levitt for help in design and statistical analysis and to Stewart Lawrence for preparing the necessary computer programs for the analysis of the perceptual study. Dr. Charles Noback was helpful concerning anatomical questions, and the Doctors Victor Caronia, William Oliver, and Loren Catena assisted in providing dental injections. Dr. Oliver was particularly helpful in scheduling subjects at the University of Pennsylvania School of Dentistry. Dr. Robert Ringel provided and administered the oral form discrimination test and his cooperation is appreciated.

The author wishes to thank the staff of Haskins

Laboratories, including Lorraine Russell who transcribed the tapes phonetically, Dr. Tom Gay who recorded the master tape, and Fredericka Berti who assisted in the analysis. Indispensable to this study were Dr. Masayuki Sawashima and Dr. Hajime Hirose of the Faculty of Medicine, University of Tokyo, who inserted the electrodes.

Above all, the author wishes to express her gratitude to Dr. Katherine S. Harris who inspired and guided the present work.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd.)

LIST OF TABLES

LIST OF TABLES (cont'd.)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (cont'd.)

CHAPTER I

INTRODUCTION

This dissertation is an approach to the unanswered question of the nature of kinesthetic control in speech. Is ongoing speech monitored and controlled by taction and kinesthesis or is it a learned motor program which once established in the central nervous system executes its commands relatively free of such monitoring? The application of this type of investigation to speech pathology is both basic and practical. We need basic information about muscle function and nerve function in speech and how they relate to control the speaking system. Therapists need to know to what extent normal speakers depend upon sensory information from the muscles. This information should underlie decisions about the need for oral sensory discrimination training.

A. Feedback Theory

When asked to study the possibility of developing anti-aircraft artillery which would be capable of tracking planes and predicting their future positions, the mathematician

Norbert Weiner investigated the nature of physiological feedback.[1] Weiner coined the term "cybernetics" from the Greek kubernetes meaning "steersman." Cybernetics refers to the science of self-regulating mechanisms. In engineering such a machine is called a servomechanism. The physiological regulation of automatic activity in the human body is termed homeostasis. Homeostasis, a self-regulating process, is achieved by means of feedback. Feeback is information about the actual performance of a system rather than expected performance. On the basis of this feedback, the system makes adjustments to compensate for error. Examples of this in body functions are temperature control of the body, endocrine secretions, and blood chemistry level. Voluntary action is also thought to be performed and controlled through feedback. When we reach for an object on a table, the visual and kinesthetic feedback provided through our senses of sight, muscle movement, and touch presumably inform us of our progress and predict the amplitude of motor response needed to reach the object. Lacking even one of these feedback mechanisms, we might fall short of our goal or reach past it.

Weiner consulted several eminent physiologists and

---

[1] N. Weiner, The Human Use of Human Beings (New York: Doubleday Anchor Books, 1954), 2nd ed.

neurologists who had long been interested in the relationships between sensation and performance of motor acts. Since the classic study by Mott and Sherrington in 1875 demonstrated that a deafferented limb of a monkey could not make purposeful movements, it has been thought that somatic sensation is necessary for voluntary movement.[1] This conclusion has been challenged by recent studies on limb deafferentation by Taub and Berman.[2] Also performed on monkeys, these experiments demonstrate that monkeys are capable of making purposive movements with deafferented limbs, especially with bilateral deafferentation. They concluded that once a motor program has been written into the central nervous system of mammals, the specified behavior, having been initiated, can be performed without any reference to or guidance from the periphery.

Although experimental psychologists and physiologists had long been searching for the nature of feedback mechanisms in animals, research and writings on feedback by those primarily interested in language and speech did not appear in the

---

[1] F. M. Mott and C. S. Sherrington, "Experiments upon the Influence of Sensory Nerves upon Movement and Nutrition of the Limbs," Proc. Roy. Soc., London, 1875, 57, 481-488.

[2] E. Taub and A. J. Berman, "Movement and Learning in the Absence of Sensory Feedback," Chap. 13, The Neuropsychology of Spatially Oriented Behavior, S. J. Freedman (Ed.),

literature until the 1950s. In 1950 Lee stumbled upon the fact that one's own speech production, if amplified and fed back to the speaker with a time delay, breaks down and becomes disfluent.[1] This report stimulated much research and writing on the subject of speech as a feedback system. In 1954, Fairbanks published a model of the speech system as a servomechanism.[2] The system is comprised of controller, mixer, effector, and sensor units which feed speech back into a comparator where actual output is contrasted with expected output. The objective of the model is to reduce any error signals to zero and to correct subsequent output. Mysak elaborated on the model introduced by Fairbanks by suggesting anatomical locations for the various units[3] and by trying to show that all speech pathologies, as well as normal speech, are the result of particular short circuits in the system.[4]

The Fairbanks model and the results of delayed auditory feedback generated many studies of auditory feedback

---

[1] B. S. Lee, "Effects of Delayed Speech Feedback," J. Acoust. Soc. Amer., 22, 1950, 824-826.

[2] G. Fairbanks, "A Theory of the Speech Mechanism as a Servosystem," J. Sp. Hear. Dis., 19, 1954, 133-139.

[3] E. D. Mysak, "A Servo Model for Speech Therapy," J. Sp. Hear. Dis., 24, 1959, 144-149.

[4] E. D. Mysak, Speech Pathology and Feedback Theory (Springfield, Ill.: Charles C. Thomas, 1966).

alterations. Auditory masking has also been studied extensively, often in combination with tactile and proprioceptive deprivation. This paper, however, is limited to a consideration of the effects of tactile and kinesthetic alterations upon speech.

The thinking on feedback theory and the developments in cybernetics also had an effect on learning theory. There was a gradual movement away from the conception of habit formation as simply the strengthening of a neural bond between stimulus and response by reward to a consideration of secondary reinforcement, that is, either positive or negative feedback. Habit formation is viewed by Mowrer as the strengthening of the neural bond between the stimuli produced by a particular rewarded response and the phenomenon of feedback which can be either external or internal.[1] Habit strength in speech is viewed as whether or not a person is disposed to make a particular response. The response is made in tentative token form and it produces either a predominantly favorable feedback or a predominantly unfavorable feedback.

Before proceeding to the speech research on oral sensation, it is helpful to briefly review the theories of the nature of tactile and kinesthetic sensation and to describe the anatomy and physiology involved.

---

[1] O. H. Mowrer, "Two-factor Learning Theory Reconsidered with Special Reference to Secondary Reinforcement and the Concept of Habit," Psychol. Rev., 63, 1956, 114-128.

B. Theories of Tactile and Kinesthetic Sensation

In order to understand oral sensation specifically, it is helpful to know something of the historical development of theories on somatic sensation in general. A brief review of the literature extracted from the extensive account by Boring is presented in order to provide a setting for the speech research to be reviewed later in the paper.

Aristotle's fifth sense, the sense of touch, does not seem to be one sense at all. In 1826, Charles Bell made the first effort to differentiate between touch and what he named "kinesthesis." He was describing in his "circle of nerves" concept a muscle sense which was independent of touch. He did not, however, conceive of separate afferent nerve innervation but merely assumed that the sense of muscle movement was perceived from the activity of the motor tract: a sensationless perception. In 1880, Bastian described kinesthesis as a complex sense of movement derived from muscles, tendons, joints, and skin. In 1889, Goldscheider anesthetized the skin and underlying tissue and tested for perception of movement. Then he anesthetized the joints by passing a faradic current through them and concluded that the joints contribute more than muscles to perception of movement. In 1900, Sherrington used the word "proprioception" to denote this sense of movement and position.

The proprioceptors were distinguished from the exteroceptors which were more superficially located and which received tactile information. The Pacinian corpuscles which are now associated with tendons and ligaments of joints were discovered in 1741 by Abraham Vater and rediscovered in 1835 by Pacini. In 1863, Kuhne named the muscle spindles as receptors for muscle sense. They were further identified in 1892 by Ruffini and in 1894 Sherrington demonstrated that they were sensory by sectioning the nerve root at the spinal cord in a monkey.[1] By 1931 Matthews had indicated that stretch is the true stimulus for this receptor.[2] The Golgi spindles in the tendons were first described by Rollett in 1876, again by Golgi in 1880, and Huber and DeWill were arguing for sensory functions attributed to these spindles by 1900. The neuromuscular spindles are currently thought to be responsive to stretch and to give information on movement and position at a reflex level, not on a conscious cortical level. (Figures 1 and 2)

Just as the sense of motion and position was separated from the sense of cutaneous touch, so did this sense of touch become differentiated into separate senses. Ernst Heinrich Weber

---

[1] E. G. Boring, Sensation and Perception in the History of Experimental Psychology (New York: Appleton-Century-Crofts, Inc., 1942).

[2] P. B. C. Matthews, "Muscle Spindles and their Motor Control," Physiol. Rev., 44, 1964, 219-287.

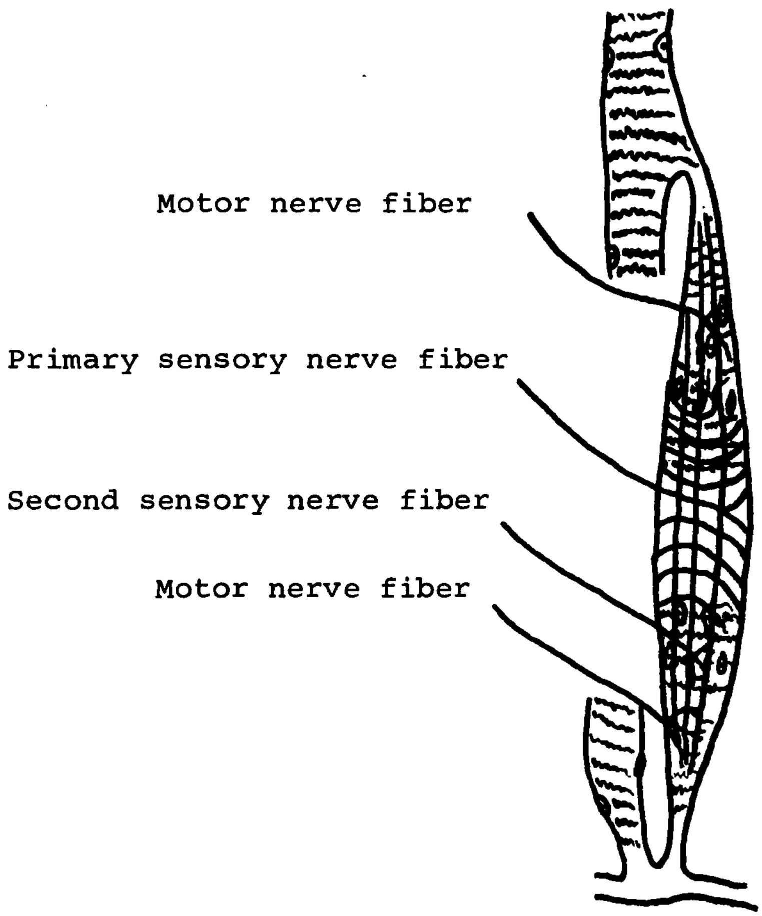


Figure 1

Schematic of a neuromuscular spindle.

Source: Zemlin, p. 519.

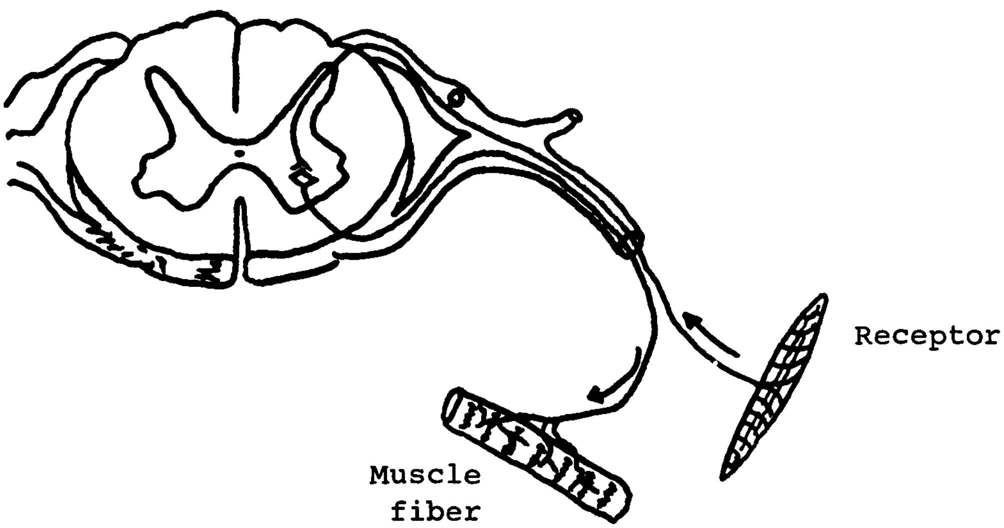


Figure 2

Schematic of a two neuron reflex arc.

Source: Zemlin, p. 522.

maintained in 1834 that although one can sense place, pressure, and temperature, they are three attributes of one sense because they are interdependent. A cold coin feels heavier than a warm coin. At the same time histologists were finding a variety of end-organs. Pressure sense and temperature sense were the first to be considered separate. There were two theories of pain. The intensive theory of pain was that enough of any stimulus would be perceived as pain. In contrast, the Specific Nerve Energies concept of pain was that there were specific nerves for pain. Most of the workers in this field considered the nerve endings as specific. It was noticed that in anesthesia the senses of cold and touch would disappear before pain which would go before heat. The senses would return in the reverse order. In the 1880's sensory spots were discovered independently in Sweden (Blix 1882), in Germany (Goldscheider 1884), and in America (Donaldson 1885). In 1895, Max von Frey attributed the sense of pain to the free nerve endings between the epithelial cells, the sense of cold to the Krause bulbs just beneath the skin, the sense of warmth to the Ruffini endings deeper down, and the sense of pressure to the free endings around hair follicles or where there is no hair, to the Meissner corpuscles. (See Figure 3) This simplistic view of separate nerve endings for separate senses was felt to apply

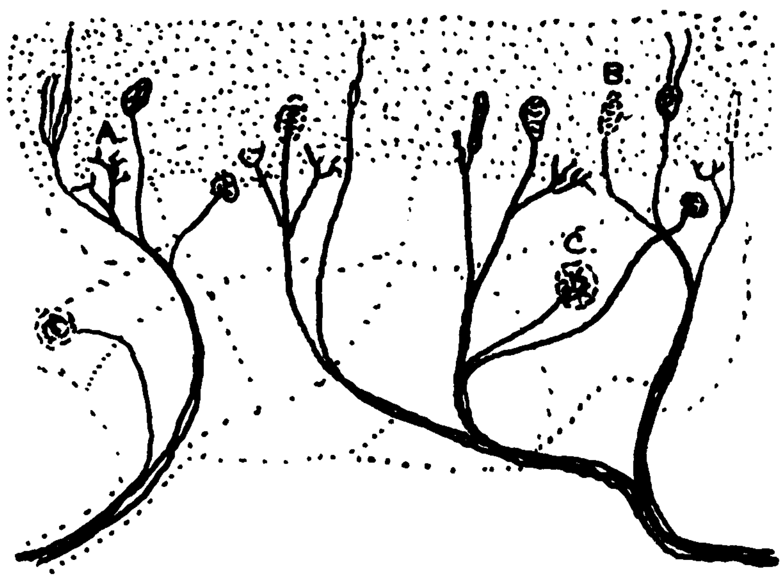


Figure 3

Schematic of a Section Through the Gingiva

Illustrating the Types of Nerve Endings,

Some of Which Are:

A. Free Nerve Endings

B. Capsulated Meissner Corpuscle

C. Krause Bulbs

Source: Bosma, p. 6.

from skin to cortex. Goldscheider reversed his position on pain, however, He held that pain had no separate receptors in the skin but was the result of the summation of pressure or thermal excitations which stimulated in addition to their proper tracts, the pain tract in the spinal cord and brain. Henry Head, writing in 1905 and 1908, described three different neural systems: Deep Sensibility, not disturbed by section of a cutaneous nerve; Protopathic Sensibility, a primitive diffuse cutaneous system, the first to return after section; and Epicritic, the most discriminate system.

By 1900, there was an increasing interest in the interdependence of the senses. Bently synthesized wet by using pressure and cold.[1] Titchener tried to separate perception (what an object felt like) from sensation (what the skin felt like), and he divided touch into pressure, warmth, cold, pain, and kinesthesia. By this time, 1959, perceptions were thought to be complex temporal-spatial patterns of the basic qualities.[2] Weddell had written in 1941 that cutaneous sensibility was a spatially and temporally dispersed pattern of impulses, a concept completely upsetting the specific nerve theory.[3] The

---

[1] Boring, op. cit.

[2] E. B. Titchener, A Textbook of Psychology, 1959.

[3] G. Weddell, "The Pattern of Cutaneous Innervation in Relation to Cutaneous Sensibility," J. Anat., 75, 1941, 346-367.

current theory is expressed by Melzack and Wall. Receptors are thought to be specialized to carry particular kinds and ranges of stimuli into nerve impulse patterns rather than modality specific information.[1]

It can thus be seen that theories on the nature of somatic sensation have evolved from a general concept of touch to detailed theories on specific kinds of stimuli which activate specialized nerve endings. The impulses sent from these end organs are thought to form spatial and temporal patterns which are perceived as a certain sensation.

C. Anatomy and Physiology

This section of the paper will detail the anatomy of the tongue, the nerve endings for taction and taste, the question of the receptors for kinesthesis, the innervation as it leads to the cortex, and some information on cortical representation of somatic perception.

The human tongue is divided by the sulcus terminalis into roughly the posterior 1/3rd and the anterior 2/3rds of the tongue body. There is a large body of connective tissue,

---

[1] Melzack and Wall, "On the Nature of Cutaneous Sensory Mechanisms," Brain 85, Part II, 1962, 331-356.

stroma, in adult tongues which separates the muscles, is the source of attachment for muscles, and contains most of the nerves. The Lamina propria gets thicker on the dorsum as it extends from the root to the anterior arch.[1] The tongue is fastened posteriorly to the hyoid bone, epiglottis, soft palate, and the pharynx. It is free anteriorly, laterally, and dorsally. The extrinsic muscles include the genio-glossus, the posterior fibers of which are thought to draw the root of the tongue anteriorly to protrude the apex. The anterior fibers retract the tongue, and the whole muscle can make the tongue concave as for sucking. The styloglossus is thought to move the tongue up and back, while the hyoglossus moves it back and down.

The intrinsic muscles include the superior longitudinal muscle which shortens the tongue and which may turn the tip and side margins up to groove the tongue. The inferior longitudinal muscles running from the root to the apex somewhat laterally, shorten the tongue or may pull the tip downward. The transverse muscles narrow and elongate the tongue. They arise from the median septum and go to the lateral margins.

---

[1]S. Adb-el-Malek, "Observations on the Morphology of the Human Tongue," _J. Anat. Lond._, 73, 1939, 201-210.

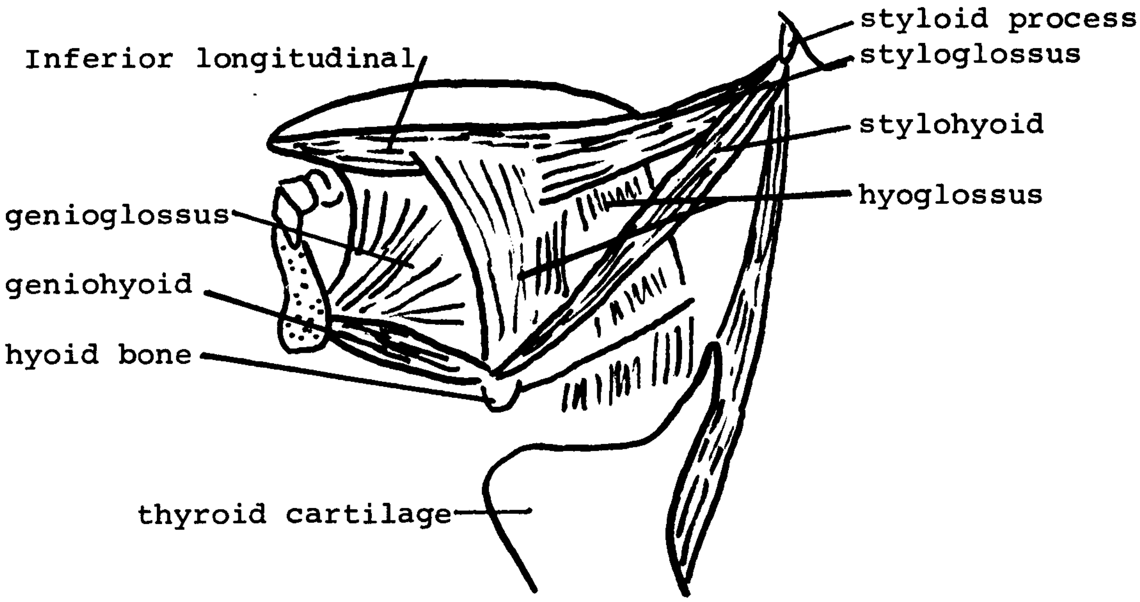


Figure 4

Schematic

Source: Zemlin, p. 281.

The vertical muscles are mostly in the anterior part of the tongue. They run from the dorsum to the inferior surface of the tongue and serve to flatten it.[1]

The complexity of the muscular arrangement, with fibers from one muscle coursing along with and across fibers from a another, combined with high innervation and unknown sensory

---

[1]H. Gray, The Anatomy of the Human Body, 28th ed., ed. C. M. Goss, (Philadelphia: Lea and Febiger, 1966).

and motor processes account for the amazingly rapid sequences of tongue configurations and positions. The muscles do not perform simple ballistic movements but seem to perform complex patterns of finely graded changes, some muscles working together, others opposing the movements.

2. Nerve Endings

The dorsal surface of the tongue is provided with more sensory fibers than any other part of the body.[1] The surface is rough due to papillae. Each papilla has nerve endings. The filiform, small coned-shaped type is most numerous. The fungiform, mushroom-shaped type contain taste buds. Under the lamina propria there are capsulated and uncapsulated endings. Some of the large glomerular terminations near the tip of the tongue are similar to genital nerve bodies.[2] Above them in the lamina propria there are smaller capsulated and uncapsulated glomerular endings. There are fibrillar extentions from the uncapsulated endings which extend to the most superficial epithelial layers. There are extremely complex nerve plexes

---

[1]S. Kamada, "Sensory Innervation of Mucous Membrane of the Oral Cavity of a Cat," Arch. Hist. Jap. 8, 1955, 243-260.

[2]H. Seto, Studies on the Sensory Innervation, 2nd ed., (Springfield, Ill.: Charles C. Thomas,

both superficial and deep. The nerve endings are most numerous in the anterior region of the dorsum.[1] The inferior surface of the tongue has well developed sensory terminations especially in the lateral margins and in the medial portion, but it is less dense than the dorsum.

These nerve endings, which Sherrington named exteroceptors, carry information which is ultimately perceived as touch or taste.

The other aspect of oral sensation, that of kinesthesis, a sense of movement and position, is much less clear. In most body movements, the kinesthetic sense is received from joint receptor organs. The stretch receptors in muscles, the spindles, act together with tendon receptors which register muscle pull to maintain the tonus. The pickup of bone angles, however, is done by joint receptors which fire at a given rate for a given angle and which change when the angle changes.[2] Sensitivity at joints is carried by Pacinian corpuscles in the tissue around the joints. The sensory endings at the tendons

---

[1] R. C. Grossman and B. F. Hattis, "Oral Mucosal Sensory Innervation and Sensory Experience: A Review," in Symposium on Oral Sensation and Perception, J. F. Bosma, ed. (Charles C. Thomas, Springfield, Ill., 1967), 5-62.

[2] J. E. Rose and V. B. Mountcastle, "Touch and Kinesthesis," Chapt. 17 in Handbook of Physiology, Vol. I, Amer. Physiol. Soc., 1959.

are spirals called Golgi tendon organs which respond to the contraction of the attached muscle. Muscle spindles, however, do not respond to contraction but are stimulated by muscle stretch which occurs when the muscle relaxes upon the contraction of its antagonist.[1]

The big question about sense organs in the tongue is "are there muscle spindles in the tongue?" The controversy has been going on for seventy years. The main proponent for the existence of muscle spindles in the tongue is Sybil Cooper. She claimed to have found cross sections of them in the superior longitudinal muscle and longitudinal sections of them in the transverse muscle. They are reported to be especially prominent near the midline of the superior longitudinal in a region proximal to the tip, in the most flexible part of the tongue. The muscle spindles were present in man and in the monkey but not in lambs or cats.[2]

Sigfrid Blom, however, is representative of a group of researchers who have concluded that muscle spindles seem to be absent from the tongue. His work seems to have been

---

[1] L. J. Jenkins, "Somesthesis," Chap. 30 in Handbook of Experimental Psychology, ed. S. S. Stevens (New York: John Wiley & Sons, 1966).

[2] S. Cooper, "Muscle Spindles in the Intrinsic Muscles of the Human Tongue," J. Physiol., 122, 1953, 193-202.

done exclusively with cats.[1] The possible existence of another sensory ending with the function of a stretch receptor has been suggested. Kawamura suggests that there must be some special sensory feedback system to manage tongue tonus and movement since the movements are so fine and skillful.[2]

The intrinsic tongue muscles and the extrinsic eye muscles are peculiar in not being associated with joint movements. They are both endowed with extremely sensitive exteroceptive systems, the retina and the tongue. It has been theorized that these systems may provide information which is used for kinesthesis in a manner similar to the way information from joints is provided by the Pacinian corpuscles.[3] Weddell and others have found what they believe to be sensory endings of a tension-recording type at the origin of the genioglossus in rats.[4]

---

[1] S. Blom, "Afferent Influences on Tongue Muscle Activity: A Morphological and Physiological Study in the Cat," Acta Physiol. Scand., 49, Suppl. 170, 1960, 1-97.

[2] Y. Kawamura, "Neuromuscular Mechanisms of Jaw and Tongue Movement," J. Amer. Dent. Assoc., 62, 1961, 545-551.

[3] Cooper, op. cit.

[4] G. Weddell, J. A. Harpman, D. G. Lambley and L. Young, "The Innervation of the Musculature of the Tongue," J. Anat., 74, 1940, 255-267.

3. Trigeminal Tract

Most of the extrinsic and intrinsic muscles of the tongue are innervated for motor movement by the Hypoglossal nerve XII. Although the innervation for kinesthesis from the tongue remains unclear, tactile sensation is carried by the lingual branch of the Trigeminal nerve V in the anterior 2/3rds of the tongue and by the Glossopharyngeal nerve IX in the posterior 1/3rd of the tongue. The Chorda Tympanic branch of the Facial nerve VII, the Glossopharynegus IX, and the Vagus X carry impulses for taste. Abd-el-Melek does not mention the lingual nerve in his description of the tongue. Many anatomy and speech texts, such as Zemlin, detail the motor innervation of the tongue and remain vague about the sensory innervation.[1] This is probably due to some unanswered questions about sensory innervation of the tongue. The Hypoglossal nerve, for example, has been thought traditionally to be purely motor. Fitzgerald and Law, however, found connective fibers between the lingual and hypoglossal nerves. The connections in man are illustrated below. The connective fibers were unaffected if the lingual nerve was sectioned but not when the hypoglossal nerve was sectioned. This finding

---

[1]Zemlin, op. cit.

indicates that sensory fibers may exist in the hypoglossal nerve in addition to the motor fibers.[1]

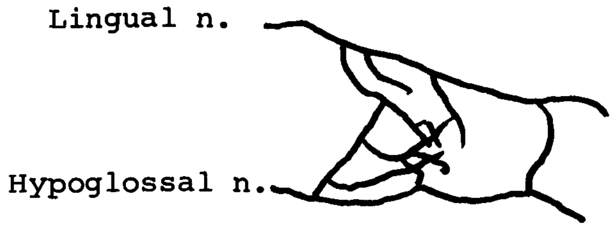


Figure 5

Source: Fitzgerald and Law, p. 180.

Blom maintains that the main afferent channels from the tongue are via the Lingual and Glossophyaryngeal nerves from the anterior 2/3rds and posterior 1/3rd of the tongue respectively. The Chorda Tympani shares by carrying information for taste. He confirms Fitzgerald and Law in the Lingual and Hypoglossal connections but observes that it is possible that the afferent components leave the Hypoglossal nerve and reach the central nervous system through some other nerve.

---

[1] M. J. T. Fitzgerald and M. E. Law, "The Peripheral Connections between the Lingual and Hypoglossal Nerves," J. Anat., 92, 1958, 178-188.

Contraction (elicited by shocking the Hypoglossal nerve), pressure, and touch on the anterior part of the tongue all produced activity in the Lingual nerve.[1]

The nerve endings of the ascending tract of the Trigeminal nerve are indicated in Figure 6. The nerve endings are chosen to represent a variety of receptors. The free terminals marked A are presumed for pain, the Merkel disks for gross tactile sense, and the Meissner's corpuscles for fine tactile sense. The superior, middle, and inferior cerebellar peduncles are indicated by S, M, and I.[2]

The Trigeminal nerve is the largest of the cranial nerves. It emerges from the side of the pons with a large sensory root and a smaller motor root.

The sensory root emerging from the Semilunar or Gasserian Ganglion is in the form of three large branch nerves, of which the Mandibular is the largest. The Mandibular nerve branches further. One branch, the Lingual nerve, is sensory from the anterior two-thirds of the tongue and the mucous membrane of the mouth and gums.[3] Another branch of

---

[1]Blom, op. cit.

[2]E. C. Crosby, T. Humphrey and E. W. Lauer, Correlative Anatomy of the Nervous System (New York: MacMillan Co., 1962), p. 176.

[3]W. R. Zemlin, Speech and Hearing Science: Anatomy and Physiology (Englewood Cliffs: Prentice-Hall, 1968), pp. 485-487.

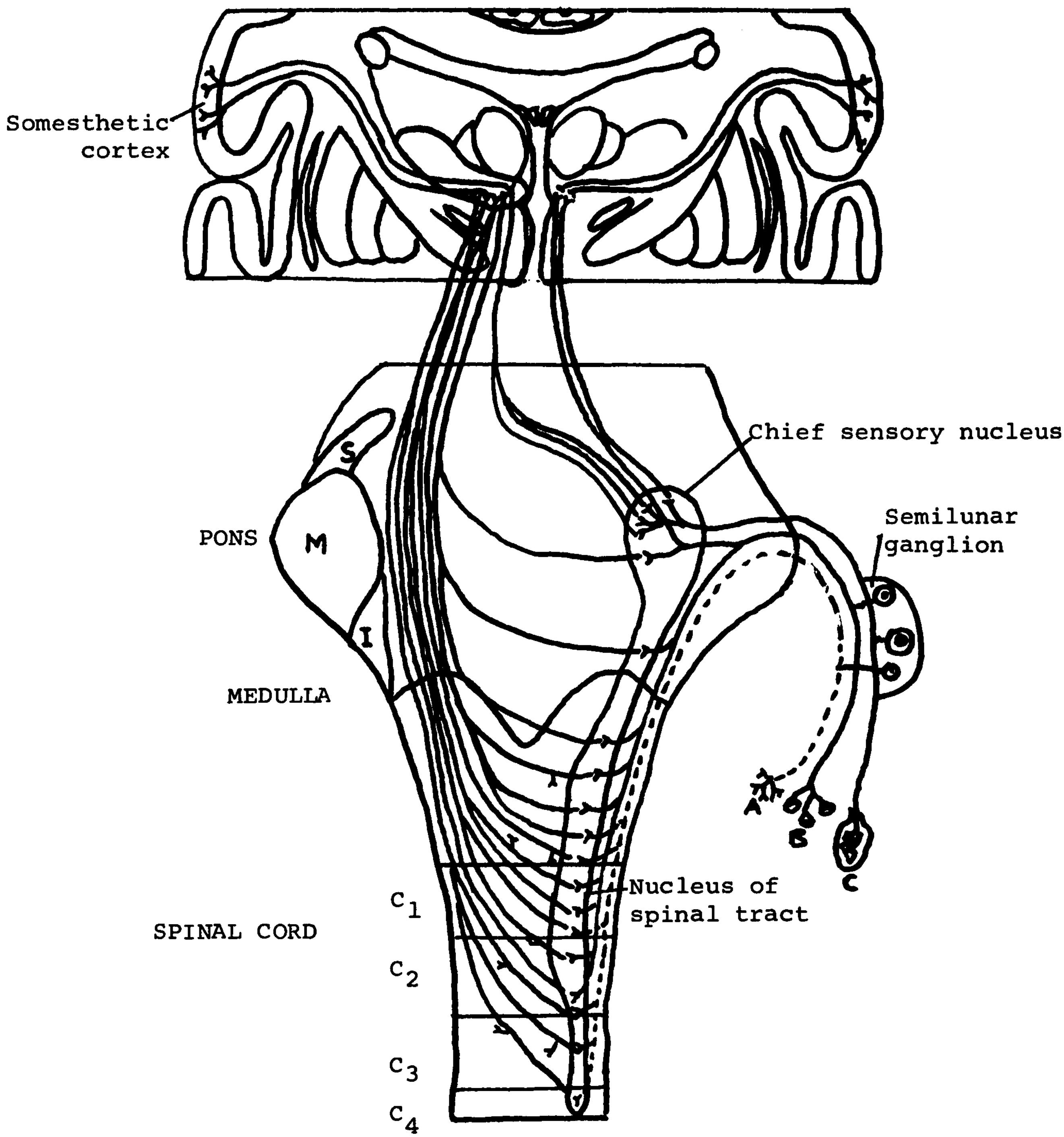


Figure 6

Schematic of Ascending Fibers of Trigeminal Nerve

Source: Crosby p. 176.

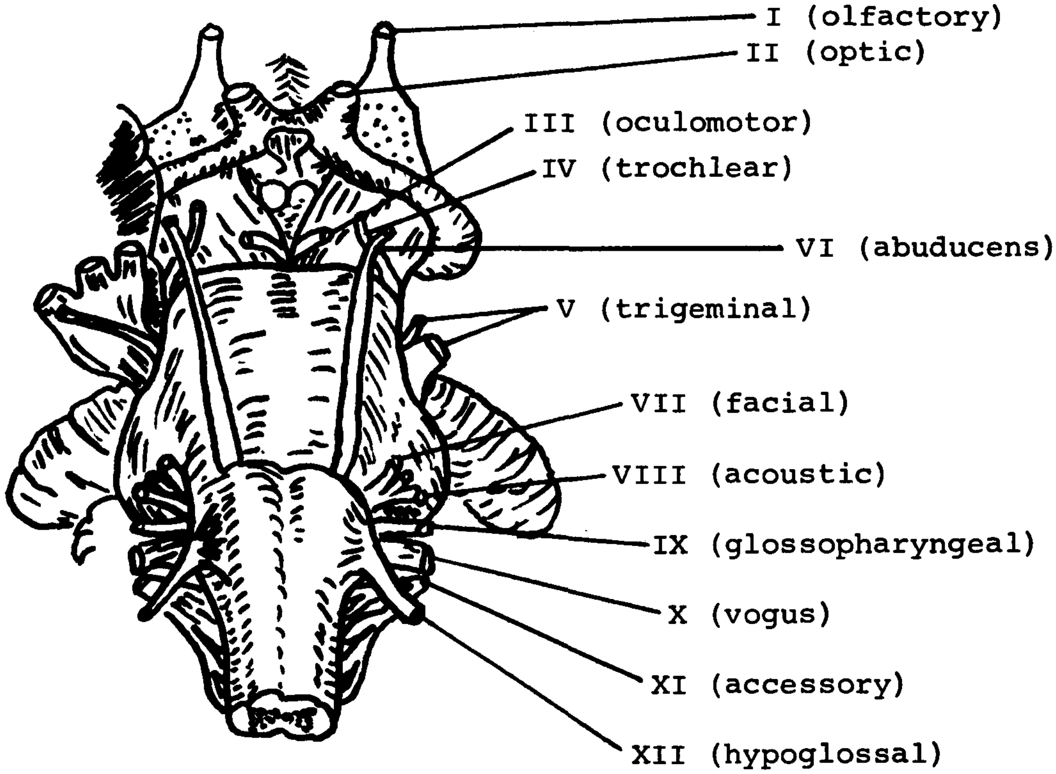


Figure 7

Emergence of the Cranial Nerves from the Base of the Brain

Source: Zemlin p. 482.

the Mandibular nerve, the Inferior Alveolar nerve, is sensory to the teeth and gums of the mandible and includes fibers which branch out into the Mylohyoid nerve, the only motor branch of the inferior alveolar nerve, innervating the Mylohyoid muscle and the anterior belly of the Digastric.[1]

[1] Charles Noback, Personal Correspondence, 1970.

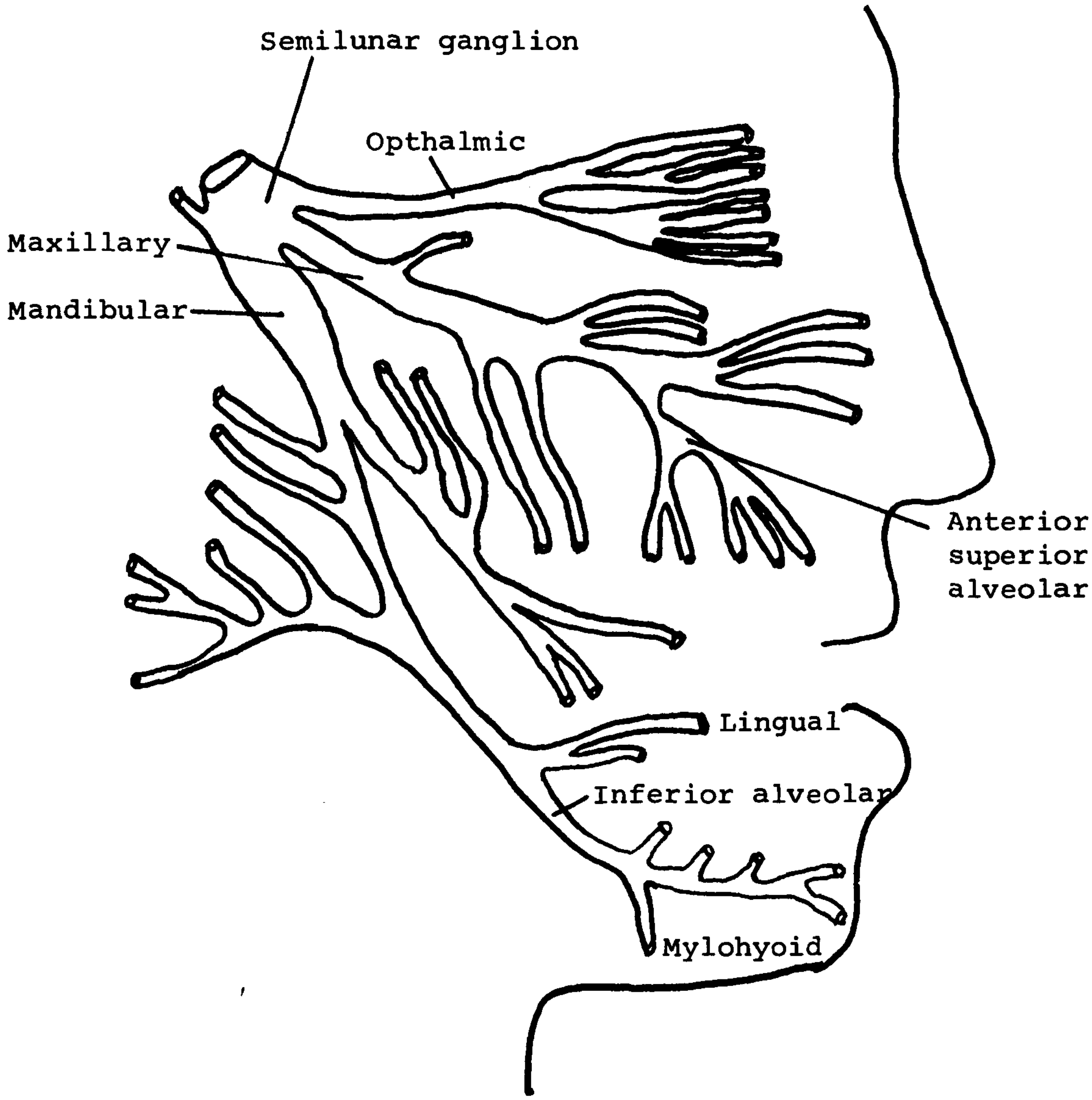


Figure 8

Schematic of the Distribution of the

Trigeminal Nerve

Source: Zemlin, p. 485.

Of all the areas innervated by the Trigeminal nerve, the perioral and intraoral is by far the most richly innervated. Following the tract from the Semilunar Ganglion up to the cortex, the sensory fibers pass into the Pons and terminate in the Sensory Nuclei V (Figure 9). Cooper suggests that the

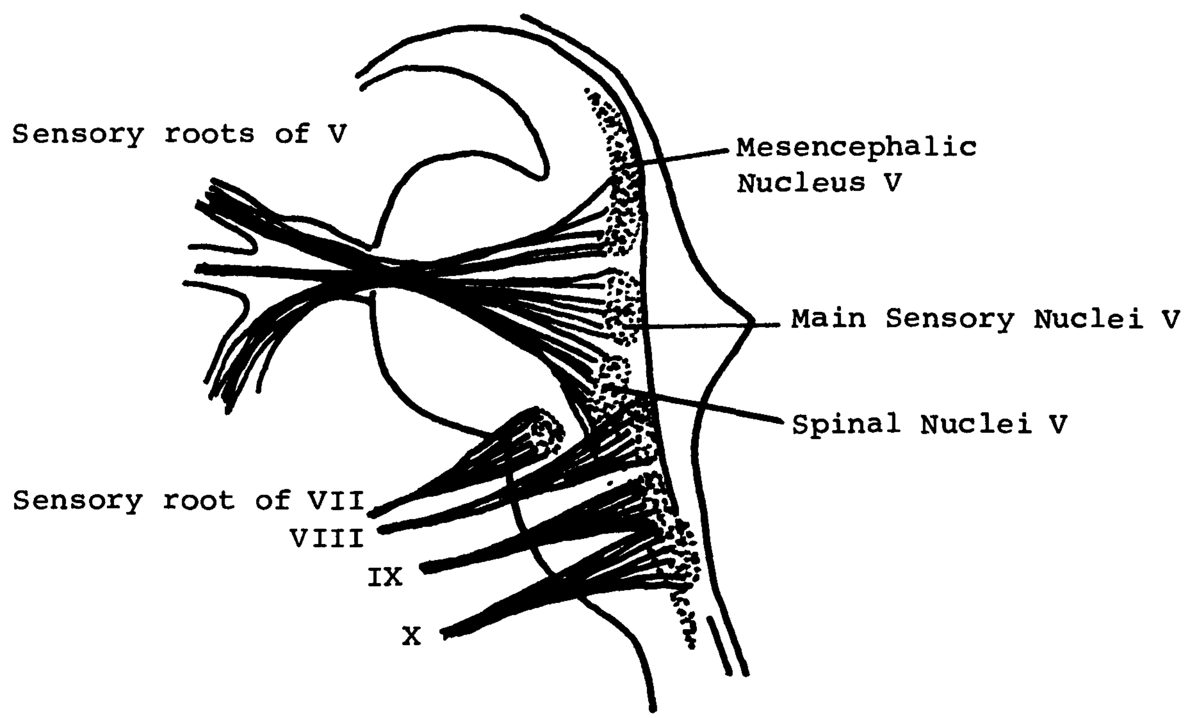


Figure 9

Schematic of the Terminal Nuclei of

Some Afferent Cranial Nerves

Source: Zemlin, p. 475. Nuclei named from Jerge, p. 48.

muscle spindles send impulses to the brain stem and spinal cord coordinating centers which send back motor impulses in a reflex arc. The stimuli from touch receptors, in contrast, are sent to the relay nuclei, the Spinal and Main Sensory nuclei, which relay them to higher centers for conscious perception.[1] She means that the spindle afferents would go to the Mesencephalic nucleus which is not a relay nucleus but is known to be associated with masticatory reflexes.

All subdivisions of the Spinal Nucleus send a crossed projection to the Thalamus. Only some subnucleus fibers go uncrossed to the Thalamus. The functional significance of this is not known. The same is true of the tracts coming from the Main Sensory Nucleus, but the oral sensory tracts appear to ascend via an ipsilateral tract.[2]

4. The Cortex

Penfield elicited somatic perception in sixty-nine patients with one hundred and forty-two cortical stimulations. Sixty-seven were contralateral, six were midline or bilateral,

---

[1] Cooper, <u>op. cit</u>.

[2] C. R. Jerge, "The Neural Substratum of Oral Sensation " in <u>Symposium on Oral Sensation and Perception</u>, <u>op. cit</u>., 63-83.

one was ipsilateral, and the rest were unknown. Not all of the points of stimulation were postcentral. One hundred and twenty-two were postcentral, and twenty were precentral.[1] Note the large number of stimulations resulting in tongue sensation in Figure 10.

A single peripheral spot can activate a multitude of cortical cells. The denser the innervation in the peripheral part, the smaller the cutaneous field that plays upon the cortical cells related to it. There is a reciprocal conversion from the cortex to the periphery. For example, there is a peripheral spot which may maximally activate a cortical spot but surrounding areas of periphery also activate that cortical spot.

Again there is the question, are the afferents mode specific? Mountcastle is uncertain about the smaller afferents, but states that the endings of myelinated afferents may be sensitive to different stimuli, even though the end organs may appear to be morphologically similar.[2] The lemniscal system is felt to be mode specific and the spino-thalamic system diffuse.

---

[1] W. Penfield and T. Rasmussen, <u>The Cerebral Cortex of Man</u> (New York: MacMillan, 1952), pp. 38-39.

[2] V. B. Mountcastle, "Some Functional Properties of the Somatic Afferent System," in <u>Sensory Communication</u>, W. A. Rosenblith, ed. (New York: John Wiley and Sons, Inc., and M.I.T. Press, 1961), pp. 403-436.

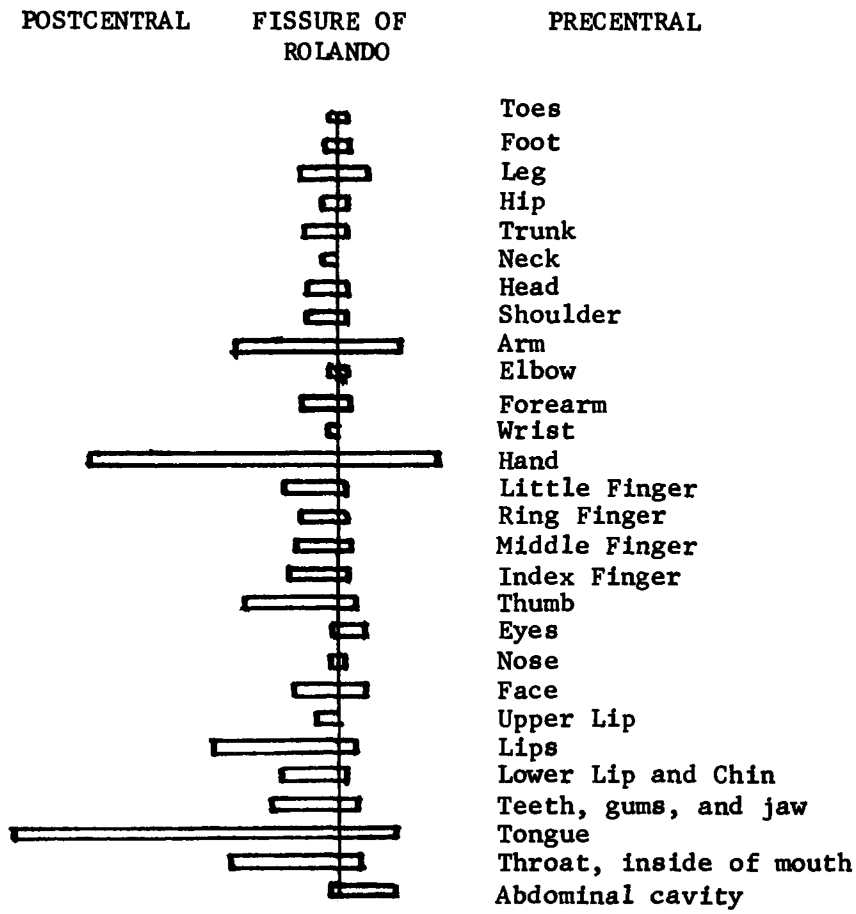


Figure 10

Sensory Sequence Chart of the Right Hemisphere

The solid vertical line represents the central fissure, extending from the mesial surface of the hemisphere above to the Sylvian fissure below.

The horizontal bars represent the proportional number of responses elicited anterior and posterior to the central fissure.

Source: Penfield, p. 22.

5. Conclusion

Developing from a simple view of sensation as a receptor to cortex relay of a specific sensation, the process now seems much more complex, with overlapping functions of end-organs, divergent pathways of fibers, a possible shift to a temporal-spatial pattern eliciting the perception, and much confusion about the interaction between the sensory and motor impulses. This complexity seems closer to reality than the simple concept. The unanswered questions are numerous. Are there muscle spindles in the tongue? Are there afferent components in the Hypoglossal nerve? Does the Mesencephalic nucleus play a part in oral sensations? Finally, what does our knowledge of anatomy and physiology teach us of oral sensation? The answer to the last question seems at present discouragingly negative, so we must turn to other ways of looking at oral sensation to gain more information.

D. Measurement of Oral Sensation

There are two ways of looking at lingual sensation, specifically, taction and kinesthesis. One way is to measure it by tests of localization, two-point discrimination, or form identification called oral stereognosis. The second approach is to study the effects of its deprivation, either pathological as in reported cases of sensory dysarthria, or experimental by anesthetizing the sensory nerves.

In 1852, Weber found that localization and two-point limen errors vary with body region. The errors of localization were larger than the errors of two-point limen.[1] Weber's theory was that the sensory circles around each stimulated point were separated by an area of unexcited fibers, accounting for the two-point perception. Recent theory (Mountcastle) holds that when certain cells are excited, other cells around the site of stimulation are simultaneously inhibited.[2]

Ringel and Ewanowski found a progression from maximal to minimal discriminatory ability to go from tongue tip, finger tip, upper lip, soft palate, and thenar eminence of right hand, in that order. The subjects were 25 adults. The mean limen values were 1.7mm for midline tongue tip, 1.72mm for right tongue tip, and 1.82mm for left tongue tip. This finding of a smaller limen value at the midline than in lateral positions applied to all of the structures tested.[3] The tip and anterior

---

[1] Boring, op. cit.

[2] Mountcastle, op. cit.

[3] R. L. Ringel and S. J. Ewanowski, "Oral Perception: I. Two-Point Discrimination," JSHR 8, 1965, 389-398.

of the dorsum normally have a two-point limen varying from 1 to 3mm. The lateral margins of the tongue and the posterior section require 1cm separation for the discrimination of two points.[1] Light touch and two-point discrimination are reported to be less sensitive in children than in adults.[2] Higher thresholds have also been found in subjects with dysarthria and muscular dystrophy.[3]

The classic instrument for measurement of sensation was a nylon filament aesthesiometer (Shaw Laboratories, Syosset, N.Y.) with which the force was controlled by pressing them to a just noticeable bend. This instrument was used in localization studies, but it was too difficult to use two instruments at the same time to obtain two-point data. A more sophisticated instrument, a dynamometer (Scherr-Tumier) indicates on a dial the force of tissue contact and two tips are mounted to touch a specified distance apart.[4] The development of an instrument, an esthesiometer, designed specifically to measure two-point

---

[1] R. C. Grossman, "Methods for Evaluating Oral Surface Sensation," J. Dent. Res., 43, 1964, p. 301.

[2] R. I. Henkin and V. Banks, "Tactile Perception on the Tongue, Palate, and the Hand of Normal Man," in Bosma, op. cit.

[3] R. L. Ringel, "Oral Region Two-Point Discrimination in Normal and Myopathic Subjects." Paper given at 1967 Symposium on Oral Sensation and Perception, Bethesda, Md., Nov. 20-22.

[4] Bosma, op. cit. pp. 162, 166.

discrimination within the oral cavity was recently reported by Ringel.[1]

Another method of measuring oral sensitivity is to test oral stereognosis. Forms are inserted one at a time into the subject's mouth without his seeing them. The subject feels each form and selects the shape from an answer sheet which pictures the objects. Perception of the forms seems normally to depend upon manipulation by the front of the tongue. When wax is put between the teeth and the lips, subjects can identify with the tongue a mean of 20.8 of 25 forms correctly, whereas with the lips they can only identify 14.3.[2] Covering the palate with wax had no effect on form identification.[3]

The effect of anesthesia on oral stereognosis of 20 forms was studied using 30 normal adults as subjects. Without anesthesia, the mean was 15.6. There was little effect if the mandibular block was unilateral (15.1), presumably because the other part of the anterior 2/3rds of the tongue could feel the

---

[1] R. Ringel, "Oral Region Two-Point Discrimination," Second Symposium on Oral Sensation and Perception, J. F. Bosma, ed., (Springfield, Ill.: Charles C. Thomas, 1970), pp. 309-319.

[2] P. B. Hollongsworth, "A Study of Form Identification on the Tongue and Lips of Young Adults," Unpub. M.Ed. Res. Project, Penn. State, August 1964.

[3] B. A. Mihacs, "Effect of Covering the Palate on Identification of Forms in the Oral Cavity," Unpub. M.Ed. Project, Penn State, August 1964.

shapes. When the block was bilateral the mean dropped to 12.5 with a range of 4 to 17. Those who were successful reported that they had to shift to the posterior part of the tongue and use deep pressure.[1]

Oral stereognosis is reported to improve as a function of age until the midteens.[2] Many attempts have been made to explore the relationship between oral stereognosis and speech performance. A relationship was found between ratings on chewing, drinking, and the Templin-Darley articulation score in athetoid children and adults and their oral stereognosis ability.[3] In another study, subjects with cerebral palsy were found to be worse in oral stereognosis than subjects who stuttered or had articulation defects. Both of these groups were inferior, in turn, to the subjects with normal speech.[4]

---

[1] R. M. Mason, "Studies of Oral Perception Involving Subjects with Alterations in Anatomy and Physiology," in _Symposium on Oral Sensation and Perception_, _op. cit_., pp. 294-301.

[2] E. T. McDonald and L. F. Aungst, "Studies in Oral Sensorimotor Function," _Ibid_., pp. 202-220.

[3] B. Solomon, "The Relation of Oral Sensation and Perception to Chewing, Drinking, and Articulation in Athetoid Children and Adults," Unpub. doctoral dissertation, Penn. State University, 1965.

[4] L. Class, "A Comparative Study of Normal Speakers and Speech Defectives with Regard to the Tactual-Kinesthetic Perception of Form with the Tongue," Unpub. Master's thesis, Ohio State University, 1956.

Subjects with cleft palate, however, scored normally on a test of form identification.[1]

Among normal subjects, there seems to be very little relationship between this ability and articulation at ages 5 and 6. A 25 item oral stereognosis test was given to 40 kindergarten and 40 first grade children. These children were also given a global articulation rating by four judges and were tested on /s/, /r/, /l/, and/θ/ with the McDonald test. There was only a slight association, with /θ/ showing the closest relationship.[2] A further report on 50 children from kindergarten through third grade showed a lack of correlation between a 10 item oral stereognosis test and an articulation test of VCCV combinations.[3]

To offset this lack of correlation between oral stereognosis and articulatory ability, preliminary work is being done with a form discrimination test, in which the subjects must

---

[1]Mason, op. cit.

[2]L. F. Aungst, "The Relationship between Oral Stereognosis and Articulation Proficiency," Doctoral dissertation, Penn. State University, 1965.

[3]E. T. McDonald and L. F. Aungst, "Apparent Independence of Oral Sensory Functions and Articulation Proficiency," Second Symposium on Oral Sensation and Perception, op. cit., pp. 391-395.

merely respond "same" or "different." This test has shown a relationship between this ability and the articulatory ability of 60 elementary school children.[1] There was also some relationship found between oral stereognosis ability and the ability to learn new phonemes, /œ/, /ç/, and /x/. The subjects were 76 children, 6 to 8 years old, from which the 10 with the highest oral stereognosis score and 10 with the lowest score were chosen. The relationship was found between this ability and the learning of the two consonants.[2]

Additional evidence of moment by moment feedback operating in the learning of a new task is provided by Sussman who demonstrated that subjects needed oral sensation to better track an auditory signal with the tongue.[3]

It may be that oral stereognosis tests and two-point discrimination tests are not testing the pattern of factors crucial to well learned, rapid, and skillful articulation. None of these tests require temporal processing as well as

---

[1] R. Ringel, _et al_., "Orosensory Discrimination and Articulation," _J. Speech Hear. Dis_., 35, 1969, pp. 3-11.

[2] J. L. Locke, "Oral Perception and Articulation Learning," _Perceptual and Motor Skills_, 26, Part 2, 1968, pp. 1259-1264.

[3] H. M. Sussman, "The Laterality Effect in Lingual-Auditory Tracking," Ph.D. dissertation, University of Wisconsin, 1971.

spatial. Also they do not test the ability to judge the movement and position of the tongue itself.

E. Effects of Sensory Deprivation

1. Pathological Deprivation

One way to explore the nature of oral sensation is to study subjects in which an oral sensory deficit is pathological. Chase presented a case study of a seventeen year old girl with reportedly normal motor development and hearing. She had trouble swallowing, chewing, and speaking. Most of her speech consisted of vowels. A neurological exam revealed dull sensation from pin prick on her face and in her mouth. There was no deep pressure sensation in the mouth, no ability to protrude or lateralize the tongue, and no gag reflex.[1] This case was used to demonstrate the interrelationships between sensory and motor functions. Tests on the same girl performed at Haskins Laboratories revealed that perception of speech was within normal limits. Electromyography revealed her inability to differentiate muscles. She demonstrated a massive contraction over a large area. A phonetic evaluation

---

[1]R. A. Chase, "Abnormalities in Motor Control Secondary to Congenital Sensory Deficits," in Symposium on Oral Sensation and Perception, op. cit., pp. 302-309.

showed voiceless stops but no voiced stops, incorrect voiced fricatives, and her usual speech was limited to vowels, diphthongs, glottal stops, and prosodic features.[1] There was insufficient evidence that motor damage to the oral area might not have been a contributing factor. In contrast, McDonald and Aungst wrote of a 21 year old male congenital spastic quadriplegic with good articulation despite poor oral stereognosis, poor two-point discrimination, and difficulty in voluntary tongue movements.[2] Thus it can be seen that it is difficult to obtain specific information on the relationship between oral sensation and speech from clinical cases with multiple handicaps.

2. Experimental Deprivation

Possibly the most productive method of studying the relationship between sensory feedback from the oral area and articulation is to block the sensory nerves of normal speakers with anesthesia.

It has been a long observed fact that when one comes

---

[1] P. MacNeilage, T. P. Rootes and R. A. Chase, "Speech Production and Perception in a Patient with Severe Impairment of Somesthetic Perception and Motor Control," J. Speech Hear. Res., 10, 1967, 449-467.

[2] E. T. McDonald and L. F. Aungst, op. cit., p. 391.

from the dentist's office there is often a disturbance of clearly articulated speech until the effect of the anesthesia has disappeared. This dental effect suggested a means of testing hypotheses regarding the role of feedback in speech and prompted the series of studies which will be reviewed in this section of the paper.

McCroskey was the first to report that blocking oral sensation had an adverse effect on articulation. The effects of four treatments on the speech of 6 speakers reading three lists were reported. Each list of 24 words comprised a multiple-choice intelligibility test. The four treatments were normal, .18 delayed auditory feedback, nerve block, and combination DAF and Nerve block. The block involved bilateral mandibular and intraorbital injections. The tapes of the 6 subjects were heard by listeners who judged and counted errors in articulation. The decrease in the mean number of words articulated correctly is of interest. Under the normal condition the mean was 131, under DAF 127.3, under nerve block 115, and with DAF added to the nerve blocks the mean was 113.33. The chief effect of altering auditory feedback was to increase duration, whereas the chief effect of interfering with kinesthetic feedback was to decrease the number of correctly articulated words.[1]

The effect on articulation of this sensory loss was interesting but there was no information about the effect on manner or place of articulation since all of the judgments were simple right or wrong values. The same tapes were, therefore, used for a second experiment. The tapes of the six speakers under the conditions of normal and nerve block were presented to two judges who made phonetic transcriptions. Substitution and distortion errors were reported to be prominent. The authors said very little, however, about the particular phonemes affected.[2]

In a third study, published in 1963, Ringel and Steer confirmed the findings of McCroskey. They studied the effect of six treatments on the average peak level, the articulation, the fundamental frequency, and the speech duration. The six treatments were normal, 94 dB white masking noise, topical spray anesthesia, McCroskey's nerve blocks, auditory masking with topical spray anesthesia, and auditory masking with nerve

---

[1] R. McCroskey, "The Relative Contribution of Auditory and Tactile Clues to Certain Aspects of Speech," Southern Speech J., 24, 1958, 80-94.

[2] R. McCroskey, N. Corley and G. Jackson, "Some Effects of Disrupted Tactile Cues upon the Production of Consonants," Southern Speech J., 25, 1959, 55-60.

blocks. The subjects were 13 young adults. Four experienced judges listened to the tape recordings and indicated the number of deviations on a prepared evaluation sheet. The results confirmed that phonation time ratio and mean syllable duration are increased when the auditory feedback is eliminated. The main effect of the nerve block was to increase the number of judged errors in articulation. Out of an unstated number of possible errors, the mean number of errors was 4.7 under normal speaking conditions, 6.9 with auditory masking, 6.5 with topical anesthesia, 23.1 with nerve blocks, 10.5 with topical anesthesia and auditory masking, and 24.4 under nerve blocks combined with auditory masking. The significant effect occurred during the condition of nerve block with very little additional deterioration upon the addition of auditory masking.[1]

Investigators have warned of the questionability of viewing kinesthetic feedback as the sole contributor to the articulatory impairment demonstrated under nerve block.[2] The fourth study to be considered, therefore, was the first to test the technique of experimental deprivation to see if it really

---

[1] R. L. Ringel and M. D. Steer, "Some Effects of Tactile and Auditory Alterations on Speech Output," J. Speech Hear. Res., 6, 1963, 369-378.

[2] J. L. Locke, "Letters to the Editor," J. Speech. Hear. Res., 11, 1968, 668-669.

does eliminate oral sensation without affecting the motor ability as had been previously assumed. Schliesser and Coleman recorded five male subjects reading 42 sentences under conditions of nerve block with masking, nerve block alone, masking alone, and normal. The anesthesia included bilateral mandibular blocks and topical anesthetic on the anterior hard palate. The auditory masking was mixed white and sawtooth noise with the sawtooth 10dB more intense. The subjects monitored themselves on the VU meter. Several additional tests were administered to the subjects both with and without anesthesia. The tests included one of oral stereognosis, a test of mobility requiring /mʌ/, /dʌ/, /gʌ/, and /pʌtʌkʌ/, each produced as fast as possible for three trials of 10 seconds each, and finally, the subjects were tested on a non-speech activity: tongue lateralization. Articulation judgments were made on 15 second segments, the samples rated relative to a standard.

The authors conclude from the study that there is a complete elimination of sensation in the tongue and very little interference if any of the motor innervation. There was 100% identification of the 10 shapes in normal condition and only 10% after the nerve block. On the tests of tongue mobility and lateralization, there was no statistically significant difference found between the mean rates under normal condition and under the anesthesia condition. The articulation was judged to be within acceptable limits and was judged in the most distorted samples to approximate a "moderate" speech problem. The point was made that the effects of the nerve blocks are slight and do not dramatically alter intelligibility as a reader of previous studies might have assumed.[1] It was not possible to specify the effects on specific phones in any of these studies.

Several investigators interested by the McCrosky study and the Ringel and Steer study attempted to further specify the effects of the nerve block. Work was being done on this subject somewhat concurrently by Gammon, Smith, Daniloff, and Kim working together,[2] by Scott,[3] and by the author. Gammon sought to specify the degree of misarticulation under anesthesia and to study the effects upon stress and juncture patterns. A prose passage for phonetic analysis was read by the subjects

---

[1] H. F. Schliesser and R. O. Coleman, "Effectiveness of Certain Procedures of Alteration of Auditory and Oral Tactile Sensation for Speech," Percept. Motor Skills, 26, 1968, 275-281.

[2] S. A. Gammon, P. J. Smith, R. G. Daniloff and C. W. Kim, "Articulation and Stress/Juncture Production under Oral Anesthetization and Masking," J. Speech Hear. Res., 14, 1971, 271-282.

[3] C. M. Scott, "A Phonetic Analysis of the Effects of Oral Sensory Deprivation," Ph.D. thesis, Purdue University, 1970.

in addition to 30 sentences paired according to juncture differences (e.g., "redcoat" and "red coat") or according to stress differences (e.g., "impact" and "impact"). The results were that there was a 20% rate of misarticulation, especially involving fricatives and affricates. The errors were most prominent in the labial and alveolar regions. They found substitutions of plosives for fricatives, and bilabials became labiodentals. Stress and juncture patterns, however, were correctly produced under nerve block.

Scott investigated in detail the phonetic changes brought about by oral anesthesia. The analysis was made on speech samples of two adult males under normal and nerve block conditions. The material included 24 spondees and some vowels, stops, and fricatives in neutral phonetic settings. The nerve blocks were more extensive than those previously undertaken, including bilateral mandibular, bilateral infraorbital, medial nasopalatine, and bilateral posterior palatine blocks. The analysis of the data involved intraoral air pressure measurements, spectographic analysis, and narrow phonetic transcription. The results indicated subtle changes in articulation under nerve block, the consonants always retaining, however, their intended manner of articulation. The distortions included less close sibilant production, retracted place of articulation among stops and fricatives, a slower release of the voiceless stops (there were no voiced stops), a non-reflexion of /r/ and consonant /r/, upper lip inactivity in bilabial stops, and less protrusion for /w/. The vowel production was perceived as normal, but spectographic measurements revealed a slight F2 lowering for /i/ and /u/ indicating some change in articulation.

A further comparison of the "sensory deprived" speakers with six dysarthric speakers uttering 11 spondee words revealed the speech of the two groups to be different. The dysarthrics most noticeably exhibited voice quality deviations and voicing confusions. This result indicates motor damage to the dysarthric group not suffered under nerve block conditions in the normal subjects. In addition, the dysarthric group tended to substitute stops for fricatives indicating a wider deviation from the intended target than that demonstrated by the anesthetized subjects.

The speech research on oral sensation is still in its infancy and several basic concepts remain unclear. There is some confusion in the literature between taction and kinesthesis. Using identical nerve blocks, one investigator designates the effect as tactile disruption while another investigator calls it interruption of kinesthetic feedback. It is true that the physiological correlates of kinesthesis of the tongue remain unknown. When one loses the sense of position and movement of the tongue, however, that should be called a loss of kinesthesis. The loss of the sense of touch of teeth against tongue, tongue against palate, lip against lip, as examples, should be termed a loss of tactile sensitivity.

Another tendency in the speech literature as it relates to the research on oral anesthesia and speech is to generalize from the studies on adult speech to formulate ideas about feedback in speech in general. The subject of feedback in children learning speech should be kept quite separate from research done on adult speakers.

F. Statement of the Problem

Based upon the interesting results found by McCroskey and by Ringel and Steer, it was felt that it might be productive to further investigate the phonemes vulnerable to nerve block and to attempt to gather some information on the alteration of electrical potential in certain accessible tongue muscles.

In the early research on speech under oral anesthetization, there was little specific information on the nature of the speech effect as mentioned above. Since phonetic transcriptions had not been provided, it was difficult to imagine the distortions produced.

The possibility that the effect might be due to the influence of the anesthesia upon motor fibers to the muscles rather than sensory fibers has not been fully explored. The motor tests administered to the subjects have been the diadochokinetic test of the /pʌ tʌ kʌ/ variety which are possibly too easy to test for a breakdown of more precise motor adjustments. A more direct method of testing the possibility of motor involvement would be to record the electrical potential produced by muscular contractions under both normal and nerve block conditions.

An inherent variable in this method of research which has not been recognized in previous reports is the technique of injection of anesthesia. The critical injection as will be shown later is the mandibular block which produces the speech effect, the palatal blocks adding little if anything to the articulatory deterioration. Although there is only one injection on each side for this nerve block, there are two, sometimes three, individual nerves which are the targets. The technique has been to inject the solution at different depths to affect the buccal, lingual, and inferior alveolar branches respectively.

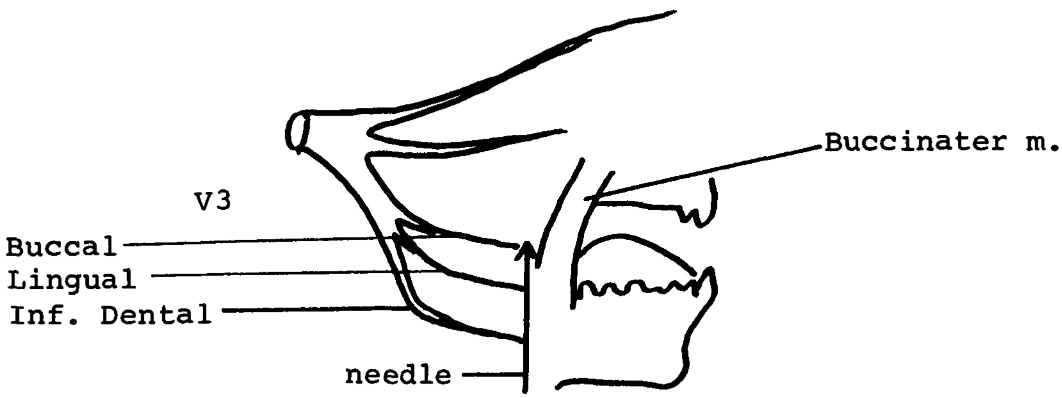


Figure 11

McCroskey's Method

Bilateral Mandibular Blocks; 1.5 cc used on each side; 2% Xylocaine. Three pairs of nerves (Buccal n., Lingual n., and Infer. Dental). Injection at mandibular foramen. The Buccal and Lingual nerves were anesthetized with same injection at three different depths of needle insertion (Lingual n., medial and anterior to the inferior alveolar at the level of the mandibular foramen, Buccal n. at apex of retromolar triangle.)

The primary target for dentists is the inferior alveolar as it is sensory to the teeth and gums of the mandible. For speech research the nerve of special interest is the lingual as it is sensory for 2/3rds of the tongue. It is possible, however, to attempt to inject the lingual nerve without infiltrating the inferior alveolar nerve. Since the motor fibers to the mylohyoid muscle and to the anterior belly of the digastric muscle are located in the alveolar nerve, it is not practically possible to anesthetize the inferior alveolar nerve without affecting the mylohyoid nerve. This variable turned out to be quite important in the results of the following studies.

The purpose of this investigation is to explore the effects of oral nerve blocks on certain extrinsic suprahyoid muscles of the tongue and on the speech performance of adult speakers. Is the effect upon speech slight or severe? What phonemes are distorted? Is the effect due to sensory loss, motor loss, or both? Which muscles are affected?

The investigation has three parts. A perceptual study of the speech of normal adult speakers with and without the nerve block is accompanied by two electromyographic studies of certain extrinsic tongue muscles and suprahyoid muscles in normal adult speakers with and without nerve block.

CHAPTER II

PERCEPTUAL STUDY

The purpose of the perceptual study was to investigate the nature of the effects of bilateral mandibular blocks upon the speech of normal speakers. Two pilot studies were necessary to develop an array of stimuli to elicit the desired speech samples to be tape recorded. The pilot studies are reported in the Appendix.

The subjects were 7 university students, all normal speakers of standard English. The recording was done in a quiet interior room at the University of Pennsylvania School of Dentistry. Each subject had two sessions. The conditions of normal and nerve block were rotated as far as possible. Each session consisted of the subject repeating 66 sentences after a recorded speaker heard through earphones from a second tape recorder.

The anesthesia was administered by a dentist using the standard dental technique for producing a mandibular nerve block, a procedure similar to that used by McCrosky and by

Ringel and Steer. The puncture was made at the apex of the pterygomandibular triangle which is about 7mm. above the occlusal surface of the teeth. (Figure 12) 2% Xylocaine was used. Half of the solution was deposited about halfway back toward the posterior wall of the mandibular sulcus. This usually anesthetizes the lingual nerve. When the needle reaches the ramus, the rest of the solution is deposited around the inferior alveolar nerve before it enters the

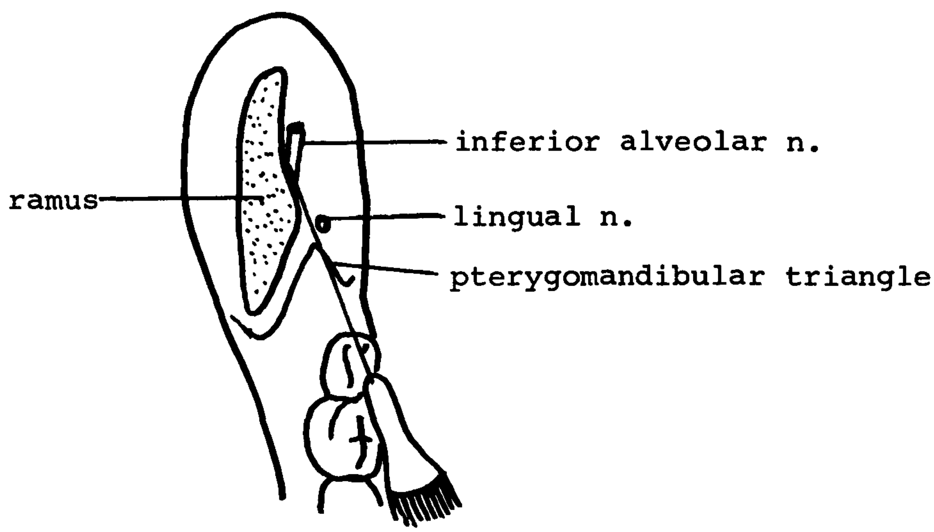


Figure 12

Cross-section of Ramus

Injection Technique

mandibular canal. (Figure 13) 1.5cc of solution on each side was usually sufficient,[1] but more was used in some instances until the subjects lost sensation, as there is individual variation. The anesthesia lasted for the session which took little more than one-half an hour. The utterances which were taped appear in Table 1.

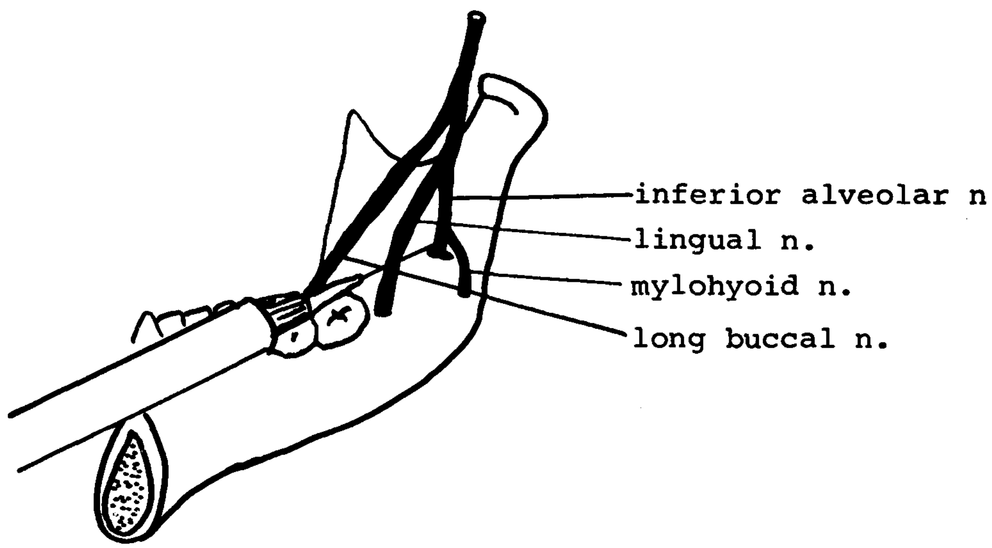


Figure 13

Inner Surface of Ramus With Needle

In the Right Mandibular Sulcus

---

[1]The depth of anesthesia was evaluated by the dentist who used a probe as he would in an ordinary clinical procedure. In retrospect this seems insufficient, although it is the method used in previous studies.

Table 1

Utterances Taped for Perceptual Study

The mother is sweeping the kitchen.
The girl is making a peanut butter and jelly sandwich.
There are grapes and oranges on the table.
There are some matches on the stove.
The little girl is talking on the telephone.
It's hard to lift a lot of dishes.
There's a knife and a spoon.
The boy's in his pajamas.
He's brushing his teeth with a toothbrush.
His sister is washing her face.
The father is shaving with a razor.
The mother and child are sleeping.
She's putting stamps on three letters.
She got some presents for her birthday.
She's saying thank you for the sweater.
Here's a shirt and a pair of pants.
The kids are throwing snowballs.
He's zipping his jacket.
She's putting on her gloves.
The boy has two shovels.
There's a sled.
The garbage cans are by the garage.
There are bicycles in the garage.
That's a school.
There's a flag.
There's a pencil on the desk.
There are some books on the chair.
There's smoke coming from the chimney.
The boy is building with blocks.
This boy is making valentines with scissors and paste.
It's the month of February.
There are five cats.
They have whiskers.
They scratch the baskets.
They play with the string.
A new leaf is on the tree.
The bird has a nest.
Spring is here.

Table 1 (continued)

He caught a big fish.
It's hard to grasp a frog.
There's a bridge.
She's splashing in the ocean.
To smell a flower you breathe in.
The spider spins a lovely web.
The squirrel is on a box.
That's a wasp.
There are snakes at the zoo.
There's a giraffe in a cage.
There are some zebras.
The mouse is eating cheese.
The colt is thirsty.
He's drinking some milk.
They have a bed of straw.
That smiling boy is first in line.
That's a rooster.
The baby is looking at his shoe.
This engine has to be fixed.
There's a taxi.
The boy is watching T.V.
The girl is swinging and laughing.
That's a clown.
He has a yellow mouth with yellow lips.
He has red cheeks.
There's Casper the Friendly Ghost.
He's flying away from the Earth.
There are stars in the sky.

A. Listening Test

The recordings collected from the 7 speakers amounted to over 3½ hours of data. It was decided to extract from this material a reasonable body of utterances to construct a listening test. This test would be used for listener judgments of speech deterioration and for narrow phonetic transcriptions by transcribers. A wide range of phonemes was considered important. The test was heavily weighted, however, with utterances which from pilot studies were found vulnerable, so that the affected samples could be analyzed in some depth.

Two listening tapes were produced by splicing 38 phrases containing the word of interest. The 38 utterance samples were selected from the speech of each subject under both conditions, joined into matched pairs, randomized, and spliced with one second between each one of a pair. Four seconds of silence was spliced between each pair of utterances. Each speaker was presented one at a time. There was randomization within the section for each speaker and among utterances. One-half of the utterances for a given speaker were nerve block sample first, one-half normal sample first. Also, each utterance occurred almost one-half nerve block first, one-half normal first. A practice section for the listeners of 10 additional pairs of utterances were put before the main body of the listening test.

The final listening tapes were presented to 16 university students: eight listeners heard tape 1 first, the other eight heard tape 2 first. They were instructed to check a if the first example of the pair seemed worse, or check b if the second example seemed worse. If unsure, they were instructed to guess. Within each utterance which appeared on the check sheet given each listener, a phoneme was underlined to direct the listener's attention. The results cannot be attributed to any effect on that phoneme alone, however, as listeners often got cues from the utterance as a whole, as for example when a speaker would slow down in order to produce an utterance. A sample check sheet is provided. (Table 2) The phoneme representation in the listening test is presented in a rough accordance with the traditionally described place of production in Table 3.

The errors in listener judgment were counted and tabulated according to speaker and according to utterance. An error in listener judgment means that the listener could not distinguish between the nerve block condition and the normal condition. There may have been other instances when he could not tell but happened by chance to guess correctly. The errors in listener judgment according to speaker can be seen in Table 4.

Table 2

Utterances Selected To Be Spliced Onto Listening Tapes:

Sample Check Sheet

SPEAKER G

	a.	b.
with scissors		
there are grapes and		
the squirrel		
there's smoke		
in his pajamas		
is watching		
the bird		
It's hard		
with the string		
that's a school		
on the table		

SPEAKER G (continued)

	a.	b.
peanut butter		
spring is here		
to be fixed		
the garbage cans		
there are bicycles		
are sleeping		
the kids are		
is swinging and		
he's brushing		
with blocks		
the girl		
is shaving		
the spider		
there's a giraffe		

SPEAKER G (continued)

	a.	b.
the mother		
on three letters		
is sweeping		
for her birthday		
they scratch the		
a lot of dishes		
the mouse		
throwing snowballs		
on the telephone		
she's splashing		
they have whiskers		
there are stars		
a knife		

Table 3

Phoneme Representation in Listening Test

Labial area:
- mouse /m/
- peanut /p/
- bird /b/
- telephone /f/
- shaving /v/

Dental area:
- birthday /θ/
- mother /ð/

Alveolar area:
- table /t/
- dishes /d/
- knife /n/
- letters /l/
- giraffe /r/
- bicycles /s/
- scissors /z/
- brushing /ʃ/
- watching /tʃ/
- pajamas /dʒ/

Velar area:
- cans /k/
- girl /g/
- swinging /ŋ/

/s/ plus labial:
- spider /sp/
- grapes /ps/
- sweeping /sw/
- smoke /sm/

/s/ plus alveolar area:
- snowballs /sn/
- stars /st/
- it's /ts/
- sleeping /sl/
- whiskers /rz/
- kids /dz/

/s/ plus velars:
- school/sk/
- blocks /ks/

/s/ 3 phoneme anterior clusters:
- string /str/
- splashing /spl/
- spring /spr/

/s/ 3 phoneme clusters with velar:
- squirrel /skw/
- scratch /skr/
- fixed /kst/

Table 4

Errors in Listener Judgments According to Speaker*

Listeners	Speakers A.	B.	C.	D.	E.	F.	G.
1	17	17	10	10	16	11	14
2	20	17	5	15	14	15	9
3	11	20	4	6	15	10	10
4	14	25	6	19	15	16	7
5	9	17	5	15	19	13	13
6	15	20	3	13	9	13	15
7	7	21	5	9	10	17	9
8	13	21	9	11	9	14	9
9	14	20	7	11	17	16	16
10	16	19	10	17	12	14	17
11	16	17	8	13	16	11	13
12	14	21	7	16	19	14	21
13	16	22	6	11	14	14	16
14	24	22	3	5	12	15	17
15	16	18	7	14	19	19	15
16	24	18	1	8	12	10	17
TOTALS	246	315	96	193	228	222	218

* A listener error means that the listener could not tell the difference between the nerve block utterance and the normal. Possible errors--for each speaker - 608 304 expected by chance.

Since there were 608 possible errors for each speaker (38 utterances as heard by 16 listeners), 304 errors would be expected by chance, even if there were no effect on the speech by the nerve block. For example, it can be seen that the nerve block had no effect on speaker B (315 errors) as determined by listener judgment. Speaker C, in contrast, was most affected, as the listeners made relatively few errors of judgment (96) between the normal and the nerve block utterances.

The errors in listener judgment were tabulated according to utterance. (Table 5) Speaker B was removed as there was no effect judged to be perceptible in his speech. The possible number of listener errors for each utterance was 96 (6 speakers as heard by 16 listeners), of which 48 would be expected by chance. The utterances are grouped according to general place of production. The mean number of listener errors is given for each group. Since the first four groups contain words selected to incorporate certain single consonants, and the last five groups were selected to test consonant clusters, especially the /s/ clusters, it can be seen that in general the singletons deteriorate less than the clusters as judged by listeners. The utterances seem to divide themselves into three general classes, the least affected, more affected, and most affected. The labials, the dentals, and the

Table 5

Errors in Listener Judgment According to Utterance

96 Possible Errors - 48 expected by chance

	Total Errors	Group Total	Group Mean
mouse	39		
peanut	58		
bird	41		
telephone	24		
shaving	40	202	40
birthday	40		
mother	56	96	48
table	25		
dishes	35		
knife	46		
letters	32		
giraffe	23		
bicycles	39		
scissors	24		
brushing	38		
watching	35		
pajamas	31	328	33
cans	52		
girl	40		
swinging	35	127	42
spider	15		
grapes	30		
sweeping	29		
smoke	17	91	23

Table 5 (continued)

	Total Errors	Group Total	Group Mean
snowballs	21		
stars	8		
it's	23		
sleeping	31		
whiskers	31		
kids	36	150	25
school	26		
blocks	37	63	32
string	21		
splashing	33		
spring	11	65	22
squirrel	23		
scratch	18		
fixed	40	81	27

velars were judged least affected since the listener errors approach chance level. The consonants produced in the alveolar area and the /s/ plus velar clusters are somewhat more affected. The most affected groups, as listeners made relatively few errors of judgment, are the 2 consonant clusters; /s/ with labials and /s/ with alveolars, and the 3 consonant clusters; /s/ with anterior consonants and /s/ with a velar and anterior consonant.

The factors which would seem to determine which utterances are most apt to deteriorate under nerve block are precision of gesture and rapidity of movement. The labials, labiodentals, and interdentals require less precision of gesture than do the sibilants and the affricates. The more consonants in a clustered utterance, the more one would expect complex overlapping and rapidly changing gestures. These complex movement patterns seem most vulnerable to breakdown under mandibular nerve block. The utterances in order of listener errors are ranked in Table 6.

Two separate analyses of variance programmed to include an arc sine transformation (a change of scale to normalize the data) were conducted on the data.[1] The first analysis considered the 16 listeners and the 7 original speakers. It was

---

[1]M. G. Natrella, Experimental Statistics, National Bureau of Standards Handbook 91, 1963, 20.1-20.8.

Table 6

Utterances in Order of Listener Errors, Ranked

Utterance	Listener Errors	Rank
stars	8	1
spring	11	2
spider	15	3
smoke	17	4.5
sweeping	17	4.5
scratch	18	6
string	21	7.5
snowballs	21	7.5
squirrel	23	10
it's	23	10
giraffe	23	10
scissors	24	12.5
telephone	24	12.5
table	25	14
school	26	15
grapes	30	16
sleeping	31	18
whiskers	31	18
pajamas	31	18
letters	32	20
splashing	33	21
dishes	35	23
swinging	35	23
watching	35	23
kids	36	25
blocks	37	26
brushing	38	27
bicycles	39	28.5
mouse	39	28.5
girl	40	31.5
fixed	40	31.5
birthday	40	31.5
shaving	40	31.5
bird	41	34
knife	46	35
cans	52	36
mother	56	37.5
peanut	56	37.5

found that there was no significant variation among the 16 listeners at either the .05 or .01 level of confidence. Thus the listeners were using essentially the same criteria in their judgments with fairly general agreement. The variation among speakers, however, was highly significant at both levels. (Table 7) The speakers, then, varied considerably in their performance as judged by listeners.

Table 7

<u>Analysis of Variance</u>

16 Listeners 7 Speakers

	Sums of Squares	df	Mean Square	F
A. Listeners	0.73412	15	0.04894	1.3
B. Speakers	5.69956	6	0.94992	25.3*
AB. Interaction	3.37167	90	0.03746	

The second analysis considered the 38 words uttered by the speakers according to listener judgments and the speakers. The speaker who evidenced no effect was removed for this analysis. It was still found that there was a significant variation among the remaining 6 speakers. The variation among utterances was significant at the .05 level but not significant at the .01 level, indicating marginal significance. Speakers, then, varied widely, and words varied also. (Table 8)

Table 8

Analysis of Variance

6 Speakers 38 Utterances

	Sums of Squares	df	Mean Square	F
A. Speakers	11.83366	5	2.36673	6.82*
B. Utterances	20.84227	37	0.56330	1.62*
AB. Interaction	64.15301	185	0.34667	

The first part of the perceptual study, the listener judgments of the speakers, revealed a wide variation among speakers. The extent of this variation was quite surprising to the experimenters as there had been no previous mention of speaker variation in the literature.

B. Phonetic Transcriptions

Although it was evident that ordinary intelligent listeners were able to distinguish the nerve block effect in certain phonemes of certain speakers, it remained to analyze the effect more carefully. Two experienced transcribers made narrow phonetic transcriptions of six of the speakers. The transcribers worked on material and speakers not used in the study to standardize their phonetic system. It was decided that the direction of the distortions should be indicated whenever possible. For example, if the /s/ were to sound somewhat like /θ), the transcription would be /s^{θ}/, whereas if it were more toward /ʃ/, it would be transcribed /$s^{ʃ}$/. If the /s/ were slurred but in an undetermined direction, the indication was /s̬/.

The transcribers made the transcriptions independently. Transcriber agreement was quite high. For the 228 utterances transcribed, there was transcriber agreement that there was no effect in 67% of the data. (Table 9) There was agreement both that there was a distortion effect and on the nature of that distortion in another 20% of the data. 3% of the total number of utterances had transcriber agreement that there was a deviation but the direction or place of the distortion in the utterance was judged differently. For the final 10% of the data,

Table 9

Narrow Phonetic Transcriptions - Transcriber Agreement

Speaker	Agree they are same. No distortions.	Agree different. Agree on distortion.	Agree different. Disagree on distortion.	Disagree
A	31	2	1	4
C	17	14	3	4
D	21	7	2	8
E	34	3	1	0
F	22	12	0	4
G	28	7	0	3
	153	45	7	23
	(67%)	(20%)	(3%)	(10%)

one transcriber heard differences which the other did not consider to be distortions.

Transcriber judgments according to speaker indicate, as did the listeners, that the speakers varied widely in the degree of speech deterioration evidenced in the sample utterances. Listeners and transcribers agreed that speaker C was the most affected, and that speaker B was not affected. The other speakers were judged in the same general order of severity of deviation with the exception of speaker F who was found more affected by the block as judged by transcribers than as judged by the listeners. As demonstrated in Table 10, speakers C and D were both affected, speakers F and G somewhat less affected, and speakers E and A were judged to have very little deterioration.

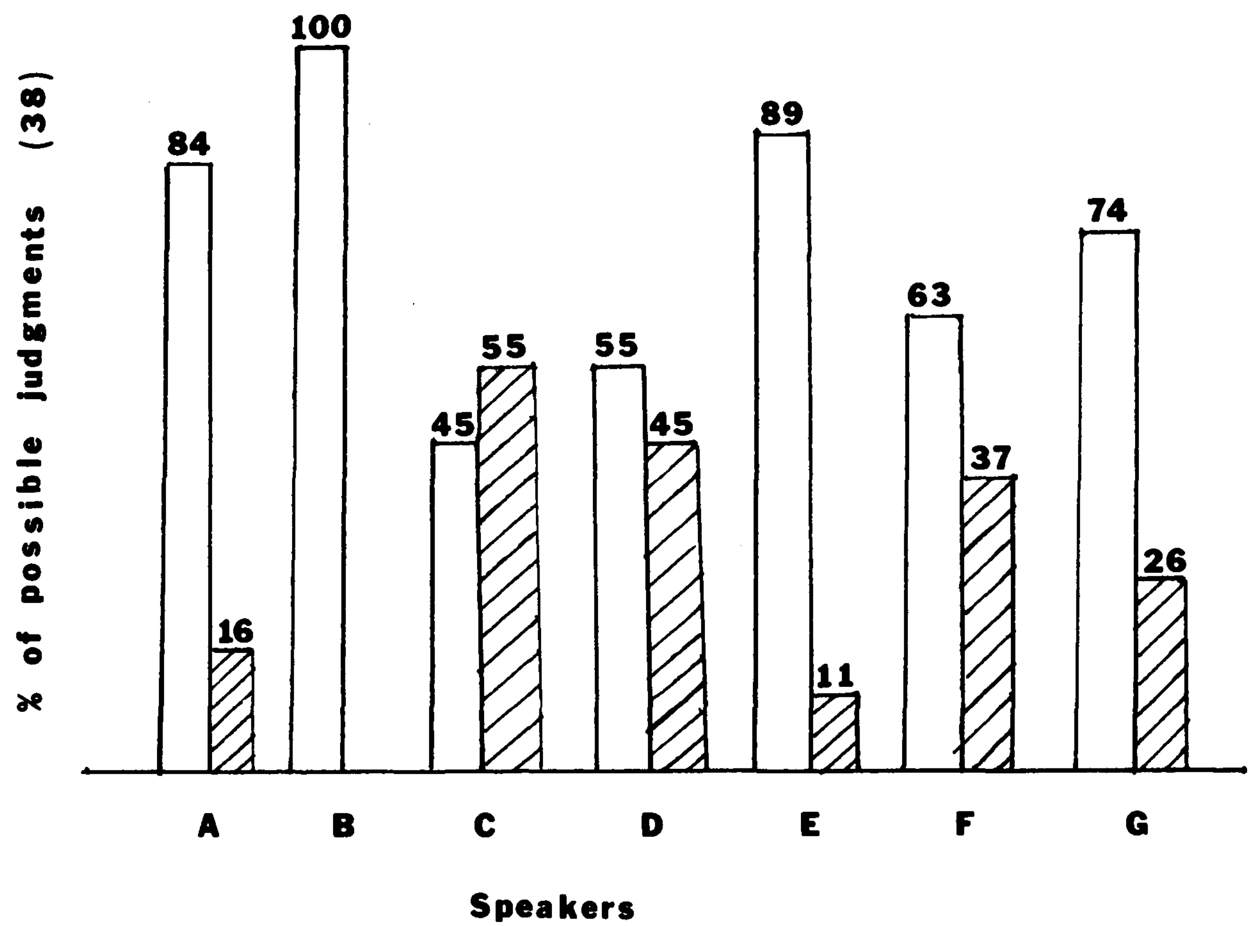
The important information to be derived from the transcriptions was the scope and nature of the speech deterioration on a phonetic level. It was considered necessary to determine, first of all, if the transcribers were making judgments on utterances similar to the judgments made by the 16 listeners. The utterances had been ranked according to listener errors. It was decided to rank the utterances according to transcriber judgments of deterioration to see if the two rankings correlated.

Table 10

Speaker Variation As Judged By Transcribers

TRANSCRIBER JUDGMENTS OF NO DISTORTION UNDER ANESTHESIA

TRANSCRIBER JUDGMENTS OF DISTORTION UNDER ANESTHESIA



The utterances were given scores to indicate their relative degree of distortion as interpreted by the two transcribers. An utterance received a score of zero if there was no difference noted by either transcriber between the normal and nerve block condition in any speaker. A score of ½ indicated that a difference was noted by one transcriber in one speaker, and 3/4 indicated that a difference was noted by one transcriber in 2 speakers. Scores of 1, 2, 3, or 4 were assigned if there was transcriber agreement that there was a distortion in 1, 2, 3, or 4 speakers respectively. After each utterance was assigned a score, the utterances were ranked from the most affected by the block to the least affected. (Table 11) The ranking given by the transcribers correlated significantly with the ranks given by the sixteen listeners. Using Spearman's Rank Correlation ($\rho = 1 - \frac{6\sum D^2}{N(N^2-1)}$), the correlation was .65. To test the significance of ρ with N-2 degrees of freedom ($t = \rho\sqrt{\frac{N-2}{1-\rho^2}}$), t was 5.07 which was significant at both the .05 and .01 levels of significance. Although there was a significant correlation between utterances ranked by listeners and by transcribers, that does not necessarily mean that listeners and transcribers were using the same criteria.

Phonetic transcriptions of the speech of the 7 speakers were made by transcribing only the utterances in which differences were heard. There were no transcriptions made, therefore,

Table 11

Rank Correlation Between Transcribers and Listeners

Utterance	Transcription Score	Transcriber Rank	Listener Rank
spring	4.5	1.5	2
stars	4.5	1.5	1
scissors	4	3.5	12.5
school	4	3.5	15
squirrel	3.5	5.5	10
watching	3.5	5.5	23
spider	3	8	3
whiskers	3	8	18
scratch	3	8	6
letters	2.5	10	20
mouse	2	11.5	28.5
string	2	11.5	7.5
dishers	1.75	14	23
snowballs	1.75	14	7.5
giraffe	1.75	14	10
blocks	1.5	18	26
brushing	1.5	18	27
bicycles	1.5	18	28.5
grapes	1.5	18	16
smoke	1.5	18	4.5
sweeping	1	23	4.5
sleeping	1	23	18
it's	1	23	10
kids	1	23	25
splashing	1	23	21
telephone	.75	26	12.5
knife	.5	28	35
swinging	.5	28	23
shaving	.5	28	31.5
table	0	34	14
pajamas	0	34	18
girl	0	34	31.5
bird	0	34	34
fixed	0	34	31.5
birthday	0	34	31.5
mother	0	34	37.5
cans	0	34	36
peanut	0	34	37.5

of the speech of speaker B. The actual transcriptions are provided in Table 12. Seven of the utterances by speaker A were transcribed, 21 of the utterances by speaker C, 17 by speaker D, 4 by speaker E, 16 by speaker F, and 10 by speaker G.

The were no errors transcribed for the labials, the labiodentals, the interdentals, the velars, nor for /d/ or /n/.

Among the single consonants, the affricates were most often distorted. Also affected were /s/, /z/, /ʃ/, /t/, and /l/. All of the /s/ two-consonant clusters were distorted, especially /st/. Among the /s/ three-consonant clusters only the final /kst/ remained undistorted by the block. The /s/ was the distorted portion of the cluster in all cases, with additional distortion on /r/ in two utterances with /spr/ and /skr/ clusters.

All of the errors noted by the transcribers were errors of place. They were never sufficiently deviant to cross phoneme boundaries. Rather the target phoneme took on characteristics of a neighboring phone, the utterance being perceived by the transcribers as between the two phonemes. The direction of each error is indicated in Table 13. The most prominent distortion was for the /s/ to deviate toward /ʃ/. In all cases

Table 12

PHONETIC TRANSCRIPTIONS OF 38 UTTERANCES BY 6 SPEAKERS

(Only the utterances in which differences were heard are transcribed.)

SPEAKER A

	Transcriber 1		Transcriber 2	
UTTERANCE	NORMAL	BLOCK	NORMAL	BLOCK
spring is here	sprɪŋ	şprɪŋ		
there are stars	stɑ^{r}z	ştɑ^{r}z		
that's a school	skul	ş^{ʃ}kul	skul	ş^{ʃ}kul
the squirrel	skwɝl	ş^{ʃ}kwɝl	skwɝl	skw:ɝl
there are grapes and	greɪps	greɪpş		
are sleeping	slipɪʔ	s^{θ}lipɪʔ	slipɪŋ	ş^{t}lipɪŋ
a knife			naɪf^{θ}	naɪf

SPEAKER C

	Transcriber 1		Transcriber 2	
UTTERANCE	NORMAL	BLOCK	NORMAL	BLOCK
spring is here	sprɪŋ	ş^{ʃ}pr̥ɪŋ	sprɪŋ	şpr^{w}ɪŋ
there are stars	stɑ^{r}z	ştɑ^{r}z	stɑrz	s^{ʃ}tɑrz
with scissors	sɪzɚz	ş^{ʃ}ɪzɚz	sɪzɚz	sɪz^{θ}ɚz
that's a school	sku:l	şku:l	skul	şkul
the squirrel	skwɝl	ş^{ʃ}kwɝl		
is watching	wɑtʃɪŋ	wɑtʃ^{ʃ}ɪŋ	wɑtʃɪŋ	wɑtʃ^{ʃ}ɪŋ
the spider	şpaɪdɚ	s^{f}paɪdɚ	spaɪdɚ	ş^{θ}paɪdɚ
they have whiskers	ʍɪskɚz^{s}	ʍ^{w}ɪs^{θ}kɚz^{s}	wɪskɚz	wɪs^{θ}kɚs^{θ}
they scratch	skrætʃ	skrætʃ^{ʃ}	skrætʃ	s^{θ}kr^{w}ætʃ
on three letters			lɛtɚz	l̥ɛtɚz
the mouse	maʊs	maʊs^{θ}	maʊs	maʊs^{θ}
with the string	strɪŋ	ş^{ʃ}trɪŋ	strɪŋ	ş^{ʃ}trɪŋ
throwing snowballs	snoʊbɑlz	şnoʊbɑlz	snoʊbɑlz	s^{θ}noʊbɑlz̥
there's a giraffe	dʒɝæf	dʒ^{ʒ}ɝæf		
he's brushing	brʌʃɪŋ	br̥ʌʃɪŋ	brʌʃɪŋ	brʌʃ^{θ}ɪŋ
there are bicycles	baɪsɪkl̩z	baɪşɪkl̩z	baɪsɪkɪlz	baɪş^{θ}ɪkɪlz
there are grapes	greɪps	gr̥eɪps	greɪps	greɪp^{f}s^{θ}
it's hard	ɪts	ɪtş^{ʃ}	ɪts	ɪtş^{θ}
the kids	kɪdz	kɪdz̥	kɪdz	kɪdz^{ʒ}
she's splashing	splæʃɪŋ	şplæʃɪŋ	splæʃɪŋ	şplæʃɪŋ

SPEAKER D

	Transcriber 1		Transcriber 2	
UTTERANCE	NORMAL	BLOCK	NORMAL	BLOCK
spring is here	sprɪŋ	s^{ʃ}:prɪŋ	sprɪŋ	s^{ʃ}:pr̥^{w}ɪŋ
there are stars in	stɑ^{r}z	s^{ʃ}tɑ^{r}z	stɑrz	s^{ʃ}tɑrz
with scissors and	sɪzərz	şɪzərz	sɪzɚz	sɪz^{ʃ}ɚzʒ
that's a school	skul	s:kul		
the squirrel is	skwɝl	ş^{ʃ}kwɝl	skwɝl	s^{ʃ}kwɝl
the spider	spaɪdɚ	ş^{ʃ}paɪdɚ	spaɪdɚ	s^{ʃ}paɪdɚ
they have whiskers	wɪskɚz	wɪşkɚz̥		
on three letters			lɛt^{d}ɚz	lɛt^{d}ɚz^{ʒ}
the mouse is	maʊs	maʊş^{ʃ}	maʊs	maʊs^{ʃ}
with the string	stɪrɪŋ	ş^{ʃ}trɪŋ	strɪŋ^{g}	ş:trɪŋ^{g}
throwing snowballs	snoʊbɑlz	ş^{ʃ}noʊbɑlz		
with blocks	blɑks	blɑkş^{ʃ}	blɑks	blɑks^{ʃ}

SPEAKER D (cont'd.)

	Transcriber 1		Transcriber 2	
UTTERANCE	NORMAL	BLOCK	NORMAL	BLOCK
there are bicycles	bæɪsɪklz	baɪs̬ɪklz		
there's smoke	smoʊk	s̬^{ʃ}moʊk		
on the telephone	tɛləfoun	t̬ɛləfoun		
is swinging			swɪŋ^{m}ɪŋ	swɪŋɪŋ
garbage cans	kænz	k̬ænz	kænz	kæns̬^{ʃ}

SPEAKER E

	Transcriber 1		Transcriber 2	
UTTERANCE	NORMAL	BLOCK	NORMAL	BLOCK
that's a school	skul	s̬kul	skul	s̬kul
is watching	watʃɪŋ	wat̬ʃ^{ʃ}ɪŋ	watʃɪŋ	watʃɪŋ
alot of dishes	dɪʃ^{t}ʃəz	dɪʃəz	dɪʃ^{t}ʃɪz	dɪʃɪz
there's a giraffe	dʒɝæf	d̬ʒɝæf	dʒɛ^{ɪ}ræf	d̬ʒɛ^{ɪ}ræf

SPEAKER F

	Transcriber 1		Transcriber 2	
UTTERANCE	NORMAL	BLOCK	NORMAL	BLOCK
spring is here	sprɪŋ	s^{ʃ}prɪŋ	sprɪŋ	s^{ʃ}prɪŋ
there are stars	sta^{r}z	sʃta^{r}z	sta^{r}z	s^{ʃ}t̬a^{r}z
with scissors	sɪzɚz	s̬ɪz̬ɚz	sɪzɚz	sɪz̬^{ð}ɚz
that's a school	skul	s̬ʃkul	skul	s^{ʃ}kul
the squirrel	skwɝl	sʃkwɝl	skwɝl	sʃkwɝ̬l
is watching	watʃɪŋ	wat̬ʃɪŋ	watʃɪŋ	watʃ^{t}ɪŋ
the spider	spaɪdɚ	s̬^{ʃ}paɪdɚ	spaɪdɚ	sʃpa̬ɪdɚ
they have whiskers	ʍɪskɚz	ʍ̬^{h}ɪs̬^{ʃ}kɚz	ʍɪskɚz	ʍɪs̬^{ʃ}kɚz
they scratch the	skrætʃ	s̬krætʃ	skrætʃ	s̬kræt̬ʃ^{s}
on three letters	lɛt^{d}ɚz	l̬ɛt^{d}ɚz	lɛt^{d}ɚz	l̬ɛt^{d}ɚz
alot of dishes			dɪʃɪz	dɪʃɪz
throwing snowballs	snoubɑlz	s̬^{ʃ}noubɑlz		
he's brushing	brʌʃɪŋ	br̬ʌʃɪŋ		
there's smoke	smoʊk	s̬ʃmoʊk	smoʊk	s^{ʃ}moʊk
is sweeping the	swipɪŋ	s̬^{ʃ}wipɪŋ	swipɪŋ	s^{ʃ}wipɪŋ
is shaving			ʃ^{f}eɪvɪŋ	ʃeɪvɪŋ

SPEAKER G

	Transcriber 1		Transcriber 2	
UTTERANCE	NORMAL	BLOCK	NORMAL	BLOCK
spring is here	sprɪŋ	s̬^{ʃ}prɪŋ	sprɪŋ	s^{ʃ}pr^{w}ɪŋ
there are stars	sta^{r}z	sʃta^{r}z	sta^{r}z	sʃta^{r}z
with scissors	sɪzɚz	sɪz^{ʒ}ɚz	sɪzɚz	sɪz̬ɚz
is watching	watʃɪŋ	wat̬ʃɪŋ	watʃɪŋ	wat̬ʃ^{t}ɪŋ
they have whiskers	ʍɪskɚz	ʍ^{w}ɪsʃkɚz	wɪskɚz	wɪ̬s^{ʃ}kɚz
they scratch the	skrætʃ	s̬^{ʃ}krætʃ	skrætʃ	s̬^{ʃ}krætʃ
on three letters	lɛt^{d}ɚz	lɛt^{d}ɚz^{ʒ}	lɛt^{d}ɚz	lɛt^{d}ɚz^{ʒ}
there's a giraffe	dʒɝæf	d̬ʒɝæf		
with blocks	blɑks	blɑks^{ʃ}		
on the telephone			tɛləfoun	t̬ɛl̬əfoun

Table 13

Direction of Error For Distortions Under Mandibular Block

	ç	ʃ	ʒ	θ	f	t	w
t	2						
l	2						
s-	1	1					
-s-	2			1			
-s		2		2			
-z-	1	1					
tʃ	2	3				2	
ʃ	1			1			
dʒ	3		1				
s(w)		2					
s(p)		4		1	1		
-(p)s	1			1			
s(m)		3					
s(n)	1	2		1			
s(t)	2	7					
-(t)s		1		1			
sl				1		1	
-s(k)-	1	4		2			
-(k)s		1					
-(r)z	1	1		1			
-(d)z	1		1				
-(n)z		1					
(g)r	1						
(sp)r							1
(sk)r							1
s(tr)	1	3					
s(pl)	2						
s(pr)	2	7					
s(kw)		6					
s(kr)	2	2		1			

the distortion seems to be the result of the tongue failing to reach target position or target precision. In the case of the /r/, the lips were rounded but the tongue did not achieve the target shape, producing an /r/ with some of the characteristics of /w/.

It is interesting that two studies conducted concurrently with this one came up with similar results, despite the difference in injections, this study using a simple mandibular block, the other studies adding several palatal blocks. Both Gammon and Scott found the speech highly intelligible despite the nerve blocks. The speech effect was described by Gammon as "minor" and by Scott as "subtle," indicating the surprise with which we observe this effect.[1, 2] The Scott data and this study agree that the changes under nerve block are changes in place of production, and that the affected phonemes retain their manner characteristics. We found the less close sibilant production and the non-retroflexion of /r/ described by Scott. The stops and fricatives which she observed as retracted were transcribed by us as failing to reach target position but not always in a retracted deviation. The distortions were more often underachievement of elevation so that the phonemes might better be described as inferior to intended position. The /ʃ/, for example, becomes /ʃ$^{\theta}$/. The relatively motionless upper

---

[1]Gammon, op. cit. [2]Scott, op. cit.

lip responsible for the delabialization of rounded phonemes such as /w/ which Scott reports was not found in our subjects because they did not receive the infraorbital injection. In general, however, the two studies are supportive of one another.

The work of Gammon *et al*. is in agreement with this study on some points and not on others. Their finding of 20% misarticulation under nerve block is in close accord with our transcriber agreement on distortions of 20% and transcriber observation of distortions, whether agreed or not, on 23% of the data. (Table 9) We also agree that the velars remain intact and that the phonemes produced in the alveolar area are significantly affected. Gammon observed changes in manner, the most prominent one being that fricatives became plosives, changes which we never observed. Similarly, they report that bilabials became labiodentals, and that labiodentals became alveolars. It is more probable that certain fricatives, for example, took on characteristics of certain plosives as they lost some of their fricative nature, as /tʃ^{t}/. As Scott observed, the use of a matrix upon which one plots changes in manner or place as employed by Gammon may force the recording of complete changes which may have been, in reality, merely tendencies in that direction.

In neither the Gammon nor the Scott study was there mention of the extreme variability in speech effect found among speakers. Furthermore, the theoretical implications of the studies can seemingly be advanced in contrasting directions. Gammon and others call the speech effect a result of the loss of taction, on the basis that vowels which would seem to depend more upon kinesthesis do not deteriorate.[1] Scott advances the idea that although taction is diminished, it is unclear whether kinesthesis is affected, due to the unknown pathways of proprioceptive reception and innervation. She feels that some "knowledge" of apical and blade refinements, important for some phonemes, is lost under oral anesthesia.[2]

C. Conclusions

Several results emerged from the perceptual study of the effects of bilateral mandibular nerve block upon speech. First, the effect was found to be subtle, limited, and manifest only in rapid, connected speech. In an array of utterances

---

[1]Gammon, op. cit., p. 280.

[2]Scott, op. cit., p. 96.

heavily weighted with difficult consonant clusters, deterioration of articulation was noted by listeners in surprisingly little of the data. Transcribers agreed upon distortions in only 20% of the total data, agreeing that there were no perceptible distortions in 67% of the utterances.

Secondly, the effect was found to be highly variable. Although all subjects reported loss of sensation, the effects on speech ranged from completely unaffected to markedly affected. As one can see from referring to Table 10, the subjects varied from no effect to distortions in 45% of the utterances with significant variation among the subjects in between.

Finally, the effect was discovered in these cases to be limited to certain phonemes. It would be distorting the facts to report that the effect was largely with the fricatives, because although /s/ was by far the most common phoneme to deteriorate, and /z/ and /ʃ/ also underwent changes, there was seemingly no effect upon /ð/ or /θ/ and very little upon /f/ or /v/. The affricates were affected, but the plosives suffered very little. /p/, /b/, /k/, and /g/ were not affected at all nor was /d/ although /t/ was sometimes slurred. The nasals were not noticeably affected. /r/ was affected and /l/ somewhat, but the most conspicuous effect remained an /s/ effect.

The distortions which were most evident and most consistent, such as the /s/ taking on characteristics of the /ʃ/, seemed to be the result of less precise approximation of the tongue with the palate to create the friction. Since there is presumably no contact with the palate to determine the gesture as there is with /k/ or /t/, the position and movement of the tongue would depend more upon a position sense or kinesthetic sense than it would a tactile sense. The same observation holds true for the production of /r/, also affected by this nerve block. Tactile cues may be received by /t/,/tʃ/, and /dʒ/, however, which are also affected phonemes under mandibular block. It would seem that if the interruption of feedback is the critical factor, it must involve both tactile and kinesthetic feedback, or at least kinesthetic.

It remained to study the electrical potential produced by the contraction of certain tongue muscles both under normal conditions and during nerve block to explore the specific muscular effects of the deprivation. Two separate electromyographic experiments were conducted to study this phenomenon further.

CHAPTER III

FIRST ELECTROMYOGRAPHIC STUDY

The results of the perceptual study revealed several aspects of the speech effect under anesthesia which prompted further research. The first factor of interest was the variability of effect. With all the subjects reporting loss of oral sensation, there was no effect on the speech of speaker B, very little effect on speaker A, and the other speakers ranged in articulatory deterioration to speaker C, who was the most affected. This variety of effect could be the result of individual differences in muscle use, or in dependence upon sensory feedback. On the other hand, the explanation may lie in the method of injection and the amount of anesthesia used by the dentist.

Another aspect of the speech effect under anesthesia which prompted further investigation was the predominance of articulatory distortions among the sibilants and affricates, especially /s/ in consonant cluster. It was decided to investigate the electrical potential produced by the contraction of some of the muscles which are thought to be implicated in lingual movement.

A. Method

Two separate electromyographic experiments were conducted in an attempt to find out what happens to certain suprahyoid muscles as subjects speak under conditions of nerve block as compared to normal conditions.

Since the nerve block condition seemed to produce an /s/ effect, muscles which are thought to contribute to tongue elevation were reviewed as discussed by Van Riper and Irwin,[1] by Zemlin,[2] and by Hirano and Smith.[3] The contributing muscles are reviewed in Appendix B. The muscles which seemed to be accessible, clearly identifiable, and of interest for this study were the genioglossus, geniohyoid, mylohyoid, and the anterior belly of the digastric muscles. The orbicularis oris was included as a reference.

The monopolar electrodes used were DISA concentric needle electrodes with a diameter of .45mm. Needle placement was made through the cutaneous tissue under the chin to the

---

[1] C. Van Riper and J. V. Irwin, Voice and Articulation (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1958), pp. 377-380, 402-404.

[2] W. R. Zemlin, Speech and Hearing Science (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1968), pp. 140-144, 277-282, 293, 558-562, 567.

[3] M. Hirano and T. Smith, "Electromyographic Study of Tongue Function in Speech: A Preliminary Report," Working Papers in Phonetics, 7, UCLA, 1967, pp. 46-56.

depth required. Correct placement was checked by observing the oscilloscope while protruding the tongue for genioglossal activity, saying "ta" for geniohyoid activity, lowering the mandible for digastric activity, and saying "ka" for mylohyoid activity. Correct placement was checked periodically throughout each run. (Figure 14)

The subject for the first experiment was the author, a normal adult speaker. Two runs were produced, the first without nerve block, and the second run with bilateral mandibular blocks. A total of 7.5cc of 2% Xylocaine was injected by a dentist, 3cc in each side and an additional 1.5cc on one side. The technique was similar to that used by McCroskey, the model for all previous studies.[1] A partial run was recorded with a medial nasopalatine block of 1cc and an anterior palatine block of 2cc added, but this part of the study was not analyzed as the speech effects were not noticeably different from the run with the bilateral mandibular blocks alone. It seems that loss of sensation from the anterior portion of the hard palate and the alveolar ridge adds very little to the speech effect evidenced with the mandibular blocks.

For the electromyographic studies, material was

---

[1] McCroskey, <u>op. cit</u>.

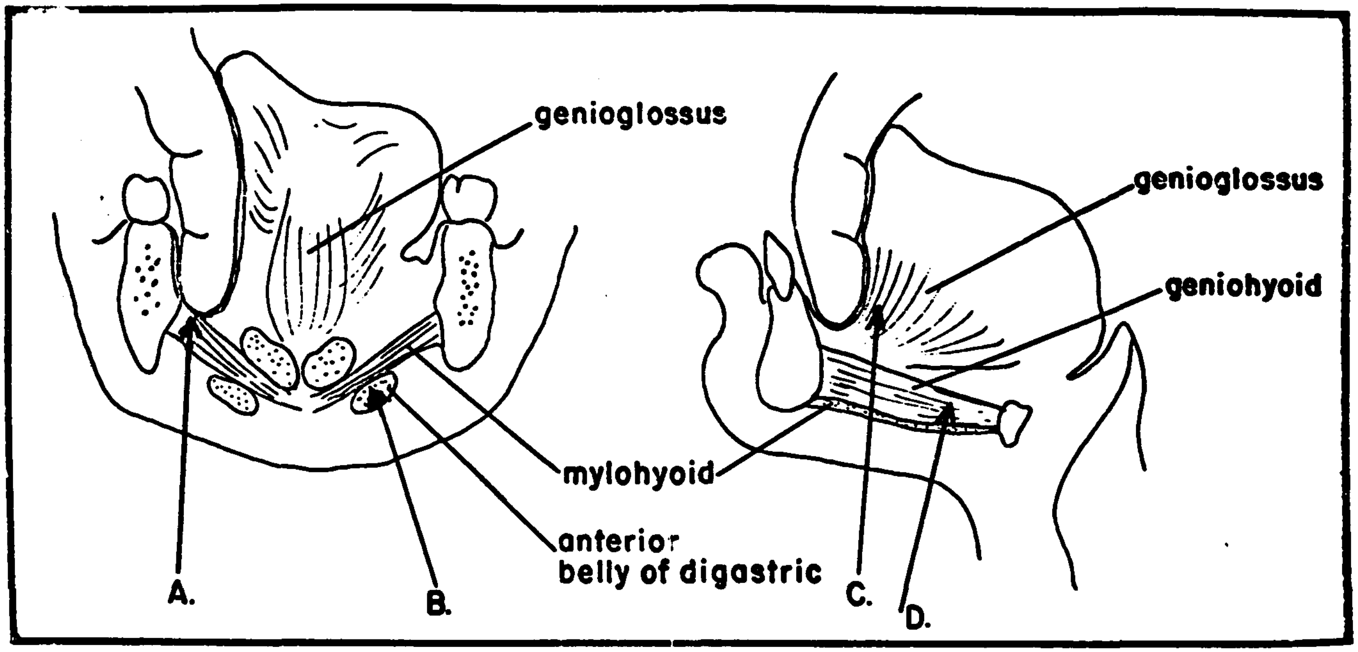


Figure 14

Muscles Examined in Electromyographic Study

Arrows indicate direction of needle insertions. Front and Sagittal Views.

selected from the utterances used in our previous work. Eleven utterances in sentence form, using the format "It could be the ________," were used to permit the necessary rapid connected speech. Each utterance was represented twice in a randomized list of 22 utterances. There were 10 such lists, each individually randomized. Each utterance was spoken 20 times during the course of one run. The utterances were as follows:

It could be the snowballs splashing.
It could be the cat's whiskers.
It could be the fixed sweater.
It could be the school blocks.
It could be the thirsty wasp.
It could be the sleeping taxi.
It could be the spider string.
It could be the squirrel nest.
It could be the rooster scratch.
It could be the spring grapes.
It could be the stove smell.

The 220 utterances for each run were printed and mounted on large cards which were flipped as the subject read them, with equal stress attempted on each of the final two words.

After the nerve block injections, it was observed by the experimenters that the activity on the oscilloscope of the mylohyoid muscle and the anterior belly of the digastric muscle dropped dramatically to a state of relative inactivity. The electrodes were checked and found to be in place, but as long as the anesthesia was effective those muscles were "paralyzed." The speech of the subject under nerve block revealed the typical mandibular block effect of distorted sibilants, the /s/ clusters being most prominently affected.

A 16 channel magnetic tape was produced recording the electrical output of the muscles, which were monopolar recordings; that is, the difference was recorded between the active tissue of the muscles and the inactive tissue of the ear lobe. Some of the channels were used for audio signals, such as the utterances produced by the subject and the comments for record keeping produced by the experimenters. Each utterance was numbered by a pulse code which was laid down on the tape and eventually on the computer output.

The output of the channels was put onto paper tape both at the time of the run and later for inspecting and for locating the individual tokens. Each utterance was represented 20 times during each run, and a single point in time, a line up point, was selected so that all of the tokens of a single type could be averaged by computer for each electrode. The line up point was chosen at a point of particular interest and marked on the simultaneous recording of the subject's audio recording.

Each tape was subjected to 5 computer programs to check that the code pulses were in order, to set the gains of the playback amplifiers at levels appropriate for the analog-to-digital converter, to make control tapes of the line up points and distances from point zero for each utterance, to set each EMG channel at the optimum level, and finally to average the data on the control tapes.

The paper output of this process is a list of numbers for each channel, indicating the averaged value of each electrode in microvolts every five milliseconds. The three runs were hand plotted.[1]

B. Conclusions

Inspection of the data reveals that the muscular activity recorded during speech under normal conditions remained high during the nerve block condition with the exception of two muscles. The mylohyoid muscle and the anterior belly of the digastric muscle became inactive during the nerve block condition. Compare the graph of these two muscles during the production of the utterance "sleeping taxi" under normal conditions (Figure 15) with the graph of the same electrode placements during nerve block. All 11 utterances showed the same drop in activity for the mylohyoid muscle and the

---

[1]T. Gay and K. S. Harris, "Some Recent Developments in the Use of Electromyography in Speech Research," J. Speech Hear. Res., 14, 1971, 241-246.

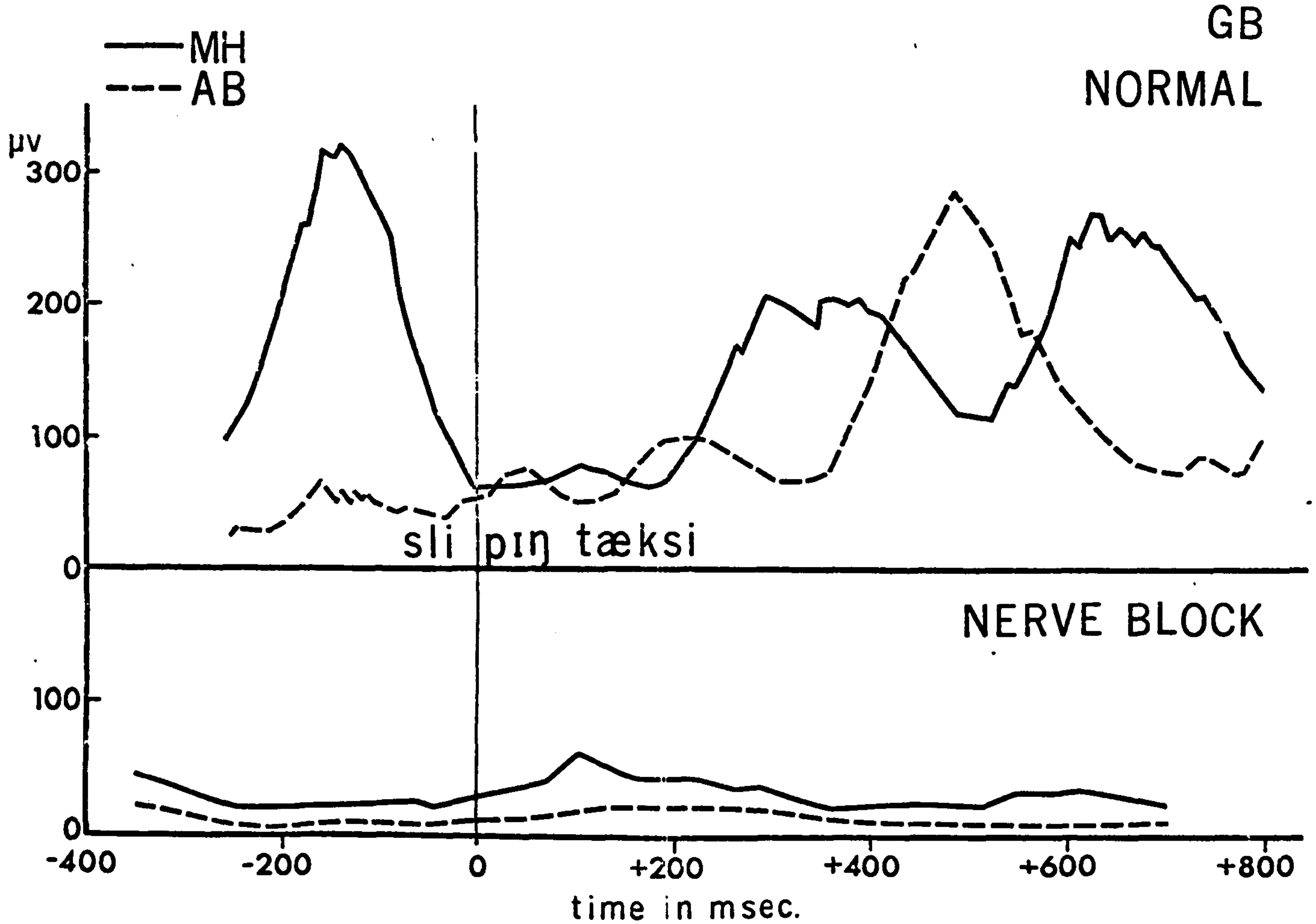


Figure 15

<u>EMG Recording of the Mylohyoid Muscle and the Anterior Belly of the Digastric Muscle During Normal and Nerve Block Conditions</u>

anterior belly of the digastric during anesthesia. (Appendix C)

A closer look at the anatomy at the injection area showed us that we should not have been surprised. The mandibular injection which has traditionally been used for these studies deposits half of the solution in the area of the lingual nerve, then moves on to deposit the rest of the solution in the area of the inferior alveolar nerve. (Figure 12) Just before the inferior alveolar nerve enters the mandibular foramen into the mandibular canal, it gives off the nerve fibers of what is known as the mylohyoid nerve, the only purely motor component of the otherwise sensory inferior alveolar branch of the trigeminal nerve. (Figure 13) The mylohyoid nerve is motor to the mylohyoid muscle and to the anterior belly of the digastric muscle, the two muscles which dropped in activity during the nerve block condition.

The next consideration was whether the inactivity of either of these muscles could have contributed to the noted speech deterioration. If the speech effect is primarily due to sensory loss, then the loss of feedback from the tongue tip region would probably be responsible. If the motor loss is responsible, however, then the anterior belly of the digastric muscle and the mylohyoid muscle are the possibilities.

The normal function of the anterior belly of the digastric muscle is to open the jaw. Electromyographic data on this muscle, obtained by recording muscle activity during simple "CVp" utterances, showed no action for /i/ and /u/ and a large peak for /a/.[1] Since there was no perceptible speech effect of the nerve block upon vowels, and since the action of the anterior belly would not reasonably be expected to affect the apical gestures which deteriorated under nerve block, it seems unlikely that its motor loss could have the speech effects observed. It may be that other mouth openers compensate.

The normal function of the mylohyoid muscle was found by both Harris[2] and Smith[3] to be highest for the production of /k/. Its contraction seems to lift the body of the tongue. In the more complex utterances of the present study, it can be seen that the mylohyoid muscle peaked normally in preparation for the /s/ consonant clusters and for the velars. (Figure 16) Notice the activity at the beginning of "spring,"

---

[1]K. S. Harris, "Action of the Extrinsic Musculature in the Control of Tongue Position: Preliminary Report," <u>Status Report on Speech Research</u>, Haskins Labs, New Haven, Jan.-June 1971, 87-96.

[2]*Ibid*.

[3]T. J. Smith, "A Phonetic Study of the Function of the Extrinsic Tongue Muscles," Doctoral dissertation, University of California, 1970.

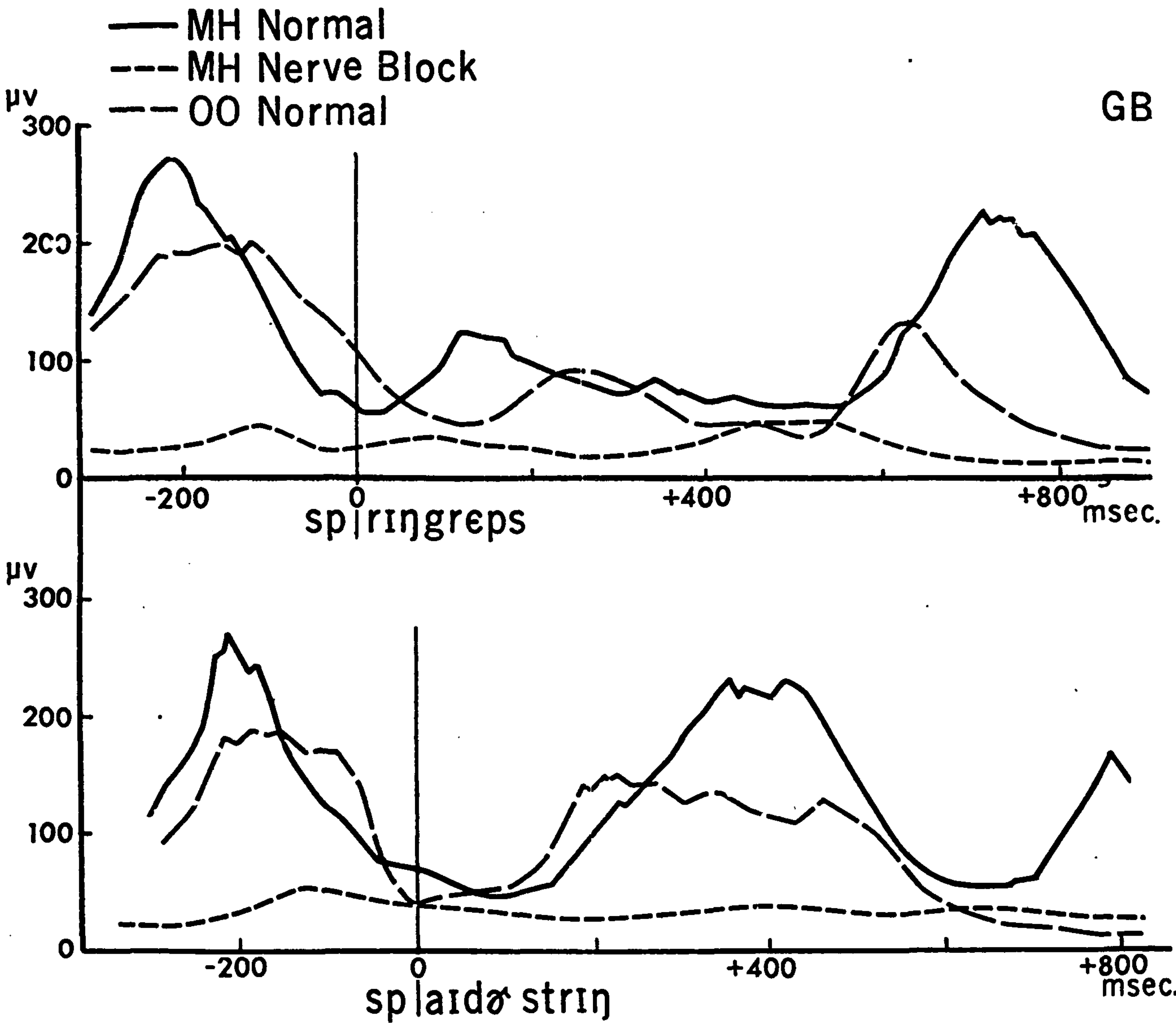


Figure 16

<u>Mylohyoid Muscle Peaked in This Subject Under Normal Conditions for /s/ Consonant Clusters and for Velars</u>

"spider," and "string," and at the end of "grapes" and "string." Observe the drop in activity of the mylohyoid muscle during the nerve block condition. The peaks of activity under normal speaking conditions, then, coincided with the speech distortions produced under the nerve block condition, with the exception of the velars.

The nerve block did not distort the velars sufficiently to be perceived as a distortion. The production of /k/ remained intact, as it had in all previous reports of nerve block experiments. The explanation may lie in the comparatively gross production of /k/ and the fact that we, as listeners, accept as /k/ a less precise gesture than we do for /s/.

It seems, therefore, that the effected "paralysis" of the mylohyoid muscle might reasonably be related to the speech effect, since, for this subject, the mylohyoid muscle appears to be important in lifting and steadying the body of the tongue for consonant clusters, especially those with /s/. It can be seen in Table 14 that the peak values of mylohyoid activity often corresponded in this subject with production of /s/ consonant clusters. The activity dropped significantly during the nerve block condition. This subject produces /s/ with the tongue tip down, making it imperative that the body of the tongue be raised to produce the friction. Deprived of

Table 14

Peak Values in Microvolts For Mylohyoid Muscle in First Electromyographic Experiment During Nerve Block and Normal Conditions

springrapes

Normal	345	155	285
NB	30	35	20
msec.	(-225)	(125)	(715)

roosterscratch

Normal	175	200	310	370
NB	30	40	40	20
msec.	(-775)	(-440)	(-125)	(325)

catswhiskers

Normal	315	355	380	370
NB	35	40	40	20
msec.	(-800)	(-505)	(-140)	(200)

fixedsweater

Normal	485	210	140
NB	45	45	15
msec.	(45)	(325)	(585)

thirstywasp

Normal	185	310
NV	30	35
msec.	(-855)	(-255)

schoolblocks

Normal	380	400
NB	50	30
msec.	(-145)	(640)

stovesmell

Normal	335	355
NB	30	50
msec.	(-215)	(325)

squirrel nest

Normal	215	150
NB	50	25
msec.	(-175)	(635)

snowballssplashing

Normal	415	340	430
NB	30	55	25
msec.	(-140)	(500)	(900)

(/ng/ not plotted)

spiderstring

Normal	355	300	210
NB	35	40	25
msec.	(-210)	(365)	(790)

sleepingtaxi

Normal	425	265	355
NB	30	40	40
msec.	(-155)	(300)	(635)

motor ability in the mylohyoid and deprived of lingual sensation, the /s/ clusters were distorted. It is impossible to conclude which of these factors, if not both, is responsible for the distorted speech, but it cannot be assumed, as it has in previous studies, that the effect is due to loss of sensory feedback.

In summary, the clear conclusion of this first electromyographic experiment was that a motor component existed in what was previously assumed to be a sensory deprivation. The motor loss was evident in two of the suprahyoid muscles, the mylohyoid muscle and the anterior belly of the digastric muscle. One of these muscles, the mylohyoid, is normally active for this subject for /s/ clusters and velars. Since this subject produces /s/ with a high dorsum, it is reasonable to assume that the motor loss in the mylohyoid muscle may have contributed to the speech deterioration during effective anesthesia.

CHAPTER IV

SECOND ELECTROMYOGRAPHIC STUDY

The purpose of the second electromyographic study was to verify the result of the first study, which was that mylohyoid motor loss accompanied the distorted speech during the nerve block condition, and also to further study the changes in muscle activity by comparing the electrical potential in normal speech with the electrical potential during nerve block.

A. Method

The subject of this EMG study was Katherine Harris, who, as a member of the Haskins staff, was covered by insurance.

The material consisted of 30 utterances in the frame " the _____". They were randomized into four lists repeated alternatively four times, making sixteen lists of thirty utterances each. Fifteen of the utterances were chosen from the Scott list in an attempt to observe the muscle changes in the distorted speech which might explain the phonetic changes which she had transcribed. The other fifteen utterances were selected from the sentences in the first study and from the perceptual study.

Two runs were produced. Done on the same morning, the first one was conducted under normal conditions, the second under blocked condition.

The electrodes were 50 micron wires hooked to remain in place. Correct placement was checked by observing the oscilloscope while lifting the tongue for genioglossal activity, tensing the floor of the mouth while relaxing the tongue for geniohyoid activity, saying "ka" for mylohyoid activity, opening mouth with jaw effort for anterior belly of digastric activity, saying "pa" for orbicularis oris activity, and lifting head or opening mouth under pressure for sternohyoid activity. The genioglossus and geniohyoid were also checked during swallowing, as their activity differs in timing.[1] Electrodes were placed in both sides of the mylohyoid muscle and in both anterior bellies of the digastric muscles.

After the normal run, a total of 7.5cc of 2% Xylocaine was injected into the oral region of the subject. There

---

[1]H. Hirose, "Electromyography of the Articulatory Muscles: Current Instrumentation and Technique," Status Report on Speech Research, Haskins Labs, New Haven, Jan.-June 1971, 73-86.

are two general types of dental injections, supraperiosteal injections and block injections. A supraperiosteal injection, sometimes called an infiltration, is a procedure in which the anesthetic solution is deposited on the periosteum opposite the roots of certain teeth. The solution is carried by diffusion through the periosteum and bony plate to the nerves. The only infiltration injection used in this experiment was the anesthetization of the posterior superior alveolar nerve. A block injection is one in which the anesthetic solution is deposited between the brain and the field of operation. The solution penetrates the nerve trunk or nerve fibers and blocks either the sensations coming from the distal field or the motor impulses coming from the brain. All of the injections used in this study were nerve blocks except the one to the posterior alveolar nerve. A summary of the injections given follows.[1] (Table 15) The reason that such extensive injections were administered was to enable the experimenters to compare results with the Scott data. In the present study, the dentist attempted to hit the lingual nerve and to avoid the mylohyoid nerve. The intent was to produce a purely sensory block without any motor effects.

---

[1] Manual of Local Anesthesia in General Dentistry, ed. Professional Division, Cook-Waite Laboratories, Inc., New York, rev. 2nd ed., 1971.

Table 15

Injections of Anesthesia Administered in Second EMG Study

Cranial Nerve	Branch	Amount of Solution	Location of Injection	Area of Sensation
V (mand.)	Inf. Alveol. n. Lingual n.	1.5cc ea. side	pterygomand. triangle	mand. alv ridge, lip gums ant. 2/3 tongue
V (mand.)	Long Buccal n.	.5cc ea. side	1st molar	buccal
V (max.)	Infraorbital Ant. Sup. Alv. Middle Sup. Alv.	.5cc ea. side	infraorbital foramen	upper lip alv. ridge ant. teeth
V (max.)	Nasopalatine n.	.5cc midline	post. to central incisors	ant. 1/3 palate
V (max.)	Post. Sup. Alv. n.	.5cc ea. side	2nd molar	molars
V (max.)	Greater Palatine n.	.5cc ea. side	palate 3rd mol.	post. 2/3 palate

A rough check of two-point discrimination was made, and when the experimenters and subject were satisfied that sensation was lost in the tongue and the palate, Ringel's 55 item oral discrimination test[1] of ten plastic forms was administered by Ringel. When the subject had returned to normal, the Ringel test was again administered. The subject made 9 errors in normal condition and 15 errors in the nerve block condition, the difference being errors of shape, not size. Confusion of shape occurred 3 times in normal condition and 9 times in nerve block condition. Nevertheless, the experiments were surprised that there was so little difference in performance on this test. It was noted that the subject used the usual tongue manipulations during normal condition but relied on deep pressure against the palate when sensation was decreased. This technique was reported as the method used by successful subjects in the previously mentioned study on the effect of anesthesia on oral stereognosis.[2]

The multichannel magnetic tapes which were produced for each of these runs were analyzed in much the same way as the first experiment. There were some refinements in the

---

[1]R. Ringel, et al., "Orosensory Discrimination and Articulation," J. Speech Hear. Dis., 35, 1969, 3-11.

[2]Mason, op. cit.

computer programs. A concise description of the analysis procedure is reported by Port.[1]

B. Conclusions

As a result of the first electromyographic experiment, the investigators were particularly interested in this second study in the activity of the mylohyoid muscle. Since there were bilateral placements of electrodes in both the mylohyoid muscle and the anterior belly of the digastric muscles, the investigators had an opportunity to study the activity on both sides of these muscles. During the normal run, before the injections of anesthesia, the mylohyoid and the anterior bellies showed activity similar to the first subject. The anterior belly peaked for mouth opening and the mylohyoid for velar gestures and somewhat for the /s/ clusters.

During the condition of nerve block, however, there was a decrease in activity in both muscles on the right side. The right anterior belly of the digastric was in all cases significantly less active than normal after the anesthesia. The right mylohyoid was consistently less active than normal for velar gestures, but for the /s/ clusters it was sometimes less active and sometimes more active than normal. The

---

[1]D. K. Port, "The EMG Data System," Status Report on Speech Research, Haskins Labs, New Haven, Jan-June 1971, 67-72.

decreased activity on the right side in this experiment was not as pronounced as it had been in the first EMG study, indicating that the attempt on the part of the dentist to avoid the motor mylohyoid nerve was partially successful. The limited effect on the right side was presumed by the investigators to be the result of some infiltration of the anesthetic in the area of the mylohyoid nerve.

In contrast with the decreased activity observed on the right side of the mylohyoid and anterior belly of the digastric muscles, the left side of these muscles were usually more active than normal while the anesthesia was in effect. Figure 17 demonstrates the asymmetry of effect. The right peak in each of the four graphs represents the labial closing for /p/ in "duckpond." It can be seen that the right side of both muscles was quite active during normal speech but dropped in activity during speech with nerve block. The left electrode placement in the mylohyoid was in a slightly less active field than the right side. That is, there were fewer motor units firing near the electrodes on the left side. The left side placement of the electrode into the anterior belly of the digastric was in a particularly inactive field. The problem of electrode placement into a more or less active field of the muscle is less important in this study than in many, because

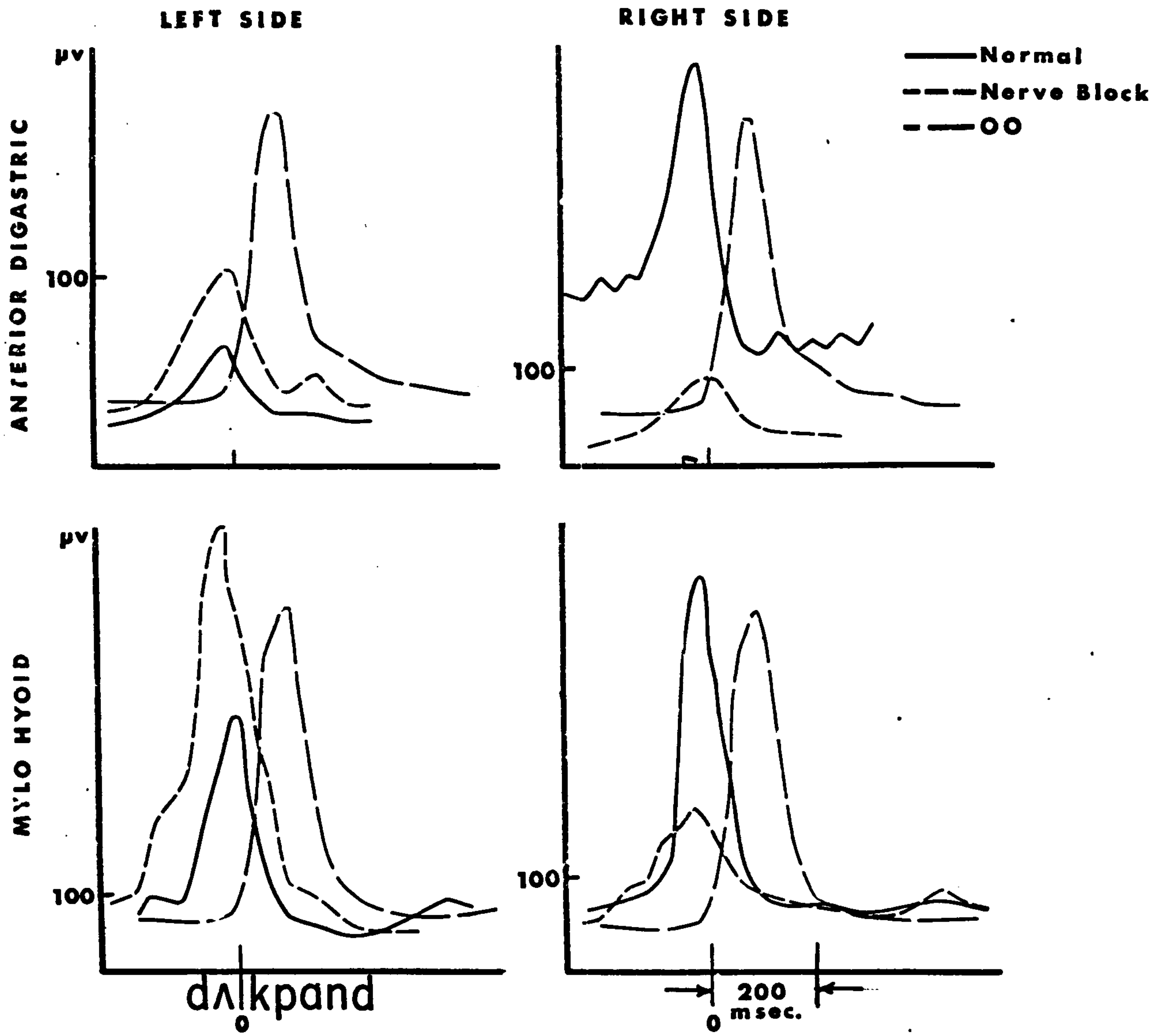


Figure 17

<u>Decreased Right Side Activity and Increased Left Side Activity during Nerve Block of the Mylohyoid and Anterior Belly of the Digastric Muscles</u>. The

our interest is in comparing the activity recorded at a single site under two different conditions, normal and nerve block. Relative values, therefore, are more important than absolute values. A final look at Figure 17 shows both muscles on the left side to be more active during nerve block than they were normally.

We have no explanation of these results except to assume that the anesthetic solution had a motor effect on one side of the subject and that there was some reorganization of motor function on the opposite side to compensate for the motor loss. Typically, bilateral injections of anesthesia result in some asymmetry of effect. In the perceptual study, we sometimes had to reinject a subject on one side, due to insufficient loss of sensation. The subject for the first EMG study required an additional 1.5cc of Xylocaine on one side to equalize the desensitivity. It is reasonable to assume, therefore, that there would be the same possibilities for as metry of motor effect, depending upon the amount of infiltration of the anesthetic solution into the fibers of the motor mylohyoid nerve.

The most prominent result of this study, therefore, was that despite considerably less anesthesia and an attempt to avoid the mylohyoid nerve, there was a unilateral drop in mylohyoid and anterior belly of digastric activity during anesthesia, although the other apparently unaffected side demonstrated efforts at compensation, by showing more than normal activity.

A second interesting result of this EMG experiment was that the subject's articulation appeared to be clear under nerve block. There were no discernible phonetic distortions. The speech sounded as acceptable under the nerve block condition as under the normal condition. The utterances were louder under nerve block, a common side effect,[1] and produced what might be described as overarticulation.

This variability of nerve block effect among subjects was observed during the perceptual part of this series of studies. It is unclear why there was no speech effect. It might be a difference in muscle use, as this subject produces /s/ with tip of the tongue raised and might not rely on mylohyoid muscle activity as much as the first subject, who produces /s/ with dorsum of the tongue raised, keeping the tip down. Another explanation for no speech effect might be a difference in anesthesia, either in amount or in technique of injection. It is customary in these studies to inject anesthesia until the subject reports loss of sensation. In the mandibular block, loss of sensation is reported immediately when the lingual

---

[1]See, e.g., R. Ringel and M.D. Steer, op. cit., p. 372.

nerve has been hit directly, as it was in the case of this second subject. Only 1.5cc of Xylocaine solution was injected into each side, whereas 4.5cc in each side were necessary before the subject of the first experiment lost sensation. The solution presumably anesthetized the mylohyoid nerve of the first subject, as we have indicated mylohyoid muscle and anterior belly of the digastric muscle inactivity. In this subject there was less anesthesia needed to effect loss of sensation and the solution apparently did not penetrate the mylohyoid motor nerve fibers on one side.

The third result of the second electromyographic study was a fairly consistent pattern of muscle reorganization under nerve block. Table 16 summarizes the muscle activity in general for each utterance during nerve block as it compares to its own activity normally. The orbicularis oris was usually either the same as normal or more active than normal. The genioglossus tended to be the same. Inexplicably, the geniohyoid was less active during nerve block. The rest of the muscles follow a reasonable pattern of adjustment. The right side of the mylohyoid muscle and the anterior digastric lost activity during nerve block, as previously discussed. The scatter plot of the differences in peak values of the

	More Active Than Normal	Less Active Than Normal	Same As Normal	Different Than Normal
OO	11	5	13	1
GG	1	8	21	
GH		29	1	
SH	22		7	1
MHR	4	14	7	5
MHL	24		6	
ADR		30		
ADL	15		15	

Table 16

Relative Muscle Activity During the Nerve Block Condition For Each Utterance right anterior digastric during the two conditions is clear. It was always higher normally than during anesthesia. (Figure 18) The right mylohyoid showed the same decreased activity for the normally active velar gestures, but for the high front gestures such as /t/ or /s/ clusters, there was increased activity during nerve block. (Figure 19)

Shifting our attention to the left mylohyoid and anterior digastric, we see that again the anterior belly clearly increases activity during nerve block, perhaps as compensation for the less active left side. (Figure 20) The left mylohyoid, however, is somewhat more complex. It, too, was more active during nerve block. Notice that for the less active front consonant gestures, there was less increase in activity during nerve block than for the already normally active velars. (Figure 21) While the right mylohyoid activity dropped for the velars, the left side increased. Finally, the sternohyoid was interesting as it was consistently more active during nerve block than normal, and might reasonably be expected to compensate for the inactivity of the anterior digastric. The anterior belly of the digastric opens the jaw as does the sternohyoid. (Figure 22) In summary, the muscles do seem

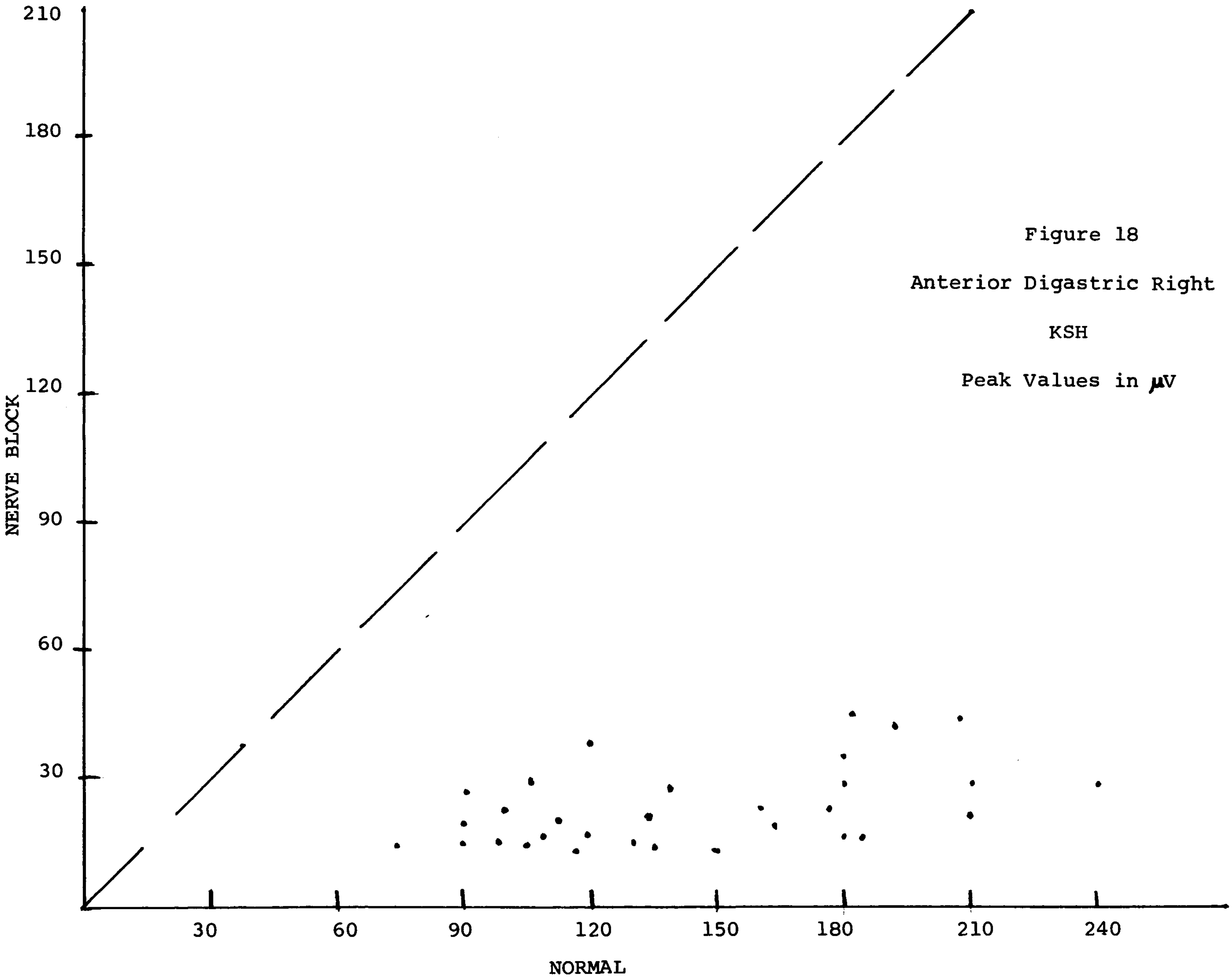


Figure 18

Anterior Digastric Right

KSH

Peak Values in μV

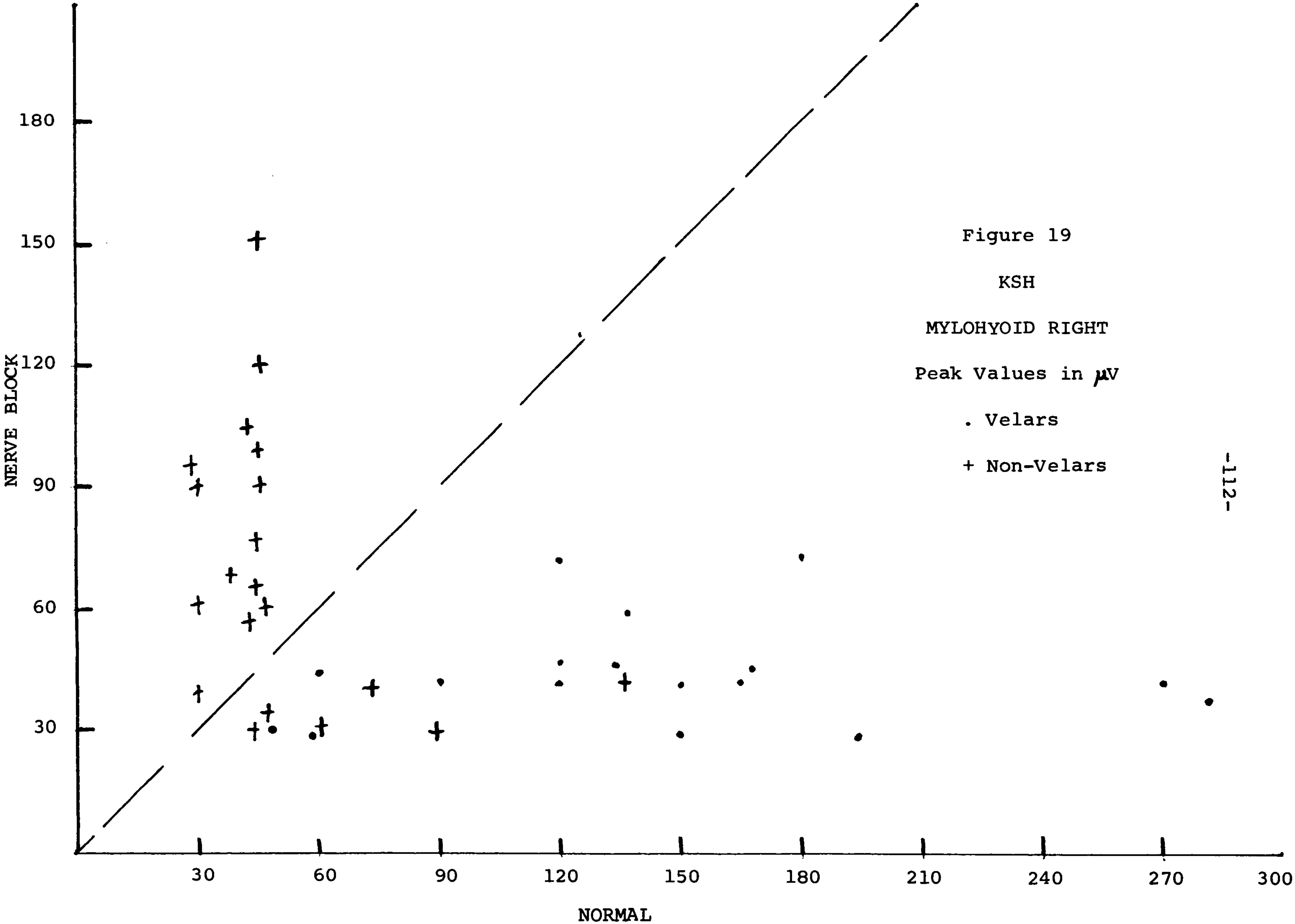


Figure 19
KSH
MYLOHYOID RIGHT
Peak Values in μV
. Velars
+ Non-Velars
NERVE BLOCK
180
150
120
90
60
30
30
60
90
120
150
180
210
240
270
300
NORMAL

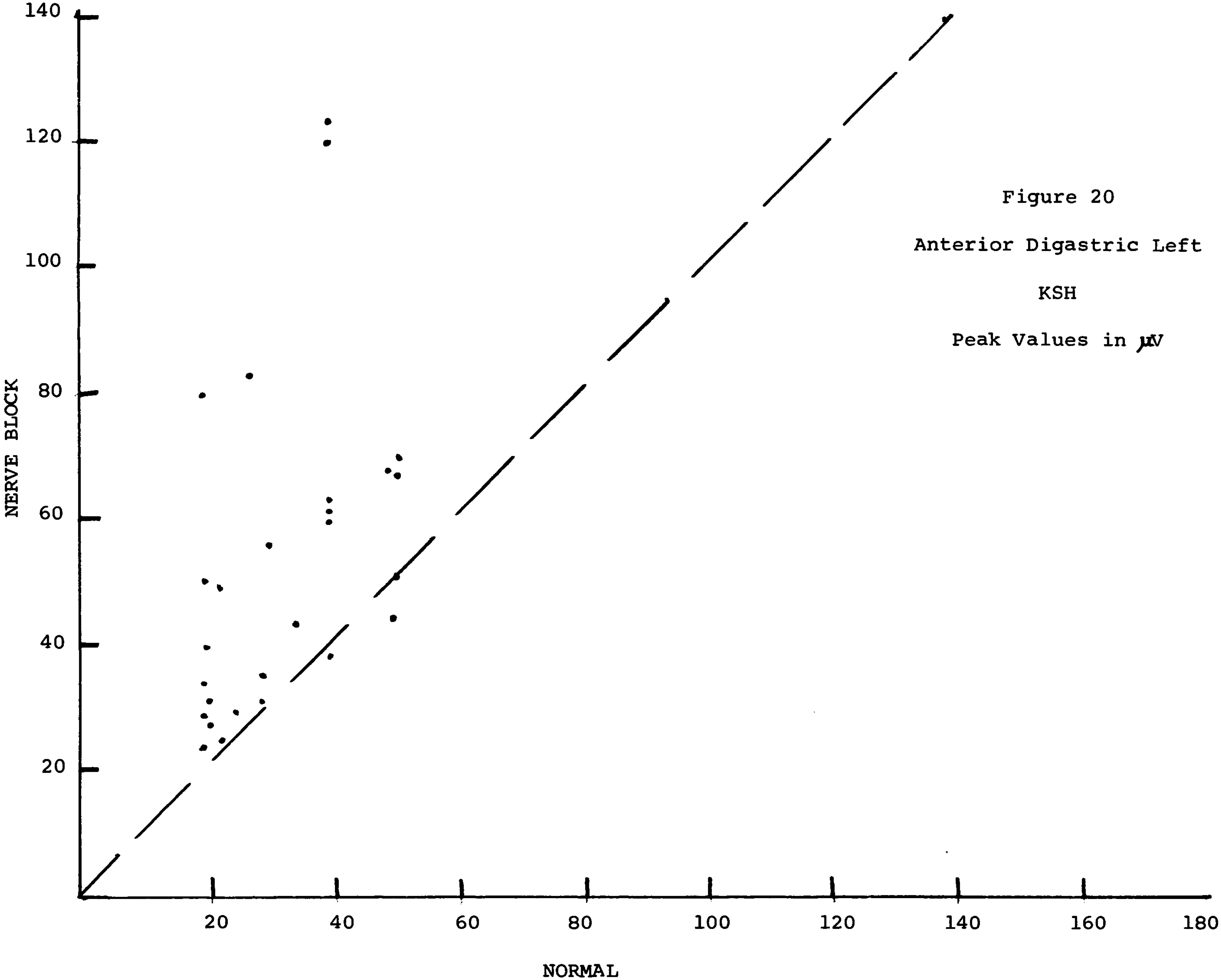
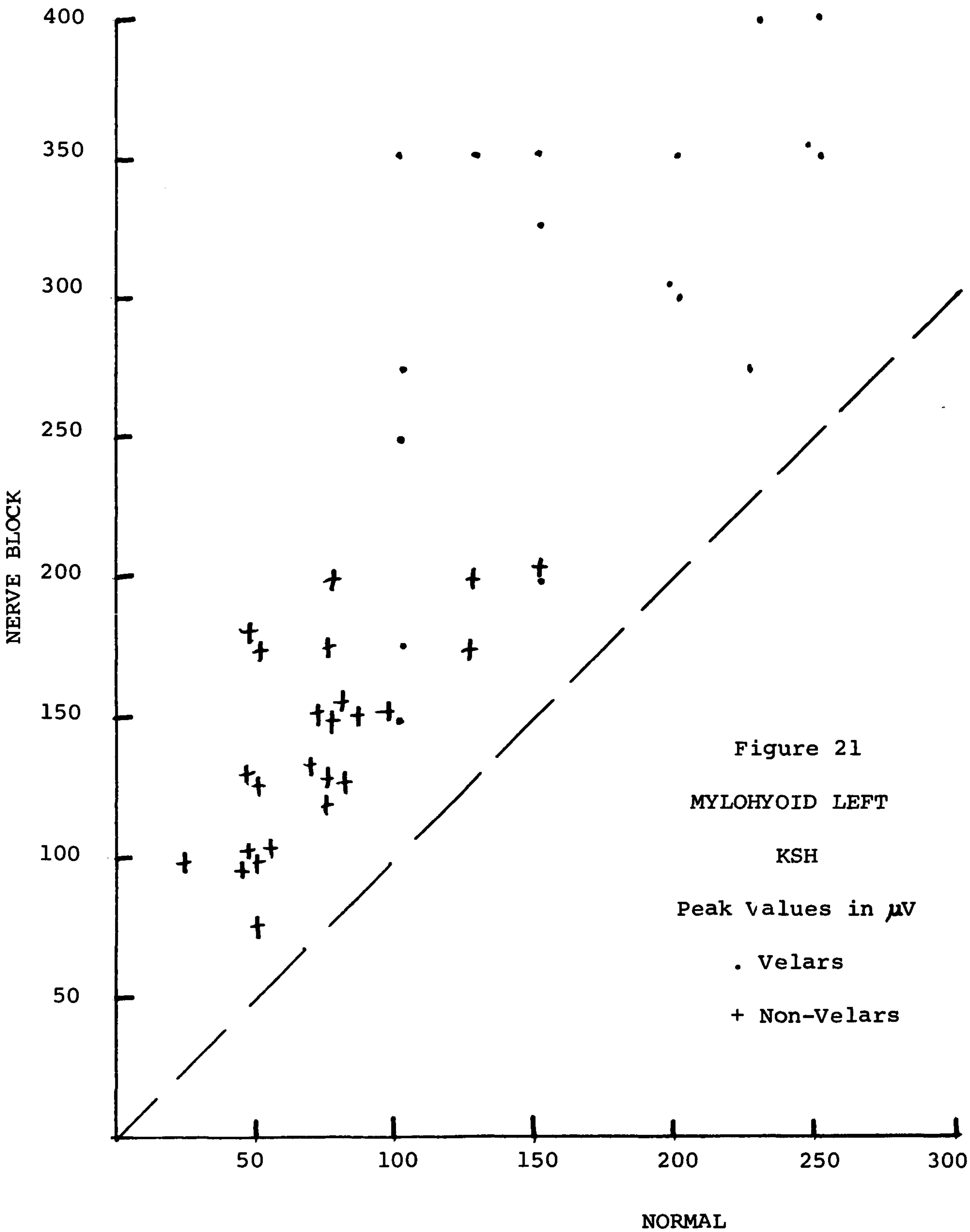


Figure 20

Anterior Digastric Left

KSH

Peak Values in μV



400
350
300
250
200
150
100
50
NERVE BLOCK
50
100
150
200
250
300
NORMAL
Figure 21
MYLOHYOID LEFT
KSH
Peak Values in µV
. Velars
+ Non-Velars

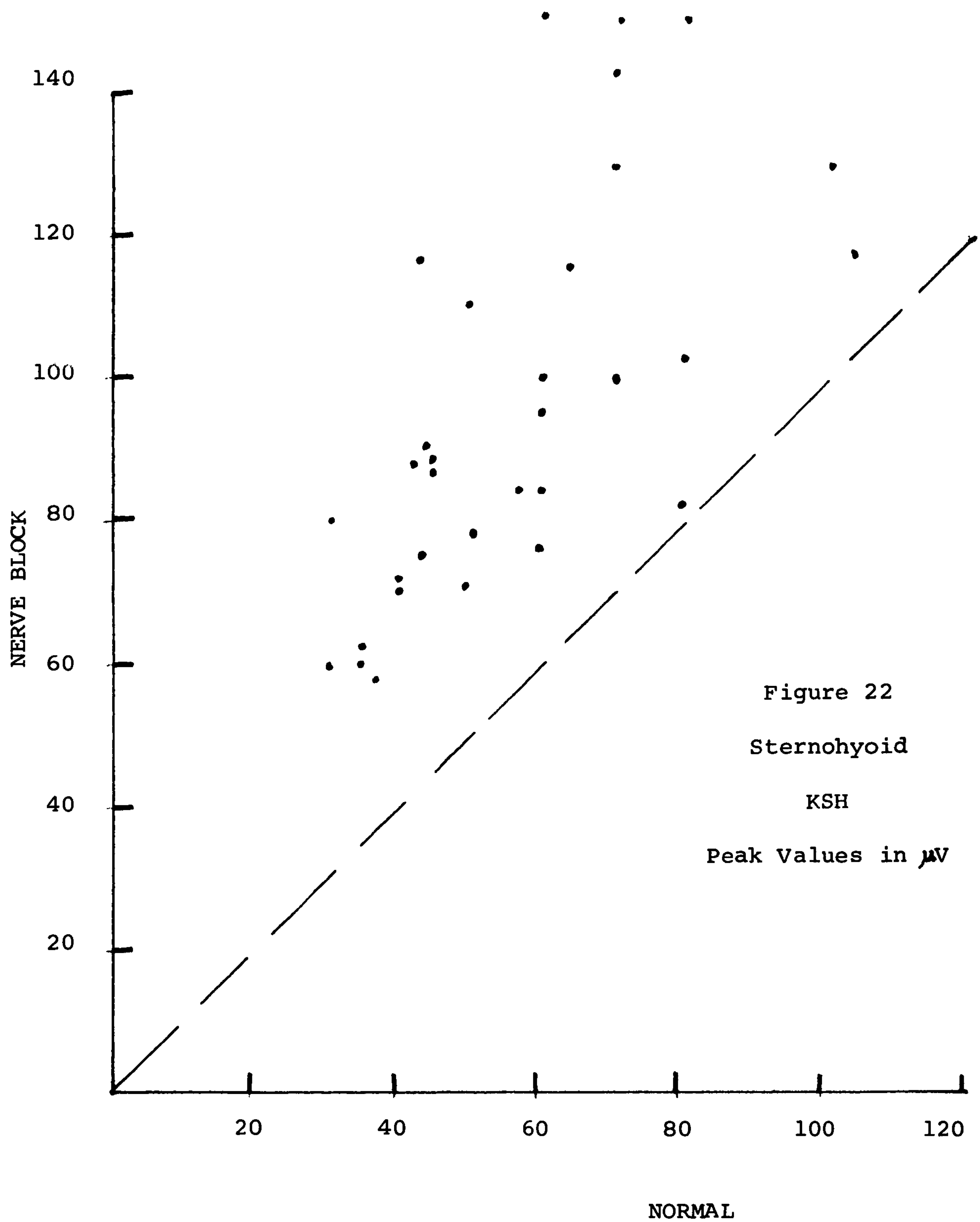


Figure 22

Sternohyoid

KSH

Peak Values in µV

to be behaving differently during the nerve block condition. They do not seem to change their pattern of function as much as their amplitude. Finally, there are some instances which look like compensatory action as a result of decreased activity on the opposite side or in another muscle.

Whether the speech of this subject might have remained sharp and clear even had the mylohyoid nerve been bilaterally affected by the anesthesia resulting in mylohyoid muscle "paralysis," as seemed to be the case with the first subject, remains unclear. Is the speech deterioration, when it exists, related to a loss of tactile and kinesthetic sensation as has traditionally been suggested? Or might it be related to a loss of motor function which these studies force us to consider? Or might it possibly be related to some reorganization of the unaffected muscles in an attempt to compensate for the motor loss, an attempt which perhaps succeeds except on phonemes demanding rapidity and precision of gesture such as /s/ and /r/ in consonant clusters?

CHAPTER V

RESULTS AND DISCUSSION

A. Summary of Results

Three experiments were performed in an attempt to gather information on the effects upon speech, perceptually and electromyographically, of certain nerve blocks. Several questions were asked. Is the effect upon speech slight or severe? What phonemes are distorted? Is the effect due to sensory loss, motor loss, or both? Which muscles are affected? A perceptual study of the speech of normal adult speakers with and without the nerve blocks was followed by two electromyographic studies of certain extrinsic tongue muscles and suprahyoid muscles in normal adult speakers with and without nerve blocks.

Perceptual Study

The most important result of the perceptual study was that both listeners and transcribers found the speech effects of bilateral mandibular nerve blocks to be limited to a small inventory of phonemes. The most prominent distortion was /s/ especially in consonant clusters. Also affected were /tʃ/, /dʒ/, /z/, /ʃ/, /r/, /l/, and /t/. No distortion was large enough to cause listeners to hear a phoneme different from that intended. It had been established in pilot studies that the speech effect was evident only in rapid connected speech.

The second result of this study was the subject variability evidenced. Although all subjects reported loss of sensation, as conventionally tested, the effects of the nerve blocks on speech ranged from completely unaffected to markedly affected.

First Electromyographic Experiment

The first electromyographic experiment demonstrated that two of the suprahyoid muscles studied, the mylohyoid muscle and the anterior belly of the digastric muscle, were inactive during the nerve block condition. These two muscles are innervated by the mylohyoid nerve, the only motor component of the otherwise sensory inferior alveolar branch of the trigeminal nerve. Normal activity of the anterior belly of the digastric muscle did not correspond with any noticeable speech effect during the nerve block. The mylohyoid muscle peaked normally in this case for /k/ and for /s/ clusters. Since the production of /s/ clusters deteriorated during the nerve block condition, the possibility of the motor loss in the mylohyoid muscle contributing to this speech effect could not be ruled out.

Second Electromyographic Experiment

The second electromyographic experiment showed a moderate unilateral drop in mylohyoid and anterior belly of digastric activity despite an effort by the dentist to avoid the mylohyoid nerve. The other side demonstrated more than normal activity, apparently compensatory. The subject's speech remained undistorted by the nerve blocks. Finally, there was a fairly consistent pattern of muscle reorganization under nerve block. The muscles did not seem to change their pattern of activity as much as their amplitude of activity. Some instances look like compensatory action as a result of decreased activity on the opposite side or in another muscle.

The conclusion which we must draw from these experiments is that there is an error of method in the experimental technique which we have been using to study tactile and kinesthetic loss of sensation on speech. The most critical injection of anesthesia, the mandibular block, produces not only a sensory loss but a motor loss. These studies have demonstrated, furthermore, that the use of EMG is important in experiments on sensory deprivation as a direct check on motor function.

B. Discussion

Closed Loop Control

The question of control is important in developing any theory of speech production. The studies of speech under oral sensory deprivation suggest that closed loop control is operative through lingual nerve feedback.[1] The present study fails to give full support to that theory, as it reveals a motor paralysis which may be at least partially responsible for the articulatory distortions.

In normal speakers, there are several sensory channels, auditory, visual, kinesthetic, and tactual which can be used for self-monitoring speech; some of these channels are used for reception of the speech of others as well. Redundancy of

---

[1] Ringel and Steer, op. cit.

the perceptual system of auditon has been recognized. We get much more information than is necessary for comprehension of what is said. There seems also to be considerable redundancy in the systems used for monitoring our own speech. Perhaps we use these systems, specifically audition by air and bone conduction, vision, proprioception, and taction, during the learning of speech, but after the process of speaking becomes relatively automatic and facile, we monitor less and switch from one channel to another as we monitor. Even during the difficult process of learning to speak a language, it is possible to use the other channels if one is deficient. It is a laborious task, however, to learn speech if the auditory system is profoundly incapacitated as we know from the experiences of prelingually deaf speakers. We lack evidence of purely tactile and kinesthetic loss of sensation as it is difficult to rule out motor involvement in either congenital sensory dysarthria or in lingual anesthesia.

As speech is being learned in people with normal systems, the visual and auditory cues received from the language environment are compared with the auditory, tactile, and kinesthetic cues of one's own productions. There is some evidence that there is a gradual switch to a more automatic process and that the matching gradually diminishes. In the matter of auditory discrimination, for example, the ability to make phonetic discriminations is related to one's own articulatory development up to roughly the age of nine, whereas in older children and adults this relationship ceases to exist.[1] Once speech has been learned and is presumably under more automatic control, audition may be damaged with only gradual effect on speech. This effect does not approach the effect of loss of audition before or during the speech learning years. An experienced speaker can speak reasonably well without hearing himself.[2] Also, the effect of blocking lingual sensation, as we have seen in this and other studies, has little effect on speech, which remains essentially intelligible. It seems that one can speak reasonably well without feeling oneself speak. The fact that there is some loss of precision, regardless of how slight, under nerve block, must be explained in any model of a speaking system. Let us consider the evidence for closed loop monitoring by audition, taction, and kinesthesis.

---

[1] P. S. Weiner, "Auditory Discrimination and Articulation," J. Speech Hear. Dis., 32, 1967, 19-28.

[2] McCroskey, op. cit.

Evidence for closed loop control by auditory monitoring was strengthened when the effects on speech of delayed auditory feedback were reported.[1] Anecdotal experience suggests, however, that a speaker under delayed auditory feedback may resume normal speech if he is able to shift his attention to the tactile and kinesthetic cues of his speech or to the material which he is reading. We have seen how high level masking does not alter articulation but does prolong the voicing, much as the delay in auditory feedback produces temporal changes, primarily syllable repetition and increased duration.[2] Closed loop auditory control, then, seems related to vocalic activity.

Evidence for closed loop control by tactile monitoring, which is information about contact between lips, between tongue and palate, lip and teeth, tongue and teeth has been strengthened by several studies. When the upper lip is anesthetized, for example, the labials and labiodentals are distorted.[3, 4] There is a possibility, however, of motor

---

[1] Lee, op. cit.

[2] G. Fairbanks, "Selective Vocal Effects of Delayed Auditory Feedback," J. Speech Hear. Dis., 20, 1955, 333-346.

[3] P. Ladefoged, Three Areas of Experimental Phonetics (London: Oxford University Press, 1967).

[4] Scott, op. cit.

paralysis in these studies, as it is conceivable that the anesthesia might affect the motor fibers to the orbicularis oris, fibers from the buccal branch of the facial nerve.[1]

The fact that in this investigation the production of /k/ withstood mylohyoid inactivity may give further support to the importance of tactile control, as the sensory feedback to the soft palate and to the posterior portion of the tongue was maintained. A contrasting explanation might be that the motor paralysis (with or without the sensory loss effect) evidently produces slight deviations which may not be perceptually noticeable with /k/ but which are sufficient to distort the more precise production of /s/.

Evidence for closed loop control by kinesthetic monitoring, which is the sensation of movement and a sense of position, is also suggested by the studies mentioned. As we have seen in the anatomy and physiology section of this paper, jaw movement seems to be under closed loop control, but tongue control is less clear. We do not understand the physiological mechanisms for such control in the tongue, whereas we do have physiological evidence of the gamma loop

---

[1]A. H. Butt, "The Effects on Speech of Labial Anesthesia: A Photographic Study." M.S. thesis, Purdue University, 1971, p. 89.

functioning in the jaw. It seems reasonable that there be some kinesthetic mechanism to control fine articulations of the tongue tip, especially those configurations which cannot depend upon tactile information for control as there is little or no contact. Examples of these would be /s/ and /r/. The fact that these productions are distorted upon anesthetization of the tongue would seem to support the case for tongue kinesthetic control. We must further investigate mylohyoid muscle paralysis, however, before we come to any conclusions about closed loop control of tongue movement and position.

Speech seems to be generally open loop with highly flexible closed loop mechanisms available to the speaker in certain demanding instances and which the speaker seems able to use alternately, that is, switch from one system to another, as well as use them together.

Differential Monitoring

One possibility we must not fail to consider is that we have never achieved total blockage of the feedback systems. It has been our experience that to block out the bone conducted sound of our own voices is painful if not impossible. In the same way, lingual and palatal anesthetization may leave many other clues from sensory endings in the back of the tongue in addition to sensory information from receptors well below the area of anesthetization. It might be that pronounced effects would result from complete blockage of either system.

We, as listeners, may hear other speakers differentially, using a lateralized reception of the voice and of the consonant noise. There is some evidence of dominant cortical use for perception of noise (right ear effect for consonants) whereas the voice is heard bilaterally or with some tendency to a left ear effect.[1, 2] Our own speech may be similarly differentiated during speech learning and self-monitoring. We may monitor vocalic information by audition, establishing kinesthetic correlates but depending largely upon audition. Similarly, we may monitor consonantal noise largely by kinesthesis and taction using audition as a secondary check.[3, 4] There is some evidence that the left

---

[1] D. Kimura, "Functional Asymmetry of the Brain in Dichotic Listening," Cortex, 3, 1967, 163-178.

[2] D. Shankweiler and M. Studdert-Kennedy, "Identification of Consonants and Vowels Presented to Left and Right Ears," Quart. J. Exper. Psychol., 19, 1967, 59-63.

[3] Ohman, op. cit.

[4] D. A. Huntington, K. S. Harris and G. N. Sholes, "An

hemisphere controls sensorimotor information from the tongue. When oral sensation is decreased, the laterality effect is heightened, indicating that the right hemisphere suffers more with anesthesia as compared to the left hemisphere which is presumably more capable of operating under reduced redundancy.[1]

Future Research

Future research should be directed toward separating the possible contributions of motor inactivity and diminished sensory feedback in producing the speech distortions evident under nerve block conditions. Investigation of the speech effect produced by selectively blocking the lingual nerve would indicate to what extent diminished sensory feedback from the anterior part of the tongue distorts the speech. Alternatively, blocking the mylohyoid nerve alone would indicate the relative importance of the motor function of the mylohyoid muscle in the production of the phonemes vulnerable

---

Electromyographic Study of Consonant Articulation in Hearing --Impaired and Normal Speakers," J. Speech Hear. Res., 11, 1968, 147-158.

[1] H. M. Sussman, "The Laterality Effect in Lingual-Auditory Tracking," Ph.D. dissertation, University of Wisconsin, 1971.

to distortion under nerve block. It would be advisable in future investigations to use more sophisticated methods of testing loss of sensation, both taction and kinesthesis. EMG should be used, in addition, to check motor function.

CHAPTER VI

SUMMARY

This dissertation must be viewed as a juxtaposition of three separate but related experiments, which are as interesting in contrast as they are in comparison.

The perceptual study indicated something of the phonetic nature of the speech effect under nerve block. The effect of bilateral mandibular injections of 2% Xylocaine on the speech of normal adults was found to be subtle and limited to certain phonemes demanding rapid and precise gestures. The distortions were most prominent on /s/ in consonant clusters. One notable finding not mentioned in previous literature was the subject to subject variability. Although all 7 subjects reported loss of oral sensation, the effect on speech ranged from no effect in one speaker to a significant number of speech distortions in another speaker, with much variation among subjects in between the two extremes.

By comparing the perceptual study with the first electromyographic study, it was noted that the phonemes vulnerable to speech breakdown corresponded for the most part with high suprahyoid muscle activity during the normal run. When the anesthesia took effect, however, two muscles became inactive. It was determined that the two muscles, the mylohyoid and the anterior belly of the digastric, were innervated by the mylohyoid nerve, motor nerve fibers which branched off from the otherwise sensory inferior alveolar branch of the trigeminal nerve. The temporary motor "paralysis" seemed clearly the result of infiltration of the anesthesia into the mylohyoid nerve. It was concluded that a motor component existed in what was previously assumed to be a sensory deprivation and that the speech effect was caused by sensory loss, motor loss, or both.

The second electromyographic experiment, in contrast with the first, revealed a unilateral decrease in mylohyoid and anterior digastric muscle activity with the other side showing more than normal activity during nerve block, presumably as compensatory action. The speech of the second subject remained undistorted, reinforcing the possibility that motor incapacity may have played an important part in reported instances of speech distortion under nerve block conditions. A second possibility is individual variation in dependence upon sensory feedback. Some speakers may need information on lingual movement and position which other speakers do not need. A third possible explanation of the speech effect might be a combination of a motor incapacity and a dependence on mylohyoid muscle activity for the affected consonants. A speaker who produces /s/ with the tongue tip down may need the mylohyoid muscle to raise the tongue body for the necessary friction more than would the speaker who raises the tip of the tongue for the friction.

Future research should be directed toward separating the possible contributions of motor and of sensory feedback in producing the distortions of speech under nerve block conditions. It would be interesting to inject anesthesia into the mylohyoid nerve alone, producing a purely motor block, to see what effect it would have upon speech. Alternatively, the anesthesia could be inserted into the lingual nerve, producing a purely sensory block in order to investigate the effect upon speech. Recording the electrical potential from the intrinsic muscles of the tongue as well as the more extrinsic muscles would be informative despite the complexity of some of the intrinsic muscle fibers. It would also be helpful to record the muscle activity as the anesthesia is taking effect and wearing off.

Finally, the question of afferent control in speech might be further illuminated by comparing the speech of skilled speakers with the same speakers learning new phonemes or with children still unskilled in speech, to see if unskilled speakers develop into skilled speakers with a progression of relative importance of peripheral control as opposed to central control. Any comprehensive study of afferent control systems should include auditory masking as well as oral sensory deprivation to explore the use of separate channels and the possibility of channel switching.

APPENDICES

APPENDIX A

PILOT STUDY I

The subjects were two 38-year old males and a 4-year old male. The child is the son of one of the older subjects; the other adult subject stutters. The subjects listened to a taped male speaker reading a balanced CVC list of 204 words with an alerting tone. The repetitions of these words by the subjects were recorded on tape under three conditions. Condition (1) was the normal auditory feedback and normal tactile and proprioceptive feedback. For condition (2) a separate tape was prepared with a copy of the master tape of the words to which white noise was added on the left channel for delivery through earphones to mask the subjects' responses. The right channel had additional white noise to deliver through a bone vibrator to mask the lower frequencies of the subjects' responses. Condition (3) involved responding to the original tape, the subjects having been injected on each side of the mandible with 2% Xylocaine which blocks the buccal, lingual, and inferior dental nerves of the third branch of the trigeminal nerve. A dentist performed the nerve blocks. Sensation from the anterior 2/3rds of the tongue was eliminated.

This is McCroskey's method. The infraorbital block was considered by the author to be unnecessarily painful while adding little proprioceptive information, only tactile information from the palate and was not used.

Phonetic transcriptions were made of the 204 CVC words for each subject under each of the three conditions. Confusion matrices were plotted for articulatory distortions under the condition of anesthesia.

The results of this pilot study ere:

1. Under condition (2) auditory masking, vowels were often prolonged relative to condition (1), normal feedback.

2. Under condition (3) nerve block, distortions were observed in fricatives and consonant clusters.

These confusions were observed to be less frequent in the responses of the child.

CVC LIST FOR PILOT STUDY I

1. help	22. zag	43. stoops	64. booth
2. pledge	23. reach	44. bilk	65. wreathe
3. weave	24. stock	45. hulk	66. gasp
4. lips	25. thief	46. jog	67. smoothe
5. wreath	26. coop	47. shook	68. feast
6. felt	27. theme	48. plume	69. jest
7. zest	28. cult	49. thatch	70. chief
8. crisp	29. stood	50. zig	71. god
9. touch	30. these	51. teeth	72. clang
10. palp	31. vat	52. moot	73. dune
11. stash	32. hoof	53. foot's	74. wasp
12. niece	33. clog	54. jeeps	75. heath
13. soothe	34. move	55. leave	76. tooth
14. ding	35. puss	56. van	77. lodge
15. that's	36. doom	57. cheese	78. jam
16. mesh	37. talk	58. vets	79. roof
17. deep	38. shoes	59. loops	80. gap
18. badge	39. smooch	60. pooch	81. shove
19. belk	40. hook	61. mash	82. plebe
20. gulp	41. took	62. scalp	83. than
21. stilt	42. teethe	63. thud	84. dab

<u>CVC LIST</u> (cont'd.)

85. choose
86. thing
87. puts
88. hood
89. fun
90. sting
91. knelt
92. please
93. this
94. that
95. dub
96. vast
97. clash
98. soot
99. sheath
100. stop
101. cob
102. zen
103. push
104. cleave
105. mops
106. hasp
107. them
108. good
109. fuzz
110. smith
111. tots
112. such
113. veldt
114. culp
115. wisp
116. guest
117. bulk
118. silk
119. moose
120. smut
121. soup
122. fez
123. bing
124. jots
125. shoots
126. with
127. noose
128. chin
129. rib
130. plot
131. book
132. milk
133. vest
134. give
135. then
136. plug
137. knob
138. cook
139. love
140. posh
141. lisp
142. nest
143. sulk
144. zips
145. would
146. tube
147. chap
148. put
149. rook
150. loom
151. judge
152. breathe
153. whelp
154. smash
155. zing
156. could
157. mob
158. clasp
159. smudge
160. kilt
161. thing
162. fig
163. death
164. goose
165. thus
166. smelt
167. nudge
168. welt
169. chops
170. vim
171. vet
172. zip

CVC LIST (cont'd.)

173. plop
174. smug
175. foot
176. chest
177. should
178. clots
179. rasp
180. shops
181. pulp
182. wedge
183. hatch
184. says
185. watch
186. kelp
187. sheathe
188. bush
189. juice
190. thieve
191. chaff
192. stuff
193. seethe
194. gin
195. zoom
196. cliff
197. plod
198. rough
199. nook
200. dodge
201. thug
202. clings
203. news
204. look

JCB FATHER

Initial Consonants Nerve Block

	f	v	θ	ð	s	z	st	sm	other
f	8								
v	1	7							
θ			7		1				
ð		1		7					
s			4		4				
z				1		7			
st					3		5		
sm								7	1 /ʃm/

Final Consonants Nerve Block

	t	f	θ	s	z	ʃ	tʃ	dʒ	st	sp	ps	ts	lk	lt	other
t	6		2												
f		6	1	1											
θ			7	1											
s			1	6		1									
z				1	7										
ʃ						8									
tʃ						1	7								
dʒ								7							1 /dz/
st									7						1 /ʃt/
sp										6					2 /s^{θ}p/
ps											6				2 /ps^{θ}/
ts												7			1 /ts^{θ}/
lk													7		1 /θk/
lt														7	1 /lt^{s}/

Figure 23

Consonant Confusion: JCB Father

JCB SON

Initial Consonants Nerve Block

	f	v	θ	ð	s	z	st	sm	dʒ	other
f	8									
v		8								
θ	1		7							
ð				8						
s					7					1 $s^ʃ$
z						6				2 ʒ
st					1		5			2 ʃt
sm								7		1 ʃm
dʒ									7	1 ʃ

Final Consonants Nerve Block

	t	f	θ	s	z	ʃ	tʃ	dʒ	st	sp	ps	lk	lt	ts	other
t	7														1 /ʔ/
f		8													
θ		2	6												
s				8											
z					8										
ʃ						8									
tʃ							8								
dʒ								8							
st									8						
sp									1	7					
ps											8				
lk												5			3 /k/
lt													8		
ts														8	

Figure 24

Consonant Confusion: JCB Son

A.H.S.

Initial Consonants Nerve Block

	f	v	θ	ð	s	z	st	sm	other
f	7		1						
v		8							
θ			8						
ð		5		3					
s					8				
z						8			
st							6		/ʃt/ 2
sm								5	/ʃm/ 3

Final Consonants Nerve Block

	t	f	θ	s	z	ʃ	tʃ	dʒ	st	sp	ps	lk	lt	other
t	8													
f		8												
θ		1	7											
s				6		1								/ʒ/ 1
z					8									
ʃ						8								
tʃ							8							
dʒ								7						/ʒ/ 1
st									8					
sp										6				/ʃp/ /θp/
ps											7			/pʃ/
lk												8		
lt													8	

Figure 25

Consonant Confusion: A.H.S.

PILOT STUDY II

The first pilot study had revealed mild distortions with certain phonemes and it was thought that the CVC list did not give enough information about the particular phonemes involved, the fricatives. A list which would test the fricatives in greater depth was sought. It was also considered that a picture test would most accurately elicit the normal speech of the subjects. Templin found no significant difference between imitative and spontaneous methods in testing 100 normal 2-6-year old children.[1] More recent studies have indicated, however, that certain phonemes are produced correctly by significantly more children in the imitative condition,[2] and pictures elicit more errors.[3] The McDonald test was considered but the author tried it out on several 4-year old children who failed to join the word pairs consistently. A test of 151 pictures on 3 x 4 inch cards was constructed and

---

[1] M.C. Templin, <u>Certain Language Skills in Children</u>, Inst. of Child Welfare Monograph No. 26 (Minn: University of Minnesota Press, 1957).

[2] G. M. Seigal, H. Winitz and H. Conkey, "The Influence of Testing Instruments on Articulatory Responses of Children," <u>J. Speech Hear. Dis</u>., 28, 1963, 67-76.

[3] M. W. Smith and S. Ainsworth, "The Effects of Three Types of Stimulation on Articulatory Responses of Speech Defective Children," <u>J. Speech Hear. Res</u>., 1967, 333-338.

assembled on six rings to facilitate flipping the cards over and maintaining the order which was previously randomized.

The subjects for this pilot study were originally three 4-year old boys and their fathers, but one father did not complete the study. One of the father-son pairs was the same as in the first pilot study.

The experimenter flipped each set of cards and said the words which were the desired responses before each test. Condition (1) was normal feedback. Condition (2) was the bimandibular block. The auditory masking condition was eliminated because the level of noise necessary to completely eliminate the low frequencies in the subjects' responses was uncomfortably high even when the subject monitored his voice with the VU meter to keep it from overriding. Another reason for the elimination of this condition was a shift of interest on the part of the author from the study of the relative importance of auditory and proprioceptive feedback in children and adults to a study of the specific phonemic confusions caused by lack of proprioceptive feedback in children and in adults.

Two of the three children showed very little effect of the nerve block. The third child showed some loss of sharpness on tongue tip sounds and fricatives and the loss of sensation in the lips affected his labials and labio-dentals. The father, who was new to this study, showed less effect than the first father; marked distortions observed only on /f/, /t/, /tʃ/, /s/, and some of the clusters.

Phonetic transcriptions and confusion matrices were not made for these tapes as the experimenter could tell by listening that the differences between this test and the CVC list used in the first pilot study were insignificant. It became obvious from the deterioration of articulation in the samples of natural, connected speech on tapes from both the first and the second pilot studies that the only type of material which would give adequate information on the effect of proprioceptive deprivation on speech would be connected speech.

PICTURE LIST FOR PILOT TEST II

teeth	vanilla	chickens	spring
scissors	Casper	splash	toast
scratch	ghost	glass	fishing
garage	Thanksgiving	vine	seven
school	straw	books	thread
cats	chair	mouth	cage
whiskers	throw	lips	glove
shoe	bathroom	nose	zebra
box	stamps	breathe	bicycle
mother	shovels	knife	spill
sweeping	sled	presents	teacher
washing	face	father	laughing
taxi	grapes	brother	sleeping
razor	slide	sister	telephone
soldier	matches	stove	garbage
smoke	giraffe	xylaphone	tablespoon
nails	frog	five	TV
baskets	pants	church	smell
snake	jelly	feather	spider
string	whistle	Earth	smile
mask	sky	blocks	bridge

PICTURE LIST FOR PILOT TEST II (cont'd.)

left	thank you
jumped	pajamas
thirsty	fixed
leaf	next
squirrel	birthday
thumb	desk
sheep	shirt
kitchen	sandwich
toothbrush	rooster
bathtub	spoon
stairs	mouse
pictures	cheese
dishes	next
engine	grasp
first	zipper
star	snow
valentine	sweater
pencil	wasp
sneeze	orange
give	fish
flag	month

APPENDIX B

REVIEW OF TONGUE MUSCLES

Possible Contributors to Tongue Elevation for the /s/ Effect

(According to Van Riper and Irwin, and Zemlin)

I. Intrinsic Muscles of the Tongue

Superior Longitudinal m. Some of the lateral fibers may help

Origin: Base of tongue
Course: Horizontally anteriorly
Insertion: Tip of tongue
Innervation: Hypoglossal (M) Trigeminal (S)
Function: Shortens tongue, turns up tip

Inferior Longitudinal m. May pull the tip down a bit

Origin: Base of tongue, laterally on either side
Course: Horizontally anteriorward
Insertion: Tip of tongue
Innervation: Hypoglossal (M) Trigeminal (S)
Function: Shortens tongue or turns tip down

Transverse m. May groove tongue by lifting lateral margins

Origin: Median raphe of tongue
Course: Laterally
Insertion: Submucous tissue at lateral margin
Innervation: Hypoglossal (M) Trigeminal (S)
Function: Narrows the tongue

Vertical m. May groove or flatten middle area of tongue

Origin: Dorsum of tongue
Course: Vertically downward
Insertion: Sides and base of tongue
Innervation: Hypoglossal (M) Trigeminal (S)
Function: Flattens the tongue

II. Extrinsic Muscles of the Tongue

Genioglossus m. May raise tongue forward and up, elevating hyoid

Origin: Mental spine of the mandible
Course: Posteriorly, radiating as it courses
Insertion: Superior fibers insert into tongue from root to tip, middle fibers into sides of pharynx, and inferior fibers into the body of hyoid bone.
Innervation: Hypoglossal (M) Trigeminal (S)
Function: Protrudes tongue, depresses tongue, or elevates hyoid bone.

Styloglossus m. May elevate and groove dorsum

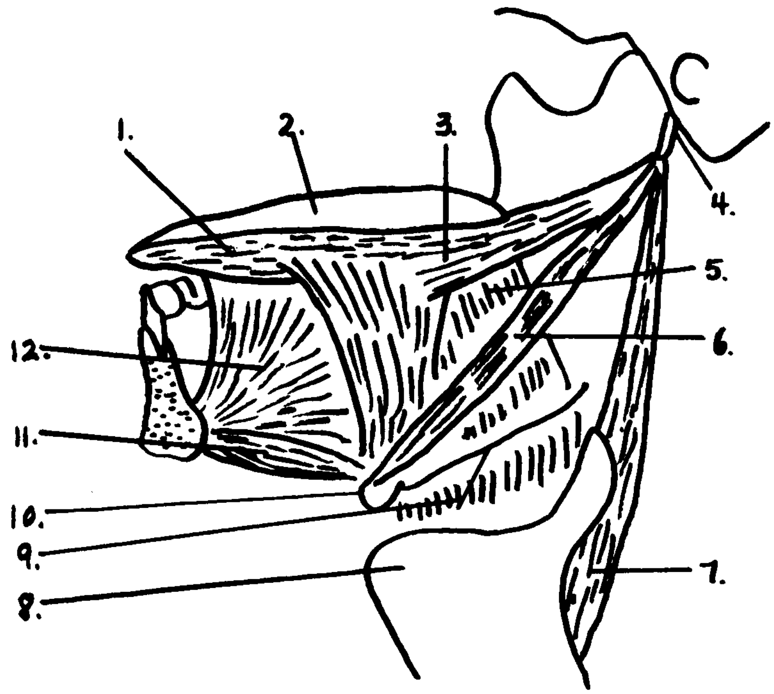
Origin: Styloid process and from ligament connecting styloid process to hyoid bone
Course: Down and anteriorly
Insertion: Sides of tongue and some to tip to retract tongue when moved forward as for plosives
Innervation: Hypoglossal (M) Trigeminal (S)
Function: Elevates and retracts tongue, grooves dorsum

Hyoglossus m. Probably not a contributing muscle

Origin: Body and greater cornu of hyoid bone
Course: Vertically, radiating as it courses
Insertion: Into the tongue at the sides
Innervation: Hypoglossal (M) Glossopharyngeal and/or Trigeminal (S)
Funcetion: Lowers tongue

Palatoglossus m. Probably not a contributing muscle

Origin: Inferior surface of soft palate, anteriorly
Course: Down and laterally
Insertion: Sides of tongue
Function: Raises back of tongue or lowers soft palate



1.	Inferior longitudinal	7.	Stylopharyngeus
2.	Dorsum of tongue	8.	Thyroid cartilage
3.	Styloglossus	9.	Greater cornu
4.	Styloid process	10.	Hyoid bone
5.	Hyoglossus	11.	Geniohyoid
6.	Stylohyoid	12.	Genioglossus

Figure 26

Schematic of Extrinsic Tongue Musculature and

Some Associated Structures

Source: Zemlin, 281.

III. Suprahyoid Muscles: Elevate Hyoid

Digastric m. Anterior belly may be active in /s/

Origin: Inner surface of mandible near symphysis
Course: Down and posteriorly
Insertion: Intermediate tendon at hyoid bone
Innervation: Mylohyoid n.
Function: Depresses jaw or elevates hyoid forward

Digastricus m. (Posterior belly) Probably does not contribute

Origin: Mastoid process
Course: Down and anteriorly
Insertion: Hyoid bone and intermediate tendon
Innervation: Facial nerve
Function: Elevates and retracts hyoid bone

Mylohyoid m. Unpaired muscle which forms floor of mouth

Origin: Mylohyoid line
Course: Trough-like sheet, medially and posteriorly
Insertion: Median raphe anteriorly and hyoid bone posteriorly
Innervation: Mylohyoid nerve
Function: Elevates hyoid bone and tongue

Geniohyoid m.

Origin: Mental spine of mandible superior to mylohyoid
Course: Backward and downward
Insertion: Body of hyoid bone
Innervation: C1 and C2
Function: Elevates and draws hyoid bone forward, depress jaw

Stylohyoid m. Probably not contributing to /s/ effect

Origin: Styloid process
Course: Down and anteriorly
Insertion: Hyoid bone
Function: Elevates hyoid bone

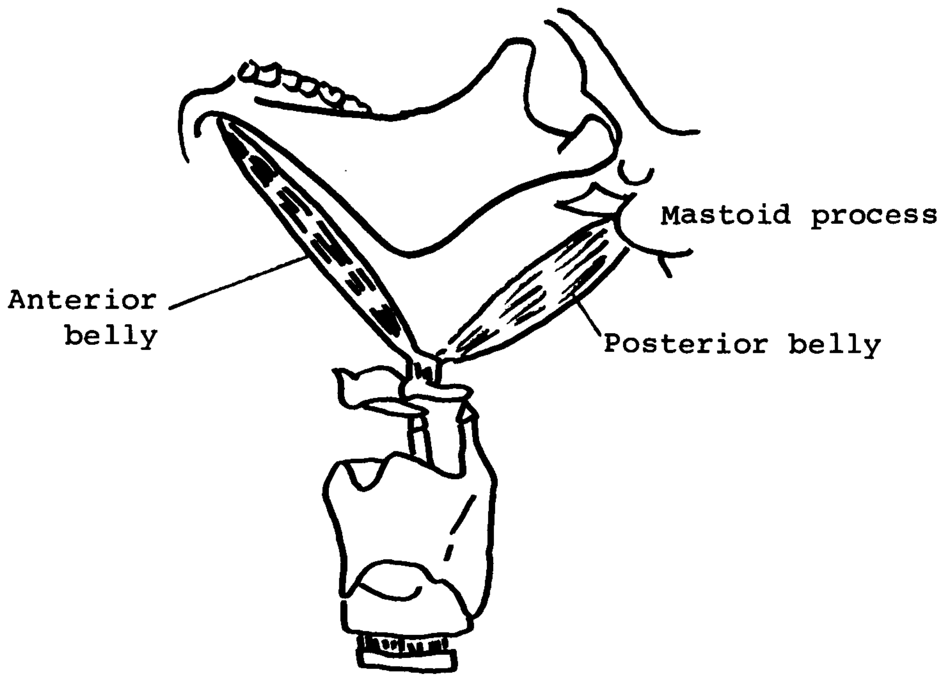


Figure 27

Schematic of Digastric Muscle

Source: Zemlin, p. 141.

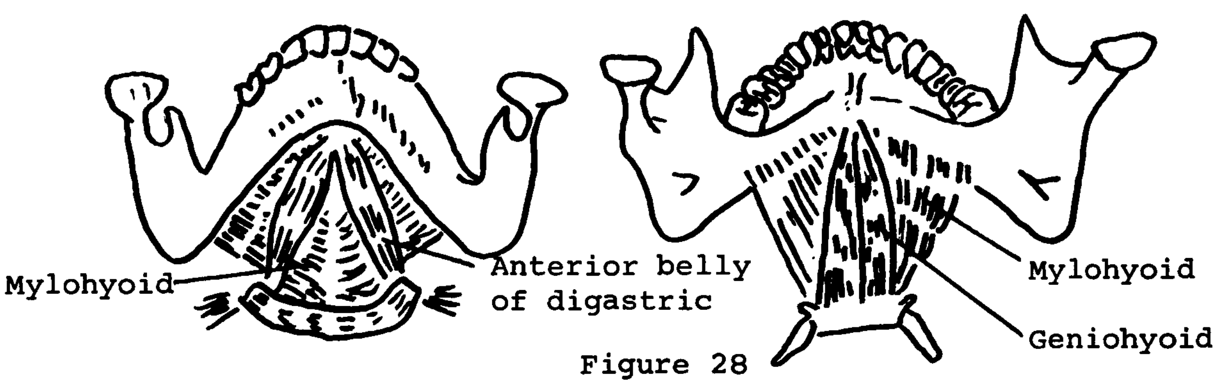


Figure 28

Schematic of Mylohyoid and Geniohyoid Muscles

Source: Zemlin, p. 142.

IV. Infrahyoid Muscles

(Probably do not contribute since they depress laryngeal structure.)

V. Muscles of Mastication

External pterygoid m. Protracts mandible and may assist in /s/

Origins: Greater wing of sphenoid and lateral pterygoid plate
Course: Horizontally back, converging
Insertion: Condyle of mandible
Innervation: Trigeminal V3
Function: Protracts mandible

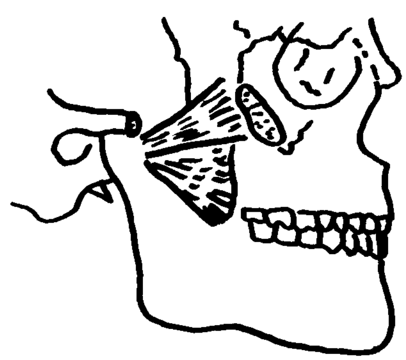


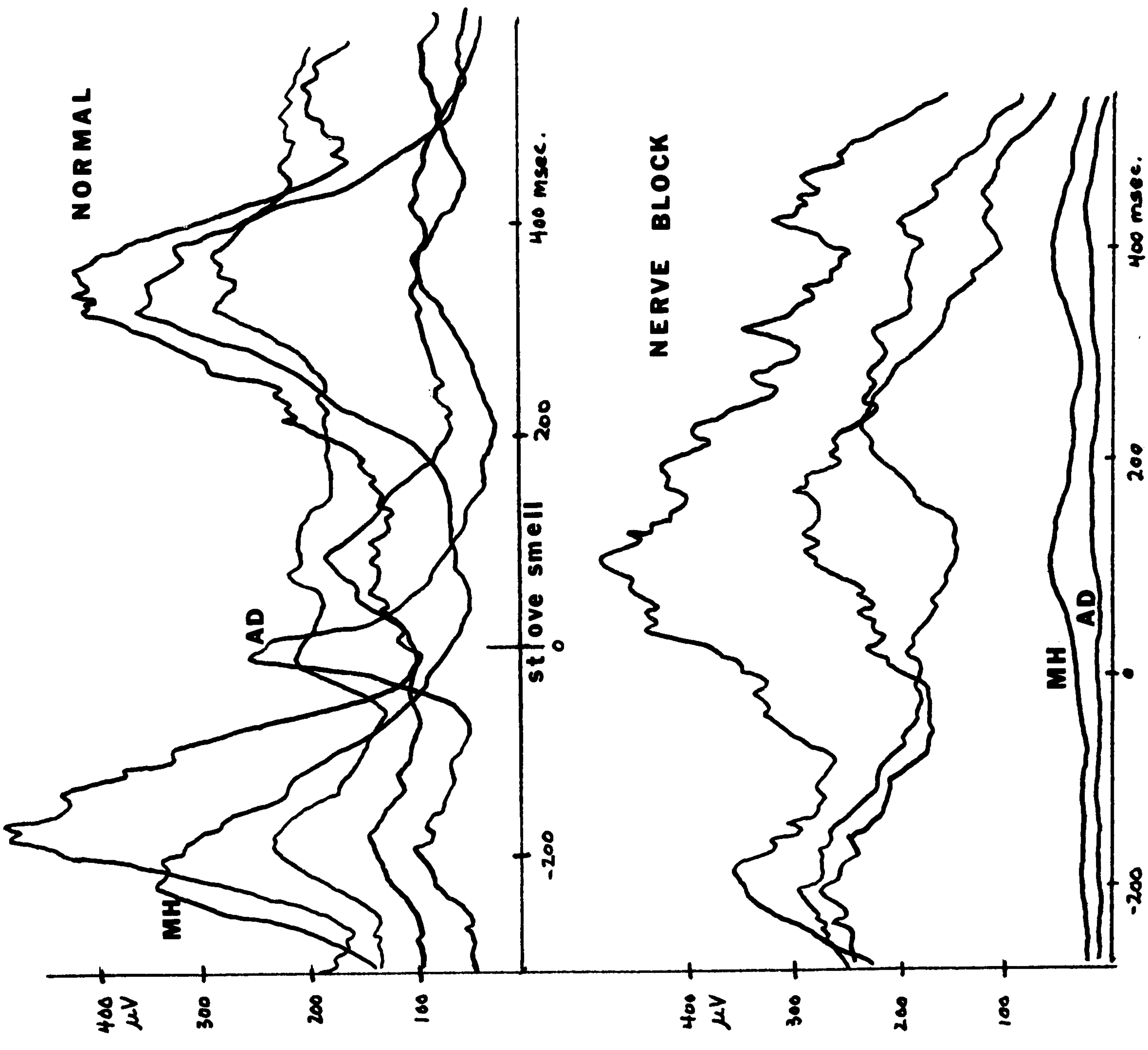
Figure 29

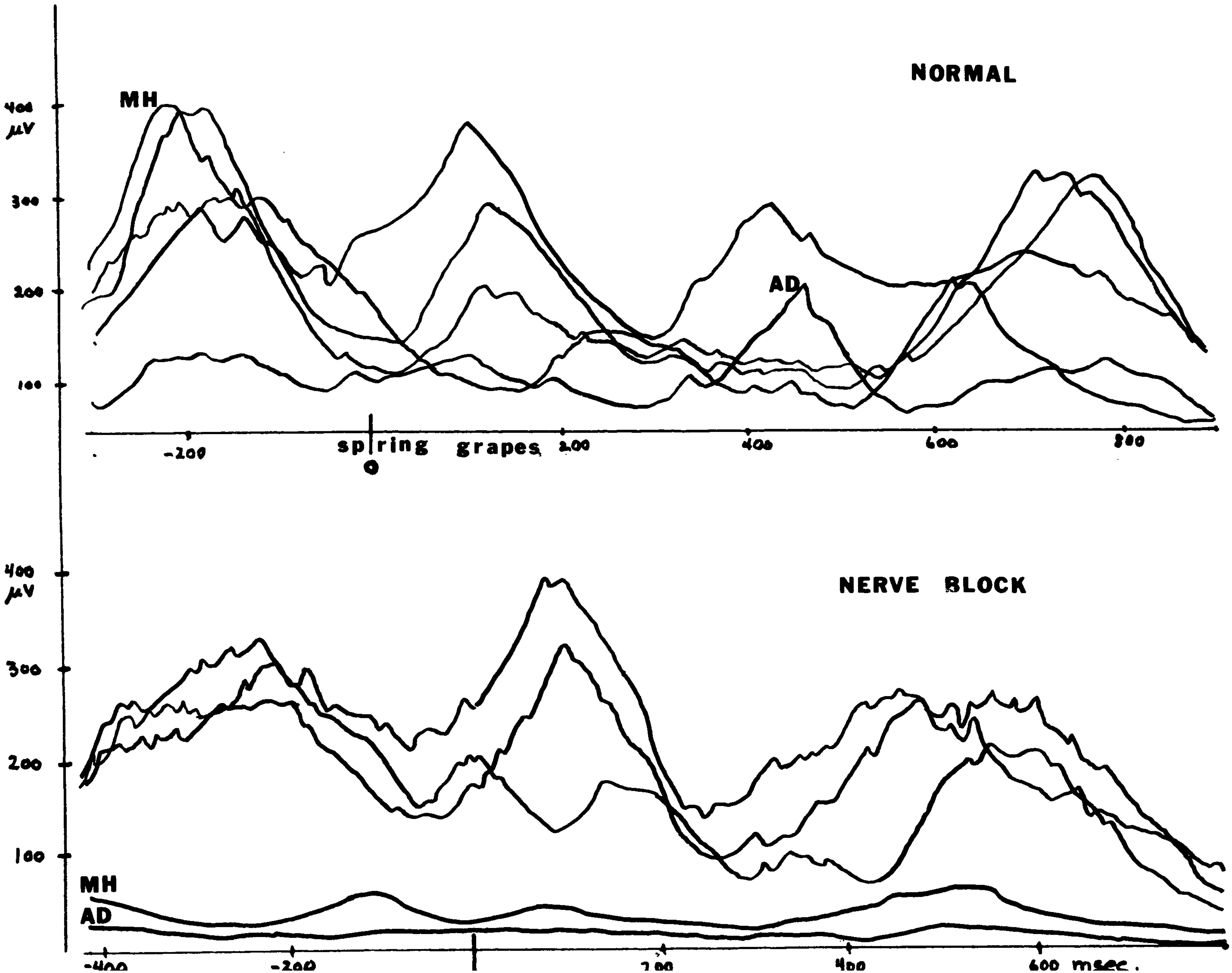
Schematic of External Pterygoid m.

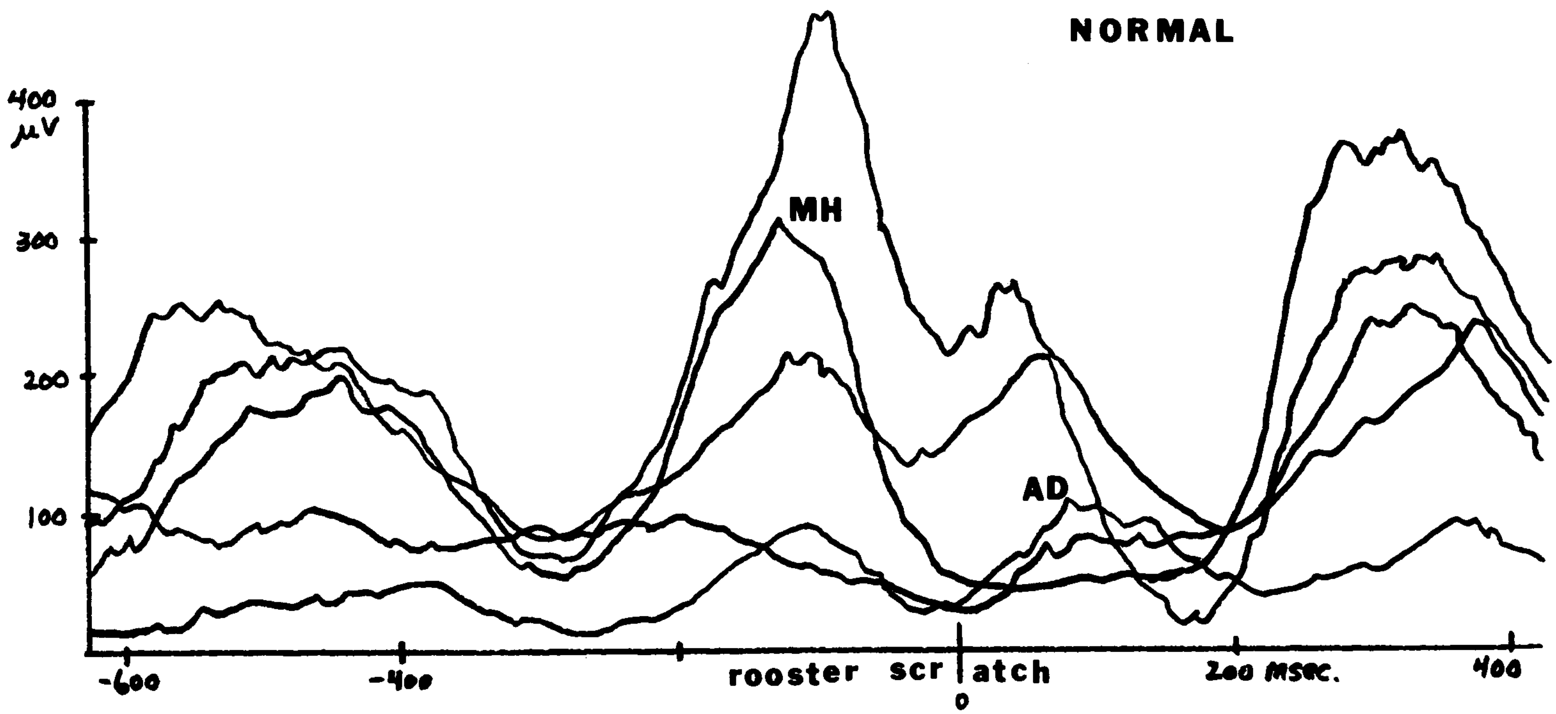
Source: Zemlin, p. 293.

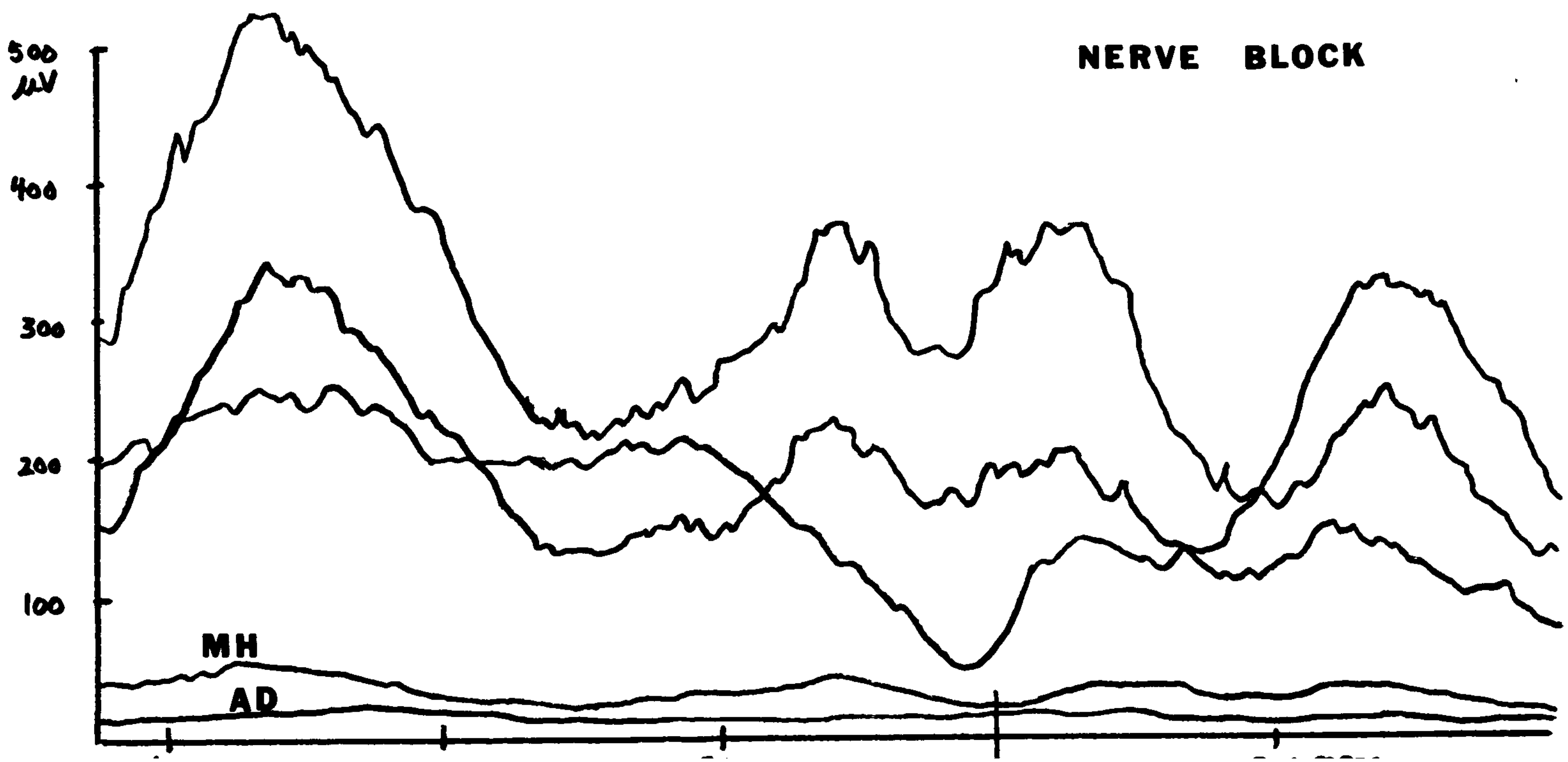
APPENDIX C

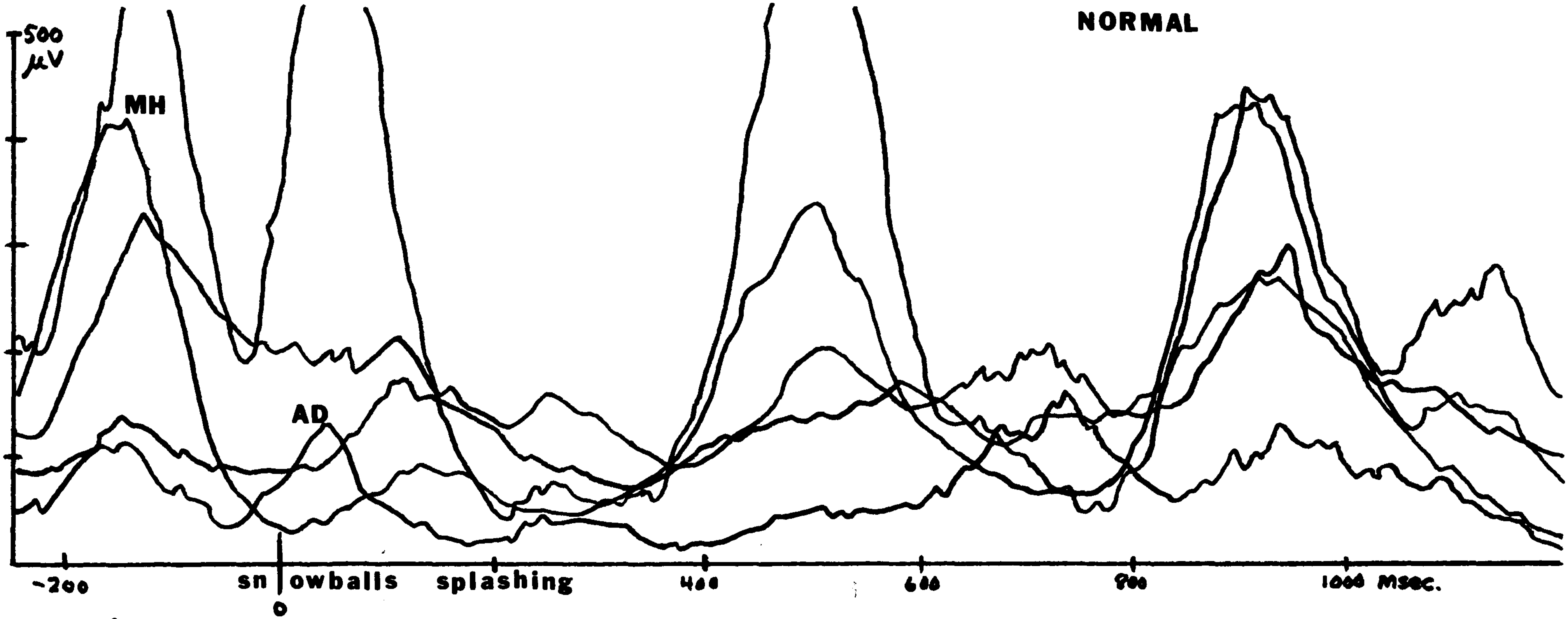
EMG GRAPHS FIRST STUDY

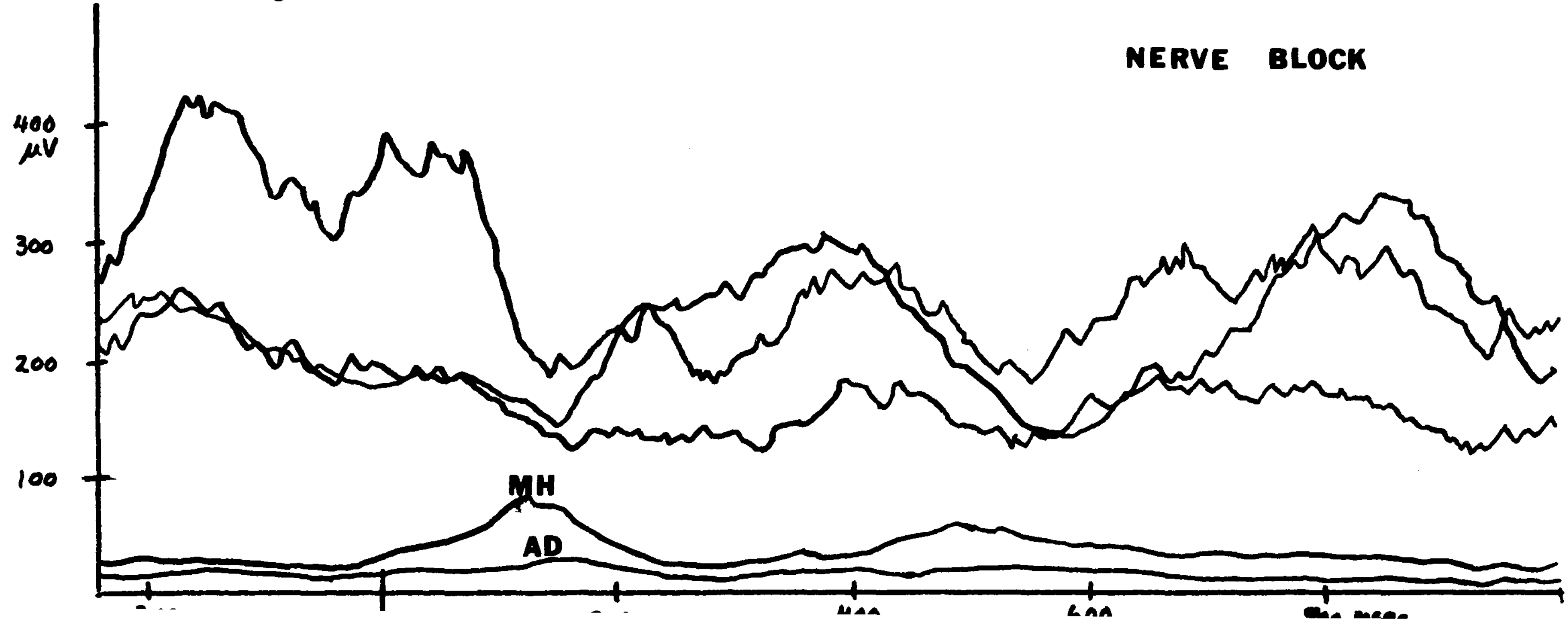


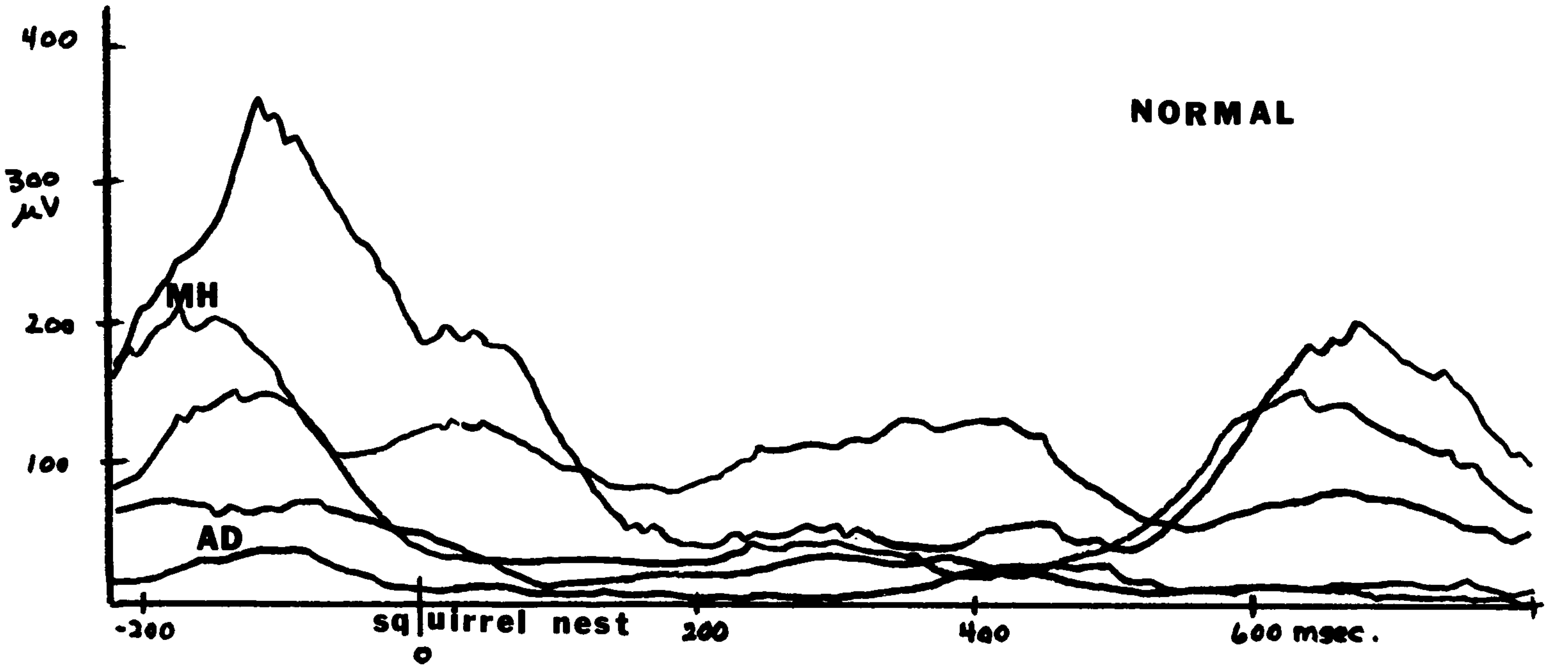

NORMAL
MH
AD
400 µV
300
200
100
-200
spring grapes
0
200
400
600
800
NERVE BLOCK
400 µV
300
200
100
MH
AD
-400
-200
200
400
600 msec.

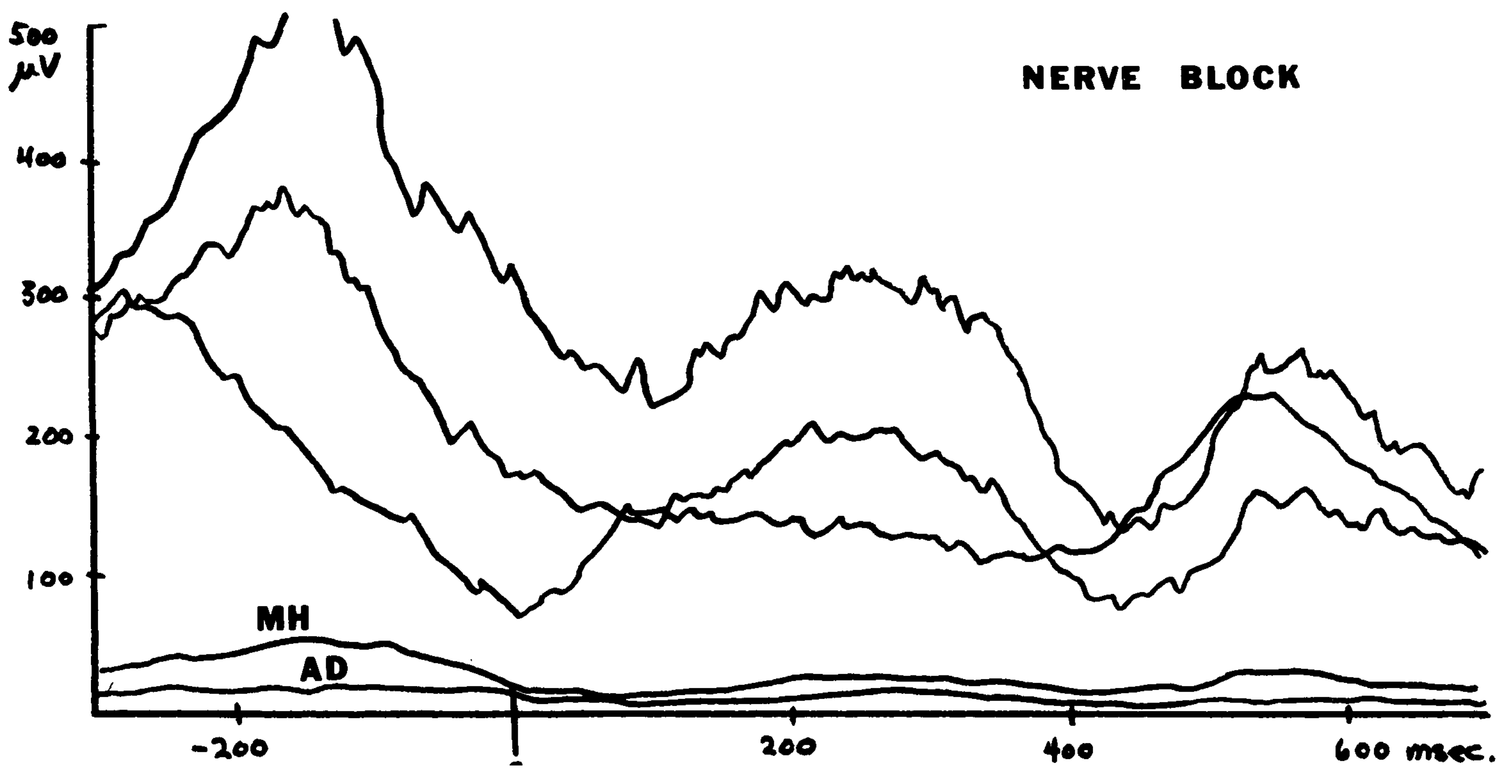

NORMAL
400 μV
300
200
100
MH
AD
-600
-400
rooster scr | atch
0
200 MSec.
400

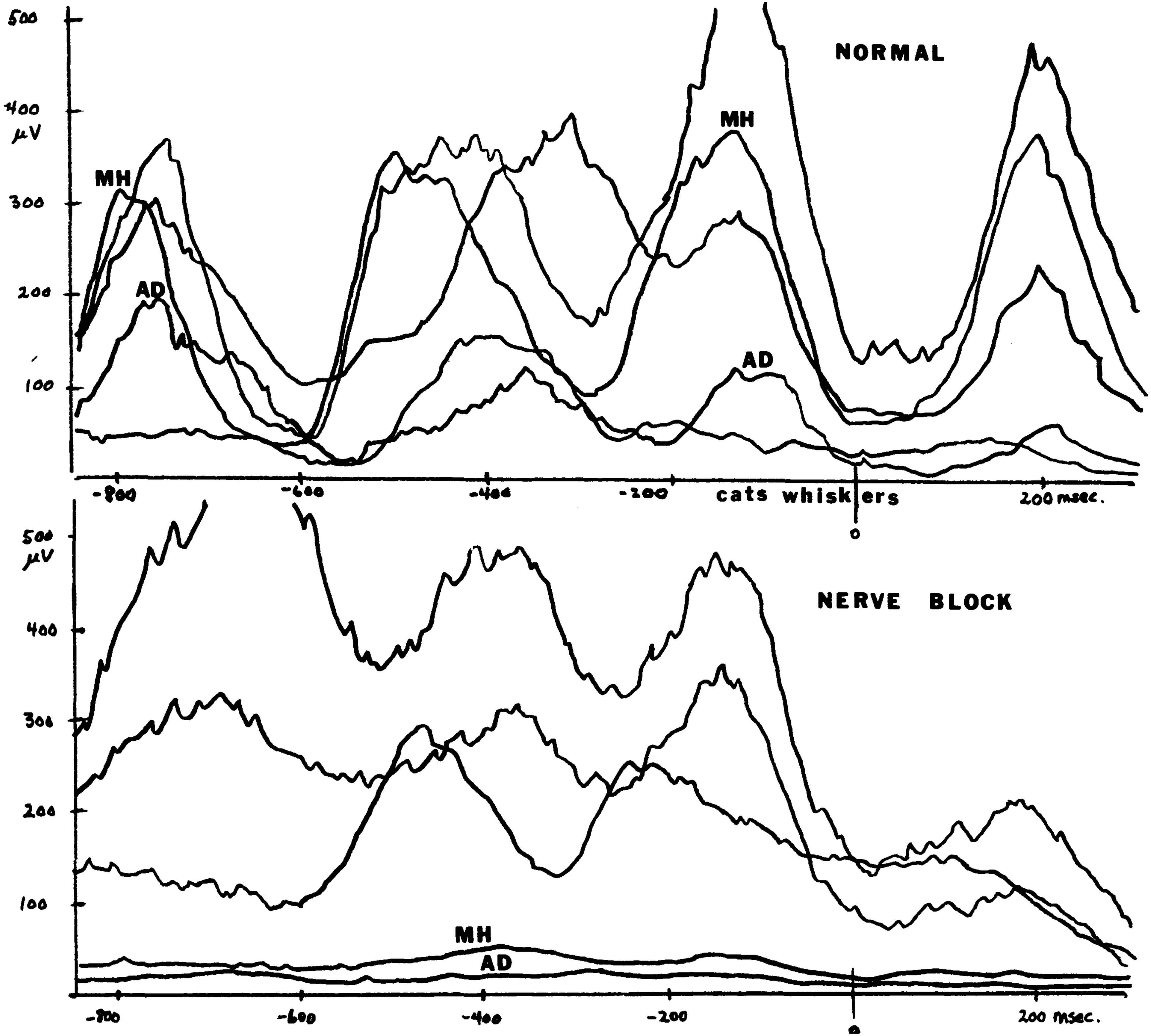

NERVE BLOCK
500 μV
400
300
200
100
MH
AD

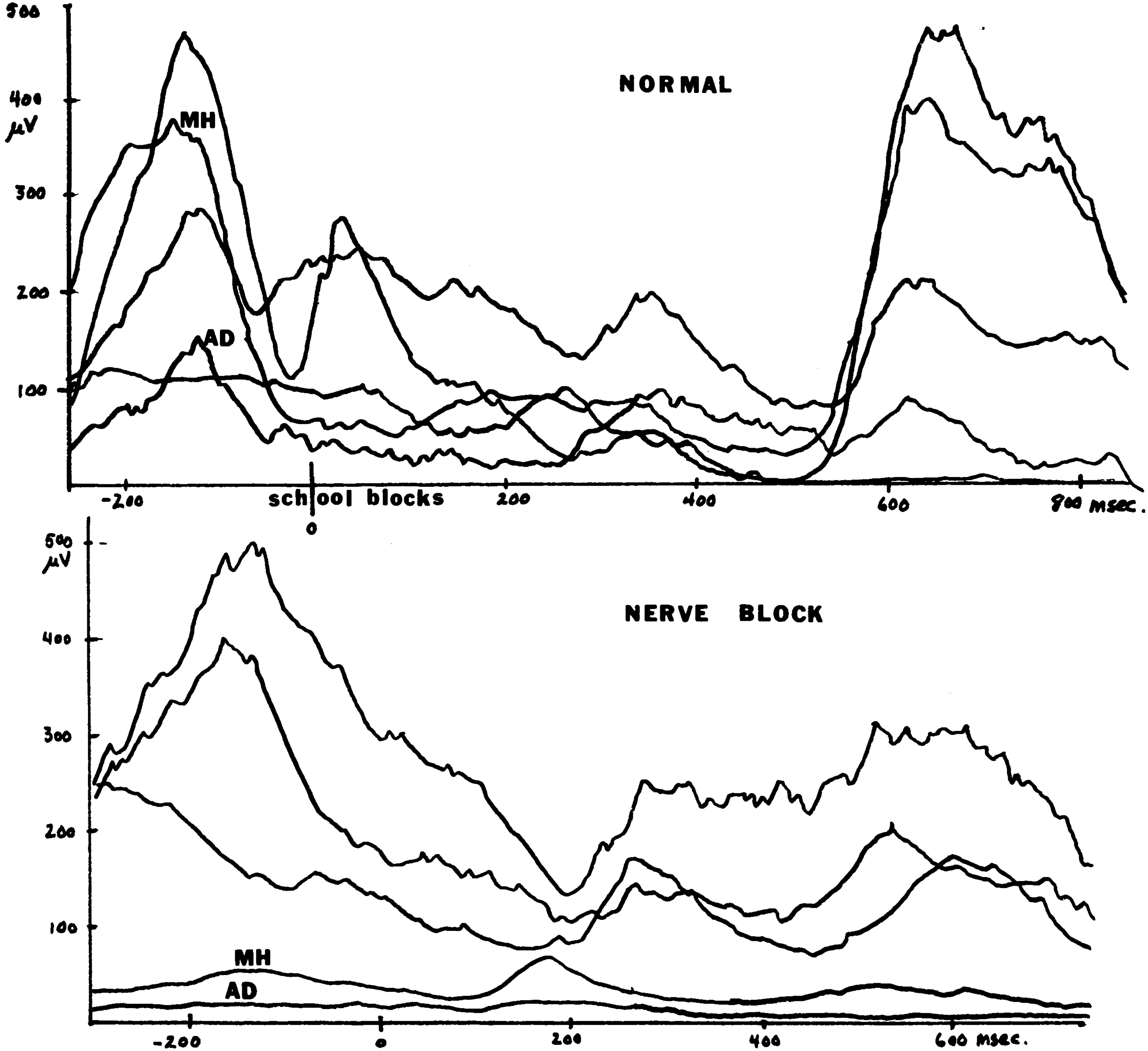

NORMAL
500
μV
MH
AD
-200
sn owballs splashing
0
400
600
800
1000 msec.


NERVE BLOCK
400
μV
300
200
100
MH
AD

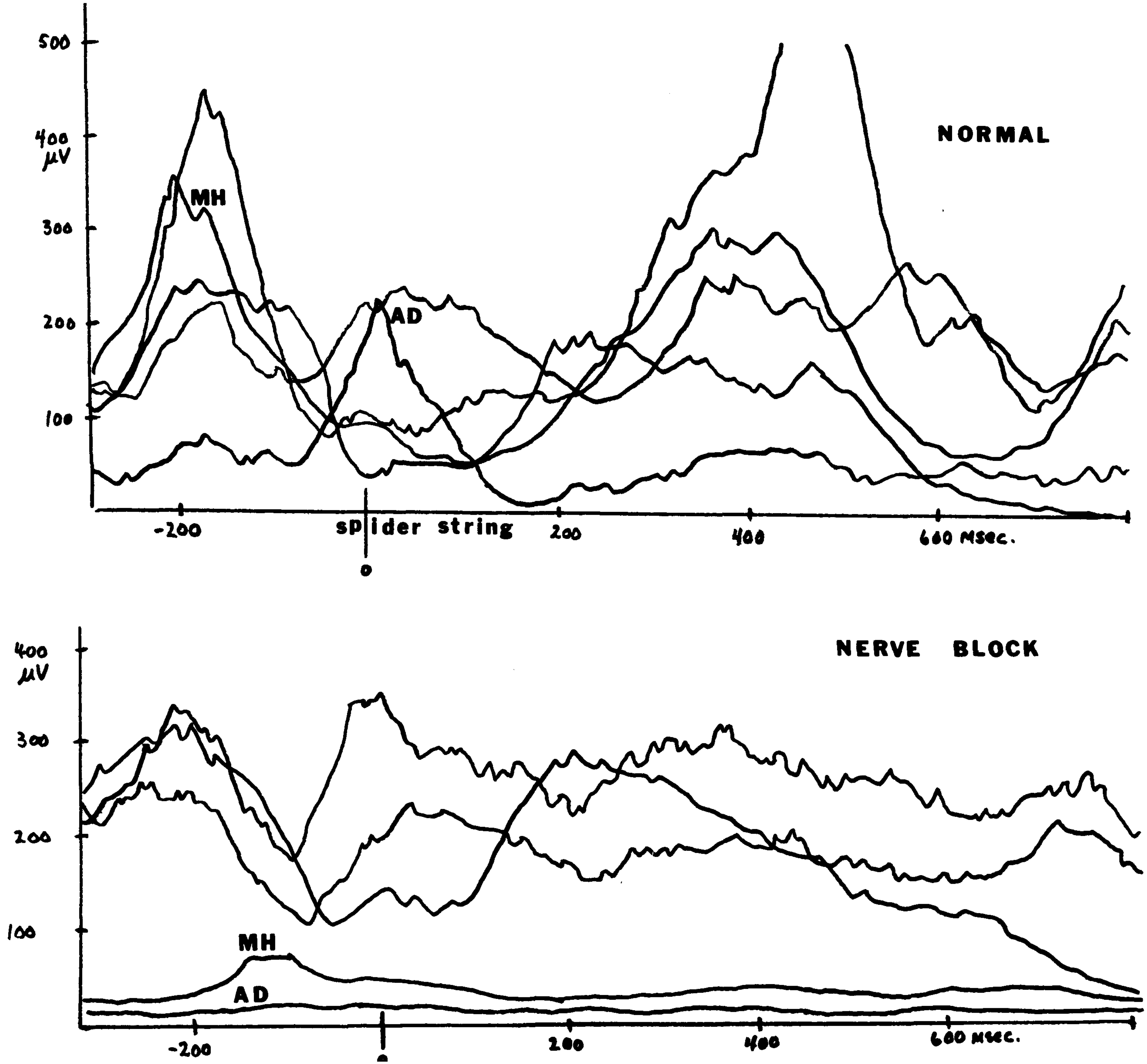

400
300 µV
200
100
NORMAL
MH
AD
-200
squirrel nest
0
200
400
600 msec.

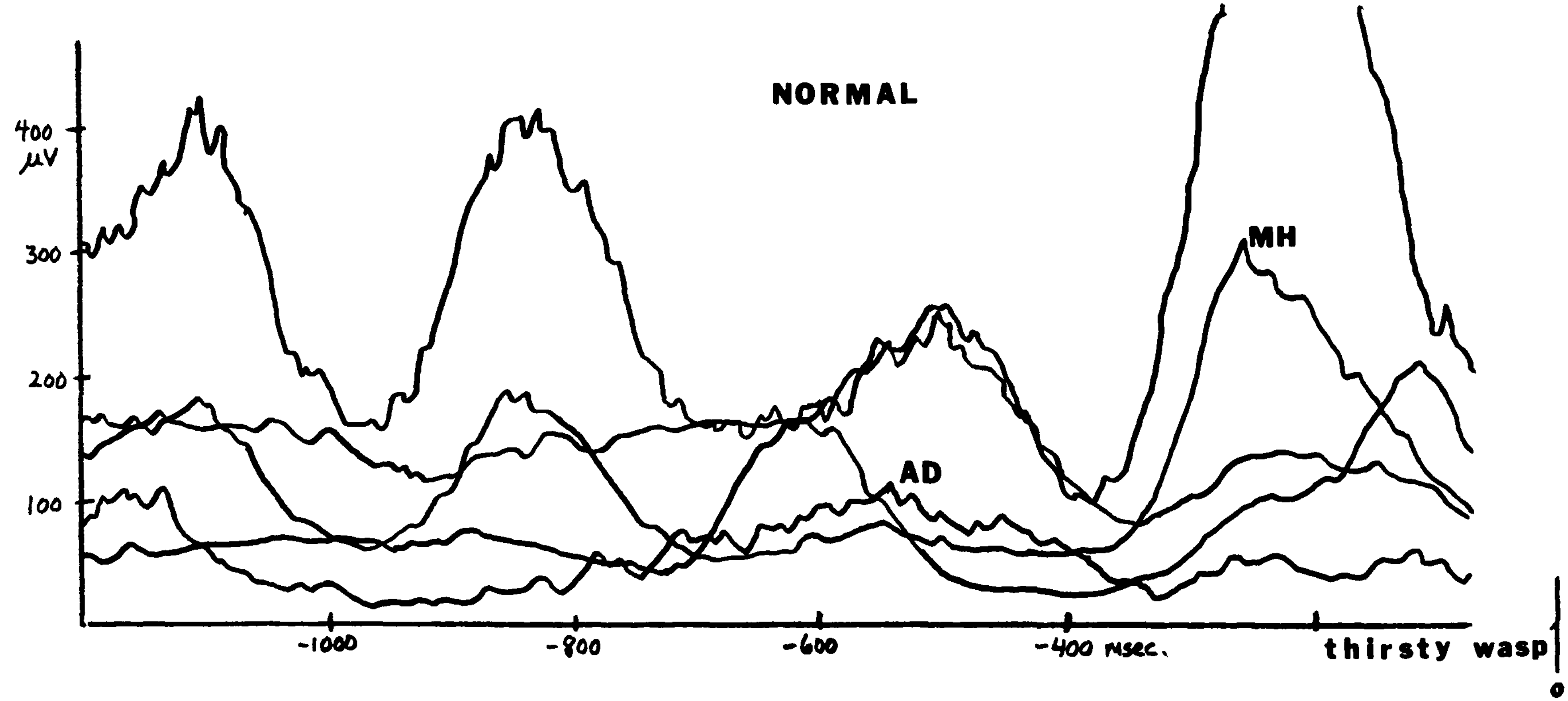

500 µV
400
300
200
100
NERVE BLOCK
MH
AD
-200
200
400
600 msec.

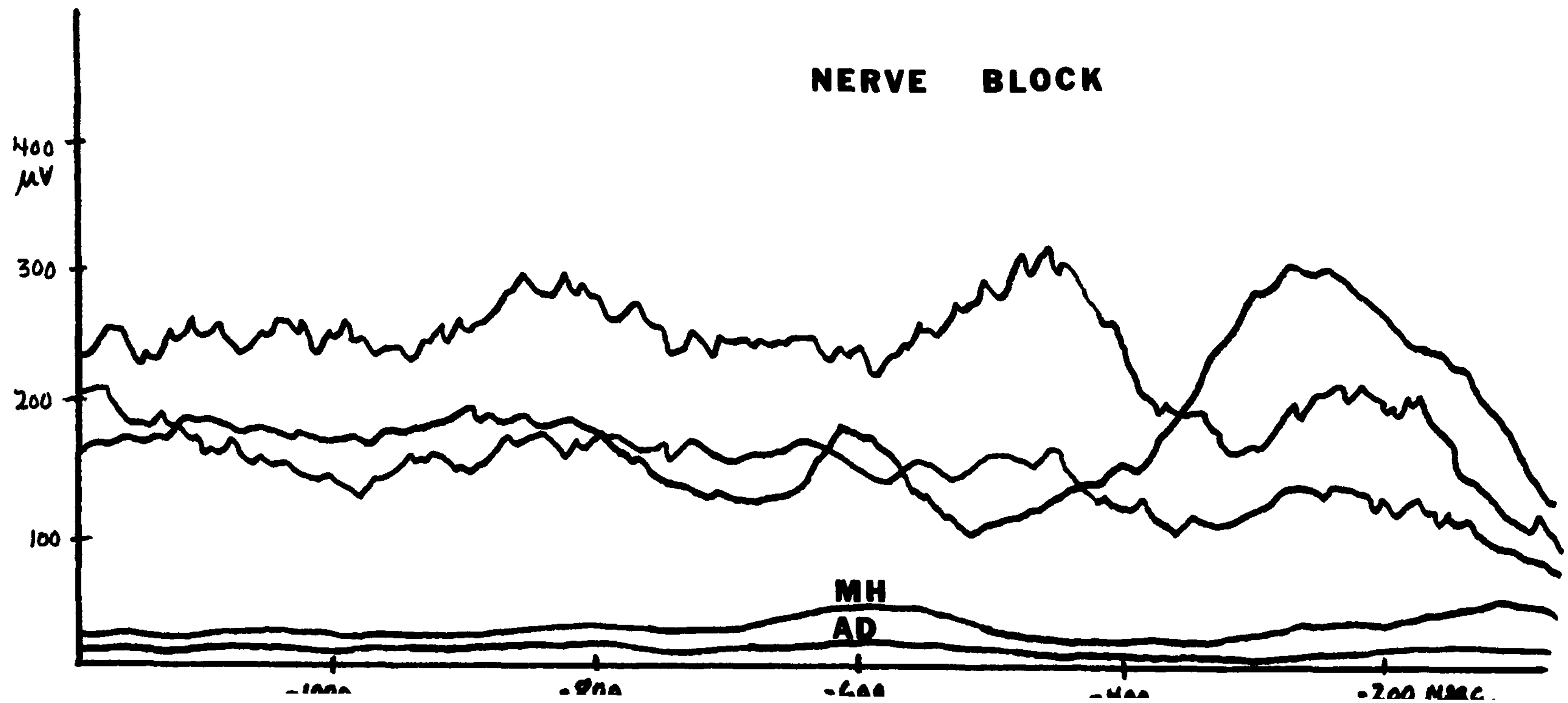

NORMAL
MH
AD
MH
AD
500
400
µV
300
200
100
-800
-600
-400
-200
cats whiskers
0
200 msec.
NERVE BLOCK
500
µV
400
300
200
100
MH
AD
-800
-600
-400
-200
0
200 msec.

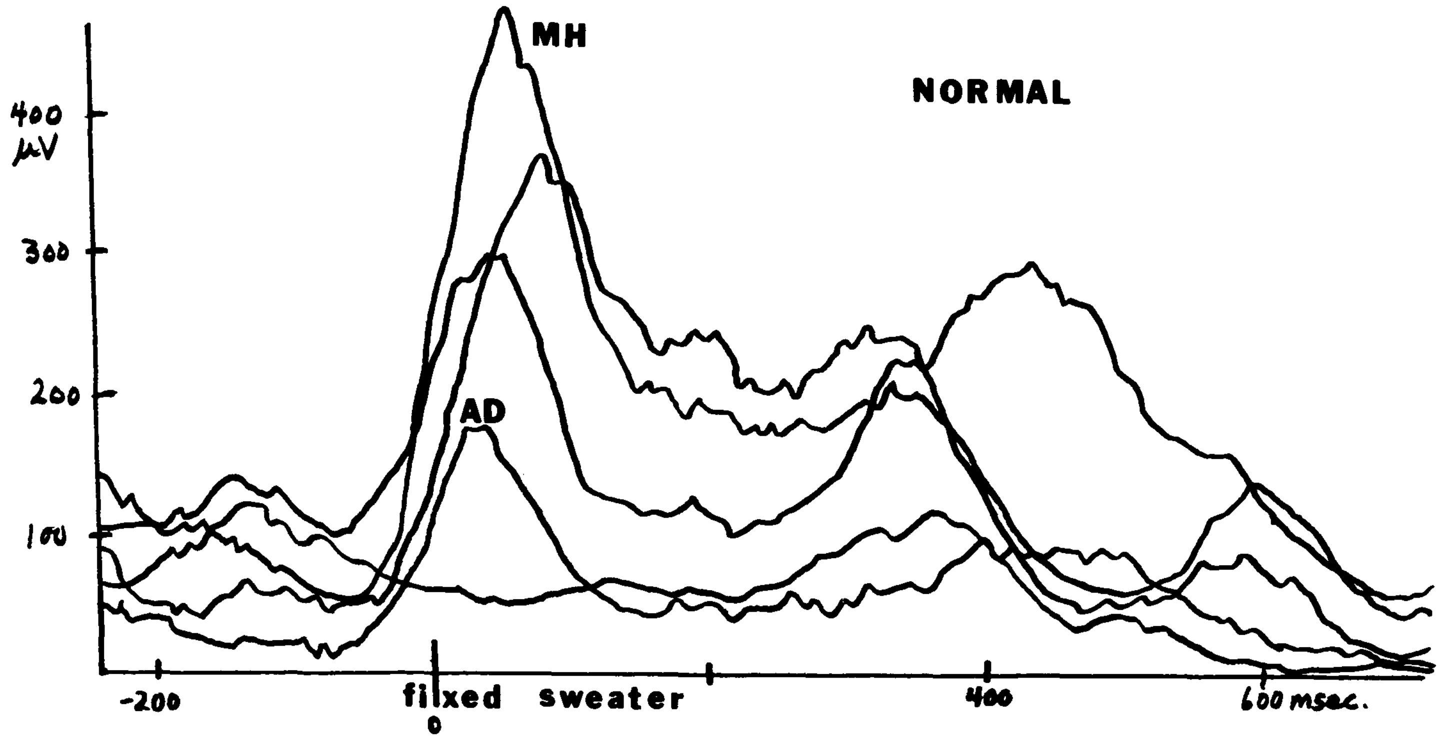


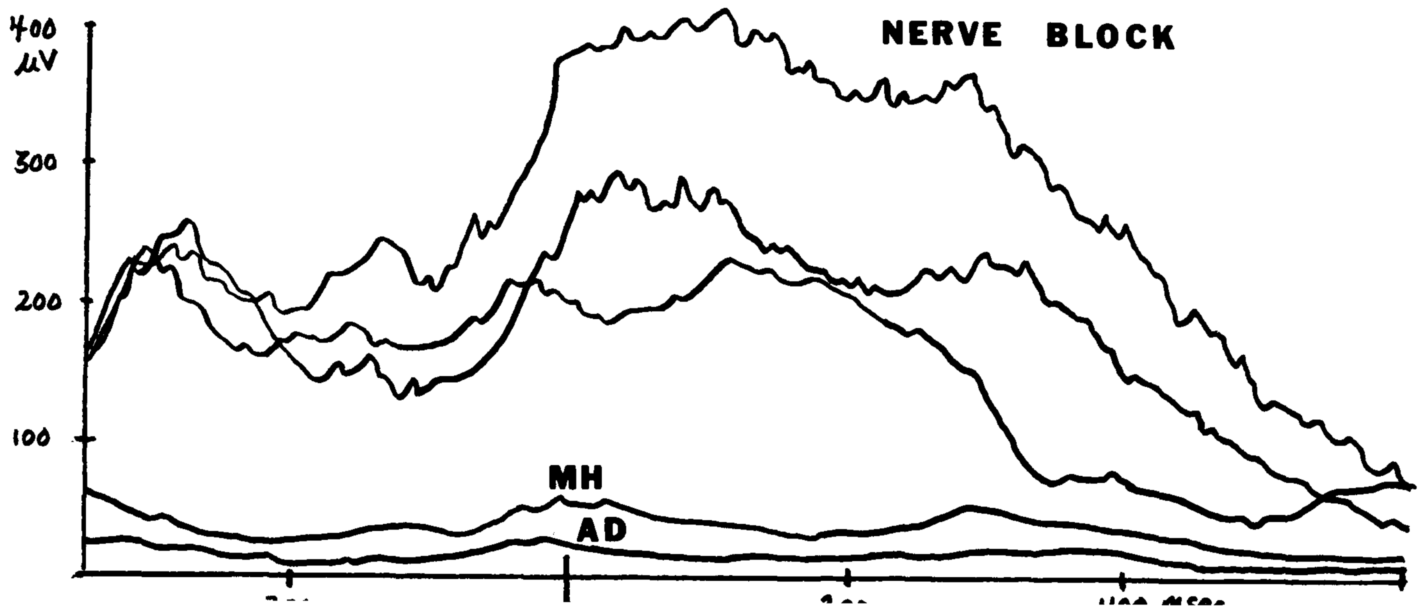
500
400
μV
300
200
100
NORMAL
MH
AD
-200
school blocks
0
200
400
600
800 msec.
500
μV
400
300
200
100
NERVE BLOCK
MH
AD
-200
0
200
400
600 msec.


500
400
µV
300
200
100
NORMAL
MH
AD
-200
spider string
0
200
400
600 Msec.
400
µV
300
200
100
NERVE BLOCK
MH
AD
-200
0
200
400
600 Msec.


NORMAL
400 μV
300
200
100
MH
AD
-1000
-800
-600
-400 msec.
thirsty wasp
0


NERVE BLOCK
400 μV
300
200
100
MH
AD


MH
NORMAL
400
μV
300
200
100
AD
-200
fixed sweater
0
400
600 msec.


NERVE BLOCK
400
μV
300
200
100
MH
AD

BIBLIOGRAPHY

Abd-el-Malek, S., "Observations on the Morphology of the Human Tongue," J. Anat. Lond., 73, 1939, 201-210.

Bastian, H.S., "The Physiology of Thinking," Fortnightly Rev., 1869.

Bekesy, G. von, "The Structure of the Middle Ear and the Hearing of One's Own Voice By Bone Conduction," J. Acoust. Soc. Amer., 21, 1949, 217-232.

Blom, S., "Afferent Influences on Tongue Muscle Activity," Acta Physiol. Scand., 49, Suppl. 170, 1960, 1-97.

Boring, E. G. Sensation and Perception in the History of Experimental Psychology. New York: Appleton-Century-Crofts, Inc., 1942.

Bosma, J. F., "A Syndrome of Impairment in Oral Perception," in Bosma, J.F. (ed.), Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1967.

Butt, A. H., "The Effects on Speech of Labial Anesthesia: A Photographic Study." M.S. thesis, Purdue University, 1971.

Chase, R. A., "Abnormalities in Motor Control Secondary to Congenital Sensory Defects," in Bosma, J.F. (ed), Symposium on Oral Senation and Perception. Springfield, Ill.: Charles C. Thomas, 1967.

Cooper, S., "Muscle Spindles in the Intrinsic Muscles of the Human Tongue," J. Physiol., 122, 1953, 193-202.

Crosby, E. C., Humphrey, T., and Lauer, E. W. Correlative Anatomy of the Nervous System. New York: MacMillan Co., 1962.

Dubner, R., "Peripheral and Central Input to the Main Sensory Trigeminal Nucleus of the Cat," in Bosma, J. F. (ed.), Second Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1970.

Evarts, E. (Chairman), "The Central Control of Movement: A Report Based on an NRP Work Session," Neurosciences Res. Program Bull., Vol. 9, No. 1, 1971.

Fairbanks, G., "Selective Vocal Effects of Delayed Auditory Feedback," J. Speech Hear. Dis., 20, 1955, 333-346.

________. "Systematic Research in Experimental Phonetics: 1. A Theory of the Speech Mechanism as a Servosystem,: J. Speech Hear. Dis., 19, 1954, 133-199.

Fairbanks, G., and Guttman, N., "Effects of Delayed Auditory Feedback Upon Articulation," J. Speech Hear. Res., 1958, 12-22.

Fitzgerald, M. J. T., and Law, M. E., "The Peripheral Connections Between the Lingual and Hypoglossal Nerves," J. Anat., 92, 1958, 178-188.

Gay, T. and Harris, K. S., "Some Recent Developments in the Use of Electromyography in Speech Research," J. Speech Hear. Res., 14, 1971, 241-246.

Geldard, F. A. The Human Senses New York: John Wiley and Sons, 1953.

Gibbs, C. B., "The Continuous Regulation of Skilled Responses by Kinesthetic Feedback," Brit. J. Psychol., 45, 1954, 24-39.

Granit, R. Receptors and Sensory Perception. New Haven: Yale University Press, 1953.

Gray, H. Anatomy of the Human Body, C. M. Goss (ed.). 28th edition. Philadelphia: Lea & Febiger, 1969.

Grossman, R. C., "Methods for Evaluating Oral Surface Sensation," J. Dent. Res., 43, 1964.

Grossman, R. C., and Hattis, B., "Oral Mucosal Sensory Innervation and Sensory Experience," in Bosma, J. F. (ed.), Symposium on Oral Sensation and Perception. Springfield: Ill.: Charles C. Thomas, 1967.

Guttman, N., "Experimental Studies of the Speech Control System," Doctoral thesis, University of Illinois, 1954.

Harris, K. S., "Action of the Extrinsic Musculature in the Control of Tongue Position: Preliminary Report," Status Report on Speech Research, Haskins Labs., New Haven, Jan.-June 1971.

________. "Physiological Aspects of Articulatory Behavior," to be published in Vol. 12, Current Trends in Linguistics.

Henkin, R. I., and Banks, V., "Tactile Perception on the Tongue, Palate, and the Hand of Normal Man," in Bosma, J. F. (ed.), Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1967.

Hirano, M., and Smith, T., "Electromyographic Study of Tongue Function in Speech: A Preliminary Report," Working Papers in Phonetics, Seven, U.C.L.A., Nov. 1967, 46-56.

Hirose, H., "Electromyography of the Articulatory Muscles: Current Instrumentation and Technique," Status Reports on Speech Research, Haskins Labs., New Haven, Jan.-June 1971.

Hollingshead, H. W., "Head and Neck," in Goss, C. M. (ed.), Gray's Anatomy for Surgeons, Vol. I. New York: Paul B. Hoeber, Inc., 1951.

Huldt, S., "Factors Influencing the Efficiency of Dental Local Anesthesia in Man," Acta Odont. Scandinav. (Suppl. 13), 11, 1953.

Huntington, D. A., Harris, K. S., and Sholes, G. N., "An Electromyographic Study of Consonant Articulation in Hearing Impaired and Normal Speakers," J. Speech Hear. Res., 11, 1968, 147-158.

Jamieson, E. B., Illustrations of Regional Anatomy. Section II, 8th Edition, 1956.

Jerge, C. R., "The Neural Substratum of Oral Sensation," in Bosma, J. F. (ed.), Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1967.

Kamada, S., "Sensory Innervation of Mucous Membrane of the Oral Cavity of a Cat," Arch. Hist. Jap., 8, 1955, 243-260.

Kawamura, Y., "A Role of Oral Afferents for Mandibular and Lingual Movements," in Bosma, J. F. (ed.), Second Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1970.

________. "Neuromuscular Mechanisms of Jaw and Tongue Movement," J. Amer. Dent. Assoc., 62, 1961, 545-551.

Kimura, D., "Functional Asymmetry of the Brain in Dichotic Listening," Cortex, 3, 1967, 163-178.

King, R. B., "Interaction of Peripheral Inputs within the Trigeminal Complex," in Bosma, J. F. (ed.), Second Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1970, 119-131.

Kozhenevnikov, V. A., and Chistovich, L. A., Rech: Artikulyatsiya i Vospriyatiye. (Speech: Articulation and Perception), Moscow, Leningrad: Nauka, 1965. Washington, D. C.: Joint Publications Research Service, U.S. Dept. Commerce, 1966.

Ladefoged, P. Three Areas of Experimental Phonetics. London: Oxford University Press, 1967.

Lane, H., "A Motor Theory of Speech Perception: A Critical Review," Psychol. Rev., 72, 1965, 275-309.

Lashley, K. S., "The Problem of Serial Order in Behavior," in Jeffress, L. A. (ed.), Cerebral Mechanisms in Behavior. New York: Wiley and Sons, 1951, 112-136.

Lee, B. S., "Artificial Stutter," J. Acoust. Soc. Amer., 22, 1950, 824-826.

Lenneberg, E. H. (ed.). New Directions in the Study of Language. Cambridge, Mass.: Massachusetts Institute of Technology Press, 1964.

Liberman, A. M., "Some Results of Research on Speech Perception," J. Acoust. Soc. Amer., 29, 1957, 117-123.

Locke, J. L., "A Methodological Consideration in Kinesthetic Feedback Research," Letters to the Editor, JSHR 11, 1968, 668-669.

________. "Oral Perception and Articulation Learning," Percept. and Motor Skills, 26, 1968, 1259-1264.

Luchsinger, R., and Arnold, G. E. Voice-Speech-Language. Belmont, Calif.: Wadsworth, 1965.

Luria, A. R. Human Brain and Psychological Processes. New York: Harper and Row, 1966.

MacNeilage, P. F., "The Motor Control of Serial Ordering of Speech," Psychol. Rev., 77, 1970, 182-196.

MacNeilage, P. F., Rootes, T. P., and Chase, R. A., "Speech Production and Perception in a Patient with Severe Impairment of Somesthetic Perception and Motor Control," J. Speech Hear. Res., 10, 1967, 449-467.

Manual of Local Anesthesia in General Dentistry. Ed. Professional Division, Cook-Waite Laboratories, Inc. New York. Rev. 2nd ed., 1971.

Mason, R. M., "Studies of Oral Perception Involving Subjects with Alterations in Anatomy and Physiology," in Bosma, J. F. (ed.), Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1967.

Matthews, P. B. C., "Muscle Spindles and their Motor Control," Physiol. Rev., 44, 1964, 219-287.

McCroskey, R. L., "The Relative Contribution of Auditory and Tactile Cues to Certain Aspects of Speech," Southern Speech J., 24, 1958, 84-90.

McCroskey, R. L., Corley, N. W., and Jackson, G., "Some Effects of Disrupted Tactile Cues Upon the Production of Consonants," Southern Speech J., 25, 1959, 55-60.

McDonald, E. T., and Aungst, L. F., "Apparent Independence of Oral Sensory Functions and Articulatory Proficiency," in Bosma, J. F. (ed.), Second Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1970.

________. "Studies in Oral Sensorimotor Function," in Bosma, J. F. (ed.), Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1967.

Melzack, R., and Wall, P., "On the Nature of Cutaneous Sensory Mechanisms," Brain, 85, 1962, 331-356.

Monheim, L. M. Local Anesthesia and Pain Control in Dental Practice, 3rd edition. St. Louis: C. V. Mosby Co., 1965.

Moser, H. M., and Houck, R. E., "A Study of the Lingual Orientation of Normal and Articulatory Defective Speakers on a Test of Lingual Identification of Selected Arrangements of Haptic Forms," in Bosma, J. F. (ed.), Second Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1970.

Mott, F. W., and Sherrington, C. S., "Experiments upon the Influence of Sensory Nerves upon Movement and Nutrition of the Limbs," Proc. Roy. Soc., 57, London, 1895, 481-488.

Mountcastle, V. V., "Some Functional Properties of the Somatic Afferent System," in Rosenblith, W. A. (ed.), Sensory Communication. M.I.T. Press and New York: Wiley and Sons, Inc., 1961.

Mowrer, O. H., "Hearing and Speaking: An Analysis of Language Learning," J. Speech Hear. Dis., 23, 1958, 143-152.

________. "Two-Factor Learning Theory Reconsidered, with Special Reference to Secondary Reinforcement and the Concept of Habit," Psychol. Rev., 63, 1956, 114-128.

Mysak, E. D. Speech Pathology and Feedback Theory. Springfield, Ill.: Charles C. Thomas, 1966.

Noback, Charles R. The Human Nervous System: Basic Elements of Structure and Function. New York: McGraw-Hill, 1967.

Öhman, S. E. G., "Coarticulation in VCV Utterances: Spectographic Measurements," J. Acoust. Soc. Amer., 39, 1966, 151-168.

Paillard, J., "The Patterning of Skilled Movement," in Field, J., Nagoun, H. W., and Hall, V. E. (eds.), Neurophysiology, Vol. III, American Physiological Society, Washington, D.C., 1960.

Penfield, W. and Rasmussen, T. The Cerebral Cortex of Man. New York: The MacMillan Co., 1949.

Penfield, W., and Roberts, L. Brain and Speech Mechanisms. Princeton, N.J.: Princeton University Press, 1959.

Perkell, J. S. Physiology of Speech Production: Results and Implications of a Quantitative Cineradiographic Study. Cambridge, Mass.: The M.I.T. Press, 1969.

Port, D. K., "The EMG Data System," Status Report on Speech Research. Haskins Labs, New Haven, Jan.-June 1971.

Rasmussen, A. T. The Principal Nervous Pathways, 3rd edition. New York: The MacMillan Co., 1945.

Ringel, R. L., "Oral Region Two-Point Discrimination in Normal and Myopathic Subjects," in Bosma, J. F. (ed.), Second Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1970.

________. "Some Effects of Tactile and Auditory Alterations on Speech Output," Doctoral thesis, Purdue University, 1962.

Ringel, R. L., Burk, K. W., and Scott, C. M., "Tactile Perception: Form Discrimination in the Mouth," in Bosma, J. F. (ed.), Second Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1970.

Ringel, R. L., and Ewanowski, S. J., "Oral Perception: 1. Two Point Discrimination," J. Speech Hear. Res., 8, 1965, 389-398.

Ringel, R. L. and Steer, M. C., "Some Effects of Tactile and Auditory Alterations on Speech Output," J. Speech Hear. Res., 6, 1963, 369-378.

Rootes, T. P., and MacNeilage, P. F., "Some Speech Perception and Production Tests of a Patient with Impairment in Somesthetic Perception and Motor Function," in Bosma, J. F. (ed.), Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1967.

Rose, J. E., and Mountcastle, V. B., "Touch and Kinesthesis," in Handbook of Physiology. Vol. I: Neurophysiology. Amer. Physiol. Soc., Washington, D. C., 1959, 387-429.

Ruch, T. C., and Fulton, J. F. Medical Physiology and Biophysics, 18th edition. Philadelphia: Saunders, 1960.

Rutherford, D., and McCall, G., "Testing Oral Sensation and Perception in Persons with Dysarthria," in Bosma, J. F. (ed.), Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1967.

Schaeffer, J. P. (ed.). Morris' Human Anatomy, 11th edition. New York: The Blakiston Co., 1953.

Schliesser, H. F., and Coleman, R. O., "Effectiveness of Certain Procedures of Alteration of Auditory and Oral Tactile Sensation for Speech," Percept. Motor Skills, 26, 1968, 275-281.

Scott, C. M., "A Phonetic Analysis of the Effects of Oral Sensory Deprivation," Doctoral thesis, Purdue University, 1970.

Seto, H. Studies on the Sensory Innervation, 2nd edition. Springfield, Ill.: Charles C. Thomas, 1963.

Shankweiler, D., and Studdert-Kennedy, M., "Identification of Consonants and Vowels Presented to Left and Right Ears," Quart. J. Exp. Psychol., 19, 1967, 59-63.

Shelton, R. L., Arndt, W. B., and Hetherington, J. J., "Testing Oral Stereognosis," in Bosma, J. F. (ed.), Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1967.

Sherrington, C. S. The Integrative Action of the Nervous System. London: Constable, 1906.

Siegal, G. M., Winitz, H., and Conkey, H., "The Influence of Testing Instruments on Articulatory Responses of Children," J. Speech Hear. Dis., 28, 1963, 67-76.

Siegenthaler, B. M., and Hochberg, I., "Reaction Time of the Tongue to Auditory and Tactile Stimulation," Percept. Motor Skills, 21, 1965, 387-393.

Sinclair, D., "Cutaneous Sensation and the Doctrine of Specific Energy," Brain, 78, 1955, 583-614.

Smith, M. W. and Ainsworth, S., "The Effects of Three Types of Stimulation on Articulatory Responses of Speech Defective Children," J. Speech Hear. Res., 1967, 333-338.

Stevens, K. N., House, A. S., and Paul, A. P., "Acoustical Description of Syllabic Nuclei: An Interpretation in Terms of a Dynamic Model of Articulation," J. Acoust. Soc. Amer., 40, 1966, 123-132.

Storey, A., "Extra-trigeminal Sensory Systems Related to Oral Function," in Bosma, J. F. (ed.), Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1967.

Strong, L. H., "Muscle Fibers of the Tongue Functional in Constant Production," Anat. Rec., 126, 61-80.

Sussman, H. M., "The Laterality Effect in Lingual-Auditory Tracking," Ph.D. dissertation, University of Wisconsin, 1971.

Taub, E., and Berman, A. J., "Movement and Learning in the Absence of Sensory Feedback" in Freedman, S. J. (ed.), The Neuropsychology of Spatially Oriented Behavior. Dorsey Press, in press.

Templin, M. C. Certain Language Skills in Children. Institute of Child Welfare Monograph No. 26. Minn.: University of Minnesota Press, 1957.

Titchener, E. B. A Textbook of Psychology. 1959.

Van Riper, C., and Irwin, J. V. Voice and Articulation. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1958.

Weddell, G., "The Pattern of Cutaneous Innervation in Relation to Cutaneous Sensibility," J. Anat., 75, 1941, 346-367.

Weddell, G., Harpman, J. A., Lambley, D. G., and Young, L., "The Innervation of the Musculature of the Tongue," J. Anat., 74, 1940, 255-267.

Weinberg, B., Lyons, M. J., and Liss, G. M., "Studies of Oral, Manual, and Visual Form Identification Skills in Children and Adults," in Bosma, J. F. (ed.), Second Symposium on Oral Sensation and Perception. Springfield, Ill.: Charles C. Thomas, 1970.

Weiner, P.S., "Auditory Discrimination and Articulation," J. Speech Hear. Dis., 32, 1967, 19-28.

Wiener, N., "Cybernetics," Scientific Amer., 179, Nov. 1948, 14-19.

Wolfe, A. A., and Wolfe, E. G., "Feedback Processes in the Theory of Certain Speech Disorders," Sp. Patholog. and Therapy, 2, 1959, 48-55.

Zemlin, W. R. Speech and Hearing Science: Anatomy and Physiology. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1968.