1960

An Electromyographic Appraisal of Muscle Tensions in the Temporal and Infrahyoid Musculature

Charles Edwin Smith

Loyola University Chicago

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AN ELECTROMYOGRAPHIC APPRAISAL OF MUSCLE TENSIONS
IN THE TEMPORAL AND INFRAHYOID MUSCULATURE

by

Charles Edwin Smith

A Thesis Submitted to the Faculty of the Graduate School
of Loyola University in Partial Fulfillment of
the Requirements for the Degree of
Master of Science

June
1960
LIFE

Charles Edwin Smith was born in Chicago, Illinois, February 8, 1928.

He was graduated from Austin High School, Chicago, Illinois in June, 1946. From September 1946 to June 1950 he attended Northwestern University School of Liberal Arts and received a Bachelor of Science degree in June 1950. In June 1954 he was graduated from the Northwestern University Dental School, Evanston, Illinois, with the degree of Doctor of Dental Surgery.

The author served with the United States Air Force from August 1954 to August 1956. He began his graduate studies at Loyola University in June 1957.
ACKNOWLEDGMENTS

I wish to express my sincere appreciation to all those who have aided me in this investigation. Further, with distinct pleasure, I wish to acknowledge my indebtedness, in particular, to the following:

To Joseph R. Jarabak, D.D.S., Ph.D., Professor of Orthodontics, Loyola University, who as my advisor, provided the guidance, the supervision and, when necessary, the inspiration needed to complete this investigation.

To Patrick D. Toto, D.D.S., M.S., Associate Professor of Oral Diagnosis and Oral Pathology; G. W. Rapp, Ph.D., Professor of Bio-Chemistry and Physiology; and Y. T. Oester, Ph.D., Professor of Pharmacology, all of Loyola University, for their many helpful suggestions. I wish to further thank Drs. Toto, Rapp and Oester for serving as members of my advisory board.

To James A. Fizzell, B.S. in E.E., Consultant for the Department of Orthodontics, Loyola University School of Dentistry, for his technical advise on the statistical discipline used in this study.

To Miles Hlinsky, B.S. in M.E., who as a friend of the author, contributed his time, skill and resources to the design and construction of the necessary mechanical apparatus.
To all those who served as subjects for the experiment.

To Miss Libbie R. Vanoucek for all the typing connected with the preparation of this thesis.

To all the above I am most truly grateful.
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CHAPTER I

A. Introduction and Statement of the Problem

It would be extremely difficult, if not impossible, to find any discussion dealing with muscle that was not in some way related, directly or indirectly, with its ability to produce tension. This same ability has been the object of the scientific curiosity that has characterized the biologist, the biochemist, the physiologist and the orthodontist alike. The orthodontist, in addition however, may be said to be somewhat selfishly motivated in that his curiosity is admittedly directed toward the assessment of the role played by muscle tension in the etiology of dental malocclusions. To date, however, the etiological picture has remained extremely obscure as evidenced not only by the expression of many vastly divergent opinions but also, and most dramatically, by the singular lack of agreement with respect to the relative importance of the environmental and hereditary factors.

Since muscles invariably function in groups, much of the dental literature deals with the general patterns of muscle behavior; and, unfortunately in many instances with even an avowed lack of precise knowledge concerning the action of the individual
muscles. In my opinion, a truly scientific understanding of the role of muscle, with respect to the etiology of malocclusions, will be obtained only when all the possible functions of the muscles concerned are quantified with respect to the effects they produce.

Since progress in the quantification of muscle action will most likely proceed from its relative to its absolute measurement, there was envisioned at the inception of this paper, only a very halting advancement of our knowledge. More specifically, it was hoped to be able to correlate the relative energy outputs of the temporal and infrahyoid musculature, as recorded by the integrated electromyogram, with various amounts of work performed during a specific mandibular movement.

B. Review of Literature

The ability of muscular tissue to produce tension as a result of its contractability has been the subject of much speculation and research for many centuries. One of the first theories, expounded by Galen\(^1\) (180 A.D.), attributed this ability to "animal spirits" and dominated physiological thought until the nineteenth century. The source of this contractile

\(^1\)For most of the material presented in the first two paragraphs of this review I am indebted to J. F. Fulton's Muscular Contraction and the Reflex Control of Movement (Baltimore, 1926).
power was first directed toward the fleshy part of the skeletal muscle by Andrea Vesalius (1543); but only after another century and the development of the microscope was Steno (1667) able to attribute the tension developed by a muscle to its individual fiber constituents. He also noted that a pennate fiber arrangement provided a muscle with power and that a parallel fiber arrangement provided rapidity of movement.

One of the most important discoveries in muscle physiology was made by Galvani in the summer of 1786 when he ascribed electrical properties to animal tissues (published 1791). However, it wasn't until 1848 that du Bois-Reymond proposed that the action current was a constant concomitant of muscular contraction. Two fundamental questions, however, had to be answered before the electrical property of muscle could be accepted as a valid quantitative measure of its mechanical response. The first, regarding the inseparability of the electrical and mechanical responses (denied by Biedermann (1895), Hartl (1904), Mines (1913), et al), was resolved in the affirmative by the work of De Boer (1917), Einthoven and Hugenholtz (1921), Arbeiter (1921), Gasser and Hartree (1924), Lewis (1925), et al. The second question regarding the existence of a functional relation between the two properties has stimulated and been the object of much investigation. Some early investigators, such as Lillie (1923), claimed that the muscle fiber action current was always
of constant size or, as mentioned by Forbes, Ray and Hopkins (1923), that the action current may have little or nothing to do with the tension developed. However, Schenk (1896), Bernstein (1897), and Bernstein and Tschermak (1902) all found that tension distinctly altered the size of the action current. Riviere (1898) and Athanasin (1912) even suggested the existence of a relation between the size of the electrical response in muscle and the work done in contraction.

The discovery of how skeletal muscle through its structural organization increases its tension has greatly contributed to an understanding of the functional relation between its electrical and mechanical responses. Bowditch made the initial contribution when he observed (1871) the "all-or-none" principle of muscle contraction in cardiac tissue. This principle was extended to the skeletal muscle fibers by the works of Gotch (1902), Lucas (1905) and Pratt (1917) whose experiments demonstrated that the development of tension depended upon the number of fibers stimulated.

The second method by which skeletal muscle normally increases its tension was demonstrated only after intensive investigation of the nerve and muscle action currents associated with muscular contraction. Piper (1908) and Buchanan (1908) were the first to study the electromyograms, obtained from the voluntary contraction of human skeletal muscles, in an attempt
to infer the nature of the normal nervous stimulus. Buchanan, using the capillary electrometer, concluded that the rapid oscillations of the electromyogram expressed a rhythm which originated peripherally, i.e., within the muscle, and therefore did not mirror the central innervation. Piper, using the string galvanometer for recording the muscle action currents, obtained a rhythmic oscillation which he interpreted as the rate of central innervation. The latter view was strongly supported by Dittler and Garten (1912) when they demonstrated a synchronizaton between the action currents from the dog's diaphragm and phrenic nerve when recorded simultaneously by two string galvanometers. This work was corroborated by Gasser and Newcomer (1921) when they increased the sensitivity of the string galvanometer through the application of the vacuum tube. Cooper and Adrian (1923-24), after studying the effect of temperature changes on the frog's gastrocnemius and central nervous system, also concluded that the reflex electromyogram resembled the discharge frequency of the spinal cord. However, it was the classic experiments of Adrian and Bronk (1928, 1929), using the capillary electrometer and valve (electron tube) amplifier, that disclosed for the first time that muscular tension was also normally graded by the frequency of its nervous stimulation. This was concluded from the increased frequency of nervous discharge observed in the isolated phrenic neurones of the rabbit during forced inspiration.
Adrian and Bronk must further be credited for giving us the first correct interpretation of the electromyogram. Their studies, using concentric needle electrodes, demonstrated the discharge of groups of muscle fibers innervated by single motor neurones. Such a functional entity has been designated by Sherrington as the "motor unit" and its isometric contraction tension has been quantitatively analyzed by Eccles and Sherrington (1930). The number of muscle fibers included in each of the motor units of various muscles was determined by Clark (1931) who also made the observation that those muscles performing the most highly differentiated movements were composed of the smallest motor units. The subsequent investigations of Smith (1934), Lindsley (1935-36), and Gilson and Mills (1941) served to corroborate Adrian and Bronk's interpretation of the electromyogram obtained from an entire muscle; to wit, that the irregular high frequency oscillations represented the asynchronous discharge of motor units, and that these varied in number and in the frequency of their discharge with the strength of the contraction.

Watts in 1924 attempted to quantitate this functional relation (between the electrical and mechanical responses) in the frog's sartorius muscle during an isometric contraction. Using a tension lever and the string galvanometer, he found that the electrical disturbance in the muscle, resulting from submaximal
indirect stimuli, paralleled the tension development and suggested that the variation in the magnitude of the electrical responses was due to the number of muscle fibers in action rather than any change in the response of each fiber. However, most of the early work failed to demonstrate any correlation between the electrical and mechanical responses (Schaefer 1940).

Rosenblueth, Wills and Hoagland (1941), using the frog's sartorius muscle, concluded that the end-plate potentials and slow positive components of the electromyograms masked any relation that possibly existed between the tension and the fiber potentials. Loofbourrow in 1948 correlated the amplitude of the electromyogram with the isometric tension in the anterior tibialis muscle of the anesthetized cat when that muscle was submaximally excited via the motor cortex. No such correlation was demonstrated if the muscle was stimulated directly or via its motor nerve. Existence of a linear relation between the tension exerted by a muscle and its integrated action potentials was first demonstrated by Lippold (1952) for a voluntary isometric contraction of the human calf muscle; surface electrodes were used for recording the action potentials which were integrated mechanically. This observation was extended to include voluntary isotonic contractions in the human calf muscle by the
work of Bigland, Lippold, and Wrench (1953). These electronically integrated results demonstrated the linearity between the electrical response and the changes of tension and the changes in velocity. The work of Bigland and Lippold (1954) demonstrated that the previous early attempts to establish the above mentioned relationships for the isotonic contraction of muscle probably failed because the velocity of the movements was not controlled. Their results showed that for a constant tension, the electrical activity increased directly with the velocity of shortening, but remained independent of the speed when the muscle was being lengthened. Also demonstrated was the direct proportion between the integrated electrical activity and the tension in a muscle during a constant (or zero) velocity of shortening (or lengthening). During the lengthening, however, the electrical activity required to produce a given force of contraction was found to be smaller than when the muscle was shortening. This showed that the tension that can be exerted by muscle increased as the velocity of shortening decreased to zero and then became negative; i.e., when the muscle was actively lengthened.

Fick (1882), primarily for the purpose of investigation, defined two types of muscle contraction: (1) isotonic, where the muscle shortened under a constant load and (2) isometric, where the contraction involved no change in muscle length.
Fenn's (1936) classification focused attention upon the ability of muscle to produce tension and proposed three categories of muscular contraction: (1) tension during shortening, (2) isometric tension and (3) tension during lengthening. The muscles of the head and neck, associated with mandibular movements and normally operating in antagonistic pairs (or groups), have provided examples of both lengthening and shortening during their contractions.

The early investigators championed opposing viewpoints regarding the muscular activity involved in the mandibular opening and closing movements. One of these viewpoints was admirably expressed by S. Wilson Charles (1925) when he stated that "The mandible is depressed and elevated by the interaction of the four muscles--external pterygoid, masseter, internal pterygoid and temporal--acting as a group." Contrary to the views of Stallard (1923) and Wadsworth (1924), Charles claimed that even with the slightest mandibular depression, the condyle was brought forward by the external pterygoid muscles. The "so-called" mandibular depressors (digastric, geniohyoid, etc.,) were claimed by Keith (1915), Johnston (1922), Partridge (1924) and Charles (1925) to be only concerned with speech or swallowing. They felt that these muscles were not positioned for the best mechanical advantage during mandibular depression; also that they were
required to move and control the tongue during mastication and therefore could not have simultaneously depressed the mandible. Joyce Partridge (1924) stated that "... by opening the mouth against pressure, and at the same time performing the act of swallowing, ... it will be found that the hyoid moves up and down in the usual way, thus eliminating hyoid muscles as active depressors." Charles (1926) claimed that there wasn't any proof that the hyoid muscles depressed the mandible under any circumstances. Seward, even as late as 1940, expressed the same opinion. Lord (1937) stated that normal mandibular depression was caused by the action of the external pterygoid muscles with aid, in the form of stabilization, from the stylomandibular and sphenomandibular ligaments. However, for the "forced" opening movement he claimed that the inframandibular muscles assisted the two ligaments in opposing the forward pull of the external pterygoids. Root (1946) was in complete agreement with Lord and presented two cases which he claimed clinically demonstrated these functions for these muscles. The opposite viewpoint, supported by Riesner (1936) and Friel (1926), proposed that the mouth opening movement was caused by the inframandibular muscles. The more recent interpretations lie between these two extreme viewpoints and encompass a broader analysis of the head and neck musculature including the influence of posture.
Thompson and Brodie (1942), searching for an explanation of the stability of mandibular rest position, examined the function of the muscles in the maintenance of the balanced posture of the head. They proposed that such a posture was maintained by a balanced antagonism between the post-cervical muscles on the one hand and gravity plus a series of muscle groups acting together on the other hand. This anterior chain of muscles included the masticatory, suprahyoid and infrahyoid groups. Thus, these muscle groups, lying anteriorly, and being concerned with mastication, respiration, deglutation and speech, were said to function, through a complex coordination, with the post-cervical muscles in simultaneously maintaining the balanced posture of the head. They claimed that in normal mouth opening the external pterygoid pulled the head of the mandible downward and forward and that the suprahyoid group only tensed enough to prevent the hyoid bone from descending. The suprahyoid and infrahyoid musculature was accordingly supposed to assume a primary role in mandibular depression only when the external pterygoids had been interfered with as in condylar resections.

McCullum (1943), in his analysis of the oral muscle physiology, described the external pterygoids as the main protruders of the mandible with no capacity for mandibular depression. The advancement of the mandibular "hinges" by the action of the
above muscles was to permit wide "opening" movements without impinging upon the tissues behind the mandibular angles. Because of their location, the geniohyoids were given the credit for opening the mouth. Assistance from gravity was acknowledged and the digastrics, the omohyoids, the extrinsic muscles of the tongue and the floor of the mouth were also said to be contributors to the movement. The suprahyoid and the infrahyoid muscles were supposed to antagonize the closing components of the muscles of mastication.

Moyers (1950), in his electromyographic analysis of the muscles involved in the various mandibular movements, found activity present in both the external pterygoid and the digastric muscles during mandibular depression. Of the two, the external pterygoid was the first to elicit the high amplitude action potentials and these persisted until the movement ceased. Though tensing in the anterior belly of the digastric was almost immediately apparent, the spike potentials did not reach their maximum amplitude until sometime after those in the external pterygoid. The length of this time interval decreased as the extension of the head or the resistance encountered during mandibular depression was increased. Once initiated, they too were observed to persist throughout the completion of the movement. The late activity observed in the digastric indicated, according
to Moyers, a possible effort to retract the chin point during mandibular depression. On the basis of its location, Moyers further stated, that the digastric may possibly be the supra-hyoid muscle most frequently associated with mandibular depression. Further, the spiking activity observed in this muscle during all mandibular movements suggested that it functioned in maintaining the position of the hyoid bone and in stabilizing of the various mandibular movements. Activity, equal in amplitude to that of the digastric, was observed in the sternohyoid muscle during mandibular depression and therefore both the suprathyroids and the infrahyoids were thought to possibly have a function in maintaining the position of the hyoid bone during mandibular movements, speech and swallowing. Though a forced opening demonstrated an earlier and stronger "contraction" of the digastric, this muscle was observed to always take part in mandibular depression. Thus, he concluded that the external pterygoid initiated mandibular depression but that the digastric contributed to the smoothness of its completion. And further, this manifestation of the close cooperation and interaction of the muscles involved in the mandibular movements indicated the important coordinating influence of the central nervous system. Moyers, detected consistent activity in the anterior fibers of the temporal in some subjects during mandibular depression which according to him substantiated the finding of Bierman and Yamshan (1948)
who reported that, "At the initiation of a movement, potentials can occur in the antagonists."

Sicher (1951), in discussing the temporomandibular joint, proposed the opinion (in opposition to Charles', 1925) that this joint bears considerable pressure. As evidence, he cites the avascularity of the fibrous layers covering both the mandibular and temporal surfaces of the joint and of the central area of the articular disc. As further evidence he notes, significantly, the organization of the fiber bundles in the fibrous connective tissue covering of the articulating bones. Thus, similar to the arrangement in cartilage, the fibers in the deep layers being perpendicular to the surface, are adapted to withstand pressure, whereas the fibers in the superficial layers, being parallel to the surface, are adapted for gliding under pressure.

Sicher (1951) has also taken exception to Lord's (1937) viewpoint with respect to the functional significance of the accessory ligaments. Sicher has stated that these structures, namely, the sphenomandibular and stylomandibular ligaments, have no functional relation with the mandibular articulation and in no way influence mandibular movements.

In discussing the various functional mandibular movements, Sicher (1951) has described the opening and closing movements of the mandible as a combination of rotatory and translatory
movements. The former of these two movements, namely, rotatory, was described as occurring in the lower compartment of the temporomandibular joint around a frontal axis positioned approximately through the centers of the two condyles. The movements of this axis through space were referred to as translatory movements and were attributed to the upper compartment of the joint.

The amount of the rotatory and translatory movements were said to be unequally proportioned and to vary with the degree of opening or closing. Thus, the movement between occlusal position and rest position was described as a purely rotational movement, whether occurring during opening or closing. Translatory movement, on the other hand, was said to predominate during the first third of the closing movement from the wide open position. The remainder of the closing movement (until rest position was attained), and the entire range of the opening movement (when initiated from the rest position) was said to consist of a smooth combination of translatory and rotatory movements.

Sicher (1961) has classified the various mandibular muscles associated with the different movements of the lower jaw into three groups: (1) elevators; (2) depressors; (3) protractors. No retractor group was created since this function was accomplished by portions of both the elevators and the depressors.

The elevator group represented the closing muscles and
included the masseter, temporal and internal pterygoid muscles. Portions of the masseter and temporal muscles were described as also having strong retrusive capacities.

The depressor group included the digastric, geniohyoid, and mylohyoid muscles; it also was described as having a capacity for mandibular retraction. The level at which the hyoid bone was fixed by the infrahyoids as well as its position relative to the mandible, was said to determine the extent to which this muscle group functioned with respect to both its depressing and retracting capabilities.

The third group of muscles, the protractor group, consisted of the two external pterygoids and was said to function as the protractor of the mandibular condyles.

In describing the action of the muscles in mandibular movements, Sicher has said that it was wrong to attribute the opening movement of the jaws solely to the action of the external pterygoid muscle. Rather, he has pictured all mandibular movements as being brought about by the simultaneous action of numerous muscles functioning in complicated behavioral patterns. Further, he has stated that it was possible for a muscle to act synergistically with different muscles at different times. The external pterygoid exemplified such a behavior pattern since it was said to play a leading role in many different mandibular movements.
Sicher (1951) has described the opening movement as follows:

The opening movement is caused by a synergistic action of the external pterygoid muscle and the depressors of the jaw. If the movement occurs without resistance, the depressor-retractors act without any great force and it is this fact which has prevented some observers from understanding the necessary contribution of the suprathyroid muscles to the opening movement of the jaw. The contraction of the suprathyroid muscles can be ascertained if the opening movement is extreme. The protracing force of the external pterygoid muscle acting upon the condyle and disc and the simultaneous depressing but especially the retracting force of the geniohyoid and digastric muscles acting upon the chin blend in perfect manner to execute the combination of rotatory and translatory movement.

In a normal opening movement the depressors function more by their retracting component than by a true depression. They change, however, their direction as well as their power, if the opening is done against considerable resistance, for instance in fibrous ankylosis of the temporomandibular joint or after loss of the external pterygoids by fracture of the mandibular neck or by removal of the condyles. In such cases the hyoid bone is not only fixed in its position, but first strongly lowered by the action of the infrahyoid muscles.

An interesting functional analysis of the head and neck musculature has recently been presented by Last (1954). In this presentation, he described three fundamental movements occurring in the head and neck region. These were (1) the movement of the skull with respect to the cervical spine, (2) the movement of the mandible with respect to the skull and (3) the movement of the floor of the mouth with respect to the mandible. Each of these movements was said to be controlled
by a separate set of muscles.

Last (1954) attributed the movements as well as the posture of the head to the action of the extensor and flexor muscles of the skull. The extensors consisted of the post-vertebral neck muscles, primarily the semispinalis capitis, one of the long extensor muscles at the back of the neck. The rectus capitis posterior minor was also given an extensor action. The opposing flexor muscles included the prevertebral muscles as well as the anterior fibers of the sternomastoids. Gravity was also said to aid in flexion if the body was in an erect position. The only long skull flexor in the prevertebral group was the longus capitis muscle. The rectus capitis anterior (minor), connecting the skull and atlas, was said to oppose the rectus capitis posterior minor. However, the anterior fibers of the sternomastoid muscles were described as the powerful flexors of the atlanto-occipital joint and were, according to Last, the true opponents of the extensors. The muscles of mastication were, contrary to the view of Brodie, given no function in the movements of the head or in the maintenance of its posture.

Mandibular depression was pictured by Last (1954) as a simple rotation of the mandible about an axis that passed approximately through the mandibular foramina. This movement was described as being effected by the synergistic action of
the external pterygoids, the double bellied digastrics and the infrahyoids; the external pterygoids pulling the mandibular condyles forward, the digastrics pulling the chin backward and downward. The action of the digastric, in depressing the chin by pulling from the mastoid process, was said to be influenced by the level of its central tendon, which, through a pulley arrangement with the hyoid bone, was held down by the action of the infrahyoid musculature. According to Last, this was the most important function of the infrahyoids.

Last’s (1964) analysis of the movements of the floor of the mouth was of particular interest with respect to the function of certain muscles often associated with mandibular movements; for example, the mylohyoid and geniohyoid. His description depicted the floor of the mouth (mylohyoid muscle) as a diaphragm suspended from the mandible and attached posteriorly at its midline raphe to the mobile hyoid bone. The position of this bone antero-posteriorly was determined by the relative action of the geniohyoid and stylohyoid muscles each of which had a secondary elevating effect. The elevation of the hyoid was counterbalanced by the depressing action of the infrahyoid muscles. The floor of the mouth, or mylohyoid, was said to be its own elevator and its posterior portion was described as the principal elevator of the hyoid bone. Thus, none of the muscles that
moved the hyoid bone with respect to the mandible were depicted as the primary movers of the latter. Rather, the hyoid bone was moved by its own musculature so as to maintain its appropriate position in all movements of the mandible. Further, the hyoid bone moved with the slightest movement of the tongue; the musculature of the former thereby assisting that of the latter in speaking, chewing and swallowing.

The conventional description has generally attributed the elevation of the mandible to the action of the temporal, masseter and internal pterygoid muscles. Carlsoo’s (1952) exhaustive investigation of the mandibular elevators correlated anatomico-mechanical analyses and electromyographical studies with respect to the functional integration and coordination of the various portions of these muscles during the different mandibular movements. His studies also included the action of these elevator muscles during the opening movement and involved subjecting the mandible to loads that acted with a closing moment (i.e., that resisted mandibular depression). The findings demonstrated the following: (1) these muscles lacked the mechanical qualifications for this movement; and (2) the complete absence of activity in all of these muscles during this movement.

Coincident with maximal opening, Sicher (1951) has
significantly noted, that in order to prevent dislocation of the mandibular condyle the closing movement must be initiated by the action of the retrusive portions of the temporal, masseter and depressor muscles; the movement only then being subsequently completed by the action of the powerful elevator.

The capacity for variation in the action of the temporal muscle with respect to certain dentofacial deformities has been noted by Moyers (1950). He observed equal activity in the three component portions of this muscle (as subdivided by him) during mandibular elevation as well as during the maintenance of the physiological rest position for normal (dentofacial) individuals. A lack of this balance was noted in individuals with a Class II Division I dentofacial deformity. Also, the usual synergistic activity between the temporal muscles during mandibular elevation was observed to be temporarily altered in some adolescents during the periods of deciduous tooth exfoliation.

Fruzansky (1952) described the synergistic behavior of two of the mandibular elevators, namely, the temporal and masseter muscles, during various mandibular closing movements; more specifically, during the masticatory stroke. The patterns of this synergism were also noted to be capable of alteration; this time by various disturbances in the occlusion.
Jarabak (1954) conducted an electromyographic investigation specifically designed to study the adaptability of the temporal and masseter muscles; especially with respect to overclosure. His appraisal of their behavior during mastication involved the examination of (1) a subject with normal occlusion and (2) a cleft palate subject both before and after the excessive interocclusal space had been reduced by an orthodontic interocclusal splint. The subject with the normal occlusion demonstrated a synchronous pattern of contraction for the temporal and masseter muscles. The existence of a division of labor between the temporal and masseter muscles was also noted for this subject; the temporal functioning as the mandibular elevator and the masseter contributing to the power of the masticatory stroke. In contrast, however, the cleft palate subject, with the excessive interocclusal space, presented an asynchronous contraction between the temporal and masseter muscles; but not so between the two temporals or the two masseter muscles. The temporal muscle, under these conditions, and in addition to its usual functions, contributed power to the masticatory stroke. When the excessive interocclusal space was reduced by an orthodontic splint these muscles assumed a behavior pattern similar to that of the normal occlusion and thereby demonstrated the immense potential for adaptability.
Pruzansky (1952) suggested the use of integrators for the quantitative measurement of masticatory efficiency and Pruzansky, Pesek and Osborn reported in 1958 that the electrical activity of the masseter was always greater on the working side than on the balancing side in persons with normal occlusion.
CHAPTER II

MATERIALS AND METHODS

A. Subjects

Ten white, male, adult subjects ranging from twenty-two to thirty-five years of age were selected for this study. The selection was not influenced by their dental malocclusion, the loss of dental units, or the facial type.

B. Electrodes and Electrode Placement

Eight standard silver surface electrodes, three-eighths of an inch in diameter, manufactured by the Grass Instrument Company, Quincy, Mass., were used throughout this experiment. These electrodes were arranged in pairs; one pair being placed over each of the temporal muscles, approximately 3.0 inches apart and a second pair being placed over each of the sternohyoid muscles, approximately 1.5 to 2.0 inches apart (Figure 1). This pairing of the electrodes was substituted for the conventional ear reference electrode, so as to minimize the action potential pick-up from the adjoining musculature not under investigation. This, of course, would be most fully accomplished in the case of the relatively isolated temporal muscle. The pick-up from the sternohyoid muscle would, however, include
FIGURE 1

ELECTRODE PLACEMENT
some of the action potentials from the deeper and immediately adjacent muscles which together have been commonly referred to as the infrahyoid musculature.

The electrode placement over each temporal muscle was as follows: one of the paired electrodes was positioned over the anterior margin of the muscle just posterior to the fronto-sphenoid process of the zygoma (as determined by palpation); the second electrode was positioned over the principal belly of the muscle and on a vertical line through the pre-auricular point.

The electrode placement for each sternohyoid muscle was as follows: one of the paired electrodes was placed near the anterior midline of the neck at about the level of the cricoid cartilage. This placement of the electrode minimized the possibility of its displacement with maximum mandibular depression. The second electrode, also near the anterior midline of the neck, was placed inferior to the first, at about the level of the superior border of the jugular notch.

Prior to the actual placement of the electrodes, the selected areas were shaved, cleansed with soap and water, and rubbed with acetone. This was done to remove surface oils and to produce a mild erythema, thereby reducing the skin resistance and facilitating the pick-up of the muscle action potentials.
Each electrode was affixed to the skin with a film of flexible collodion (Figure 2). Offner electrode paste was forced beneath the disc electrodes with a Leur lock syringe to which was attached a blunted .004 gauge needle having an opening prepared with a #557 cross-cut fissure dental burr (Figure 3). A Simpson Ohmmeter was then used to ascertain the skin resistances which were not permitted to exceed three thousand ohms (Figure 4).

A silver plate electrode (1.5x1.9 in.) serving as a ground was taped to the medial aspect of the subject's left forearm immediately after this portion of the subject's skin was cleansed and coated with electrode paste (Figures 1 and 2).

C. Electrode Apparatus

To limit the pick-up of the surface electrodes to the action potentials of the muscle immediately beneath them, the subject was seated in and grounded to a Faraday cage constructed of a hermetically sealed double layer of copper screening enclosing a volume 5x6x7 feet. The leads from the electrodes and ground were attached to a terminal box located within the cage from whence the signals were relayed, via a shielded cable, into a six-channel Offner Electroencephalograph, Type A, modified for electromyographic work (Figure 5). The auxiliary equipment which was used consisted of the following (Figure 5): (a) a signal generator and calibrator which provided a known
FIGURE 2
ARMAMENTARIUM FOR ELECTRODE PLACEMENT
FIGURE 3

ELECTROLYTE INTRODUCTION BENEATH DISC ELECTRODE
FIGURE 4

SIMPSON OHMMETER
FIGURE 5

ELECTRONIC EQUIPMENT
signal for the calibration of the amplifying and recording equipment; (b) four integrators which summed and quantified the muscle voltages; (c) an Offner six-pen crystograph ink writer, Type 500/501 A (Figures 5 and 6) which permanently recorded the data and was operated at a paper speed of 2.5 cm./second; and (d) a time-base marker which consisted of a synchronous multivibrator driving an extra pen located on the margin of the chart paper and at a speed of ten pips per second.

Tracing the signals through the equipment described above may contribute to an appreciation of the function of the electronic apparatus. The minute voltage signals, originating in the muscles in microvolt magnitudes and picked up by the paired electrodes from each of the four muscles, were sent through a shielded cable to a box of selector switches from whence they were directed into their respective amplifying channels. Each of these amplifying channels amplified the signals approximately fifty thousand times and then passed them into an integrator where they were summed electrically for short periods of time and their summed magnitudes were then transmitted to one of the crystograph pens. Four of the crystograph pens were thus used to record these integrated muscle voltages (Figure 7).

Simultaneously, two of the above mentioned signals, namely, those picked up from the left temporal and the left infrahyoid
FIGURE 6

CRYSTOGRAPH AND TIME-BASE MARKER
### EXPERIMENTAL DATA

**Figure 7**

Sample electromyogram obtained from experimental data.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Type</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;F&quot;</td>
<td>Integrated</td>
<td>Right infrahyoid</td>
</tr>
<tr>
<td>&quot;E&quot;</td>
<td>Integrated</td>
<td>Right temporal</td>
</tr>
<tr>
<td>&quot;D&quot;</td>
<td>Monitored</td>
<td>Left temporal</td>
</tr>
<tr>
<td>&quot;C&quot;</td>
<td>Integrated</td>
<td>Left temporal</td>
</tr>
<tr>
<td>&quot;B&quot;</td>
<td>Monitored</td>
<td>Left infrahyoid</td>
</tr>
<tr>
<td>&quot;A&quot;</td>
<td>Integrated</td>
<td>Left infrahyoid</td>
</tr>
</tbody>
</table>

*Chart No. 159, Oceanic Electronics Inc. Chicago, Ill.*
musculature, were also fed into two other amplifying channels that were not integrated. These voltage signals were sent from these amplifiers directly to the remaining two crystallograph pens and thereby provided an instantaneous record of the muscular activity which was used for the monitoring of the experimental exercises to be described later (Figure 7). This monitoring activity in no way affected the integrated potentials.

As was previously mentioned, some of the minute muscle voltages, after being amplified, were sent into an integrator which summed them electrically. By way of explanation, these amplified voltages, alternating in character, were first rectified and then sent into a capacitor which increased its terminal voltage with each bit of electrical energy acquired. When the terminal voltage reached a low, predetermined value it triggered a gas-filled tube that caused a relay to short circuit the capacitor, thereby discharging it and allowing it to start charging anew (integrator circuit diagram shown in Figure 8). Each time the relay discharged the capacitor, it sent out one impulse causing the crystallograph pen connected to that channel to scribe one pip. The frequency with which the pips were recorded on the chart paper in a given period of time was signaled by the relay and was directly proportional to the rate at which the energy was fed into the capacitor. Thus, this mechanism
CIRCUIT DIAGRAM FOR INTEGRATORS
provided a means of obtaining quantitative data from the electromyographic process (Figure 7).

The instrument calibration was accomplished by recording its response to known voltage inputs from a signal generator in the following order and magnitude: 10, 20, 40, 60, 80, 100, 125, 150, 175, 200, 250, 300, 350, 400, 450, 600 microvolts (Fig. 9). These calibrations were made before and after the collection of the experimental data from each subject.

D. Mechanical Apparatus

The subject, as previously stated, was seated on an adjustable stool in the Faraday cage. In front of him was an especially constructed table and apparatus, which, when used in conjunction with a cephalostat, was designed for (1) supporting the various weights to be raised and lowered by mandibular depression and elevation, (2) maintaining the constancy of the rate of mandibular movements—depression and elevation, and (3) maintaining the constancy of the amplitude of mandibular depression and elevation. Portions of the equipment concerned with the above were located at opposite ends of the table (Figure 10). That portion nearest to the subject consisted of the following: (1) an adjustable stool, (2) an F. W. Steiner cephalostat, and (3) a number of pulleys mounted on a steel frame-work for the support of (a) various weights, and (b) a
A PORTION OF THE CALIBRATION DATA
FIGURE 10

SUBJECT OPERATING MECHANICAL APPARATUS;
MOUTH CLOSED
plastic chin covering appliance. This equipment fixed the subject's head and by virtue of the weighted pulleys provided a variable resistance to forced mandibular depression during the mouth opening movements. That portion of the equipment located at the opposite end of the table consisted of the following: (1) a motor-driven cam and (2) a pair of movable indicators. A six-inch vertical travel was imparted to one of these indicators by the aluminum shaft to which it was attached. This vertically oriented shaft was in turn raised and lowered by the above mentioned cam over and upon which it was positioned. A bearing interposed between the shaft and cam was used so as to reduce friction to a minimum. Thus, this indicator possessed a constant rate and amplitude of travel. The travel of the second indicator, which was positioned adjacent and parallel to the first, was effected by the pulley apparatus, previously mentioned, in conjunction with the subject's mandibular movements. Consequently, the juxtaposition of the two indicators throughout their travel distances would serve to maintain a constant rate and a constant amplitude of mandibular depression and elevation. This was accomplished by the subject's coordinating abilities.

At the subject's end of the table, a metal horizontal beam, suspended between two vertical rods and parallel with this edge of the table, supported four pulleys. Two of these were mounted on individual axes capable of adjustment in two
directions in the horizontal plane. The third and fourth pulleys were adjacent to one another and on a common rotatable shaft which extended to the opposite end of the table. One of these two adjacent pulleys supported a hanger which was capable of accepting weights in one-half, one, and two pound increments, to a total of ten pounds. The first two mentioned pulleys, in conjunction with the second of the two adjacent pulleys, (all three being maintained in the same vertical plane) supported the personalized plastic "overlay" or "cap" of each subject's chin (Figure 11).

The cords suspending the "chin cap" (from the end of its extensions) and the weight hanger from the above mentioned pulleys were two lengths of forty-pound test fish line. Each of these cords was fastened to, and wound in opposing directions on one of the two adjacently positioned pulleys. Because of the common attachment of the "chin cap" and weights to the same rotatable shaft (Figure 11), the subject's mandibular movements resulted in the raising and the lowering of various loads (referred to as "exercises" in this experiment). The magnitudes of the various weights used were as follows: 0.5 pound, 2.5 pounds, 4.5 pounds, 6.5 pounds, 8.5 pounds, and 9.5 pounds.

The "chin cap" was made of auto-polimerizing acrylic resin fashioned on "stone" (hydrocal) models made from alginate impressions of each subject's chin. Two concentrically parallel
FIGURE 11

SUBJECT'S VIEW OF MECHANICAL APPARATUS
one-eighth inch copper tube extensions were attached to the "chin caps", one on either side, with the aid of a jig (Fig. 12). The overall width from the end of one copper tube extension to the other was ten inches and was constant from subject to subject. This measurement equalled exactly the distance between the two pulleys that suspended this appliance. The "cap" on the subject's chin was maintained in place during the "exercises" by the liberal use of theatrical spirit gum.

Simultaneously with the mandibular movements and with the raising and the lowering of the various loads, the above mentioned rotatable shaft, extending to the opposite end of the table, and after penetrating a back-board, rotated one of two interchangeable multi-grooved cone shaped aluminum pulleys (Figure 10, 12 and 13). These grooves provided for variations in pulley diameters; which, with the assistance of two rider pulleys and a length of fish line, drove one of the two indicators situated immediately behind the vertically oriented rectangular opening in the back-board (Figure 13).

The subject, in performing the "exercises" (outlined above) attempted to coincide the travel of the above mentioned indicator with that of the second indicator (further described below). Juxtaposition of the two indicators depended upon the subject's ability to coordinate his mandibular movements with his visual perception of the two indicators. This second indicator,
FIGURE 12
MULTI-GROOVED PULLEYS AND ARMAMENTARIUM
FOR CHIN CAP CONSTRUCTION
FIGURE 13

SUBJECT OPERATING MECHANICAL APPARATUS;

MOUTH OPEN
immediately adjacent and parallel to the first, was raised and lowered a constant distance of six inches by a balanced aluminum cam which was rotated by a shaded four-pole induction motor. This motor was shielded (so as not to introduce its electromagnetic field into the Faraday cage) by a specially constructed sheet-metal housing and was supplied a constant line voltage, maintained by a shielded voltage regulator, via a shielded cable. The cam this motor turned was specifically designed to impart to this second indicator a constant rate of rise and fall and, as close as possible, an instantaneous change of direction. As each change from a rise to a fall occurred, this indicator actuated a micro-switch which, through its connection with an oscillator, produced an interruption in the time-base marker. Thus, the juxtaposition of the two indicators throughout their travel distances insured a constant rate and a constant amplitude of mandibular movements.

Due to the varying extent of the maximum mandibular depressions among the subjects, the travel distance of the first above mentioned indicator was kept equal to (and coincident with) the constant travel distance of the second by the selection of the appropriate diameter groove on one of the two multi-grooved pulleys mentioned above. For the first indicator to maintain this exactness of travel distance on successive maximum mandibular depressions, it was found necessary to keep the
subject's head oriented in a constant relation to the three planes of space. This was accomplished through the guidance received by the subject from a Steiner cephalostat mounted on one of the walls of the Faraday cage. The adjustability of the stool, in accordance with above, provided for a natural and comfortable sitting position for each subject.

E. Experimental Procedure

Prior to the data collection each subject was introduced to the apparatus and permitted to familiarize himself with the muscular strength and degree of coordination required to perform the "exercise" at the various loads. None required more than twenty to thirty minutes to obtain a fair degree of proficiency.

Subsequent to the familiarization period the eight surface electrodes were placed on the subject as previously described, the resistances were measured, and the electronic equipment was warmed up simultaneously.

The four integrated channels, recording the bilateral temporal and infrahyoid activity, were maintained at Gain 5 for all the subjects throughout the study. The equalizer settings, however, were determined individually for each subject. This was done by having the subject re-enter the cage to perform the "exercise" at the maximum and minimum loads under experimental
conditions. Equalizer settings were then adjusted so as to record the maximum activity possible at the minimum load and yet not thereby cause any overloading of the integrators or pen writers at the maximum load. Likewise, the two non-integrated channels, used to monitor the left temporal and left infrahyoid musculature, were now adjusted to give similarly adequate tracings. This resulted in a variation in their gain settings of from five to seven among the various subjects.

The subject was now removed from the cage and the calibration data collected in response, whenever possible, to all of the following peak microvolt inputs at 60 cycles per second: 10, 20, 40, 60, 80, 100, 125, 150, 175, 200, 250, 300, 350, 400, 450, 500.

Upon completion of the calibration, the subject was re-admitted to the cage and the experimental data were then collected. This consisted of performing the "exercise" (opening and closing mandibular movements) six times; each time for a period of from thirty to sixty seconds and at one of the following loads: 0.5, 2.5, 4.5, 6.5, 8.5, and 9.5 pounds. A randomized sequence was employed in the application of the various loads. These data were recorded by the oscillograph on Offner Chart Paper #158 (Figures 14, 15, 16, 17, 18, 19).

Upon completion of the sixth "exercise", the subject was
FIGURE 14

ELECTROMYOGRAM OBTAINED FROM EXERCISE

PERFORMED AT 0.5 POUNDS
FIGURE 15

ELECTROMYOGRAM OBTAINED FROM EXERCISE
PERFORMED AT 2.5 POUNDS
FIGURE 16

ELECTROMYOGRAM OBTAINED FROM EXERCISE
PERFORMED AT 4.5 POUNDS
FIGURE 17
ELECTROMYOGRAM OBTAINED FROM EXERCISE
PERFORMED AT 6.5 POUNDS
FIGURE 18
ELECTROMYOGRAM OBTAINED FROM EXERCISE PERFORMED AT 8.5 POUNDS
FIGURE 19

ELECTROMYOGRAM OBTAINED FROM EXERCISE
PERFORMED AT 9.5 POUNDS
removed from the cage and another set of calibrations were taken.

F. Experimental and Statistical Discipline

To permit statistical analysis of the data, the experimental design was fashioned to comply with the following: (1) the identifiable variances in the experiment were separated and limited, as far as possible, to known sources thereof; (2) as homogeneous a medium as possible was provided for throughout the experiment; (3) a measurable quantity capable of accurate assessment was established; and (4) various null hypotheses were postulated.

Certain technical procedure had to be performed prior to subjecting the data to the proper analysis of variance.

As previously mentioned, the interruption in the time-base marker indicated the transition from mandibular elevation to depression. Because of the mechanics of micro-switches, this transition occurred at the termination of the first third of the interruption. The first half of the time interval between two such successive transitions, as determined by the time-base marker, corresponded with mandibular depression (the mouth opening phase); the second half with mandibular elevation (closing phase). Together, the two constituted a complete mouth opening and closing "cycle". The first of each two such adjacent "cycles" was randomly selected from the "exercise" performed by
each subject at each of the various weights. The immediately succeeding "cycle" was defined as the duplicate (Figures 14 through 19).

The muscular activity was summed and quantified by the integrators and recorded by the pen deflections (pips) in accordance with the electrical output of the individual muscles (Figures 14 through 19). These data were tabulated on individual work sheets for each subject for the period of the two "cycles" mentioned above and for each of the various weights used (Table I). These enumeration data were then reduced to pip counts per second (Table II). "Initial" and "after" calibration curves (Figure 20) were next used to reduce these data to microvolt seconds (Table III) since these were the units chosen for the measurement of the energy output of the muscles.

The calibration curves were constructed from data collected in response to the a.c. inputs from a signal generator (Fig. 9). These peak microvolt inputs, each multiplied by .636, gave average microvolt input values which were used for the horizontal ordinates in the construction of the curves. The vertical ordinates, pips per second, represented average values calculated from ten-second intervals at the various specific microvolt inputs. These "initial" and "after" calibration curves (Figure 20) were used to reduce the first and second halves of
## Table I

**PIP Count Per Portion of Cycle**

<table>
<thead>
<tr>
<th></th>
<th>L Infrahyoid</th>
<th>L Temporal</th>
<th>R Temporal</th>
<th>R Infrahyoid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A (open)</td>
<td>A (close)</td>
<td>C (open)</td>
<td>C (close)</td>
</tr>
<tr>
<td>lbs #</td>
<td>lbs #</td>
<td>lbs #</td>
<td>lbs #</td>
<td>lbs #</td>
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<tr>
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<td>1</td>
</tr>
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<td>2</td>
<td>4</td>
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<td>1</td>
</tr>
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<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
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<td>1</td>
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<td>2</td>
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<tr>
<td>10</td>
<td>20</td>
<td>11</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

H. L. Vanoucek

Sept. 13, 1959
### TABLE II

**PIP Count per Second per Portion of Cycle**

**H. L. VANOUCK**

**SEPT. 13, 1959**

<table>
<thead>
<tr>
<th></th>
<th><strong>L. INFRAHYOID</strong></th>
<th><strong>L. TEMPORAL</strong></th>
<th><strong>R. TEMPORAL</strong></th>
<th><strong>R. INFRAHYOID</strong></th>
</tr>
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<tbody>
<tr>
<td></td>
<td>A</td>
<td>C</td>
<td>E</td>
<td>F</td>
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<tr>
<td>lbs</td>
<td>open</td>
<td>close</td>
<td>open</td>
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<tr>
<td>1</td>
<td>2.94</td>
<td>1.178</td>
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<td>2.355</td>
<td>1.178</td>
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<tr>
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<td>0.588</td>
<td>0.588</td>
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<tr>
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<td>0.588</td>
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<td>1.178</td>
<td>0.588</td>
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<tr>
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<td>7.06</td>
<td>0.588</td>
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<td>2</td>
<td>11.78</td>
<td>6.47</td>
<td>1.178</td>
<td>1.178</td>
</tr>
</tbody>
</table>
CALIBRATION CURVE

CHANNEL "A"  
H. L. VANOUCEK

INITIAL CALIBRATION  
SEPTEMBER 13 1959

GAIN 5  60 CYCLE

FIGURE 20

CALIBRATION CURVE

PIPS PER SECOND

MICROVOLT SECONDS
# TABLE III

**MICROVOLT CONVERSION**

H. L. VANCUECK  
SEPT. 15, 1969

<table>
<thead>
<tr>
<th>L INFRAHYOID</th>
<th>L TEMPORAL</th>
<th>R TEMPORAL</th>
<th>R INFRAHYOID</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>C</td>
<td>E</td>
<td>F</td>
</tr>
<tr>
<td>lbs #</td>
<td>open</td>
<td>close</td>
<td>open</td>
</tr>
<tr>
<td>1</td>
<td>69.0</td>
<td>31.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>56.0</td>
<td>31.0</td>
<td>10.8</td>
</tr>
<tr>
<td>4.5</td>
<td>108.5</td>
<td>56.0</td>
<td>10.8</td>
</tr>
<tr>
<td>1</td>
<td>56.0</td>
<td>0.0</td>
<td>10.8</td>
</tr>
<tr>
<td>2</td>
<td>56.0</td>
<td>0.0</td>
<td>10.8</td>
</tr>
<tr>
<td>8.5</td>
<td>206.8</td>
<td>126.25</td>
<td>11.7</td>
</tr>
<tr>
<td>2</td>
<td>255.0</td>
<td>126.25</td>
<td>11.7</td>
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<tr>
<td>6.5</td>
<td>145.0</td>
<td>63.0</td>
<td>11.7</td>
</tr>
<tr>
<td>1</td>
<td>128.25</td>
<td>63.0</td>
<td>16.5</td>
</tr>
<tr>
<td>2</td>
<td>289.0</td>
<td>160.0</td>
<td>11.7</td>
</tr>
<tr>
<td>9.5</td>
<td>289.0</td>
<td>145.0</td>
<td>16.5</td>
</tr>
</tbody>
</table>
the data, respectively.

A portion of the data, expressed in microvolt-seconds, was subjected to a histogram survey (Figure 21). Because of the lack of resemblance of the data's histogram to a normal distribution each value of the data was transformed by taking the square root of the sum of each observed value plus one and tabulated on the final work sheet (Table IV). Another histogram survey (Figure 22), using the transformed data, demonstrated a closer resemblance to a normal distribution thereby meeting one of the requirements of the analysis of variance.

The transformed data from each of the ten subjects were now incorporated into one large final work sheet and subjected to an analysis of variance. The principal sources of variance were expected to be as follows: the muscles (2 groups and 2 sides), the portions of the "cycle", the various weights, and the subjects. Their significance was determined by a comparison of their variances (mean squares) with that of the correspondingly appropriate measure of the estimated experimental error. A table of components of variance determined the selection of the latter which was made from among the values for the residue, duplicate and interaction variances. The significance of these comparisons (known as F ratios) was determined from an F table and indicated by one, two and three asterisks for the proper level.
SAMPLE DISTRIBUTION OF DATA BEFORE TRANSFORMATION

HISTOGRAM SURVEY OF DATA EXPRESSED IN MICROVOLT SECONDS BEFORE TRANSFORMATION

FIGURE 21
**TABLE IV**

TRANSFORMATIONS

H. L. VANOUCKX

SEPT. 13, 1969

<table>
<thead>
<tr>
<th></th>
<th>L INFRAHYOID</th>
<th>L TEMPORAL</th>
<th>R TEMPORAL</th>
<th>R INFRAHYOID</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>C</td>
<td>E</td>
<td>F</td>
</tr>
<tr>
<td>lbs #</td>
<td>open</td>
<td>close</td>
<td>open</td>
<td>close</td>
</tr>
<tr>
<td>2.5</td>
<td>8.367</td>
<td>5.657</td>
<td>1.0</td>
<td>3.435</td>
</tr>
<tr>
<td>2</td>
<td>7.550</td>
<td>5.657</td>
<td>3.435</td>
<td>3.435</td>
</tr>
<tr>
<td>4.5</td>
<td>10.464</td>
<td>7.550</td>
<td>3.435</td>
<td>3.950</td>
</tr>
<tr>
<td>6.5</td>
<td>10.464</td>
<td>7.550</td>
<td>3.435</td>
<td>3.950</td>
</tr>
<tr>
<td>8.5</td>
<td>7.550</td>
<td>1.0</td>
<td>3.435</td>
<td>3.950</td>
</tr>
<tr>
<td>2</td>
<td>7.550</td>
<td>1.0</td>
<td>3.435</td>
<td>3.950</td>
</tr>
<tr>
<td>6.5</td>
<td>12.083</td>
<td>8.0</td>
<td>3.564</td>
<td>3.808</td>
</tr>
</tbody>
</table>
SAMPLE DISTRIBUTION OF DATA AFTER TRANSFORMATION

FIGURE 22

HISTOGRAM SURVEY OF TRANSFORMED DATA
The homogeneous medium, mentioned previously, referred to the muscles used, i.e., the temporal and infrahyoid musculature of man.

The statistical analysis will determine whether the following null hypotheses will be accepted or rejected:

1. There is no difference in the energy output from the two groups of muscles.
2. There is no difference in the energy output from the muscles of the two sides.
3. There is no difference in the energy output of the muscles as a result of the application of various weights.
4. There is no difference in the energy output of the muscles during the opening and closing portions of the "cycle".
5. There is no difference in the energy output of the muscles of different subjects.
CHAPTER III

Experimental Results

The experimental findings were obtained from the statistical and graphical analyses of randomly selected portions of the data. As previously described, these data, consisting of the temporal and infrahyoid integrated electromyograms, were collected from ten subjects while performing numerous mouth opening and closing movements (or cycles) at each of six different magnitudes of resistance. The electronically integrated muscle voltages, recorded as a series of pips on a tracing, were counted for each portion of each cycle, reduced to pips-per-second and, with the aid of calibration curves, converted to microvolt-seconds. Because of the many zero quantities encountered a transformation \( \sqrt{N - 1} \) was employed to provide a more nearly normal distribution of the data and thereby satisfy the requirements of the analysis of variance.

The results of the statistical analyses are concisely presented in the analysis of variance table (Table V). Since the "Residue" mean square (1.464161) is a more valid measure of the experimental error (embodying the variability due to the environmental conditions, time of day, different days, temperature, and other uncontrollable random factors) than the
### TABLE V

**ANALYSIS OF VARIANCE TABLE**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>D.F.</th>
<th>S.S.</th>
<th>M.S.</th>
<th>Variance Ratio (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MAIN EFFECTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscle Groups</td>
<td>1</td>
<td>3191.431388</td>
<td>3191.431388</td>
<td>104.416286***</td>
</tr>
<tr>
<td>Muscle Sides</td>
<td>1</td>
<td>.570278</td>
<td>.570278</td>
<td>.205040</td>
</tr>
<tr>
<td>Portions</td>
<td>1</td>
<td>159.761379</td>
<td>159.761379</td>
<td>21.598003**</td>
</tr>
<tr>
<td>Weights</td>
<td>5</td>
<td>1123.236262</td>
<td>224.647252</td>
<td>46.628209***</td>
</tr>
<tr>
<td>Subjects</td>
<td>9</td>
<td>753.698683</td>
<td>83.744298</td>
<td>57.196099***</td>
</tr>
<tr>
<td><strong>INTERACTION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.G. x M.S1.</td>
<td>1</td>
<td>8.375738</td>
<td>8.375738</td>
<td>5.720503*</td>
</tr>
<tr>
<td>M.G. x P.</td>
<td>1</td>
<td>105.665030</td>
<td>105.665030</td>
<td>72.167630***</td>
</tr>
<tr>
<td>M.G. x Wt.</td>
<td>5</td>
<td>635.195834</td>
<td>127.039166</td>
<td>86.765844***</td>
</tr>
<tr>
<td>M.G. x Sub.</td>
<td>9</td>
<td>275.080486</td>
<td>30.564498</td>
<td>20.875093***</td>
</tr>
<tr>
<td>M.S1.x Por.</td>
<td>1</td>
<td>.079643</td>
<td>.079643</td>
<td>.054395</td>
</tr>
<tr>
<td>M.S1.x Wt.</td>
<td>5</td>
<td>1.021132</td>
<td>.204226</td>
<td>.139483</td>
</tr>
<tr>
<td>M.S1.x Sub.</td>
<td>9</td>
<td>25.031610</td>
<td>2.781290</td>
<td>1.899579</td>
</tr>
<tr>
<td>Por. x Wt.</td>
<td>5</td>
<td>6.495614</td>
<td>1.299102</td>
<td>.887267</td>
</tr>
<tr>
<td>Por. x Sub.</td>
<td>9</td>
<td>66.573401</td>
<td>7.397044</td>
<td>5.052070***</td>
</tr>
<tr>
<td>Wt. x Sub.</td>
<td>45</td>
<td>216.802829</td>
<td>4.817840</td>
<td>3.290512***</td>
</tr>
<tr>
<td>Duplicates</td>
<td>480</td>
<td>138.337292</td>
<td>.288202</td>
<td></td>
</tr>
<tr>
<td>Residue</td>
<td>372</td>
<td>544.667900</td>
<td>1.464161</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>959</td>
<td>7252.024399</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
"Duplicates" mean square (.288202), the former was used to determine the variance ratios of the first-order interactions. The asterisks denote the level of significance—one asterisk representing significance at the 5 per cent level, two asterisks representing significance at the 1 per cent level and three asterisks representing significance at the 0.1 per cent level. The following first-order interactions were found to be significant at the 0.1 per cent level; Muscle group x Portion interaction, Muscle group x Weight interaction, Muscle group x Subject interaction, Portion x Subject interaction and Weight x Subject interaction. The Muscle group x Muscle side interaction was found to be significant only at the 5 per cent level.

Reference to a components of variance table indicated that among the main effects, only the "Subjects" mean square (subjects having been selected randomly) was to be tested against the "Residue" mean square. The variance ratios of the remaining main effects were calculated by using their respective interaction mean squares as estimates of the experimental error. Among the main effects the variations due to the "Subjects", "Weights", and "Muscle groups" were found to be highly significant (at the 0.1 per cent level). Variation due to "Portions" (of the cycles) was almost significant at the 0.1 per cent level. No significant difference was noted between the "Muscle Sides". Thus, of the five null hypotheses postulated in the previous
chapter, only the second is statistically acceptable.

The experimental findings, with respect to the significant main effects, are presented in Table VI while those with respect to two of the interaction effects are shown in Table VII.

Table VI cites the average microvolt-second output of the temporal and infrahyoid musculature during an opening, as well as during a closing phase at each of the six loads used. Each value is the average of forty readings. Table VII indicates the average level of the infrahyoid activity of each subject at the maximum and minimum load levels during the opening as well as the closing phase. Each value is the average of four readings and is expressed in microvolt-seconds.

Graphical analyses of the experimental findings presented in Tables VI and VII are provided by Figures 23, 24 and 25. Thus Figure 23 demonstrates the existence of a linear relation between the load (i.e., the resistance to mouth opening) and the microvolt-second output (i.e., tension) of the temporal muscle during the mouth opening movement. This same figure also demonstrates the absence of such a linear relation during the closing movement (when the load assisted in mandibular elevation). It is interesting to note that the relation depicted between the load and microvolt-second output of the temporal muscle during the closing phase tended to resemble a parabolic curve. Figure 23 further illustrates that the tension produced by the temporal muscle (as measured by the
TABLE VI

THE INFLUENCE OF VARIOUS LOADS ON THE TEMPORAL AND INFRAHYOID MUSCLE ACTIVITY DURING OPENING AND CLOSING; EXPRESSED IN MICROVOLT-SECONDS

<table>
<thead>
<tr>
<th>LOAD</th>
<th>INFRAHYOID MUSCLE</th>
<th>TEMPORAL MUSCLE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>opening</td>
<td>closing</td>
</tr>
<tr>
<td>0.5</td>
<td>15.629</td>
<td>3.527</td>
</tr>
<tr>
<td>2.5</td>
<td>30.749</td>
<td>17.966</td>
</tr>
<tr>
<td>4.5</td>
<td>43.751</td>
<td>27.068</td>
</tr>
<tr>
<td>6.5</td>
<td>62.851</td>
<td>36.619</td>
</tr>
<tr>
<td>8.5</td>
<td>76.665</td>
<td>50.733</td>
</tr>
<tr>
<td>9.5</td>
<td>89.528</td>
<td>64.508</td>
</tr>
</tbody>
</table>
TABLE VII

AVERAGE RANGE OF INFRAHYOID MUSCLE ACTIVITY BETWEEN MINIMUM AND MAXIMUM LOADS DURING OPENING AND CLOSING PHASES AMONG SUBJECTS; EXPRESSED IN MICROVOLT-SECONDS

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>OPENING Min. Load 0.5 lb.</th>
<th>OPENING Max. Load 9.5 lbs.</th>
<th>CLOSING Min. Load 0.5 lb.</th>
<th>CLOSING Max. Load 9.5 lbs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18.758</td>
<td>37.975</td>
<td>4.080</td>
<td>28.031</td>
</tr>
<tr>
<td>2</td>
<td>6.958</td>
<td>32.960</td>
<td>2.179</td>
<td>49.367</td>
</tr>
<tr>
<td>3</td>
<td>4.673</td>
<td>36.634</td>
<td>0.365</td>
<td>78.977</td>
</tr>
<tr>
<td>4</td>
<td>3.056</td>
<td>57.442</td>
<td>0.823</td>
<td>56.638</td>
</tr>
<tr>
<td>5</td>
<td>12.235</td>
<td>114.605</td>
<td>3.584</td>
<td>84.677</td>
</tr>
<tr>
<td>6</td>
<td>33.857</td>
<td>89.193</td>
<td>40.088</td>
<td>61.189</td>
</tr>
<tr>
<td>7</td>
<td>4.992</td>
<td>102.734</td>
<td>0.0</td>
<td>71.897</td>
</tr>
<tr>
<td>8</td>
<td>48.744</td>
<td>235.759</td>
<td>2.694</td>
<td>129.759</td>
</tr>
<tr>
<td>9</td>
<td>36.356</td>
<td>73.978</td>
<td>2.542</td>
<td>36.088</td>
</tr>
<tr>
<td>10</td>
<td>14.665</td>
<td>57.752</td>
<td>0.868</td>
<td>74.658</td>
</tr>
</tbody>
</table>
INFLUENCE OF LOAD ON TEMPORAL MUSCLE ACTIVITY

FIGURE 23

GRAPHICAL PRESENTATION OF THE EFFECT OF LOADS ON THE ACTIVITY OF TEMPORAL MUSCLE
INFLUENCE OF LOAD ON INFRAHYOID MUSCLE ACTIVITY

FIGURE 24
GRAPHICAL PRESENTATION OF THE EFFECT OF LOADS
ON THE ACTIVITY OF INFRAHYOID MUSCLE
AVERAGE RANGE OF MICROVOLT OUTPUT FOR INFRAHYOIDS DURING OPENING AND CLOSING PHASES AMONG SUBJECTS BETWEEN MINIMUM AND MAXIMUM LOADS

FIGURE 25

GRAPHICAL PRESENTATION OF THE RANGE OF INFRAHYOID MUSCLE ACTIVITY FOR EACH SUBJECT
microvolt-second output) was, for corresponding loads, for the most part greater during the opening phase than during the closing phase. A comparison of the level of the temporal activity with that of the infrahyoid will be made after presenting the observations made from Figure 24.

There are shown in Figure 24 the relations between the output of the infrahyoid muscles and the load during the mandibular opening and closing movements. The tension developed by these muscles during the opening movement (as measured in microvolt-seconds) was found to vary approximately in proportion to the applied load. It was also found that the tension of the infrahyoids was approximately proportional to the load during the closing movements of the mandible. The lines depicting these two relations exhibit a parallelism which indicates that the level of infrahyoid activity for corresponding loads was always greater during the opening phase than during the closing phase. The fact that they do not depart significantly from parallelism is shown by the small mean square for "Portions x Weight" interaction in Table V.

Note must also be taken of the fact that the straight line relations, demonstrated in Figures 23 and 24, do not intersect the origin of the two axes on either of the graphs. The linear relations depicting the temporal and infrahyoid activities,
during the mouth opening movement, were found to intersect the Y axis at the 2.5 and 9.0 microvolt-second level respectively. The infrahyoid activity during the closing movement graphically indicated a negative 1.0 microvolt-second at a zero load. Comparison of Figures 23 and 24 further indicated an infrahyoid activity level approximately ten times greater than that of the temporal muscle. (Note the different ordinate scales used for the two graphs).

Figure 25 demonstrates the ranges of microvolt-second output of the infrahyoids during the opening and closing movements among the various subjects. With but one exception, the microvolt-second output at 0.5 pound was always greater for the opening movement than for the closing movement among the various subjects. This same situation was demonstrated at the 9.5 pound load, each subject, except one, developing a greater microvolt-second output during the opening phase than during the closing phase. The fact that these ranges (at a given load), as graphically depicted in Figure 25, are different among the various subjects is what gives rise to a significant "Portions x Subject" interaction term in Table V.

Most striking was the variability in the range of microvolt-second output between the minimum and maximum loads among the various subjects within a given phase of the "cycle"
(Figure 25). The great variability in this respect among the subjects is what gives rise to the large "Weight x Subject" interaction in Table V.
CHAPTER IV

DISCUSSION

Introduction

This chapter will present the following in the order mentioned: (1) a statement of the basic assumptions upon which this experiment was predicated, (2) a discussion of the experimental environment with respect to its constancies, inconstancies and implications, (3) an explanation of why the experiment was altered and re-performed, and (4) an interpretation of the experimental findings. The latter will include first, an interpretation of the statistically significant findings, and second, an interpretation of the graphical analysis depicting the inter-relation of these findings.

Basic Assumptions Underlying the Experiment

Nature readily and willing divulges her truths to scientific experimentation. However, she rewards misinterpretation with, if not immediate then eventual, frustration. Possibly with this in mind, Sichor (1954) has advisedly expressed concern regarding the interpretation of the electromyograms—stating that they (in recording muscle action potentials) only demonstrate when and how strongly a muscle acts but never in what capacity
the contraction occurs. He reiterates the fact that muscles may contract isotonically and isometrically; and that by the former they act as movers, by the latter they act as holders, stabilizers, and positioners. He also described the situation wherein a muscle contraction occurs in preparation to its relaxation so as to brake or balance the moving contraction of its antagonist.

Last (1955) expressed practically the same ideas when he pictured the muscles of the body as acting in opposing pairs or groups and wherein a given muscle may, on different occasions, act (1) as a prime mover, (2) as an opponent "paying out rope", or (3) as a synergist to neutralize an unwanted movement produced by another prime mover.

The above comments regarding electromyography and muscle contraction, in conjunction with the important findings of Lippold (1962), Bigland, Lippold and Wrench (1953), and Bigland and Lippold (1954), which demonstrated the proportionality between muscle tension and its integrated electromyogram, constitute the underlying assumptions upon which this investigation of the temporal and infrahyoid musculature was predicated.

Experimental Environment

This experiment analyzed the tensions produced in the temporal and infrahyoid musculature, as measured by the integrated
electromyogram, during a limited and highly stylized mandibular movement executed and performed under various degrees of resistance. The reason for imposing certain experimental restrictions and limitations was to provide a constancy to the experimental environment and thereby reduce the main sources of variation to (1) the muscle groups (i.e., the temporal and infrahyoid musculatures), (2) the subjects, which constituted a measure of the biological uniformity of the results, (3) the portions of the "cycle" (opening and closing), and (4) the weights, which imposed a force, acting with a closing moment, upon the mandible.

One of the experimental restrictions provided for an imitable mandibular movement. This was accomplished by having each subject perform a maximum mouth opening and closing movement at a velocity that was constant for and during each movement. The need for this restriction was embodied in the findings of Lippold (and co-workers, as mentioned above), that demonstrated the relation between the tension, the force and the velocity of muscle contraction, as measured by the integrated electromyogram. The proportionality of these relations confirmed the need for a constant degree and rate of mouth opening and closing.

Another restriction imposed by the experimental procedure involved the use of a Steiner cephalostat for maintaining a
consistent head posture. The need for this restriction was determined by the effect that the initial muscle length was known to have on the mechanical and electrical changes associated with muscle contraction; and which has been extensively documented in the literature (Fulton 1926, Fenn 1938, Ramsey and Street 1940, and Fulton 1949). The guidance provided the subject from a cephalostat was considered to be as adequate in providing a constant initial muscle length as would be practically necessary.

Thus, it was hoped that the above considerations would impart a constancy to the experimental environment upon which the effects of the various resistances (to mandibular movement) on the behavior of the temporal and infrahyoid musculature could be randomly selected and compared.

Certain inconstancies in the experimental environment need mentioning. One of these inconstancies pertained to the variation in the rate of mandibular movements between subjects. This variation developed because each subject was asked, in accordance with the experimental design, to accomplish each opening and closing movement in 1.7 second, even though the extent of these maximum movements varied between subjects. Since this inconstancy would be reflected in the variation between subjects, extreme caution must be exercised in the interpretation of those experimental findings that would suggest or invite a comparison.
between subjects.

A second inconstancy in the experimental environment pertained to the inequality in the areas of the muscle tissues involved. This inequality would be reflected in the magnitude of the microvolt-second responses. Consequently, this inconstancy would not only influence any comparison between subjects, but also, any comparison between muscle tissues (i.e., between the temporal and infrahyoid). Thus, the variations noted in the experimental findings regarding both muscle groups and subjects, must be analyzed with extreme care. This does not mean to say that the use of numerous subjects did not provide any valid information. On the contrary, it provided a means of validating the subjects' results on the basis of the uniformity of the observed behavior patterns.

Should the experimental environment be misunderstood, certain faulty physiological implications are likely to be inferred and thereby influence the interpretation of the experimental findings. Some of these possible erroneous implications will now be discussed.

First, it must not be inferred that the constancy of the mandibular movement imparted any similar constancy to the lengthening and shortening of the associated musculature. The basis for this statement originated in the knowledge that the mandibular elevation and depression basically involved two
movements, (1) a rotary or hinge movement and (2) a translatory or gliding movement (Sicher 1949); and that the contribution of each, at any particular moment, depended upon the extent of the opening or closing movement. Thus a variable rate of lengthening and shortening would more than likely be imparted to the associated musculature. This nature of the muscle contraction would, of course, be incapable of analysis by the electromyogram.

Another erroneous, physiological implication may possibly be suggested by the nature of the loads employed in the experiment, each of which exerted a constant closing moment of force upon the mandible. From the above, it must not be inferred that the associated mandibular musculature would likewise function against a constant load, and therefore exert a constant tension throughout each opening and closing movement. If it had, the definition for an isotonnic muscle contraction would have been satisfied (Fulton 1949). Rather, the individual muscles, associated with the mandibular movements, actually contracted against variable loads or resistances; the variability of which was created by (1) the irregular participation of synergistic and antagonistic muscles, or (2) the inconstancy in the mechanical advantage, or (3) the participation of both of the above factors.
Another faulty implication, closely related to the above, may possibly be made in relation to the experimental design. Consequently, it should be born in mind that, at no time, was an attempt made to analyze the muscle activity (with respect to its variations) during the periods of each of the mandibular movements. Rather, the analyzed data only recorded the individually accumulated muscle tensions for each entire opening and closing movement. This, therefore, in no way imparted any knowledge concerning possible synergistic or antagonistic muscle activity during each of the mandibular movements.

At this point it may be appropriate to reiterate the purpose of this investigation; namely, to study the tension response in the temporal and infrahyoid musculature associated with the varying efforts exerted during forced mandibular movements. Thus, the experimental procedure provided for a duplicability of muscle function super-imposed upon a constant environmental background. This enabled the temporal and infrahyoid musculature to be analyzed with respect to the effect of various resistances, each of which exerted a closing moment of force upon the mandible.

Experiment Altered and Re-performed

Initially, data were collected from one subject to provide information upon which to conduct a pilot study. Though the results were somewhat inconclusive, it was decided to proceed
with the experiment, collecting the data from twelve randomly selected subjects. Analysis of these results, however, demonstrated the presence of a gross experimental deficiency that was ultimately attributed to an insufficient dissimilarity between the loads employed. This disclosure came only upon the realization that muscle fatigue masked any variation developed as a consequence of the various resistances employed.

The relation between fatigue, muscle tension and the integrated electromyogram has been documented by Edwards and Lippold (1956). Their work demonstrated that, for any given tension, muscle tissue exhibited an increased electrical activity whenever it was in a fatigued state. This they attributed to the recruitment of motor units to compensate for the decreased force of contraction associated with fatigued muscle fibers.

Thus, in re-performing the experiment, upon ten randomly selected subjects, the effect of muscle fatigue was minimized by reducing the number of mouth opening and closing movements. Furthermore, a proportional reduction in the effect of muscle fatigue (with respect to the results) was also accomplished by increasing the interval between the magnitudes of the various loads. The latter, of course, resulted in increasing the range between the minimum and maximum weights. The results of this re-performed experiment provide the basis for the following discussion.
Interpretation of the Experimental Findings

This discussion will include, first, an interpretation of the statistically significant findings, and second, an interpretation of the graphical analyses each of which depicted the inter-relation of these findings.

A. Interpretation of Statistical Results

Muscles

Four areas of muscle tissue were experimentally observed and statistically analyzed with respect to (1) body symmetry and (2) muscle origin.

The fact that the former of these two failed to demonstrate any significant difference between the observed energy outputs from similar areas of bilaterally corresponding muscles, (i.e., from the left and right sides) was to be expected since all the subjects exhibited, as far as could be ascertained, a normal structural and functional bilateral symmetry.

The grouping of the muscle tissues with respect to origin, however, demonstrated a highly significant difference between the temporal and infrahyoid musculature (0.1 per cent level). This was further demonstrated in the graphical analysis (Figures 23 and 24) which required the employment of two different scales to register the energy levels from the two different sources. The greater energy level exhibited by the infrahyoid musculature cannot be explained on the basis of the inequality
between the two areas of muscle tissue recorded from, since the greater inter-electrode distance was consistently associated with the temporal muscle. The temporal, on occasion, has been recognized as being a power muscle (Jarabak 1954); especially so, when compared with the slender strap-like sternohyoid muscle. In view of the temporal muscle's recognized superiority in strength, the fact that the pick-up from the sternohyoid muscle actually represented a multi-muscle recording, cannot, I believe, account for the ten fold greater energy output of the latter. Rather, the significant difference in the energy outputs from the two muscles would more logically be interpreted as representing the actual relative energy levels reflecting a necessary functional requirement for a particular movement. This would be in keeping with the statements of Carlsoo (1952) regarding the temporal muscle's lack of mechanical qualification for mandibular depression. Thus, on this basis, the low level of temporal muscle activity during the mouth opening movement is readily understood. During the closing movement, however, the above observation is equally applicable if it is recalled that the loads imposed by the experiment act on the mandible with a closing moment. Thus, since the mandibular elevation was effected by an externally originating force, and since the temporal muscle would, therefore once again, not be mechanically qualified to exercise any control or regulation, the energy output would of necessity be at the
observed low level.

These comments were offered in behalf of an interpretation of the statistical findings which recognized the greater functional participation of the infrahyoid musculature in the prescribed experimental movements.

Weights

The combined responses from the four muscle tissue areas (recorded in microvolt-seconds for the period of opening plus closing) were statistically analyzed with respect to the effect of the various loads upon the mandibular movement. The results of this analysis demonstrated that the variation between the tensions produced was significant at the 0.1 per cent level. The source of this variation could not be attributed to any alteration in the areas of tissue recorded from since these areas remained unchanged for each subject throughout the experiment; nor could it be attributed to any changes in the rate or extent of muscle contraction since these too were maintained as uniform and constant as was experimentally possible. The variation in the tension could, however, be attributed to the varying amounts of work performed; the justification for this interpretation is presented below.

The energy underlying all physiological processes is derived from the metabolism of food stuffs and is liberated as heat and
free energy. This free energy may in turn be stored (through some synthetic chemical reaction) or it may be used to accomplish work in the physical sense (Fulton 1949). Most of the energy for the latter is liberated in the skeletal muscle and is manifested by what is synonymously referred to as muscle tension, muscle pull, or force of contraction. In this experiment, a portion of the muscle energy, liberated as a tension, was utilized in raising and lowering a series of weights and thereby accomplished work in the physical sense. The energy that produced the muscle tension need not, of course, always accomplish work—as exemplified by the isometric muscle contraction. The following definitions and relations are therefore relevant. By definition, energy is the capacity to do work; force is that which tends to cause or change the motion of matter; and work is done only when a force moves an object through a distance in the direction of the force.

The work performed in the lifting of each of the various weights may be algebraically expressed as follows:

\[ W = F \times s, \]

where \( W \) equals work, \( F \) equals force and \( S \) equals distance. From Newton's Second Law of Motion, the force \( (F) \) equals the product of mass \( (m) \) and acceleration \( (a) \):

\[ F = ma. \]
Also, from the same law, the force required to lift any mass \( m \) is equal to its own weight:

\[
\text{Weight} = mg,
\]

where \( g \) equals the acceleration of gravity.

Thus, the work done in lifting each of the various weights may be represented as follows:

\[
W = mg \times s.
\]

The distance \( s \) was, as previously mentioned, maintained constant for all the subjects throughout the experiment. The acceleration effect of gravity was likewise maintained constant (for each subject) by establishing a uniform opening and closing, thereby limiting acceleration and deceleration to the initiation and termination of each movement. Thus the work performed in each of the "exercises" depended directly upon the weights \( m \) used.

The energy for the accomplishment of this work was provided by skeletal muscle tissue and was effected through the tensions in those muscles associated with this particular mandibular movement. From the above discussion of the experimental conditions and Newton's Second Law of Motion, it may be noted that the amount of work performed was also proportional to the force \( F \), i.e., effective muscle tension as measured in the direction of displacement.
It was, therefore, possible to vary this force or tension by controlling the amount of work performed and consequently analyze the contribution of the temporal and infrahyoid musculature to this force relative to the various amounts of work performed. This analysis was possible because of the research of Lippold (and co-workers, as previously mentioned) that demonstrated the validity of the integrated electromyogram as a measure of muscle tension. The proportionality they manifested did not, however, include the establishment of any absolute units of measurement.

The results of this analysis demonstrated then, that the observed variation in the combined tension contribution from the temporal and infrahyoid musculature, relative to the amounts of work performed, was statistically significant (0.1 per cent) and approximated a linearity—which was not presented graphically in the results since neither the effect due to each of the antagonistically positioned muscles, nor the effect due to the opening and closing phases would be identifiable.

To reiterate; the effect of a constant force, when impressed upon the mandible with a closing moment, during a maximum opening or closing movement, was observed to be proportionately reflected in the accumulated tensions exhibited by the temporal and infrahyoid musculature.

Portions

The variation observed in the combined tension responses...
from the four muscle tissue areas, with respect to the opening and closing movements, was found to be significant at the 1.0 per cent level. Keeping in mind the conditions of the experimental environment, as detailed above, this variation can only be attributed to the different amounts of work associated with each of the two movements. Thus, during the opening movement, work was accomplished at the entire expense of muscle effort or energy, and resulted in the raising of various loads. By virtue of their altered position, these loads were imparted a potential energy which in turn, was expended during the closing movement in two forms: (1) it contributed to the mechanical energy effecting the mouth closing movement and (2) it appeared as heat in the muscle (Fulton 1949). However, the closing movement, in being influenced by the experimental procedure, exercised a control over the release of this potential energy; but only, however, at the expense of some muscle effort or energy. This energy expenditure was reflected in the tension of those muscles effecting the regulation of this closing movement; and furthermore, in exercising this control, tension, or force on a load (m) through a distance (s), work was, of necessity, accomplished.

Thus, the significant variation (1.0 per cent level) in the muscle tension with respect to the opening and closing movements was determined by the different amounts of work performed.
Subjects

The statistically significant difference between subjects needs cautious interpretation because of the known experimental inequalities previously outlined. These inequalities preclude any possible analysis of the relative temporal and infrahyoid activity between subjects in the performance of a given amount of work.

The variation in human anatomy is evident in the mandible not only by the diversity of its shape and size, but also by the variation in the location of its muscle attachments. These variations naturally effect the mechanical advantage of the leverage system associated with the human mandible. This was made apparent in this experiment by the variation in the extent of the maximum mouth opening movements between subjects. Since the law of conservation of energy requires that the work done by a machine be no greater than the work done on a machine, and since the work done during any one of the particular experimental exercises was constant (for all subjects), the effort or energy expenditure must likewise be constant (for all subjects) irregardless of the mechanical advantage. The above mentioned variations in human anatomy, and therefore in the mechanical advantage, did however, more than likely effect the relative participation of the various synergistically functioning muscles and thereby provided a possible source of functional variation.
between the subjects—with respect to the temporal and infrahyoid activity.

However, the statistically significant variation observed between the subjects in this experiment included not only this source of variation but also those variations previously mentioned, namely; (1) the dissimilarity in the areas of the muscle tissues recorded from and (2) the unequal rate of mouth opening among subjects (caused by the variation in the extent of maximal mouth opening). The latter was included as a possible additional source of variation since its relation to mechanical advantage and work has not as yet been demonstrated.

Thus, the statistically significant difference between the subjects, in including more than one possible source of variation, may be attributed, at best, only an inconclusive interpretation.

B. Interpretation of the Graphical Analyses

Inter-relation of Main Effects

The main sources of experimental variation exhibited certain significant inter-relations which were best demonstrated by graphical analyses and which were, therefore, presented in Figures 23, 24 and 25.

Figure 23 depicted the tension (in the anterior half) of the temporal muscle during both the opening and the closing mouth movements relative to the various amounts of work performed. The
tension was observed to increase, proportionately, with the amount of work performed by the opening movement; i.e., the tension increased in proportion to the resistance encountered by mandibular depression. As Carlsoo has pointed out, the mandibular elevators have no mechanical qualification for this particular movement (mandibular depression). He has further stated that forces or loads acting with a closing movement will abolish that "activity" which was present when the mandible was without such a load.

The findings of this experiment may not be as incompatible in this regard as would first appear, since it must be recalled (1) that Carlsoo used light loads, not exceeding 1.5 to 2 kg (3 to 4 lbs.), whereas this experiment employed loads ranging from 2.5 to 9.5 pounds and (2) that Carlsoo observed an instance of increased temporal muscle activity during an opening movement that was intentionally executed as a purely rotatory movement. With respect to this second point, Carlsoo attributed the observed activity to a possible guiding function of the muscle. This same interpretation, I believe, applies to the increased temporal muscle tension found in these experimental results. The linearity demonstrated suggested to me a credibility in that a need for a guidance function, if this is the correct interpretation, would be expected to increase proportionately with the load or work performed.
For the closing movement, Figure 23 depicted, surprisingly, a non-linear relation between the temporal muscle tension and the work performed by the movement. However, it is to be realized that these data only reflect the activity in the anterior half of the temporal muscle. It should further be remembered that Carlsoo has functionally differentiated the temporal muscle into a dorsal and a ventral portion, correlating the former with a rotational qualification and the latter with a translatory qualification with respect to the mandibular closing movement. He also states, that both portions act in both rotation and translation, the difference in activation being correlated with the mechanical potentialities of the two portions. His electromyographic investigations have also demonstrated that though the activation of the muscle portions follows closely the mechanical qualifications for particular movements, the distribution of the muscular activity by innervation patterns among portions with synergistic actions is not necessarily in direct relation to their relative mechanical potentialities. These observations may account for the lack of linearity in the tension recorded from a portion of a muscle that functions synergistically in the elevation of the mandible.

Figure 24 graphically relates the infrahyoid activity with respect to the resistance encountered during both the mouth opening and closing movements. Both relations approximated
linearities which in turn exhibited an approximate parallelism.

The linearities each related the proportional participation of the infrahyoid musculature in those controlled mandibular movements associated with various amounts of resistance or i.e., in the performance of various amounts of work.

The parallelism demonstrated the consistently greater infrahyoid activity associated with the mouth opening movement. As previously mentioned, the observed uniformity of these results, with respect to the work performed, must not be interpreted as a uniform tension response in the musculature throughout the particular movement. Only the total tension contribution for a particular movement may be said to be proportional, to the constant resistance encountered.

These experimental findings appear to agree with the interpretations of the infrahyoid function put forth by both Sicher and Last. These interpretations have previously been extensively reviewed. Thus the above mentioned linearities do not appear unreasonable—providing, of course, that one correctly interprets muscle activity as muscle tension and, furthermore, does not forget that muscle tension may be the product of isotonic or isometric contraction; neither of which are identifiable as such by an electromyogram.

It will be noted that the above linearities to not intersect
the origin of the graphs presented in Figures 23 and 24. For example, a tension was indicated for the infrahyoid musculature corresponding to a zero load with respect to the opening movement. This graphically indicated tension represented the effect of the load of the empty weight hanger which was not counterbalanced by the "chin-cap". Another contributing factor in this respect would be the effect of the friction associated with the mechanical apparatus. The energy required to overcome this friction would not be accounted for by the loads employed; but rather, would further influence the relation between the linearities depicted and the origin of the graphs.

A valid comparison of the findings between subjects was presented in Figure 25 and graphically demonstrated the uniformity in the behavior pattern of the infrahyoid musculature from subject to subject. Though the activity levels manifested were consistently greater during opening than during closing for all subjects at corresponding loads, these activity levels were not comparable (between subjects) for the reasons previously given.
CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

An electromyographic appraisal of the temporal and infrahyoid musculature was conducted on ten subjects performing two rigidly prescribed mandibular movements. These two movements consisted of (1) a maximal mouth opening movement followed by (2) a complete closing movement. Furthermore, the movements were executed under the influence of a series of loads; each exerting a constant closing moment upon the mandible. The four muscle tissue areas selected for investigation were, namely, the anterior halves of each of the temporal muscles and the lower halves of each of the sternohyoid muscles. A standard electromyographic technique was employed to pick up the action potentials associated with the muscle contractions. These potentials were quantified by an electronic integrator, expressed in microvolt-seconds, and subjected to statistical analysis which listed the following main sources of experimental variations; (1) muscle groups, (2) muscle sides, (3) weights, (4) portions of the opening-closing cycle and (5) subjects. A graphical analysis was subsequently presented to demonstrate the inter-relation of the above mentioned main sources of variation.
Conclusions

It may be concluded from this investigation that certain prescribed loads, exerting a closing moment to the human mandible will effect certain characteristic responses from (1) the ventral portion of the temporal muscle and (2) the infrahyoid musculature during (1) the mouth opening movement and (2) the mouth closing movement. These may be summarized as follows:

A. Temporal muscle (ventral portion)
   (1) the tensions observed are significantly less than those in the infrahyoid musculature.
   (2) the tensions exhibited are proportional to the impressed loads during the opening movement.
   (3) the tensions exhibited a lack of proportionality with respect to the impressed loads during the closing movement.

B. Infrahyoid musculature
   (1) the tensions observed are significantly greater than those in the temporal muscle (ventral portion).
   (2) the tensions exhibited are proportional to the impressed loads during the opening movement.
   (3) the tensions exhibited are proportional to
the impressed loads during the closing movement.

C. The energy output from the muscles of the two sides demonstrated no significant difference.
CHAPTER VI

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APPROVAL SHEET

The thesis submitted by Dr. Charles Edwin Smith has been read and approved by four members of the faculty of the Graduate School.

The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

Date 5/11/60

Signature of Adviser