1961

An Electromyographic Study of the Behavior of the Masseter and Temporal Muscles Before, During, and After Orthodontic Treatment.

Thomas Watson Fleming
Loyola University Chicago

AN ELECTROMYOGRAPHIC STUDY OF THE BEHAVIOR OF THE MASSETER AND TEMPORAL MUSCLES BEFORE, DURING, AND AFTER ORTHODONTIC TREATMENT

Part V. After Completion of Anchorage Preparation

by

THOMAS WATSON FLEMING

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

1961

LIFE

Thomas Watson Fleming was born in Chicago, Illinois, on January 9, 1933. He was graduated from Morgan Park Military Academy in Chicago in June, 1950. He began his studies at Northwestern University in September of 1950 and received the degree of Doctor of Dental Surgery in 1957.

Upon his graduation, he began his practice of general dentistry in Chicago. In June, 1959, he enrolled in the graduate school of Orthodontics at Loyola University School of Dentistry.

He is married and has two children.

ACKNOWLEDGEMENT

My sincere appreciation is extended to all those who have in any way aided in making this investigation possible, particularly to the following:

I wish to extend my gratitude, first and foremost, to Joseph R. Jarabak, D.D.S., Ph.D., Professor of Orthodontics, Loyola University, who, as my advisor, offered his invaluable guidance and supervision during the course of this investigation.

To Patrick D. Toto, D.D.S., M.S., Associate Professor of Oral Diagnosis and Oral Pathology; Gustav W. Rapp, Ph.D., Professor of Bio-Chemistry and Phsyiology; and Y. T. Oester, M.D., Ph.D., Professor of Pharmacology, all of Loyola University, for their many helpful suggestions and 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 advice on the statistical discipline used in this study.

To Bernard A. Widen, D.D.S., M.S.; Steve N. Asahino, D.D.S., M.S. and Richard J. Shanahan, D.D.S., M.S., who, as my predecessors in this

project, provided part of the groundwork for my investigation.

To Eugene H. Zylinski, D.D.S., my colleague and friend, for his assistance.

To my wife, Mary, without whose help and deep devotion this work could not have been completed.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FINDINGS

LIST OF FINDINGS

The findings for each subject consist of charts evaluating muscle behavior, with accompanying explanations, and photographs of each subject's original malocclusion and the malocclusion at the time of Experiment VI.

LIST OF FIGURES

CHAPTER I

INTRODUCTION

A. Introductory Remarks and Statement of the Problem

It is a known fact that the periodontium is one of the sites wherein lie sensory receptors which influence the neuromuscular mechanism controlling jaw movement. There is abundant literature dealing with proprioceptive activity in the stomatognathic system (Corbin, Brill, Szenthagothai, and others), however, only a few have attempted to investigate the change in the neuromuscular activity during orthodontic treatment. Since muscle behavior is controlled by sensory impulses and orthodontic forces represent a change in stimuli to the periodontal proprioceptors, it may be expected that this could influence the muscle behavior of the stomatognathic system.

This study is an attempt to determine electromyographically whether the behavior of the masseter and temporal muscles of patients changes during orthodontic treatment. The orthodontic methods used in this therapy are distinguished from other orthodontic procedures in that light forces generated from highly resilient light wires and latex elastics

were used. This part of the study will compare the behavior of the masseter and temporal muscles from the beginning of orthodontic treatment with the behavioral changes brought about by anchorage preparation. In this way it is hoped that any changes in the neuromuscular behavior pattern of the masseter and temporal muscles brought about by orthodontic treatment up to this stage may be detected.

This is a continuation of a longitudinal study reported by Widen, Asahino, and Shanahan (1960).

B. Review of the Literature

1. Electromyographic Background

The first studies on muscle during function were made possible by the work of several early investigators. Piper (1907) and Buchanan (1908) first described the bioelectric phenomena associated with the contraction of skeletal muscle. Lucas (1909) stated the "all or none" law of muscle action after observing that the contraction of skeletal muscle increased in definite steps with stimuli of increasing strength. Hill (1921) described action potential as a minute fraction of the total energy liberated when a muscle contracts. This is energy that appears as electrical energy and is picked up and recorded by the electromyograph. Clark (1931) described a motor unit as a group of

muscle fibers which are innervated by branches of an axon arising from a single anterior horn cell or lower motor neuron. The ratio of muscle fibers to the neuron may range from 1:110 to 1:165 in the temporal and masseter muscles.

Moyers (1949) first introduced electromyography to the dental profession. Since that time many papers have been written on the behavior of the temporal and masseter muscles. Moyers (1949, 1950), Pruzansky (1952), Jarabak (1954, 1956, 1957), Perry and Harris (1954), Perry (1955), Greenfield and Wyke (1956), and many others have contributed to the electromyographic literature. However, only the report by Greenfield and Timms (1958) dealt with the behavior of the temporal and masseter muscles before, during, and after orthodontic treatment.

Moyers (1949, 1950) studied subjects with normal occlusion and with Class II Division I malocclusions. He found that the resting tonus is uniformly distributed in all fibers of the temporal muscle in persons with normal dentofacial structure, but not in cases of mandibular retrogression, where the posterior fibers show more activity. He also noted that during function none of the cases in the malocclusion group demonstrated normal spike potentials in the temporal or masseter

muscles and that the posterior fibers of the temporal muscle displayed the greatest activity. He concluded that the electromyographic patterns permitted classifying different types of malocclusions and that the spike potential is alterable by orthodontic therapy.

Pruzansky (1952) found that the synergistic behavior of the masseter and temporal muscles changed with the occlusion of the teeth, and that the behavior of these muscles could be correlated with the efficiency of the masticatory apparatus. In normal occlusion, ipsilateral chewing of gum exhibited a synchronous discharge from the temporal and masseter muscles. He also noted that maximal activity of the temporal and masseter muscles is not achieved until the subject's jaws approach centric occlusion. In chewing patterns of a Class III malocclusion, where interferences prevented free lateral movement, a choppy short stroke was evident with a fast build up and a fast decline of the action current.

McDougall and Andrew (1953) studying the temporal and masseter muscles of normal adults concluded: (1) in the occlusion of the incisor teeth the masseter muscle was more active than the temporal muscle; (2) retraction against resistance resulted in activity over the posterior fibers of the temporal muscles; (3) upon occlusion the activity was more

or less equal over the masseter and temporal muscles; and (4) maximal mouth opening resulted in considerable avtivity in the temporal and masseter muscles and they hypothesized that this may have been a protective action to prevent dislocation of the temporomandibular joint. These results corroborated some of Pruzansky's findings.

Jarabak (1954) observed that the temporal muscles began to contract before the masseter muscles in a patient with excessive inter-occlusal space (17 mm.), whereas in normal occlusion there was synchrony between the muscles. Reduction of the excessive space, coupled with an increase in the size of the food platform by an orthodontic splint, resulted in electromyographic activity resembling that of normal occlusion. In the subject with the excessive inter-occlusal space the temporal muscles not only elevated the mandible, but also gave the necessary power to the masticatory stroke. In 1956, Jarabak studied subjects with normal occlusion, patients during orthodontic treatment, and adults who had gross occlusal interferences. From these studies he concluded: (1) after biting or speaking, patients with occlusal interferences exhibit a hyperactivity of the posterior fibers of the temporal muscle. This hyperactivity is eliminated and

a normal pattern of activity is obtained by the removal of the interferences; (2) the occlusal interferences can transmit stimuli to the proprioceptors of the periodontium to establish a pattern of neuromuscular activity which attempts to circumvent the interference.

Perry and Harris (1954), using transformed myograms, made a comparative study of the temporal and masseter muscles during the chewing of gum in subjects with normal occlusions and in subjects with Class II Division I malocclusions. They reported: (1) the synchrony that occurred in the masseter and temporal muscles as they reached maximal activity in normal occlusion was lost in the malocclusion; (2) the temporal muscles always began electrical activity before the masseter muscles in normal occlusion, but the order was frequently reversed in malocclusion; (3) there was less harmony and smoothness of action potential discharge on both sides in the malocclusion. Perry (1955), doing further investigations on similar types of occlusions, found that in normal occlusion the temporal muscle of the functional (ipsilateral) side manifested action potentials before the opposite temporal or either of the masseter muscles. This was in contrast to the work of both Jarabak and Pruzansky, who found synchrony. In the malocclusion subjects, however,

the first muscle to give recordable action potentials in the majority of cases was the masseter muscle of the working (ipsilateral) side. Describing the pattern of the malocclusion myogram, he said: "In all patients there was an inconsistent multiplicity of amplitude peaks and a "searching" pattern in the contraction units". Perry summarized: "Consistency and harmony of synchrony is at its highest level in the near perfect occlusion subjects."

Zwemer (1955) found that in normal occlusions the temporal muscles exceed the masseter muscles when elevating the mandible, but that in malocclusions exhibiting excessive interocclusal clearance there is a greater proportional participation on the part of the masseter muscles.

Karau (1956) compared activity of the temporal and masseter muscles of untreated Class II Division I patients with the activity of these muscles in orthodontically treated persons of the same Angle Classification. He found that untreated persons showed more temporal than masseter activity while the situation was reversed in the treatment group. He concluded that harmony of the occlusal relations of the teeth, rather than saggital relation of the mandible to the maxilla, is the primary determinant of excellence of muscular function.

Greenfield and Wyke (1956) could not isolate normal and malocclusion groups electromyographically because of inconsistancies within each group. These findings do not agree with those of Pruzansky, Jarabak, or Perry and Harris, who do make this differentiation. They stressed that the maintenance of good head posture in longitudinal electromyographic studies was imperative in acquiring reliable data.

Latif (1957) showed that the resting tonus was not uniformly distributed throughout the temporal muscle. In fifty muscles studied, posterior fibers were more active in eighty-four per cent, anterior in six per cent, and tonus was equal in anterior and posterior fibers in ten per cent. This seeming contradiction to one of Moyers' findings was assigned to variation in electrode placement.

Greenfield and Timms (1957) showed electromyograms of various masticatory movements in cases with normal occlusal relationships and they stressed the importance of bilateral recordings.

Sicher (1954) in a discussion on positions and movements of the mandible stressed the following point:

> "The electromyograph registers the action potential of a muscle; that is, it shows when and how strongly a muscle acts, but it does not and cannot show in which

capacity the muscle activity occurs. Muscles can contract isotonically or isometrically. If they contract isotonically, they shorten and retain tension; if they contract isometrically, they tense but do not shorten and thus retain their length. By isotonic contraction muscles act as movers, by isometric contraction they act as holders, stabilizers, positioners."

Hickey, et al., (1957) believed that electrical activity thought to be originating from certain muscles or areas may actually be overlapping electrical fields from other muscles. They also stated that certain reference points used in electromyography, such as the ear lobes, are not necessarily electrically inactive.

Sutton (1960) compared the effects of different electrodes on electromyographic recordings. Two general methods of detecting the electrical activity of the muscle were employed: (1) monopolar surface electrodes, which were placed on the skin overlying the muscles being studied (ideal for the temporal and masseter muscles which are easily accessible); and (2) monopolar needle electrodes, which are thrust into the substance of the muscle (useful for internal pterygoid and external pterygoid muscles which are not accessible for placement of surface electrodes). He concluded that the surface electrode recorded the least voltage, while the needle electrode with 1 mm. of tip exposed recorded the most voltage. He also found that similar electrodes

recorded differently, depending on their position in or on the surface of the muscle.

Liebman and Cosenza (1960) studied the etiology of malocclusions on persons with normal occlusion and different types of malocclusions. They reached the following conclusions:

> "(1) The pattern of electrical activity in individuals with malocclusions could be distinguished in no way from that obtained from subjects with normal occlusions. (2) No specific patterns of muscle function were found in individuals with normal occlusion or in those with malocclusions. (3) There is no correlation between the type of occlusion and the degree of electrical activity during the resting state (resting tonus) of the muscle. (4) Electrode placement, among other factors, is apparently of significance in influencing the amplitude of the recording."

They believed that comparisions between data based solely on differences in amplitude are highly questionable.

Porritt (1960), working on patients in whom inlays with intentional areas of interference were placed, came to the following conclusions: (1) a single area of interference is sufficient to change muscle contraction patterns which are balanced bilaterally to patterns which are asymmetrical. Removal of the occlusal interferences restored the symmetrical muscle contraction patterns. (2) Occlusal interferences can

cause inhibition of muscle activity during mandibular movements. Conditioning of the muscles, so that an adapted occlusal position and efficient movements of the mandible can be performed, is generally accomplished in a short time after the interferences are placed.
(3) The temporal muscle seemed more sensitive than did the masseter muscle in response to the occlusal interference.

Ahlgren (1960) was able to show electromyographic hyperactivity of mandibular retractors with the use of an Andressen activator, with a subsequent return to normal contraction patterns about two hours after its discontinuance. He found that reflex activity can be changed to a new and more favorable contraction pattern which is re-inforced and maintained by the afferent signals from the periodontal membranes of the teeth when their intercuspation has been improved by the treatment.

Bjorg (1960), using different orthodontic appliances on distocclusion cases (fixed appliances with intermaxillary elastics (each exerting 130 g.), Bimler's elastic functional appliance, and Andressen's activator), found increased activity of posture, mainly in the posterior temporal fibers while no muscle activity was found in the masseter muscles.

Widen (1960), beginning a longitudinal study, showed a definite

change in behavior patterns of the temporal and masseter muscles twenty-four hours after the placement of separating wires between the teeth. One-half of the subjects showed evidence of adaptation while seven of sixteen subjects showed an increase in duration of the chewing stroke. Asahino (1960), comparing pretreatment records with those obtained seven days after placement of separating wires, showed a greater adaptation and therefore less variability with the original records. Shanahan (1960), compared the pretreatment records with those obtained one week after placement of the first archwires. He showed an increase in duration of chewing strokes and the number of bursts of electrical activity. The temporal muscle, especially the posterior fibers, showed a more active role in initiating activity of a chewing stroke.

2. Neuromuscular Mechanism.

Since the neuromuscular mechanism controls the act of mastication, an understanding of this mechanism is essential in order to properly evaluate the results obtained from electromyographic recordings.

The law of reciprocal innervation of voluntary muscles with antagonistic action was stated in 1897. In that year Hering and Sherrington demonstrated ". . .electrical stimulation of certain points of the motor centers of the cortex cerebri of monkeys cause not only contractions of the corresponding muscles, but also a relaxation of the antagonists of these muscles." The functional aspect of this motor phenomenon is that it is one method at the disposal of the nervous system for grading the speed, smoothness, and range of movement.

Sherrington (1906) classified the sensory receptors by placing them in four general groups: (1) the exteroceptors are sensory organs of the skin (and oral mucosa) which receive sensory stimuli from the immediate external environment; (2) the interoceptors are those endings which transmit impulses from the visceral organs of the body; (3) teleceptors receive impulses from a distant environment and are found in the eyes, ears and nose; (4) the fourth and final category concerns the sensory component of the body which gives information as to the position and movement of the bodily parts in space. These endings are found in the voluntary musculature and its attached tendons as well as the labyrinthine sense organs. This fourth grouping was termed by

Sherrington the "proprioceptive system". It is, roughly, an awareness of one's self. By means of this system the brain is made aware of what is going on within the body. It is a sensory system trained upon the functioning parts of the individual and adapted to the immediate motor needs of the body. Proprioception is concerned largely with the smooth function of reflex and seems to have an early protective purpose. All impulses of a proprioceptive nature are apparently integrated in the cerebellum, which Sherrington called "the head ganglion of the proprioceptive system".

Sherrington (1917) found that blunt pressure stimulation of the gum or teeth of either the upper or lower jaw caused reflex opening of the tonically closed jaw in the decerebrate cat. This occurred by reason of the reflex center inhibition of the jaw-closers (temporalis, masseter, etc.) as well as stimulation of the jaw-opening muscles. Summarizing jaw reflexes in the cat, Sherrington says:

> "On the mouth's seizing a morsel the mandible, when it has closed, e.g., voluntarily, upon whatever is between the jaws pressing it against the gums and teeth and hard palate, by so doing, as is clear from observation of the reflex, produces a stimulus which tends to reflexly reopen the jaws. That done the central rebound of the previously reflexly inhibited jaw-closing muscles, or rather their

> motoneurones, for the inhibition is central, sets into operation once again the jaw-opening stimulus. And so, after being started by a first bite, a rhythmic masticatory reflex tends to keep itself going so long as there is something biteable between the jaws."

Allen (1919) found that the great bulk of the ascending sensory mesencephalic root fibers, taking origin from cells in the semilunar ganglion, have ended in the trigeminal motor nucleus or thereabouts. He also confirmed May and Hersley's conclusions that the descending mesencephalic root fibers enter the motor root of the trigeminal nerve. He felt that these descending mesencephalic root fibers are concerned only with muscle sense.

Creede (1932) described a simple "reflex arc" as consisting of:

> "(a) The inward path, which is composed of a receptor organ connected to an afferent nerve-fiber. Afferent nerve-fibers enter the spinal cord by the dorsal roots. (b) The nervous (or reflex) center in the central nervous system. (c) The outward path, composed of an efferent nerve-fiber and an effector organ, e.g., muscle or gland. Efferent nerve fibers leave the spinal cord by the ventral roots."

Pfaffmann (1939) obtained action potentials from the superior alveolar nerves after touch or pressure applied to the teeth, gums and even the adjacent lips. The impulses were slow to adapt, and the fact that they were quite rapidly conducted would indicate that they are

mediated by fairly large myelinated fibers. Removal of the dental pulp and destruction of the nerves in the apical canal by cautery did not affect these responses. Pfaffmann also noted strong and sudden movements of the mandible on sectioning the maxillary nerve. His findings indicated that the majority of the endings giving rise to these impulses are located in the periodontal membrane and support the histological findings that a majority of the nerve fibers supplying the periodontal membrane come from the alveolar nerves (Van der Sprenkel, 1936; Lewinsky and Stewart, 1936).

Corbin and Harrison (1940) and Corbin (1940) discussed the function of the mesencephalic root fibers found in the alveolar and palatine nerves. They said that impulses arising from the teeth (periodontal membrane), gums, and palate would not only inhibit activity of the jaw-closers through inhibition of the motor nucleus of the trigeminal nerve and thus inhibition of the activity of the muscles of mastication, but also actively elicit jaw-opening through reflex stimulation of the motor nerves supplying the mandibular depressors. They felt that anatomical findings, in conjunction with the physiological evidence of Sherrington (1917) and Pfaffmann (1939), suggest that the fibers to the

periodontal membrane, gums and palate serve to control the force of the bite and thus prevent serious damage to the teeth and gums, as well as reflexly controlling mastication.

Szenthagothai (1948) demonstrated the monosynaptic reflex arc connections from the proprioceptors (spindles) in the masseter and temporal muscles and then back to the muscles themselves. He traced fibers originating in these spindles to the mesencephalic root of the trigeminal nerve, to their synapse in the motor nucleus of the same nerve, and back to the muscles via their efferent motor nerves. Some reflex collaterals were traced to the ipsilateral motor nuclei (hypoglossal) supplying the infrahyoid muscles, which are antagonists of the masticatory muscles. He considered these as "direct inhibitory" fibers.

The nucleus of the mesencephalic trigeminal root lies in the lateral wall of the rostral portion of the fourth ventricle. Pearson (1949) described the nucleus as consisting of large cells, unipolar in higher animals and bipolar and multipolar in lower vertebrates. The processes of these cells make up the mesencephalic trigeminal root. These processes give off collaterals to the motor trigeminal nucleus and, apparently, to the motor facial nucleus and join the motor and sensory

roots of the trigeminal nerve. They are distributed to the muscles of mastication (Allen, 1919) and to the teeth and palate.

Weiss (1950) stated concerning central patterns: ". . . coordination patterns are determined centrally and that the central patterns, though normally reinforced by proprioception reflexes, take precedence over the latter under conflicting circumstances."

The problem of inhibition was brought to attention when Weber and Weber, in 1845, arrested the heart beat by stimulating the vagus nerve. In the course of time intensive searches were made for inhibitory nerves to skeletal muscles, but failure attended all efforts to demonstrate peripheral inhibition of vertebrate skeletal muscle. Thus one speaks of "central inhibition".

Carlsoo (1952) found that the most important muscle in the habitual closing movement of the mandible appeared to be the temporal. He also stressed the temporal's importance in the "habitual rest-position".

Matthews (1958) confirmed electromyographically that the stretch reflex was a true reflex, and not due to a constant motor discharge.

Jarabak (1954) concisely summarized the function of the neuromuscular mechanism of the stomatognathic neuromuscular system:

"In addition to the motor nerve supply, the motor unit also has a sensory nerve supply. The sensory nerves carry messages from the muscles back to the central nervous system; thus, in a sense they serve as a "feed-back" mechanism advising the central nervous system (most generally on a subconscious level) of what is taking place in the individual motor units of the contracting muscles. This feed-back mechanism is known as the proprioceptive system. Structurally, the sensory feed-back system leading to the central nervous system has four types of nerve endings or receptors; two of them are situated in the substance of the muscle fibers of the individual motor units, and two are in the fascia and tendons. Generally speaking, some of the receptors found in the muscles send sensory impulses to the sensorimotor cortex (Gay and Gellhorn, 1949) when the muscles are passively stretched while others are activated both by muscle stretch and by muscle contraction. Functionally this feed-back system acts in a "braking" or inhibitory capacity, guiding the degree of contraction within the motor unit.

In addition to the proprioceptive mechanism found within the substance of the motor units, the muscles of mastication are under the control of still another feed-back system whose receptors are located in the periodontal membranes and gingivae surrounding the teeth and in the mucosa in the floor of the mouth. Through these receptors sensory stimuli of touch and pressure arising from the articulation of the teeth are conducted first to the mesencephalic nucleus where a reflex arc may be formed, or they may continue from here to higher brain centers in the cortex. Thus it is conceivable to visualize that a change in the proprioceptive stimuli originating in the teeth, caused by a malocclusion, may change the pattern of function of the muscles attached to and responsible for the movements of the mandible."

3. Histological Background.

Since the periodontium is one of the sites of the sensory receptors which influence the neuromuscular mechanism controlling jaw movements, an understanding of the histological picture of this area is important.

Dependorf (1913) described networks of neurofibrils in the periodontal membrane which ended in fine pointed processes in the cementoblastic region.

Stewart (1927) described neurofibrils of the periodontal membrane as separating into fine arborizations or terminal networks. Many of these terminal neurofibrils ended in small rounded bodies.

Kadanoff (1936), using human material, observed that in the terminal plexuses of neurofibrils, some had small knob-like swellings. He saw no encapsulated neural endings in the cementoblastic layer that Dependorf had found.

Van der Sprenkei (1936), using human and mammalian material, described "end rings" in the periodontal membrane arising from myelinated fibers which he concluded served as pressure receptors regulating "chewing pressure". He postulated:

"The tooth might be regarded as an organ, fitted on

> the one hand for the function of chewing and on the other by its intradental and extradental nerve endings, which are stimulated by deformation and movement of the tooth, to act as the receptor in the reflex arcs for the regulation of the act of mastication."

Bradlaw (1936), using monkeys, reported seeing loops formed by the neurofibrils turning back from the cementum (Kadanoff). He did not see the terminal neural rings which Van der Sprenkel theorized were able to register the alterations in tension.

Lewinsky and Stewart (1937) were able to show that the nerve fibers in the periodontal membrane broke up into arborizations, many of which ended in round knob-like endings, and concluded, as a result of the work of Stewart (1927), that these spindles reacted primarily to pressure stimuli. The results obtained were similar to those which have been described by Kadanoff, who also used human material, and were unlike the findings of Bradlaw, who based his conclusions on the periodontal membrance of the monkey. They, however, differed markedly from the findings of Van der Sprenkel.

Bernick (1957), working with human material and monkeys, corroborated the findings of Stewart (1927) and in addition observed elongated spindle-like nerve endings found mainly in the lower one-third of the root.

Rapp (1957), using human material, found several types of nerve endings in the periodontal membrane. He reported seeing: (1) large neural trunks that ran from the apex of the root to the gingiva; (2) interalveolar fine fibers forming an arborization running apically and gingivally; (3) organized, encapsulated neural terminations spread throughout the periodontal membrane; (4) free nerve endings also spread throughout the periodontal membrane; and (5) neural coils along the surface of the cementum.

CHAPTER II

METHODS AND MATERIALS

A. Selection of Subjects

Sixteen patients between ten and fourteen years of age were selected for this study from the Orthodontic Clinic of the Loyola University School of Dentistry. These patients presented with Class I and Class II (Angle) malocclusions and were treated with light, resilient wires and light elastic forces.

B. Muscles Studied

The muscles selected for study were the posterior and middle fibers of the right and left temporal muscles and the right and left masseter muscles. These muscles were chosen because of their importance in masticatory function and accessability for the placement of surface electrodes. The middle temporal fibers act as elevators of the mandible. The posterior temporal fibers are concerned with lateral and posterior movements of the mandible. The masseter muscles provide power in elevating the mandible. The muscles of the right side were recorded and studied separately from the muscles of the left side.

C. Electromyographic Equipment

The electromyographic equipment consisted of a six channel Offner Encephalograph Type A modified for electromyography, a crystograph with six pen writers, a time base marker with a separate pen attached to the crystograph, a signal generator and microvolt calibrator, and a Faraday cage with an electrode terminal board mounted therein. The amplifiers were set at a gain of 5; the "Hi" and "Lo" condenser switches were set at "In" and ".05" respectively to suppress the low frequency and bring out the high frequency of the Encephalograph. The paper speed was set at 10 cm. per second and the time base marker indicated intervals of 1/10 of a second. The electromyograph was calibrated from 10 to 250 microvolts before and after each experiment (Figure 1).

D. Sound Equipment and Recordings

The components of the sound system were a bone conduction microphone (Zenith Hi-Lo, Regent Type), a matching transformer (Shure Model A 86 A), a preamplifer (Heathkit WA-P2), a tape recorder (Wollensak Stereo Model T-1515), and auxiliary amplifier system (two 12 watt amplifiers), and one channel of the electromyograph

and the crystograph (Figures 1A and 2).

The bone conduction microphone was placed on the subject's forehead and held in position by a spring-type headband. The microphone was connected in a series with the matching transformer and the preamplifier. The output from the preamplifier was sent into the tape recorder and auxiliary amplifiers. Tape recordings were made at 7 and 1/2 feet per minute with a volume level of 5, tone control at "treble" and the monitor switch at "on" position. The proceedings were monitored through the tape recorder as they were recorded to insure proper performance of the exercises. The output from the auxiliary amplifiers entered a channel of the electromyograph set at a gain of 9 and was converted into sound tracings by the crystograph. These sound tracings called "sonograms" were simultaneously recorded with the myograms. The degree of synchrony between the sonograms and the myograms was studied and found to be within 1/1000 of a second. This slight difference in synchrony between the two types of recordings was due to the time necessary for the chewing and tapping sounds to travel from the area of the teeth to the forehead, where the microphone was located. The sonograms consisted of a base line and

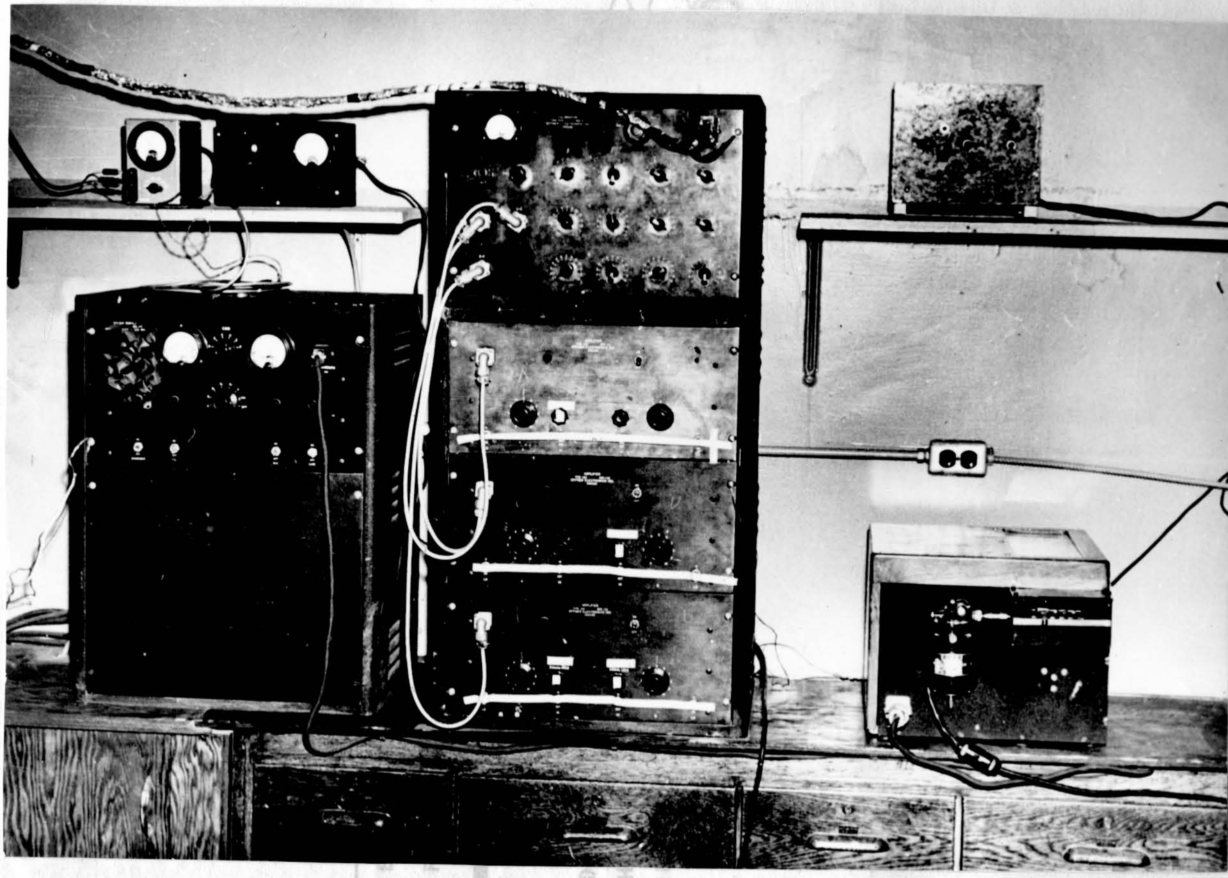


FIGURE 1

ELECTROMYOGRAPHIC EQUIPMENT

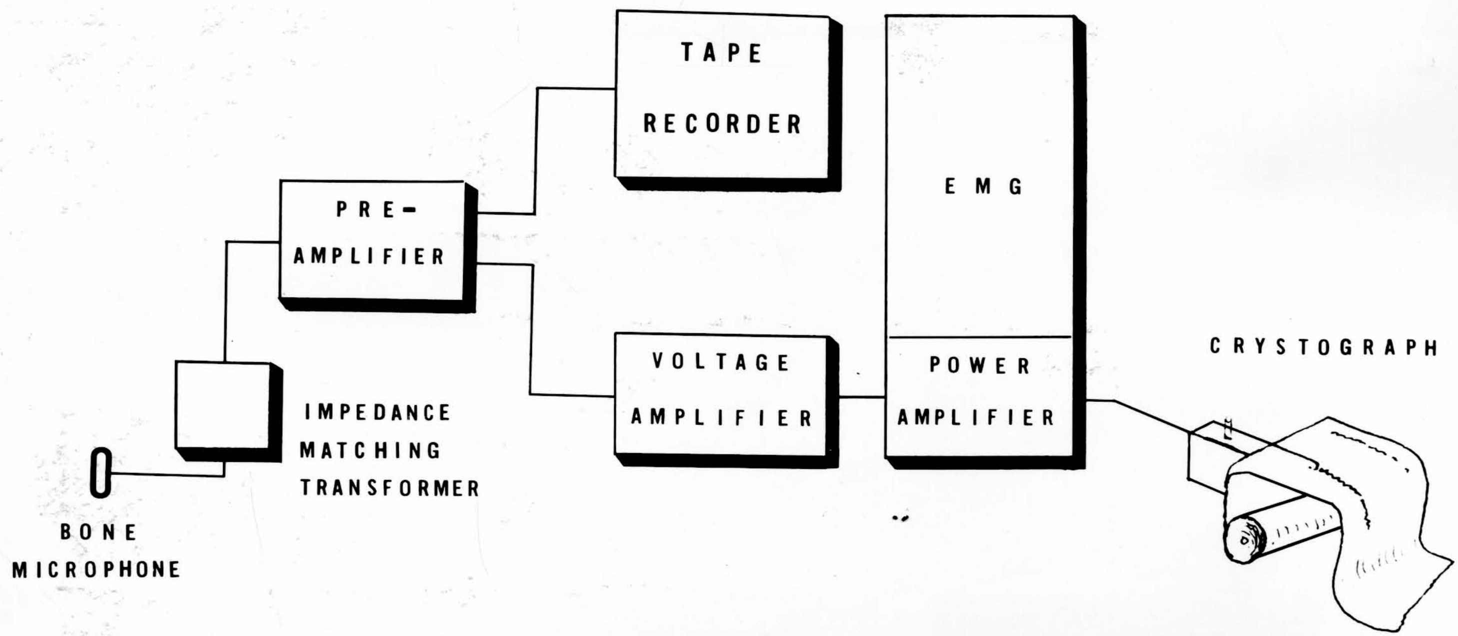


FIGURE 1 A

SOUND SYSTEM

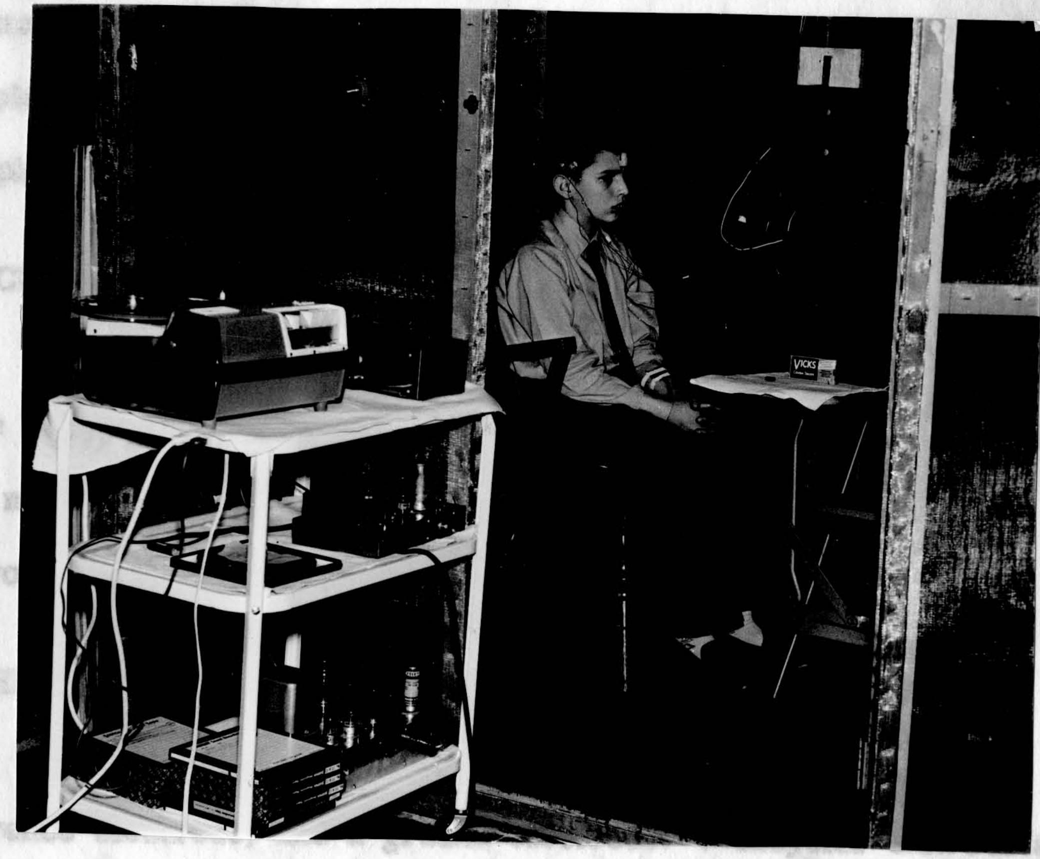


FIGURE 2

SOUND EQUIPMENT

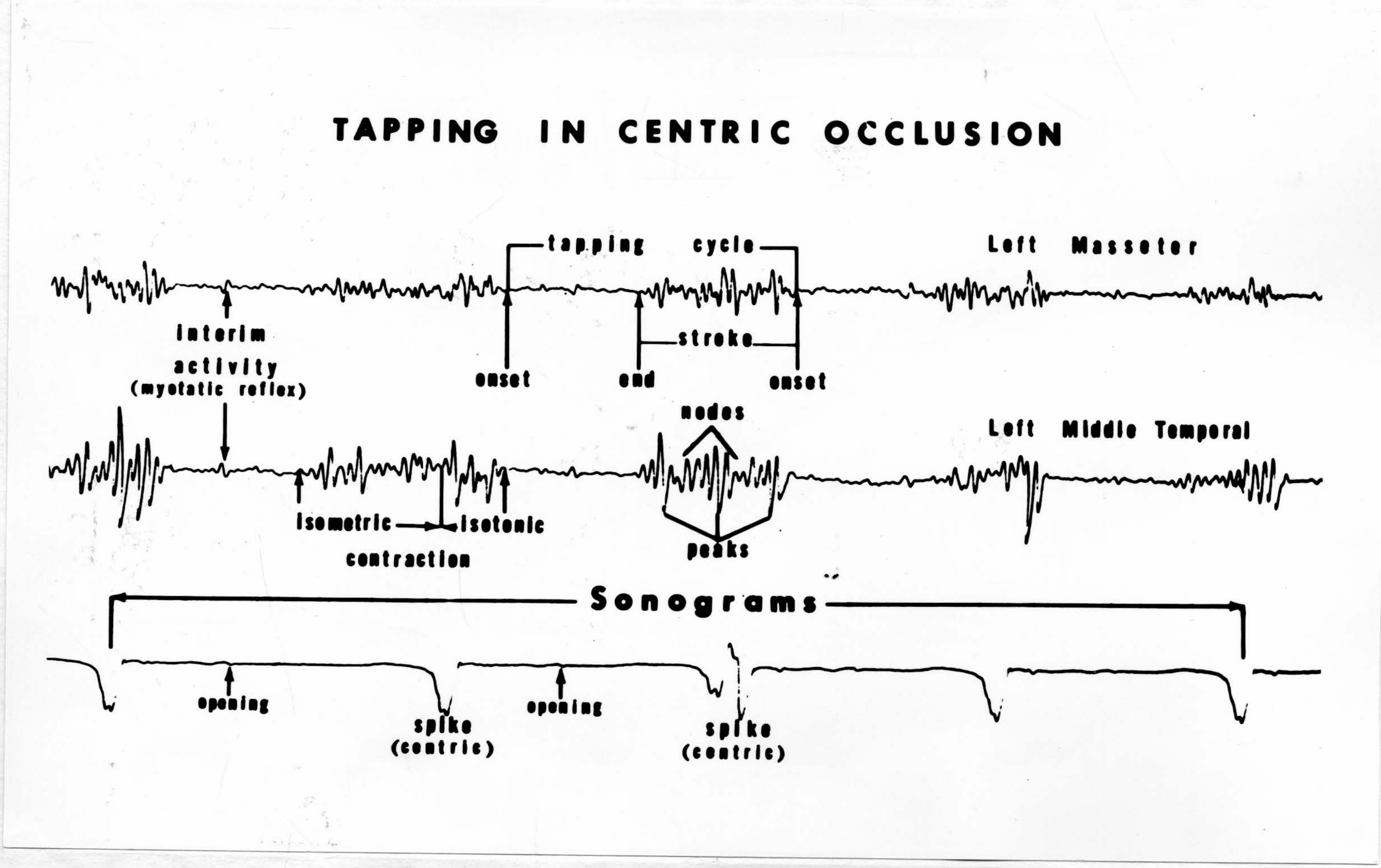

TAPPING IN CENTRIC OCCLUSION
tapping cycle
Left Masseter
interim
activity
(myotatic reflex)
onset
end
stroke
onset
nodes
Left Middle Temporal
isometric
isotonic
contraction
peaks
Sonograms
opening
spike
(centric)
opening
spike
(centric)

FIGURE 3

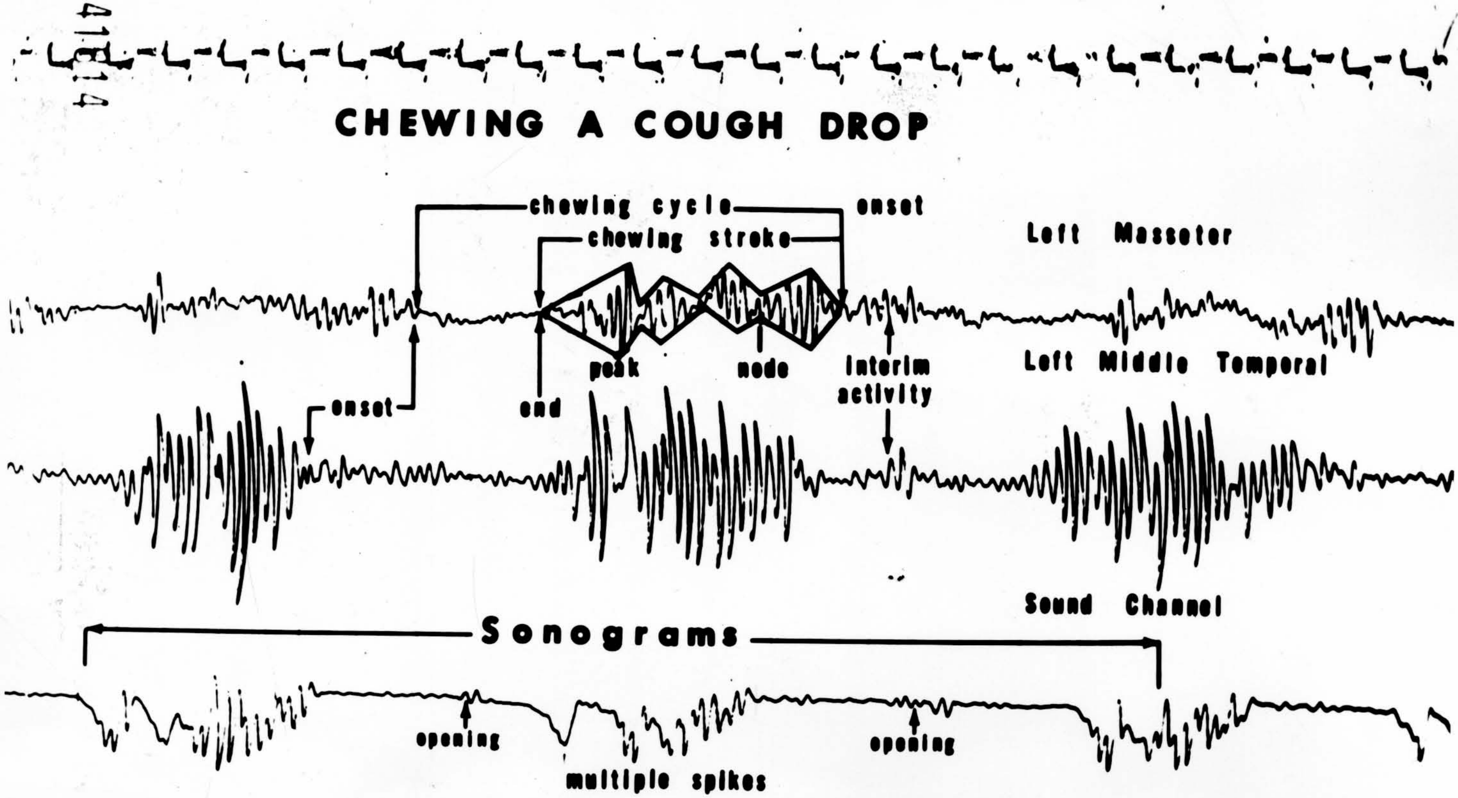

CHEWING A COUGH DROP
chewing cycle
onset
chewing stroke
Left Masseter
peak
node
interim activity
Left Middle Temporal
onset
end
Sound Channel
Sonograms
opening
opening
multiple spikes

FIGURE 4

posterior and middle temporal muscles and on the masseter muscle midway between its origin and insertion. To facilitate correct electrode placement the patient was instructed to clench his teeth and then relax, enabling the operator to palpate and select representative areas of the muscle studied. When necessary, the hair was trimmed, exposing an area approximately one-half inch in diameter. The selected areas were cleansed with soap and water, rubbed with acetone and then rubbed with electrode jelly. Skin resistance was thus reduced to 5,000 ohms or less which facilitated greater pick up of low amplitude electrical potentials of the muscles. The reference electrode was clipped to the left ear lobe after similarly preparing the skin surface. The ground electrode was attached to the left forearm after the same skin preparation (Figure 5).

Photographs of each subject showing electrode position were taken to insure proper replacement of electrodes in future experiments.

G. Experimental and Orthodontic Procedure

1. Experiment I: Before Orthodontic Treatment

The subject was seated in a Faraday cage, the electrodes connected to the terminal board, and the bone conduction microphone placed on his

forehead (Figure 5). A printed list of instructions was given to him and the procedure explained. The subject was told to recite each item on the list, which was recorded on tape, and then to perform the required exercises. There exercises were: (1) "rest", (2) tap teeth together in centric occlusion, (3) chew a cough drop on the right side, (4) chew a cough drop on the left side. Resting was enhanced by instructing the subject to relax, close his eyes, allow his arms to lie passively in his lap, his feet flat on the floor, and the head positioned with Frankfort horizontal parallel to the floor. When the crystographic pens showed minimum movement, activity at rest was recorded. Tapping was performed ten times, "slowly and hard". At the beginning of the chewing exercises the subject placed the cough drop between the teeth on the designated side and was told to "chew slowly and hard ten times". Duplicate exercises were performed to minimize the experimental error. Tape recordings of all recitations and exercises were made along with the myograms and sonograms. Rest and tapping exercises were recorded unilaterally and the chewing exercises were recorded ipsilaterally.

2. Orthodontic Procedure

FIGURE 5

ELECTRODE PLACEMENT

Each subject was fully banded using angulated brackets on each band. The posterior brackets were angulated eight degrees from the horizontal in order to give the teeth a distal tip-back when a straight wire was placed in the bracket slots.

In all of the subjects the initial, light, resilient round archwires were made of .016 inch diameter Elgiloy-Semi-spring wire. Prior to their insertion all archwires were fashioned individually for each subject, and then tempered to spring hardness. Three major configurations of archwires were used.

a. The differential forces archwire.

This archwire was used in the upper and lower dental arches. It employs vertical helical loop springs in the anterior segment of the arch; bent-in hooks located against the mesial surface of the canine brackets; and straight posterior segments with a curve in the buccal-lingual plane of space to provide necessary arch form (Figure 6).

b. A straight (horizontal) archwire.

This archwire was used in the upper and lower dental arches. It was fashioned to the shape of an ideal arch, individualized for arch width and form for each subject. These archwires carried no

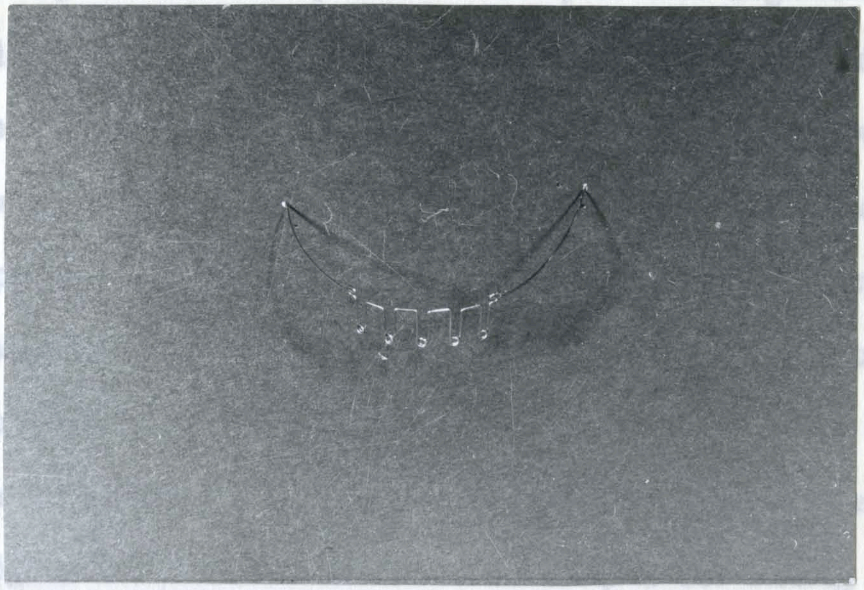


FIGURE 6

A DIFFERENTIAL FORCES ARCHWIRE

attachments, helical loops, or bent-in hooks (Figure 7).

c. A straight (horizontal) archwire with attachments.

This archwire was used in the lower dental arch. There were only slight bends incorporated in the posterior segments to conform to general arch form (Figure 8). The attachments consisted of two sections of .010 closed coil spring placed on the wire to advance two sliding hooks. The distal end of the coil spring contacted the bracket of the first premolar tooth and the hook was advanced by the coil to a position mesial to the canine tooth. The bands on the mandibular canine teeth were removed in order to allow the springs and hooks to be advanced without interference to a point mesial to the canine teeth.

Headgear hooks were attached bilaterally to the sliding hooks in the mouth. These hooks from the headgear were attached extraorally to the material from which the headgear was constructed by means of "X" type Orthospec elastics.

The elastics used in conjunction with the archwires just described were: light one-fourth inch latex elastics which exerted an average pull of two ounces when stretched a distance of one and one-fourth inches. This is the average distance used in the treatment of the malocclusions.

FIGURE 7

A STRAIGHT HORIZONTAL ARCHWIRE

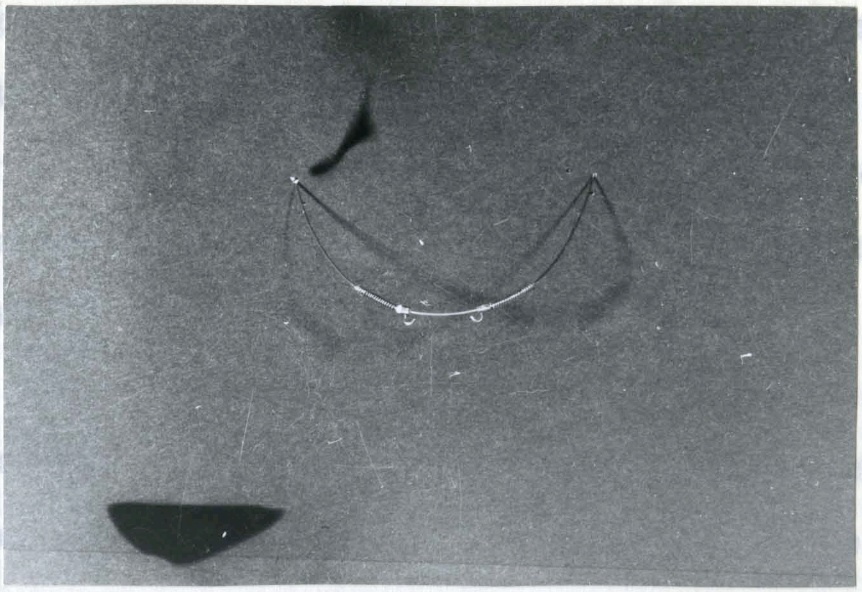


FIGURE 8

A STRAIGHT HORIZONTAL ARCHWIRE WITH ATTACHMENTS

The latex bands were worn bilaterally in one of three ways or in combinations:

1. A light intermaxillary elastic worn from a hook located on the lingual surface of the band on the mandibular first molar to the bent-in hook located mesial to the upper canine bracket.

2. A light intramaxillary elastic worn from the end of the archwire on the buccal surface of the first molar to the bent-in hook located mesial to the canine bracket of the mandibular arch.

3. A light triangular elastic worn buccally from the lower to the upper arch, the triangle had its base on the upper arch and its apex on the lower arch. The elastic worn in this fashion was attached from the end of the upper archwire on the first molar to a hook made from the ligature tie on the upper second premolar tooth, then down to a similar ligature tie on the lower second premolar tooth.

3. After Completion of Anchorage Preparation (Experiment VI).

Recordings were taken in Experiment VI in the same manner as in Experiment I, approximately twelve to sixteen weeks after placing the orthodontic appliance. In order to determine when anchorage preparation was complete the amount of distal tipping of teeth in the

buccal segments in anchorage preparation was measured on the lateral cephalometric roentgenogram. By comparing lines drawn through the long axes of the molars on progressive lateral cephalometric roentgenograms, it was possible to determine when these angles increased by eight degrees, at which point anchorage preparation was completed. The electrodes were repositioned with aid of photographs. The same instructions were given and complete records were taken as before.

H. Utilization of Sound Data to Interpret Electromyograms

The data consisted of myograms, sonograms, and tape recordings of the temporal and masseter muscles taken during tapping, chewing, and at rest. The myograms and sonograms taken at rest permitted an evaluation of the base line or minimum activity in the muscle and sound channels. Myograms compared with the sonograms taken during the tapping exercises, showed a correlation between tapping sounds and muscle activity (Figure 3). The sound of teeth meeting in centric occlusion produced a single spike sonogram. By noting the sound spike and its relation to the activity of the myogram, that part of the myogram preceding the spike was identified as the isotonic contraction of the

"free stroke", while that part of the myogram succeeding the spike was identified as isometric contraction of the centric occlusion. Thus, isotonic contractions were distinguished from isometric contractions. This information was then applied to the study of chewing activity. The chewing exercises were selected for two reasons. First, the act of chewing was mainly reflex in nature and therefore, relatively free from influence of both subject and the experimenter. Secondly, chewing the selected medium subjected the teeth and their supporting structures, muscles and joints to stresses which tested their functional ability. The cough drop, selected because of its hard consistency, made chewing difficult and at times impossible. Thus, some of the resulting myograms showed that the masseter and temporal muscles were in "a state of confusion", and a "searching pattern" was recorded having no definite boundaries. One could not tell from looking at these myograms whether or not a chewing stroke had been completed. Therefore, sound data were resorted to as an interpretative aid. By playing the tape recording of the exercise in question at 7-1/2 feet per minute, and then at 3-3/4 feet per minute (the slow motion appraisal), the actual sounds of the chewing exercises were scrutinized. The loudness of the

sounds identified the chewing strokes. These recorded sounds of the chewing strokes matched the spikes on the sonograms. The sonograms were then related to the myograms which defined the boundaries of the chewing strokes. Thus, the sound data aided the interpretation of the electromyographic data.

I. Selection of Myograms for Study

The myograms from the first three chewing strokes of the right and left sides of duplicate exercises were selected for study. Hence, a total of thirty-six myograms taken from three muscles during the first three chewing strokes of the four chewing exercises of each experiment were analyzed. Those of the succeeding chewing attempts were not selected because as chewing progressed the cough drop became an unmanageable tacky mass.

J. Defining Characteristics of the Myograms

The myograms presented three basic characteristics; amplitude, duration, and form, which were readily identified and studied. Amplitude was studied as a whole and as its parts; high amplitude "peaks", and low amplitude, sustained or transitory. Low amplitude transitory

activity bordered by high amplitude activity was called "noding" (Figure 3). Some "nodes" showed amplitude reductions down to base line levels while others showed considerable amplitude. Sustained low amplitude was prolonged minimum activity devoid of "peaks" and "nodes". Duration of the muscular activity for each chewing stroke was studied as a whole and also divided into two components, onset of activity and end of activity. The rate of increase of amplitude at the onset of activity, and the rate of decrease of amplitude at the end of activity were also noted. Form of the electromyograph was analyzed for frequency of bursts of activity. To demonstrate the form graphically, lines were drawn on the myogram connecting spikes of minimum amplitude with spikes of maximum amplitude (Figure 3). The activity between the myograms of successive chewing strokes, termed "interim activity" was also identified and studied (Figure 3).

K. Evaluation of the Electromyographic Data

Methods of Study

To gain a knowledge of the behavior of the temporal and masseter muscles within the experimental conditions, the myograms from

Experiments I through VI were analyzed and compared. The myograms were studied in the following manner:

Method I Listing and evaluating their characteristics.
Method II Analyzing the onset of the chewing activity.
Method III Measuring the duration of the chewing stroke.

The results of each method of study appear together in chart form for each subject in the "FINDINGS".

Method I - Listing and Evaluating Characteristics of the Myograms

The following characteristics were grouped and grossly evaluated: bursts, amplitude, duration, "noding", sustained low amplitude, rate of onset, rate of ending, and interim activity.

The rating scale used for evaluating all of the characteristics other than bursts (which were classified by their range) is as follows:

xxx - maximum
xx - moderate
x - minimum
0 - absent

The results appear as Part I in "FINDINGS". For example, if the amplitude in the myograms of Experiment I was high, a rating of xxx appeared opposite AMPLITUDE in the appropriate experiment column. If the amplitude of the myograms was moderate, then xx value appeared

opposite AMPLITUDE under the appropriate experimental column. To further analyze the data, the actual number of bursts were counted in each chewing stroke.

Method II - Analysis of Onset of Chewing Activity

The onset of electromyographic activity for each of the muscles in each of the first three chewing cycles (a chewing cycle was considered to be that period of time from the onset of one isotonic contraction of the muscle to the onset of the next isotonic contraction of that muscle, as determined from the electromyographic recording) of each exercise was marked. Then, a straight edge was held at right angles to the border of the paper so that it passed through the ink recordings of all three muscles. The straight edge was then moved along the record until it contacted the mark of the first muscle or muscles to begin electrical activity. The first muscle or muscles to begin electrical activity was then recorded in chart form (see Part I of "FINDINGS"). This was done for all patients in all experiments. Thus a total of twelve tabulations was made for each patient in each experiment. The results for all patients in each experiment were then totaled in chart form. The chart showed the number of times each muscle or muscle group initiated the chewing cycle in each experiment.

The data from this table were then plotted as a series of graphs which appear in Part II of "FINDINGS".

Method III - Measuring the Duration of the Chewing Stroke

The durations of the chewing strokes (a chewing stroke was considered to be that part of the chewing cycle during which isotonic and isometric contractions of the muscle were taking place) were expressed as percentages of the chewing cycles rather than by direct time measurement because the subjects were instructed to chew slowly. These instructions were necessary because some individuals chewed so fast that the myograms of the chewing strokes were so close together that they could hardly be separated from each other. Expressing duration as a percentage value helped to correct this artifact. The percentage values for each experiment were grouped histograms which allowed comparisons between Experiments I through VI to be made within each class interval along the percentage scale (see Graph II - Part II of "FINDINGS").

L. Amplitude

The amplitude was not measured because of varying sensitivity of the crystograph pen writers and also because of the variability of the

friction and damping in the tracing pens.

M. Statistical Discipline and Validation of Observer Evaluation

This study was basically a qualitative study. Few variables were controlled; the population was heterogeneous due to various treatments and malocclusions presented. Therefore each individual was a separate experimental unit unto himself. The nature of this experiment necessitated pooling of data for statistical evaluation.

Two observers gathered and analyzed the data collectively and standardized the method of interpretation.

Statistical discipline was applied to part or all of two of the three methods used to study the data.

1. The Actual Number of Bursts in a Chewing Stroke.

The bursts of electrical activity in each of the first three chewing strokes of all muscles for all subjects were counted. A random sample was taken from each subject and analyzed. Since counts do not follow the normal distribution, they are not amenable to the use of analysis of variance without transformation. The transformation used in this case was the square root of the observations.* After analyzing

*Statistical Methods, Snedecor, G.W., 5th Edition, 1957, p. 315.

the data in this manner the averages were subjected to Duncan's Multiple Range Test. This requires the use of certain tables that are published for just this purpose. Certain coefficients are derived from these tables depending upon the number of degrees of freedom used in estimating the standard deviation of error. All differences were systematically tabulated and compared with the values of difference known to be critical at the .05 level of significance. (The results of this are shown in Chart I - Part II of "FINDINGS").

2. Duration of the Chewing Stroke Expressed as a Percentage of the Chewing Cycle.

The length of each of the first three chewing cycles of all muscles for all subjects was measured. Then the length of the chewing stroke of each of the chewing cycles was measured. The chewing stroke was then calculated as a percentage of the chewing cycle. These percentages were then entered into a table in which the frequency of occurrence of each percentage was tabulated for each experiment. The experiments were arranged in columns, each of which may be thought of as a histogram representing a frequency distribution. The six different distributions were plotted and found to be similar, but not identical in appearance.

The null hypothesis would be that the data are all drawn from one parent distribution and that they are statistically alike. This would mean that the pattern of chewing did not change significantly during the stages of orthodontic treatment that distinguished these six experiments. The total data for the Experiments I through VI was subjected to the Chi-square test and judged for significance at the .001 probability level for thirty degrees of freedom.

> "Chi-square is the statistical test most generally suitable for determining whether or not an observed frequency or occurrence differs significantly from that expected in accordance with some hypothesis. Symbolically, Chi-square is defined as:
>
> $x^2 = \sum \frac{(O - E)^2}{E}$ Where $\sum$ denotes the sum of all values; O, the observed frequency of occurrence; and E, the frequency expected in accordance with an hypothesis." (Batson)

Between Experiments I through VI three independent comparisons were made. The independent comparisons were I vs. II, III vs. IV, and VI vs. I, II, III, IV, and V.

The results of these statistical findings will be found in Part II of "FINDINGS".

CHAPTER III

FINDINGS

A. Introduction

The findings are presented in two parts. The first part contains charts with accompanying explanations noting differences in electromyographic responses from functioning muscles that have occurred before and during orthodontic treatment on each of the sixteen subjects. The second part contains graphic representations utilizing selected characteristics and combining the data for each characteristic for all sixteen subjects. All findings are based on the electromyographic recordings obtained from the first three chewing cycles of each chewing exercise (see Methods and Materials page 43). Photographs of each subject's plaster tooth models are shown and classified according to Angle's Classification of malocclusion (three neutroclusion and thirteen distoclusion cases) and the treatments rendered are stated. Photographs of each subject's treatment progress toward the correction of the malocclusion at the completion of anchorage preparation (Experiment VI) are also shown.

Muscle readings were taken this far in the longitudinal study during the following periods in the treatment of these malocclusions:

Experiment I	Original malocclusion.
Experiment II	One day after placement of separating wires between the teeth.
Experiment III	One week after placement of separating wires between the teeth.
Experiment IV	One week after placement of the first archwires.
Experiment V	During anchorage preparation.
Experiment VI	After completion of anchorage preparation.

This paper concerns itself with the electromyographic recordings taken after the completion of anchorage preparation (the uprighting and distal tipping of the mandibular posterior teeth to increase their ability to resist forward movements and to increase the occlusal vertical dimension). The findings from this experiment (Experiment VI) were compared with the findings previously obtained by others (Widen, Experiments I and II; Asahino, Experiment III; Shanahan, Experiment IV; Zylinski, Experiment V). This comparison was made in order to analyze the changes in muscle response (as detected electromyograph-

ically) to altered sensory input that had taken place this far in the orthodontic procedure. Thus, a comprehensive analysis of the electromyographic changes that had occurred from before treatment was begun until after the completion of anchorage preparation is presented.

Additional electromyographic recordings will be taken and analyzed (by others) to treatment completion in order to complete this longitudinal study.

Part I Individual Subjects

Chart I Comparison of the Characteristics of the Myograms Between Experiments (Qualitative Data)

The characteristics of the myograms (bursts, amplitude, duration, "noding", sustained low amplitude, rate of onset, rate of ending, and interim activity) have been evaluated as described in Methods and Materials (page 43) and the findings are represented symbolically (see legend).

Chart II Comparison of Onset of Muscular Activity Between Experiments

The comparison of onset of muscular activity chart shows the number of times each muscle or combination of muscles (considering

only the ipsilateral side of the three muscles being studied) initiated the chewing cycle (a chewing cycle was considered to be that period of time from the onset of one isotonic contraction of the muscle to the onset of the next isotonic contraction of that muscle, as determined from the electromyographic recording; see Methods and Materials (page 46).

Part II Combined Data from Sixteen Subjects

Chart I The Average Number of Bursts in a Chewing Stoke

The actual number of bursts in a chewing stroke (a chewing stroke was considered to be that part of the chewing cycle during which isotonic and isometric contractions of the muscle were taking place) for each of the three muscles being studied for all sixteen subjects in each of the six experiments was counted. The number of bursts in a chewing stroke for all sixteen subjects in each experiment was combined to obtain the total number of bursts in a chewing stroke in each of the six experiments. The average number of bursts in a chewing stroke was then calculated for each experiment and statistically analyzed. This analysis was done to determine if there were significant differences in the average number of bursts that occurred in a chewing stroke among

the six experiments (Duncan's Multiple Range test - see Methods and Materials page 48).

Graph I Onset of Muscular Activity -- Frequency with which Each Muscle or Muscle Group Initiated the Chewing Cycle

The data from Chart II, Part I, listing the number of times each muscle or muscle group initiated the chewing cycle, were combined for all sixteen subjects in each of the six experiments and plotted in graph form. This was done to give an overall picture of the changes that took place in the first muscle or combination of muscles which initiated the chewing cycle throughout the six experiments.

Graph II Duration of the Chewing Stroke Expressed as a Percentage of the Chewing Cycle

The durations of the chewing strokes, expressed as percentages of the chewing cycles (see Methods and Materials page 47), were combined for all of the sixteen subjects in each of the six experiments and submitted to statistical appraisal. The statistical appraisal was applied to the data in order to determine if there were significant differences in the duration of the chewing stroke, expressed as a percentage of the chewing cycle, among the six experiments (the Chi-square test, see

Methods and Materials page 49). These findings were compiled as a series of histograms and converted into a composite bar graph to show the overall picture of the changes that took place in the duration of the chewing stroke expressed as a percentage of the chewing cycle during the six experiments.

B. Part I - Individual Subjects

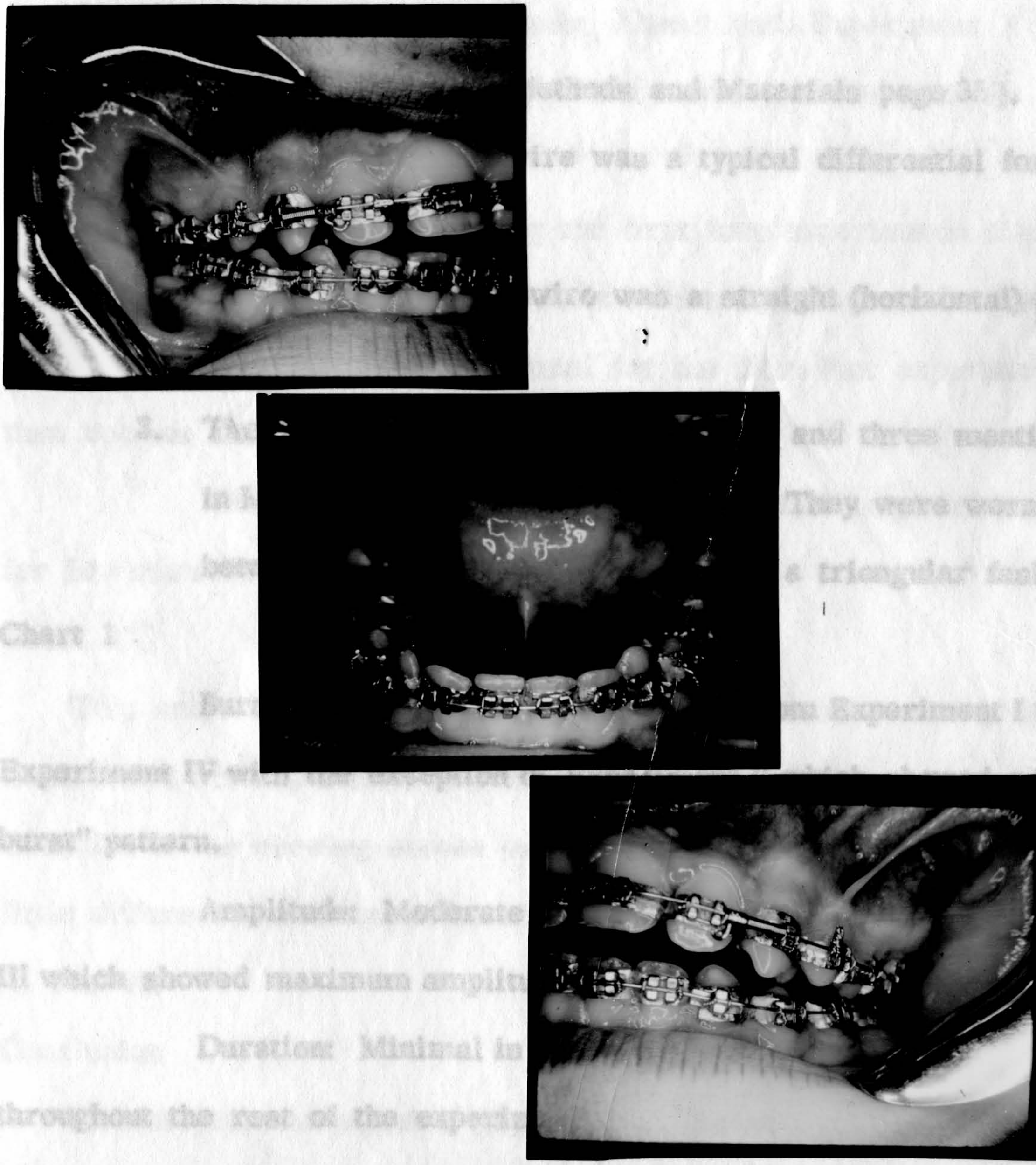
FINDINGS

Subject #1 (L.C.) Age 14

Angle Classification of Malocclusion: Class I

Subject #1 (L.C.)

Malocclusion After Completion of Anchorage Preparation



Subject #1

Treatment:

A. No teeth were extracted.

B. Appliance design. (See Methods and Materials page 35).

1. The maxillary archwire was a typical differential forces arch (Figure 6).

2. The mandibular archwire was a straight (horizontal) arch without attachments.

3. The elastics used were of types two and three mentioned in Methods and Materials (page 40). They were worn between the arches in a Class II and a triangular fashion.

Chart 1

Bursts: Showed a steady increase from Experiment I to Experiment IV with the exception of Experiment II which showed a "multi-burst" pattern.

Amplitude: Moderate in all experiments except Experiment III which showed maximum amplitude.

Duration: Minimal in Experiments I and IV and moderate throughout the rest of the experiments.

Noding: Minimal in Experiment I and then moderate throughout the remaining experiments.

Sustained low amplitude: Absent until Experiment V when it appeared at the beginning of the stroke and remained in Experiment VI.

Rate of onset: During the first four experiments this was maximal, but it decreased and became minimal in Experiments V and VI.

Rate of ending: Maximal for the first four experiments and then became moderate in Experiments V and VI.

Interim activity: Maximum throughout all experiments except for Experiments II and III, when it was moderate.

Chart 2

This subject showed a loss of synchronous initiation of activity from Experiment I to Experiment VI, while there was an increase in masseter initiation of the chewing stroke during the same time. There was very little difference in the muscles which initiated activity in Experiments IV, V, and VI.

Conclusion

This subject showed fairly good adaptation to the orthodontic procedures.

THE BEHAVIOR OF THE MASSETER AND TEMPORAL MUSCLES

CHART 1. COMPARISON OF THE CHARACTERISTICS OF MYOGRAMS BETWEEN EXPERIMENTS

Subject #1 - L.C.

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Bursts	1 to 2	Variable 1 to 3 and multiple	2 to 5	2 to 4	3 to 5	3 to 5
Amplitude	XX	XX	XXX	XX	XX	XX
Duration	X	XX	XX	X	XX	XX
Noding	X	XX	XX	XX	XX	XX
Sustained low amplitude	0	0	0	0	X Beginning of Stroke	X Beginning of Stroke
Rate of onset	XXX	XXX	XXX	XXX	X	X
Rate of ending	XXX	XX	XXX	XXX	XX	XX Variable
Interim activity	X	XX	XX	X	X	X

LEGEND: xxx = maximum, xx = moderate, x = minimum, 0 = no obvious change

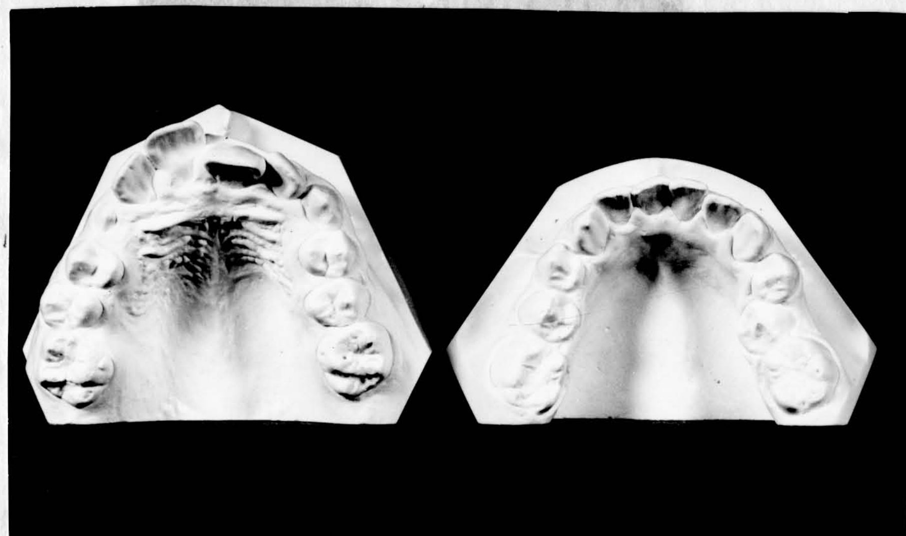
CHART 2. COMPARISON OF ONSET OF ACTIVITY BETWEEN EXPERIMENTS

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Masseter first	1	3	2	5	5	4
Masseter and middle temporal first	0	0	0	1	0	0
Masseter and posterior temporal first	0	0	1	0	0	0
Middle temporal first	0	0	0	0	0	0
Middle and posterior temporal first	0	0	2	0	0	2
Posterior temporal first	1	2	0	0	1	0
All together (Synchrony)	10	7	7	6	6	6
TOTAL NUMBER OF CHEWING STROKES	12	12	12	12	12	12

FINDINGS

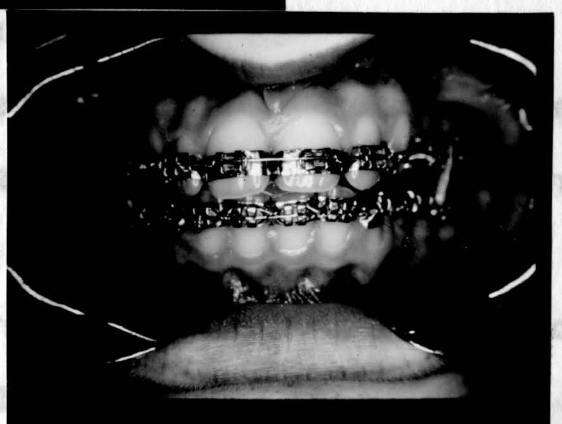
Subject #2 (E.G.) Age 11

Angle Classification of Malocclusion: Class II - Division I



Subject #2 (E.G.)

Malocclusion After Completion of Anchorage Preparation



Subject #2

Treatment:

A. No teeth were extracted.

B. Appliance design. (See methods and Materials page 35).

1. The maxillary archwire was a straight (horizontal) archwire without attachments (Figure 7).

2. The mandibular archwire was a straight (horizontal) archwire with headgear attachments and headgear to the lower arch.

3. The elastics were of the third type mentioned in Methods and Materials (page 40). They were worn in a triangular fashion.

Chart 1

Bursts: Experiments I through IV showed a similar number of bursts while Experiments V and VI showed an increase in the number of bursts.

Amplitude: Remained moderate in Experiments I through IV and then increased to maximum in Experiments V and VI.

Duration: Maximum in Experiments I through IV and then became even longer in Experiments V and VI.

Noding: Maximum in Experiments I through IV, increased more in Experiment V and increased still further in Experiment VI.

Sustained low amplitude: Progressively increased from none in Experiment I to maximum in Experiment VI, but occurred only in the masseter muscles.

Rate of onset: Remained moderate throughout all experiments.

Rate of ending: Moderate throughout except for an increase to maximum in Experiment V.

Interim activity: Maximum in Experiment I, decreased to minimum in Experiments III and IV, and became moderate again in Experiments V and VI.

Chart 2

The onset of activity in Experiments I and II was fairly evenly divided between the masseters and synchrony of all muscles. Experiments IV and V showed that synchronous initiation of chewing activity predominated. In Experiment VI there was a preponderance of the initiation of activity by the middle and posterior temporals.

Conclusion

This subject exhibited difficulty in adapting to the orthodontic procedures and showed the most difficulty in chewing in Experiment VI.

THE BEHAVIOR OF THE MASSETER AND TEMPORAL MUSCLES

CHART 1. COMPARISON OF THE CHARACTERISTICS OF MYOGRAMS BETWEEN EXPERIMENTS

Subject #2 - E. G.

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Bursts	4 to 6	4 to 6	4 to 6	4 to 5	6 to 8	6 to 9
Amplitude	XX	XX	XX	XX	XXX	XXX
Duration	XXX	XXX	XXX	XX	XXX Plus	XXX Plus
Noding	XXX	XX	XXX	XXX	XXX Plus	XXX Plus
Sustained low amplitude	0	X	X	0-X Mass. Only	XX Mass. only	XXX Mass. only
Rate of onset	XX	XX	XX	XX	XX	XX
Rate of ending	XX	XX	XX	XX	XXX	XX
Interim activity	XXX	XX	X	X	XX	XX

LEGEND: xxx = maximum, xx = moderate, x = minimum, 0 = no obvious change

CHART 2. COMPARISON OF ONSET OF ACTIVITY BETWEEN EXPERIMENTS

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Masseter first	4	4	6	4	1	2
Masseter and middle temporal first	1	0	2	0	0	0
Masseter and posterior temporal first	1	0	0	0	0	0
Middle temporal first	0	1	0	0	2	5
Middle and posterior temporal first	0	2	1	0	2	3
Posterior temporal first	0	1	0	0	0	0
All together (Synchrony)	6	4	3	8	7	2
TOTAL NUMBER OF CHEWING STROKES	12	12	12	12	12	12

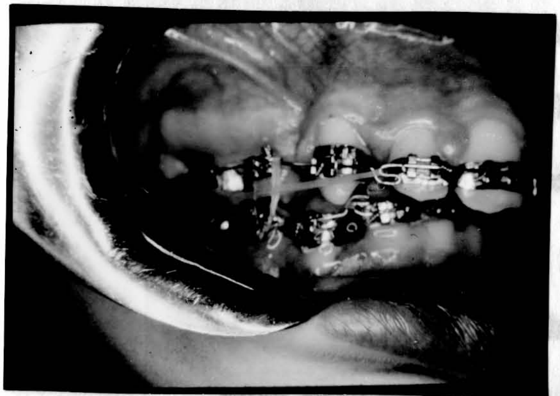
FINDINGS

Subject #3 (R.H.) Age 11

Angle Classification of Malocclusion: Class II - Division I

Subject #3 (R.H.)

Malocclusion After Completion of Anchorage Preparation



Subject #3

Treatment:

A. Extraction of the four first premolars.

B. Appliance design. (See Methods and Materials page 35).

1. The maxillary archwire was a differential forces arch with only two loops, one placed mesial to each canine tooth.

2. The mandibular archwire was a differential forces arch with only two loops, one placed mesial to each canine tooth.

3. The elastics were of all three types mentioned in Methods and Materials (page 40). There were intramaxillary elastics in the mandibular arch, and between the arches, elastics were worn in a Class II and a triangular fashion.

Chart 1

Bursts: The range of the number of bursts in Experiment VI was similar to that found in Experiments II, IV, and V, which was twice that found in Experiments I and II.

Amplitude: Moderate throughout all experiments except for an increase to maximum in Experiment III.

Duration: Showed a progressive increase from minimum in

Experiment I to a range of moderate to maximum in Experiments V and VI.

Noding: Progressive increase throughout all experiments from minimum in Experiment I to maximum in Experiment VI.

Sustained low amplitude: In the masseters throughout all six experiments.

Rate of onset: Moderate throughout all experiments.

Rate of ending: Moderate throughout all experiments.

Interim activity: Moderate until Experiment V when it became minimum and remained as such in Experiment VI.

Chart 2

The masseters, which initiated some activity in Experiments I through IV, did not initiate activity during Experiments V and VI. The temporal muscles, which initiated activity only a few times in the early experiments, became more prominent in their role as initiators of activity in Experiments IV, V and VI. Synchronous initiation of activity remained about the same for all experiments, except for an increase in Experiment II and a decrease in Experiment IV.

Conclusion

This subject displayed moderate difficulty in adapting to the orthodontic procedures.

THE BEHAVIOR OF THE MASSETER AND TEMPORAL MUSCLES

CHART 1. COMPARISON OF THE CHARACTERISTICS OF MYOGRAMS BETWEEN EXPERIMENTS

Subject #3 - R. H.

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Bursts	1 to 3	1 to 3	3 to 6	3 to 6	2 to 6	3 to 5
Amplitude	Rt. - XX Lt. - X	XX	XXX	XX	XX	XX
Duration	X	X	XX	XX	XX-XXX	XX-XXX
Noding	X	XX	XX	XX	XXX	XXX
Sustained low amplitude	Lt. Mass.	Rt. & Lt. Mass.	Lt. Mass.	Rt. & Lt. Mass.	Rt. & Lt. Mass.	Rt. & Lt. Mass.
Rate of onset	XX	X	XX	XX	XX	XX
Rate of ending	XX	XX	XX	XX	X-XX	XX
Interim activity	XX	X	XX	XX	X	X

LEGEND: xxx = maximum, xx = moderate, x = minimum, 0 = no obvious change

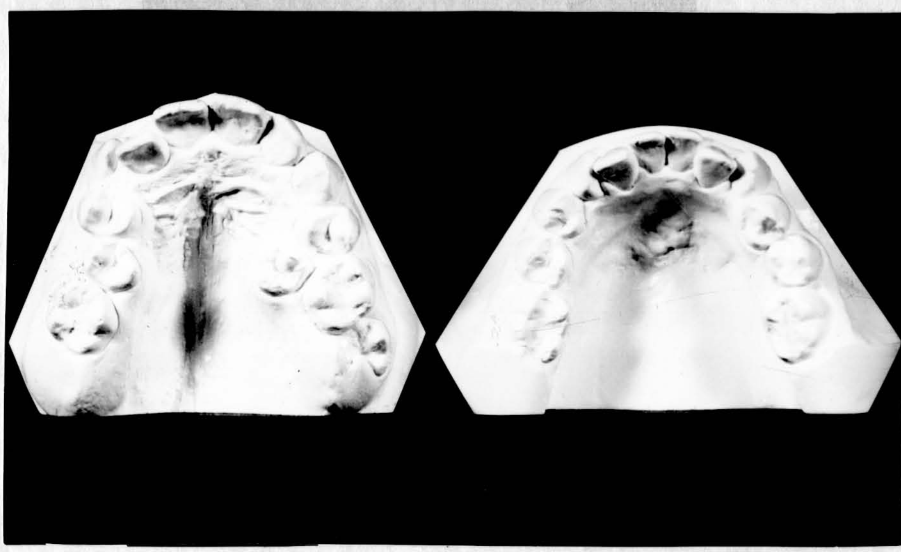
CHART 2. COMPARISON OF ONSET OF ACTIVITY BETWEEN EXPERIMENTS

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Masseter first	3	2	3	2	0	0
Masseter and middle temporal first	0	1	1	1	0	0
Masseter and posterior temporal first	0	0	0	0	0	1
Middle temporal first	0	1	0	0	1	1
Middle and posterior temporal first	1	0	3	0	4	4
Posterior temporal first	3	0	0	8	2	2
All together (Synchrony)	5	8	5	1	5	4
TOTAL NUMBER OF CHEWING STROKES	12	12	12	12	12	12

FINDINGS

Subject #4 (M.K.) Age 10

Angle Classification of Malocclusion: Class II - Division I - Subdivision



Subject #4 (M.K.)

Malocclusion After Completion of Anchorage Preparation

Subject #4

Treatment:

A. Extraction of the four first premolars.

B. Appliance design. (See Methods and Materials page 35).

1. The maxillary archwire was a differential forces arch with only two loops. They were placed between the right canine and lateral incisor and between the right central incisor and lateral incisor teeth.

2. The mandibular archwire was a differential forces arch with four loops. This is quite similar to the archwire in Figure 6 , except there is no loop between the central incisor teeth.

3. The elastics used were of the three types mentioned in Methods and Materials (page 40). There were intra-maxillary elastics in the mandibular arch, and between the arches, elastics were worn in a Class II and a triangular fashion.

Chart 1

Bursts: Showed a low range in Experiments I and II,

increased in Experiments III, IV, and V, and then decreased back to the original range in Experiment VI.

Duration: Started out as minimal and increased to moderate in Experiments IV, V and VI.

Noding: Remained moderate throughout until Experiment VI, when it showed a decrease to minimum.

Sustained low amplitude: Moderate in the masseters throughout all experiments.

Rate of onset: Moderate in Experiments I through V, and became maximal in Experiment VI.

Rate of ending: Moderate throughout the first five experiments and minimum in Experiment VI.

Interim activity: Minimum throughout all experiments except for Experiment II.

Chart 2

There was some variability in the muscles first to initiate activity. Experiments I and III were similar in that the muscles initiated activity synchronously or the masseters initiated activity, while in Experiments II and IV the masseters were the predominant muscles in initiating

activity. In Experiments V and VI synchronous initiation was predominant.

Conclusion

This subject seemed to have adapted well to the orthodontic procedures.

THE BEHAVIOR OF THE MASSETER AND TEMPORAL MUSCLES

CHART 1. COMPARISON OF THE CHARACTERISTICS OF MYOGRAMS BETWEEN EXPERIMENTS

Subject #4 - H. K.

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Bursts	1 to 3	1 to 3	3 to 5	2 to 4	2 to 4	1 to 3
Amplitude	XX	X	XX	XX	XX	XXX
Duration	X	X	X	XX	XX-XXX	XX
Noding	XX	XX	XX	XX	XX	X
Sustained low amplitude	Rt. Mass. & Post. Temp. X	XX	Rt. Mass. & Post. Temp. XX	Rt. Mass. XX	Rt. Mass. X	Mass. XX
Rate of onset	XX	XX	XX	XX	X-XX	XX-XXX
Rate of ending	XX	XX	XX	XX	XX	XX-XXX
Interim activity	X	XX	X	Mass. & Post. Temp. X	X	X

LEGEND: xxx = maximum, xx = moderate, x = minimum, 0 = no obvious change

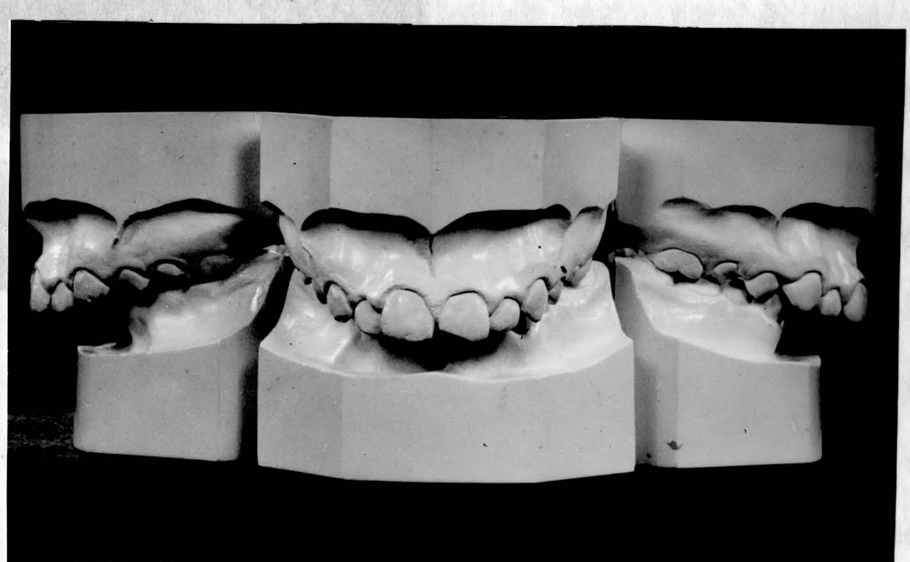
CHART 2. COMPARISON OF ONSET OF ACTIVITY BETWEEN EXPERIMENTS

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Masseter first	6	7	4	8	1	0
Masseter and middle temporal first	1	0	0	0	0	1
Masseter and posterior temporal first	0	0	0	0	0	0
Middle temporal first	0	1	1	0	1	0
Middle and posterior temporal first	0	2	0	1	2	3
Posterior temporal first	0	0	0	1	0	0
All together (Synchrony)	5	2	7	2	8	8
TOTAL NUMBER OF CHEWING STROKES	12	12	12	12	12	12

FINDINGS

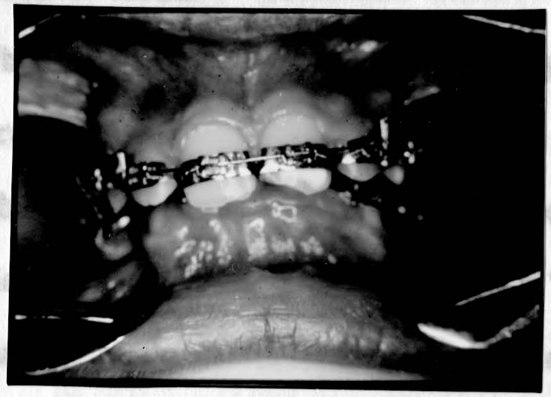
Subject #5 (M.M.) Age 11

Angle Classification of Malocclusion: Class II - Division I



Subject #5 (M.M.)

Malocclusion After Completion of Anchorage Preparation



Subject #5

Treatment:

A. Extraction of the four first premolars.

B. Appliance design. (See Methods and Materials page 35).

1. The maxillary archwire was a differential forces arch with four loops. This is quite similar to the archwire in Figure 6, except there is no loop between the central incisor teeth.

2. The mandibular archwire was a typical differential forces arch (Figure 6).

3. The elastics used were of the three types mentioned in Methods and Materials (page 40). There were intra-maxillary elastics in the mandibular arch, and between the arches, elastics were worn in a Class II and a triangular fashion.

Chart 1

Bursts: The range of bursts was similar throughout, with slight increases in Experiments III and VI.

Amplitude: Minimal from Experiment I through Experiment IV and then became moderate in Experiments V and VI.

Duration: Minimal in Experiment I through Experiment IV and became moderate in Experiments V and VI.

Noding: Remained moderate throughout all experiments.

Sustained low amplitude: Remained minimal throughout all experiments except for an increase to moderate in Experiment IV.

Rate of onset: Moderate in Experiments I through IV and became minimal in Experiments V and VI.

Rate of ending: Remained moderate throughout all experiments.

Interim activity: Minimum until Experiment VI when it became moderate.

Chart 2

From Experiment I to Experiment IV there was a decrease in the initiation of activity by the masseters and they did not initiate any activity in Experiments V or VI. The combination of middle and posterior temporals, on the other hand, failed to initiate any activity in Experiments I and II, but showed a steady increase in Experiments III, IV, and V, at which time they initiated almost all of the activity. The initiation of activity by the masseters decreased markedly in Experiment

VI. Synchrony occurred fairly frequently in Experiment I, and showed a progressive decrease up to Experiment V, when it initiated activity only once. In Experiment VI, synchrony initiated activity three-fourths of the time, while the combination of the middle and posterior temporals initiated activity the remaining times. Experiment V showed a predominance of the combination of the middle and posterior temporals initiating activity.

Conclusion

This subject showed good adaptation to the orthodontic procedures.

THE BEHAVIOR OF THE MASSETER AND TEMPORAL MUSCLES

CHART 1. COMPARISON OF THE CHARACTERISTICS OF MYOGRAMS BETWEEN EXPERIMENTS

Subject #5 - M. M.

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Bursts	2 to 3	2 to 3	3 to 4	2 to 3	2 to 3	3 to 4
Amplitude	X	X	X	X	XX	XX
Duration	X	X	X	X	XX	XX
Noding	XX	XX	XX	XX	XX	XX
Sustained low amplitude	Mass. X	Mass. X	Mass. X	Mass. XX	Mass. X	Mass. X
Rate of onset	XX	XX	XX	XX	X	X
Rate of ending	XX	XX	XX	XX	XX	XX
Interim activity	X	X	X	X	X	XX

LEGEND: xxx = maximum, xx = moderate, x = minimum, 0 = no obvious change

CHART 2. COMPARISON OF ONSET OF ACTIVITY BETWEEN EXPERIMENTS

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Masseter first	6	7	3	2	0	0
Masseter and middle temporal first	0	1	0	0	0	0
Masseter and posterior temporal first	0	0	0	1	0	0
Middle temporal first	0	0	0	0	0	0
Middle and posterior temporal first	0	0	3	5	10	3
Posterior temporal first	1	0	3	1	1	0
All together (Synchrony)	5	4	3	3	1	9
TOTAL NUMBER OF CHEWING STROKES	12	12	12	12	12	12

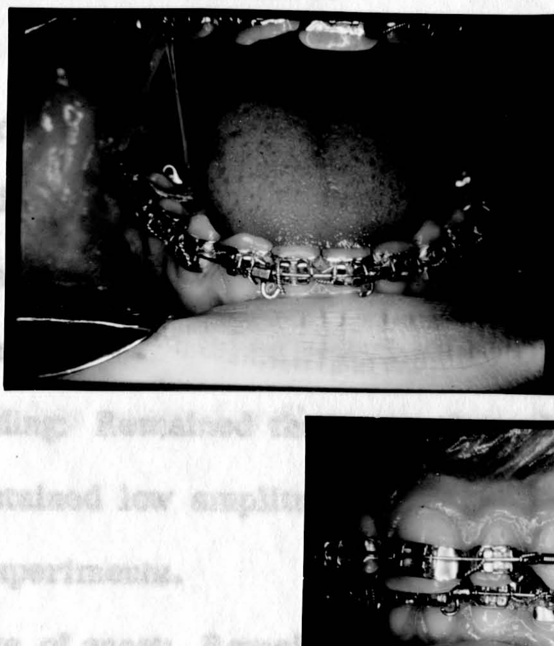
FINDINGS

Subject #6 (K.M.) Age 13

Angle Classification of Malocclusion: Class II - Division I

Subject #6 (K.M.)

Malocclusion After Completion of Anchorage Preparation



Subject #6

Treatment:

A. No teeth were extracted.

B. Appliance design. (See Methods and Materials page 35).

1. The maxillary teeth were banded, but no archwire was placed.
2. The mandibular archwire was a straight (horizontal) arch with headgear attachments and headgear to lower arch.
3. No elastics were used.

Chart 1

Bursts: Remained relatively the same throughout all experiments and were never in a high range.

Amplitude: Varied from moderate to maximum.

Duration: Remained moderate throughout all experiments.

Noding: Remained the same throughout all experiments.

Sustained low amplitude: Occurred in the left masseter throughout all experiments.

Rate of onset: Remained moderate throughout all experiments.

Rate of ending: Moderate throughout all experiments except

for an increase to maximum in Experiment IV.

Interim activity: Maximum in the first three experiments and then moderate in the next three experiments.

Chart 2

The masseters, which at first predominaated in the onset of activity, failed to initiate activity in the last three experiments. Generally, the temporals assumed a more important role in the onset of activity as the treatment progressed, except for Experiment V. Experiment III showed some possible confusion as nearly all muscles or combinations of muscles initiated activity. Experiment VI showed the combination of the middle and posterior temporals along with synchrony of all muscles initiating all chewing activity.

Conclusion

This subject has adapted well to the orthodontic procedures.

THE BEHAVIOR OF THE MASSETER AND TEMPORAL MUSCLES

CHART 1. COMPARISON OF THE CHARACTERISTICS OF MYOGRAMS BETWEEN EXPERIMENTS

Subject #6 - K. M.

Bursts	Exp. I 3 to 6	Exp. II 2 to 5	Exp. III 3 to 6	Exp. IV 2 to 6	Exp. V 2 to 5	Exp. VI 2 to 5
Amplitude	XX	XX	XX	XXX	XX	XXX
Duration	XX	XX	XX	XX	XX	XX
Noding	XXX	XXX	XXX	XXX	XXX	XXX
Sustained low amplitude	Lt. Mass.	Lt. Mass.	Lt. Mass.	Lt. Mass.	Lt. Mass.	Lt. Mass.
Rate of onset	XX	XX	XX	XX	XX	XX
Rate of ending	XX	XX	XX	XXX	XX	XX
Interim activity	XXX	XXX	XXX	XX	X-XX	XX

LEGEND: xxx = maximum, xx = moderate, x = minimum, 0 = no obvious change

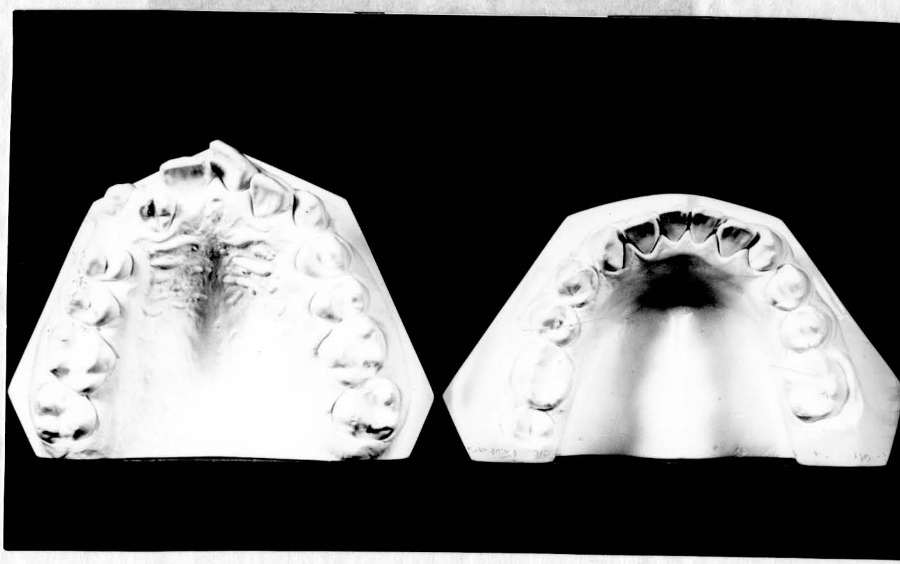
CHART 2. COMPARISON OF ONSET OF ACTIVITY BETWEEN EXPERIMENTS

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Masseter first	8	2	3	0	0	0
Masseter and middle temporal first	0	1	1	1	0	0
Masseter and posterior temporal first	0	0	2	0	0	0
Middle temporal first	0	0	1	0	1	0
Middle and posterior temporal first	1	7	3	5	2	8
Posterior temporal first	0	1	0	4	0	0
All together (Synchrony)	3	1	2	2	9	4
TOTAL NUMBER OF CHEWING STROKES	12	12	12	12	12	12

FINDINGS

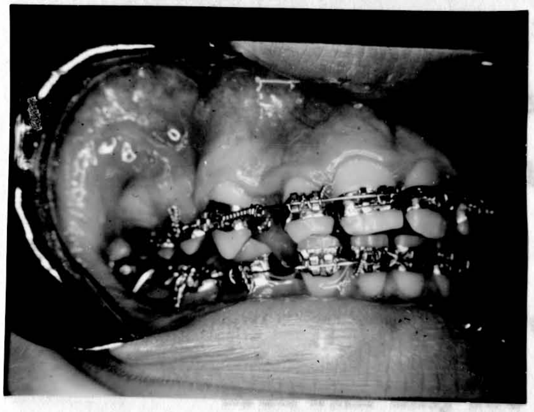
Subject #7 (J.N.) Age 13

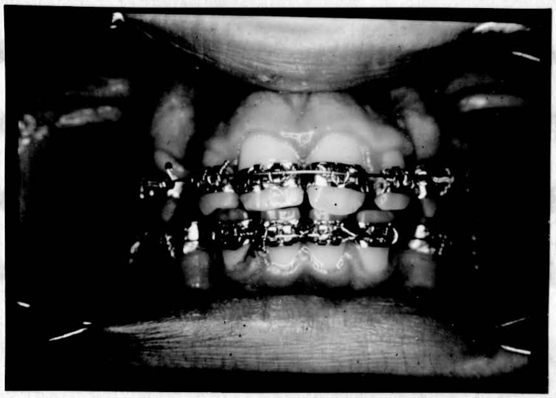
Angle Classification of Malocclusion: Class II - Division I



Subject #7 (J.N.)

Malocclusion After Completion of Anchorage Preparation





Subject #7

Treatment:

A. Extraction of the four first premolars.

B. Appliance design. (See Methods and Materials page 35).

1. The maxillary archwire was a typical differential forces arch (Figure 6).

2. The mandibular archwire was a typical differential forces arch with only two loops, one mesial to each canine tooth.

3. The elastics used were of the three types mentioned in Methods and Materials (page 40). They were intramaxillary elastics in the mandibular arch, and between the arches, elastics were worn in a Class II and a triangular fashion.

Chart 1

Bursts: Experiments I through IV exhibited a "multi-burst searching" pattern. Experiments V and VI showed more normal patterns of bursts.

Amplitude: Maximum in Experiments I, II, and IV, while it was moderate in Experiments III, V, and VI.

Noding: Remained moderate to maximum throughout all experi-

ments.

Sustained low amplitude: Occurs occassionally in the right masseter.

Rate of onset: Moderate throughout all experiments.

Rate of ending: Moderate throughout all experiments.

Interim activity: Occurred as moderate throughout all experiments.

Chart 2

In this subject there was a definite absence of the temporal muscles initiating activity by themselves except in Experiment IV. The masseters and synchrony of all muscles were the predominant initiators of activity. A definite improvement in the onset of activity was noted in Experiment V and even more in Experiment VI, as synchrony of all muscles became the predominant group in initiating chewing activity.

Conclusion

This subject exhibited considerable difficulty in masticating during the early experiments but, by Experiment VI, has adapted to the orthodontic procedures.

THE BEHAVIOR OF THE MASSETER AND TEMPORAL MUSCLES

CHART 1. COMPARISON OF THE CHARACTERISTICS OF MYOGRAMS BETWEEN EXPERIMENTS

Subject #7 - J. N.

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Bursts	Multi-bursts 6 to 8	Multi-bursts	Multi-bursts 6 to 8	Multi-bursts ("Searching")	2 to 5	3 to 5
Amplitude	XXX	XXX	XXX	XX	XX	XX
Duration	XX	XXX	XX	XXX	XX	XX
Noding	XX	XXX	XX	XX	XX	XX
Sustained low amplitude	Rt. Mass. First Chew Stroke	0	Rt. Mass. First Chew Stroke	Slightly More	0	X
Rate of onset	XX	XX	XX	XX	XX	XX
Rate of ending	XXX	XX	XX	XX	XX	XX
Interim activity	XX	XX	X	XX Post. Temp.- XXX	Mass. & Post. Temp.- XX	Post. Temp. XX

LEGEND: xxx = maximum, xx = moderate, x = minimum, 0 = no obvious change

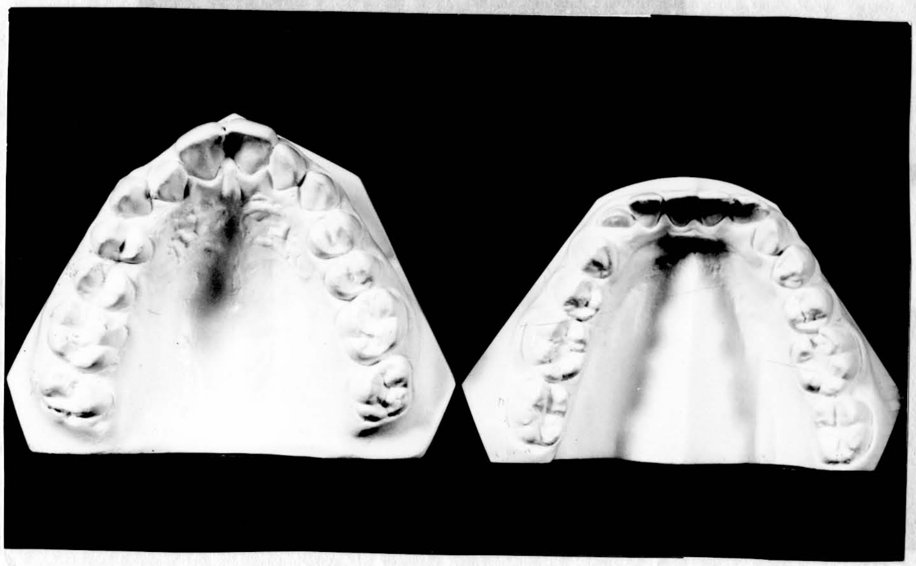
CHART 2. COMPARISON OF ONSET OF ACTIVITY BETWEEN EXPERIMENTS

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Masseter first	3	7	5	4	4	1
Masseter and middle temporal first	2	2	0	0	1	0
Masseter and posterior temporal first	0	0	0	1	0	0
Middle temporal first	0	0	0	0	0	0
Middle and posterior temporal first	0	0	1	0	0	1
Posterior temporal first	0	0	0	5	0	1
All together (Synchrony)	7	3	6	2	7	9
TOTAL NUMBER OF CHEWING STROKES	12	12	12	12	12	12

FINDINGS

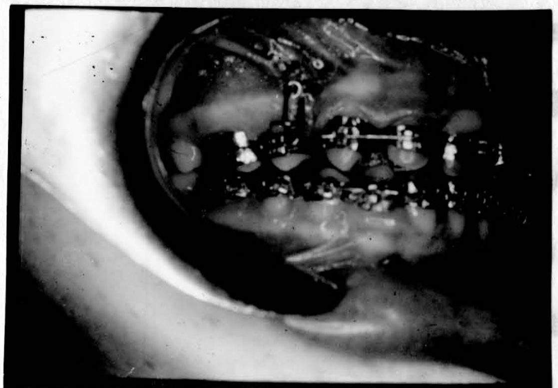
Subject #8 (L.P.) Age 12

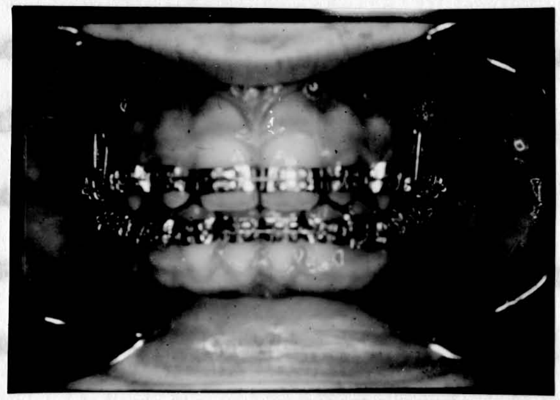
Angle Classification of Malocclusion: Class II - Division I

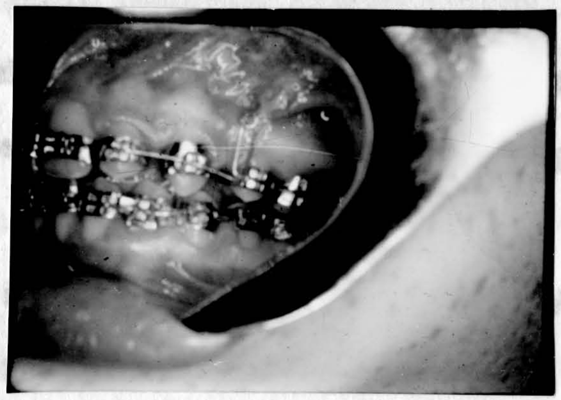


Subject #8 (L.P.)

Malocclusion After Completion of Anchorage Preparation







Subject #8

Treatment:

A. Extraction of the maxillary first premolars.

B. Appliance design. (See Methods and Materials page 35.

1. The maxillary archwire was a differential forces arch with four loops. This is quite similar to the archwire in Figure 6, except there is no loop between the central incisor teeth.

2. The mandibular archwire was a straight (horizontal) arch without attachments.

3. The elastics were of types two and three mentioned in Methods and Materials (page 40). Between the arches, elastics were worn in a Class II and a triangular fashion.

Chart 1

Bursts: Remained relatively the same in all experiments except Experiments II and IV where there were "sustained searching patterns".

Amplitude: Maximal in all experiments except II and IV.

Duration: Increased from minimal in Experiment I to

to maximal in Experiment IV and then decreased slightly in Experiments V and VI.

Noding: Maximal throughout except for Experiment II where it decreased to moderate.

Sustained low amplitude: Predominantly in the masseter throughout all experiments, but also occurred occassionally in other muscles.

Rate of onset: Remained moderate throughout all experiments except for a decrease to minimal in Experiment IV.

Rate of ending: Moderate throughout all experiments except for a decrease to minimal in Experiment IV.

Interim activity: Maximal in masseters until Experiment V when it decreased to moderate and then became minimal in Experiment VI. The posterior temporals exhibited moderate interim activity in Experiment VI only.

Chart 2

The onset of activity between experiments remained relatively the same throughout all experiments except that in Experiment VI the pattern became more stable. In Experiment VI only synchrony of all

muscles and the masseters initiated activity.

Conclusion

This subject has adapted well to the orthodontic procedures.

THE BEHAVIOR OF THE MASSETER AND TEMPORAL MUSCLES

CHART 1. COMPARISON OF THE CHARACTERISTICS OF MYOGRAMS BETWEEN EXPERIMENTS

Subject #8 - L. P.

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Bursts	2 to 6	2 to 5	2 to 6	Searching Patterns	2 to 6	3 to 6
Amplitude	XXX	XX	XXX	XX	XXX	XXX
Duration	X	XX	X	XXX	XX-XXX	XX-XXX
Noding	XXX	XX	XXX	XXX	XXX	XXX
Sustained low amplitude	Mid. Temp. X	Mass. & Mid. Temp.	Mass. X	In all Muscles	Mass.	Mass.
Rate of onset	XX	XX	XX	X	XX	XX
Rate of ending	XX	XX	XX	X	XX	XX
Interim activity	XXX Esp. Mass.	XX Esp. Mass.	XXX	XXX	XX Esp. Mass.	P. Temp. XX Others X

LEGEND: xxx = maximum, xx = moderate, x = minimum, 0 = no obvious change

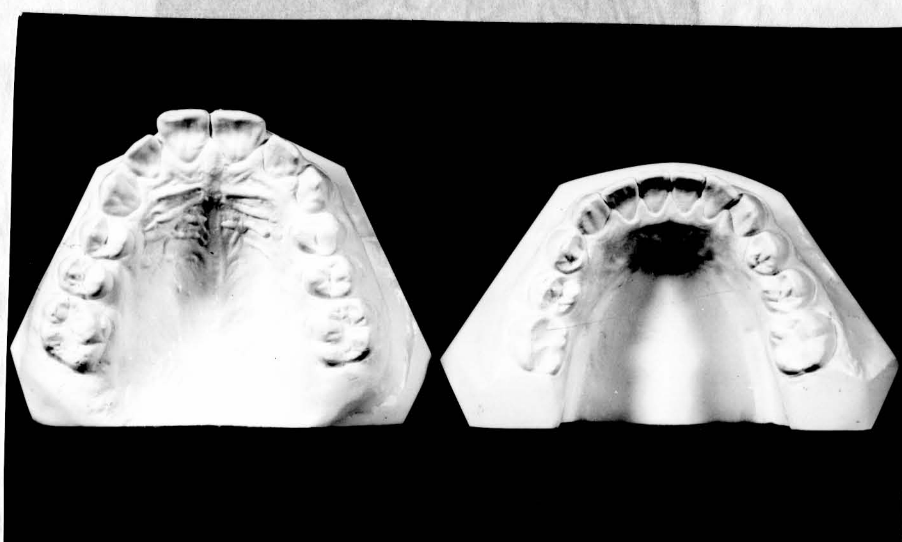
CHART 2. COMPARISON OF ONSET OF ACTIVITY BETWEEN EXPERIMENTS

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Masseter first	6	5	5	5	3	5
Masseter and middle temporal first	0	0	0	1	0	0
Masseter and posterior temporal first	0	0	1	1	0	0
Middle temporal first	0	0	0	0	1	0
Middle and posterior temporal first	2	4	3	1	3	0
Posterior temporal first	0	0	0	1	0	0
All together (Synchrony)	4	3	3	3	5	7
TOTAL NUMBER OF CHEWING STROKES	12	12	12	12	12	12

FINDINGS

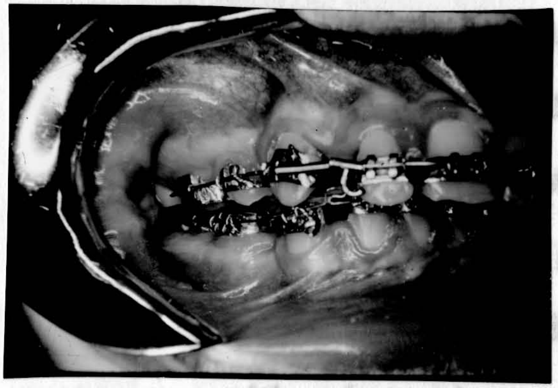
Subject #9 (C.R.) Age 10

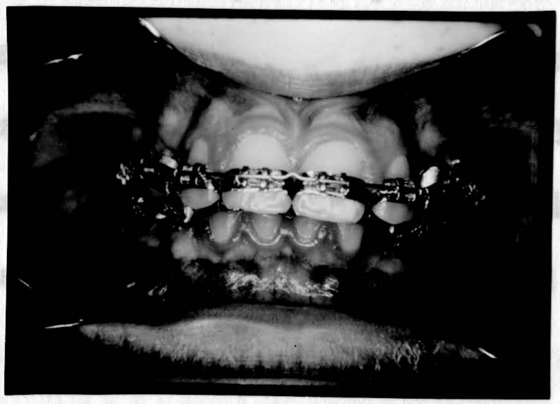
Angle Classification of Malocclusion: Class II - Division I

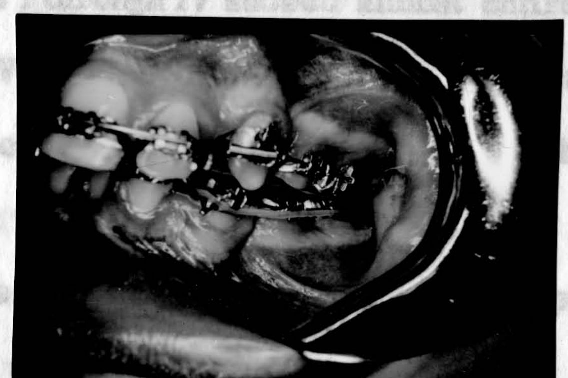


Subject #9 (C. R.)

Malocclusion After Completion of Anchorage Preparation







Subject #9

Treatment:

A. Extraction of the four first premolars.

B. Appliance design. (See Methods and Materials page 35).

1. The maxillary archwire was a differential forces arch with only two loops, one placed mesial to each canine tooth.

2. The mandibular archwire was a differential forces arch with only two loops, one placed mesial to each canine tooth.

3. The elastics used were of the three types mentioned in Methods and Materials (page 40). There were intramaxillary elastics in the mandibular arch, and between the arches, elastics were worn in a Class II and a triangular fashion.

Chart 1

Bursts: Experiments I through IV showed almost entirely "multi-bursts". In Experiments V and VI there was a definite decrease in the number of bursts with Experiment VI showing the least number of bursts for any experiment.

Amplitude: Moderate throughout all experiments except for some increase in Experiments III and IV.

Duration: Moderate throughout all experiments except for an increase to maximal in Experiment IV.

Noding: Maximal throughout all experiments except for decreases to moderate in Experiments II and VI.

Sustained low amplitude: Occurred in the masseters throughout, but became less in Experiments V and VI.

Rate of onset: Remained moderate throughout all experiments.

Rate of ending: Moderate throughout the first five experiments, but became minimal in Experiment VI.

Interim activity: Minimal throughout all experiments.

Chart 2

The occurrence of synchronous onset remained about the same in Experiments I through IV and then increased markedly in Experiments V and VI. The masseters, which at first initiated activity about one-third of the time, did not initiate activity in Experiments IV and V and only once in Experiment VI. The combination of the middle and posterior temporals initiated activity only infrequently in the first three experiments. In Experiment IV they initiated activity one-half of the time, but

their frequency of initiation of activity decreased to about one-fourth of the time in Experiments V and VI.

Conclusion

This subject, after having experienced considerable difficulty in the early experiments, seemed to have adapted well to the orthodontic procedures.

THE BEHAVIOR OF THE MASSETER AND TEMPORAL MUSCLES

CHART 1. COMPARISON OF THE CHARACTERISTICS OF MYOGRAMS BETWEEN EXPERIMENTS

Subject #9 - C. R.

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Bursts	Multibursts 6 to 8	Multibursts 6 to 8	Multibursts 6 to 8	Multibursts	2 to 6	2 to 4
Amplitude	Mass.-X Temp.-XX	Mass.-X Temp.-XX	Mass.-XX Temp.-XXX	Mass.-X Temp.-XXX	Mass.-X Temp.-XX	Mass.-X Temp.-XX
Duration	XX	XX	XX	XXX	XX-XXX	XX
Noding	XXX	XX	XXX	XXX	XXX	XX
Sustained low amplitude	Mass.-X	Mass.-X	0	Mass.-X	Mass.- 0-X	Mass.- 0-X
Rate of onset	XX	XX	XX	X	XX	XX
Rate of ending	XX	XX	XX	XX	X-XX	X
Interim activity	X	X	X	X	X	X

LEGEND: xxx = maximum, xx = moderate, x = minimum, 0 = no obvious change

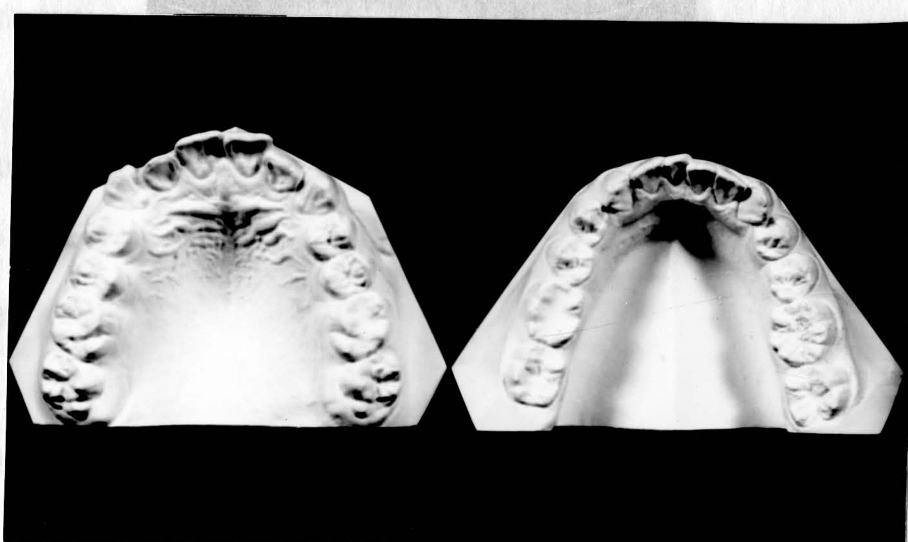
CHART 2. COMPARISON OF ONSET OF ACTIVITY BETWEEN EXPERIMENTS

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Masseter first	2	4	3	0	0	1
Masseter and middle temporal first	0	0	0	0	0	0
Masseter and posterior temporal first	0	0	1	0	0	0
Middle temporal first	0	0	0	1	0	0
Middle and posterior temporal first	2	2	1	6	3	3
Posterior temporal first	0	2	1	1	0	0
All together (Synchrony)	5	4	6	4	9	8
TOTAL NUMBER OF CHEWING STROKES	12	12	12	12	12	12

FINDINGS

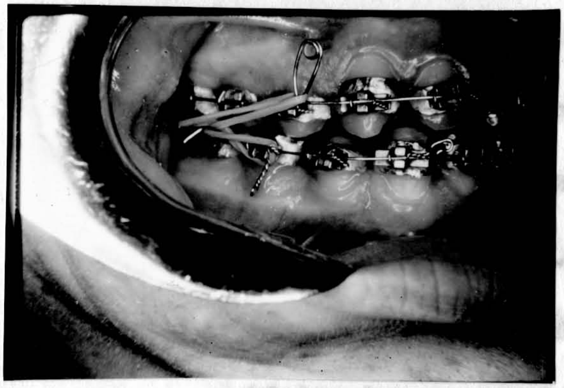
Subject #10 (H. S.) Age 14

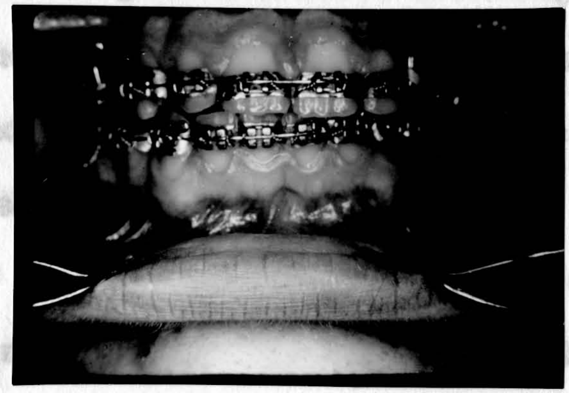
Angle Classification of Malocclusion: Class I

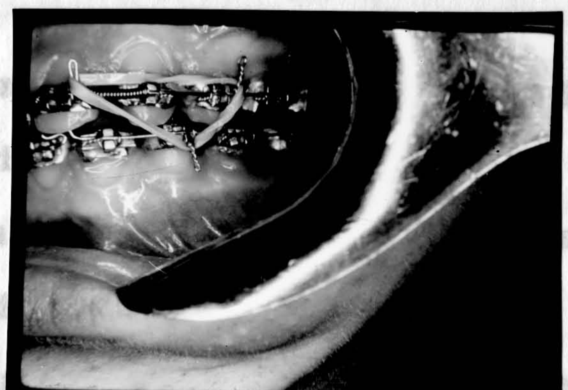


Subject #10 (H.S.)

Malocclusion After Completion of Anchorage Preparation







Subject #10

Treatment:

A. No teeth were extracted.

B. Appliance design. (See Methods and Materials page 35).

1. The maxillary archwire was a straight (horizontal) arch with no attachments.

2. The mandibular archwire was a straight (horizontal) arch with headgear attachments and headgear to the lower arch.

3. The elastics used were of type three mentioned in Methods and Materials (page 40). They were worn in a triangular fashion.

Chart 1

Bursts: Showed a gradual increase in number from Experiment I to Experiment VI.

Amplitude: Maximum throughout all experiments except for a decrease to moderate in Experiments IV and V.

Duration: Showed an increase from minimal in the first three experiments to almost maximal in Experiments V and VI.

Noding: Increased progressively from minimal in Experiment

I to maximal in Experiments V and VI.

Sustained low amplitude: Minimal until Experiment V when it showed an increase in the masseter. It decreased in Experiment VI.

Rate of onset: Remained moderate throughout all experiments.

Rate of ending: Remained maximal throughout all experiments.

Interim activity: Minimum in all experiments except IV and VI where it was moderate.

Chart 2

The masseters initiated activity a relatively constant number of times except in Experiments III and IV, when they did not initiate activity at all. Synchronous initiation of activity occurred in nearly one-half of the cases in all of the experiments except VI. In Experiment VI, the middle and posterior temporals initiated activity most frequently.

Conclusion

This subject appeared to be having difficulty adapting to the orthodontic procedures.

THE BEHAVIOR OF THE MASSETER AND TEMPORAL MUSCLES

CHART 1. COMPARISON OF THE CHARACTERISTICS OF MYOGRAMS BETWEEN EXPERIMENTS

Subject #10 - H. S.

Bursts:	Exp. I 2 to 3	Exp. II 2 to 3	Exp. III 2 to 4	Exp. IV 2 to 6	Exp. V 3 to 5	Exp. VI 4 to 7
Amplitude	XXX	XXX	XXX	XX	XX	XXX
Duration	X	X	X	XX	XX-XXX	XX-XXX
Noding	X	X	XX	XX	XXX	XXX
Sustained low amplitude	Mass.-X	X	Mass.-X	0	L. Mass-XXX R. Masc-XX	L.Mass.-XX R.Mass.-0
Rate of onset	XX	XX	XX	XX	XX	XX
Rate of ending	XXX	XXX	XXX	XXX	XXX	XXX
Interim activity	X	X	X	XX	X	XX

LEGEND: xxx = maximum, xx = moderate, x = minimum, 0 = no obvious change

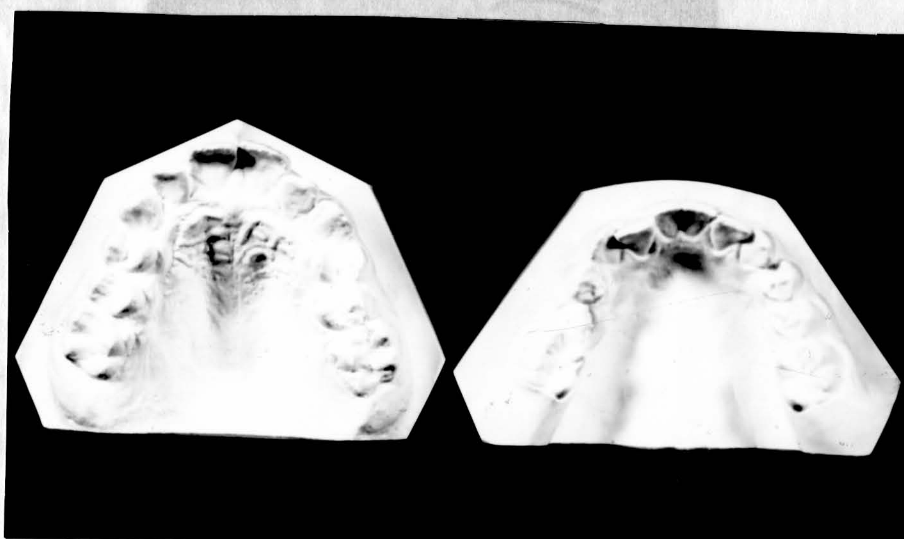
CHART 2. COMPARISON OF ONSET OF ACTIVITY BETWEEN EXPERIMENTS

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Masseter first	2	3	0	0	3	2
Masseter and middle temporal first	1	1	2	1	0	0
Masseter and posterior temporal first	0	0	1	0	0	0
Middle temporal first	1	1	0	0	0	0
Middle and posterior temporal first	3	1	5	3	3	5
Posterior temporal first	0	0	0	2	0	2
All together (Synchrony)	5	6	4	6	6	3
TOTAL NUMBER OF CHEWING STROKES	12	12	12	12	12	12

FINDINGS

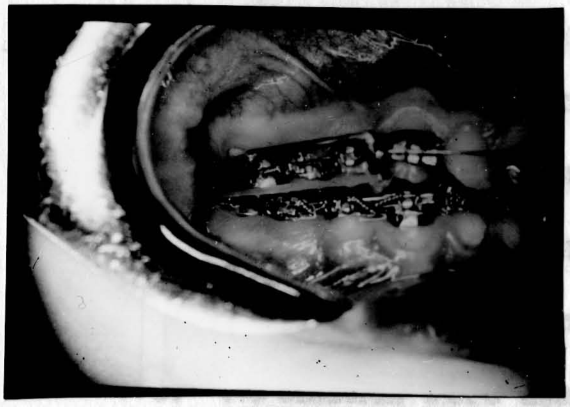
Subject #11 (E.S.) Age 12

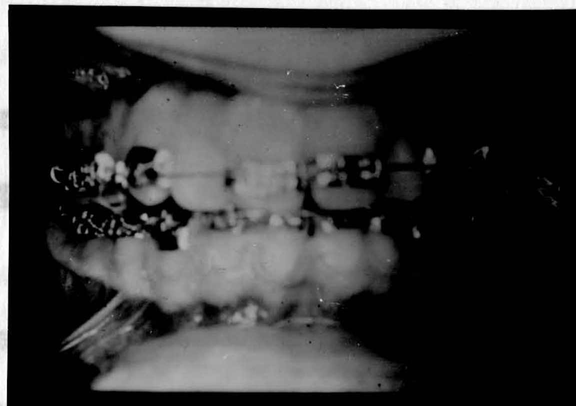
Angle Classification of Malocclusion: Class II - Division I



Subject #11 (E.S.)

Malocclusion After Completion of Anchorage Preparation





Subject #11

Treatment:

A. No teeth were extracted.

B. Appliance design. (See methods and Materials page 35).

1. The maxillary teeth were banded, but no archwire was placed.
2. The mandibular archwire was a straight (horizontal) arch with headgear attachments and headgear to the lower arch.
3. No elastics were used.

Chart 1

Bursts: A "multi-burst searching" pattern was evident throughout except for Experiment V. Experiment VI showed a return of the "searching" pattern.

Amplitude: Remained moderate until Experiments V and VI, which showed maximal amplitude in the posterior temporals and minimum amplitude in the masseters.

Duration: Duration on the left side was maximal throughout while that on the right side was moderate until Experiment VI, when it increased to maximal.

Noding: Moderate throughout all experiments except for an

increase to maximum in Experiments III and VI.

Sustained low amplitude: Evident in the right masseter throughout all experiments except for Experiment IV. In Experiments V and VI the left masseter also showed sustained low amplitude.

Rate of onset: Moderate throughout all experiments.

Rate of ending: Moderate for Experiments I through IV, but decreased slightly in Experiments V and VI.

Interim activity: Maximum to moderate for the first four experiments. In Experiments V and VI it decreased to minimal.

Chart 2

In Experiments I through III the onset of activity showed some confusion as nearly all muscles or groups of muscles participated in initiating chewing activity. In Experiment IV, synchronous initiation and initiation by the temporals showed more predominance. In Experiment V, three-fourths of the chewing strokes were initiated by a synchrony of all the muscles. In Experiment VI, the middle and posterior temporals as a group and synchrony of all muscles predominated in initiating the chewing stroke.

Conclusion

This subject exhibited a confused pattern of chewing activity and appeared to be having some difficulty in adapting to the orthodontic procedures.

CHART 1. COMPARISON OF THE CHARACTERISTICS OF MYOGRAMS BETWEEN EXPERIMENTS

Subject #11 - E. S.

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Bursts	Multiburst "Searching"	Multiburst "Searching"	Multiburst "Searching"	Multiburst "Searching"	2 to 6	Multiburst "Searching"
Amplitude	XX	XX	X	XX	X-XXX	X-XXX
Duration	L.Side-XXX R.Side-XX	L.Side-XXX R.Side-XXX	L.Side-XXX R.Side-XX	L.Side-XXX R.Side-XX	L.Side-XXX R.Side-XX	L.Side-XXX R.Side-XXX
Noding	XX	XX	XXX	XX	XX	XXX
Sustained low amplitude	R. Mass.	R. Mass.	R. Mass.	0	L. & R. Mass.	L. & R. Mass.
Rate of onset	XX	XX	XX	XX	XX	XX
Rate of ending	XX	XX	XX	XX	X-XX	X-XX
Interim activity	R.Mass-XXX Others-XX	R.Mass.-XXX Others-XX	XX	Mass.-XXX Post.Temp.-X	X	X

LEGEND: xxx = maximum, xx = moderate, x = minimum, 0 = no obvious change

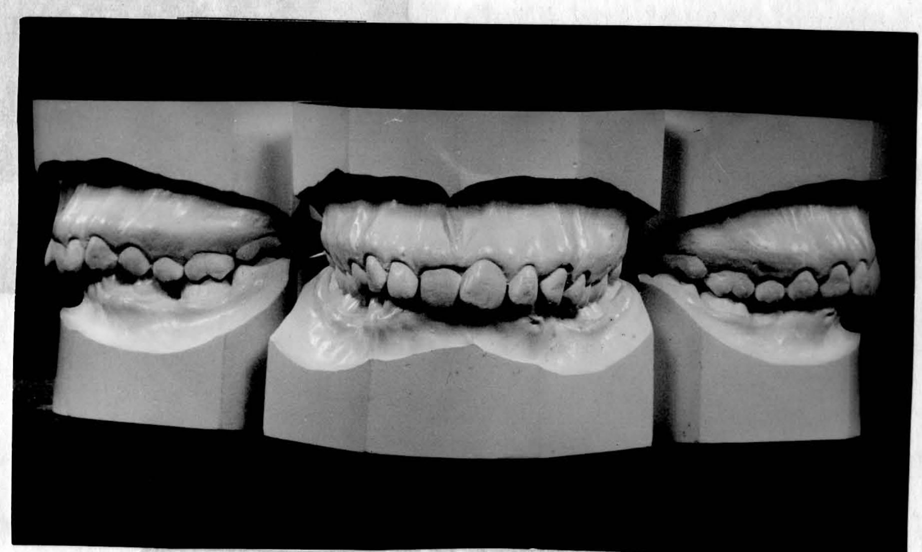
CHART 2. COMPARISON OF ONSET OF ACTIVITY BETWEEN EXPERIMENTS

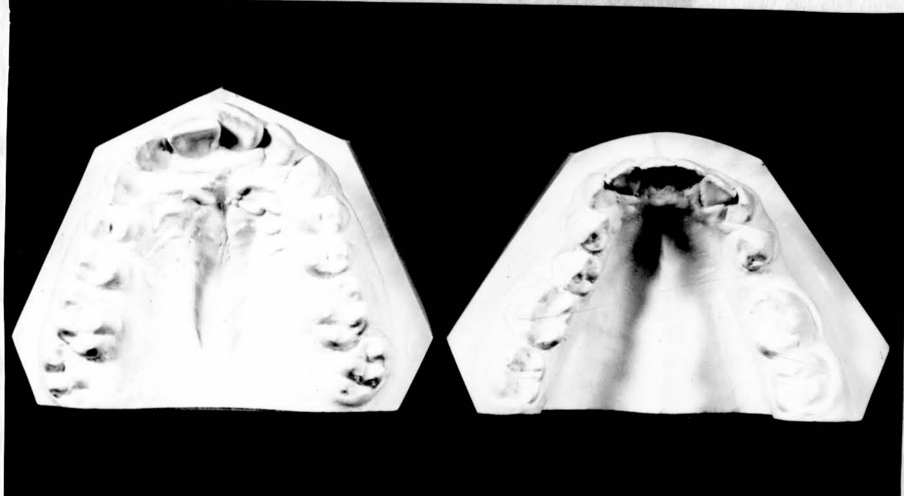
	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Masseter first	3	5	4	2	1	0
Masseter and middle temporal first	1	1	1	0	0	0
Masseter and posterior temporal first	0	1	2	0	0	0
Middle temporal first	0	0	1	0	0	0
Middle and posterior temporal first	1	2	2	2	1	7
Posterior temporal first	0	1	0	3	1	0
All together (Synchrony)	7	2	2	5	9	5
TOTAL NUMBER OF CHEWING STROKES	12	12	12	12	12	12

FINDINGS

Subject #12 (J.S.) Age 14

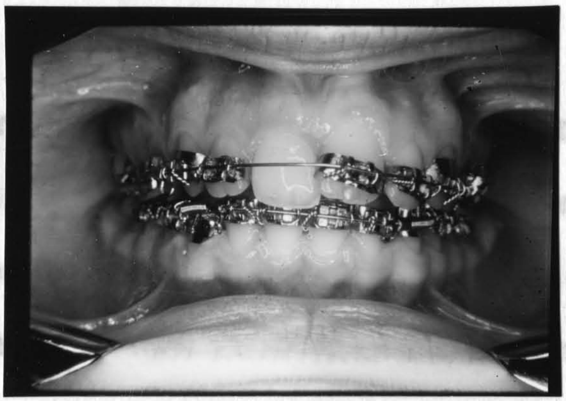
Angle Classification of Malocclusion: Class II - Division I





Subject #12 (J.S.)

Malocclusion After Completion of Anchorage Preparation



Subject #12

Treatment:

A. No teeth were extracted.

B. Appliance design. (See Methods and Materials page 35).

1. The maxillary teeth were banded but no archwire was placed.

2. The mandibular archwire was a straight (horizontal) arch with headgear attachments and headgear to the lower arch.

3. No elastics were used.

Chart 1

Bursts: In Experiments I through IV there was a "multi-burst" pattern. In Experiments V and VI this decreased to a more normal pattern of three to six bursts.

Amplitude: Remained moderate to maximum throughout all experiments.

Duration: Showed a range of minimum to moderate in Experiments I and III, while an increase to a range of moderate to maximum was evident in Experiments II and IV. In Experiments V and VI the duration decreased to minimal.

Noding: Remained minimum to moderate for the first five

experiments, but showed an increase to maximum in Experiment VI.

Sustained low amplitude: Absent until Experiment VI, when it was present in the masseters.

Rate of onset: Moderate throughout all experiments.

Rate of ending: Moderate for the first five experiments, but increased to maximum in Experiment VI.

Interim activity: Remained the same throughout all experiments.

Chart 2

In Experiments I through III the masseter was quite evident as an initiator of activity. A decrease in masseter initiation was evident in Experiment IV and there was no masseter initiation of activity in Experiments V and VI. Synchronous initiation of activity remained relatively stable in Experiments I through IV, but showed a predominance in Experiment V. Experiment VI showed a definite decrease in the occurrence of synchrony initiating the chewing stroke to the fewest number of times of any experiment. The temporals, which rarely initiated activity throughout the first five experiments, became the predominant muscles of initiation of the chewing stroke in Experiment VI.

Conclusion

This subject exhibited some difficulty in chewing during Experiments I through IV, but showed good adaptation to the orthodontic procedures in Experiments V and VI.

THE BEHAVIOR OF THE MASSETER AND TEMPORAL MUSCLES

CHART 1. COMPARISON OF THE CHARACTERISTICS OF MYOGRAMS BETWEEN EXPERIMENTS

Subject #12 - J. S.

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Bursts	Multiple	Multiple	Multiple	Multiple	3 to 5	3 to 6
Amplitude	XX-XXX	XX-XXX	XX-XXX	XX-XXX	XX-XXX	XX-XXX
Duration	X-XX	XX-XXX	X-XX	XX-XXX	X	X
Noding	X-XX	X	XX	X	XX	XXX
Sustained low amplitude	0	0	0	0	0	Mass.
Rate of onset	XX	XX	XX	XX	XX	XX
Rate of ending	XX	XX	XX	XX	XX	XXX
Interim activity	R.Side-XXX L.Side-X	R.Side-XXX L.Side-XX	R.Side-XXX L.Side-X	Continuous Low Activity	R.Side-XXX L.Side-X	R.Side-XX L.Side-X

LEGEND: xxx = maximum, xx = moderate, x = minimum, 0 = no obvious change

CHART 2. COMPARISON OF ONSET OF ACTIVITY BETWEEN EXPERIMENTS

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Masseter first	5	7	4	2	0	0
Masseter and middle temporal first	1	1	0	0	1	0
Masseter and posterior temporal first	1	1	0	1	0	0
Middle temporal first	0	0	1	1	0	0
Middle and posterior temporal first	2	0	1	3	1	7
Posterior temporal first	0	0	2	1	0	3
All together (Synchrony)	3	3	4	4	10	2
TOTAL NUMBER OF CHEWING STROKES	12	12	12	12	12	12

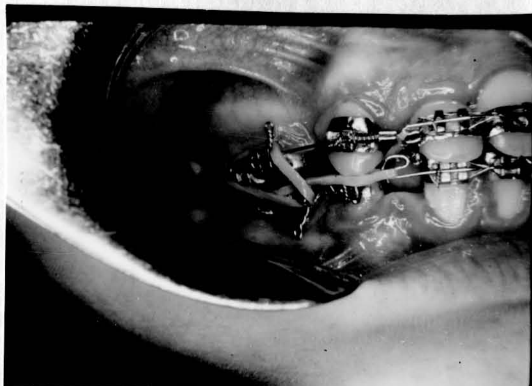
FINDINGS

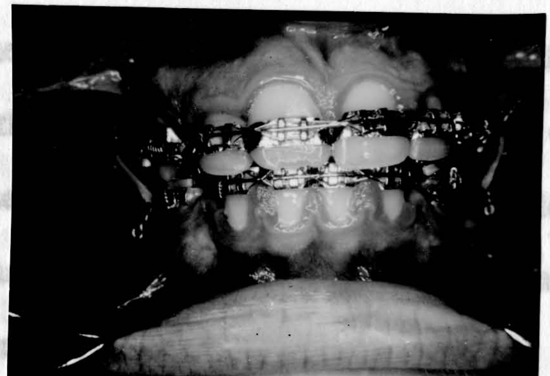
Subject #13 (A.S.) Age 11

Angle Classification of Malocclusion: Class II - Division I

Subject #13 (A.S.)

Malocclusion After Completion of Anchorage Preparation





Subject #13

Treatment:

A. Extraction of the four first premolars.

B. Appliance design. (See Methods and Materials page 35).

1. The maxillary archwire was a differential forces arch with three loops. Two loops were on either side of the right lateral incisor, and the other loop was mesial to the left canine tooth.

2. The mandibular archwire was a differential forces arch with only two loops, one mesial to each canine tooth.

3. The elastics used were intramaxillary elastics in the mandibular arch, and between the arches, elastics were worn in a Class II and a triangular fashion.

Chart i

Bursts: Experiments I and II showed very few bursts while Experiments III to VI showed an increase to a range of from two to five bursts.

Amplitude: Varied from moderate to maximum throughout all experiments.

Duration: Moderate throughout all experiments, except for a decrease to minimal in Experiments II and III.

Noding: Moderate in Experiments I and V and maximal in all other experiments.

Sustained low amplitude: Absent in Experiments I, III and IV, moderate in Experiment II, and moderate in the left masseter only in Experiments V and VI.

Rate of onset: Remained moderate throughout all experiments.

Rate of ending: Moderate for the first five experiments, but increasing to maximal in Experiment VI.

Interim activity: At first maximal, then became moderate in Experiments II and III, and then decreased to minimal in the remaining experiments.

Chart 2

The masseters, at first the predominant muscles in initiating activity, became less active in this role until Experiment V, when they initiated activity only once. In Experiment VI there was an increase in their role as initiators of activity. The temporals, at first almost

inactive in initiating activity, gradually became more active in this role, and in Experiment VI initiated activity almost one-half of the time. Synchronous onset of activity became more predominant from Experiment I to Experiment V when it was the most important group initiating chewing activity. The synchrony then decreased in frequency of occurrence in Experiment VI.

Conclusion

This subject displayed reasonably good adaptation to the orthodontic procedures.

THE BEHAVIOR OF THE MASSETER AND TEMPORAL MUSCLES

CHART 1. COMPARISON OF THE CHARACTERISTICS OF MYOGRAMS BETWEEN EXPERIMENT

Subject #13 - A. S.

Bursts	Exp. I 2 to 3	Exp. II 3	Exp. III 2 to 5	Exp. IV 2 to 5	Exp. V 2 to 5	Exp. V 3 to 5
Amplitude	XXX	XX	XXX	XXX	XX	XX
Duration	XX	X	X	XX	XX	XX
Noding	XX	XXX	XXX	XXX	XX	XXX
Sustained low amplitude	0	XX	0	0	L.Mass.- XX	L.Mass.- XX
Rate of onset	XX	XX	XX	XX	XX	XX
Rate of ending	XX	XX	XX	XX	XX	XXX
Interim activity	XXX	XX	XX	X	X	X

LEGEND: xxx = maximum, xx = moderate, x = minimum, 0 = no obvious change

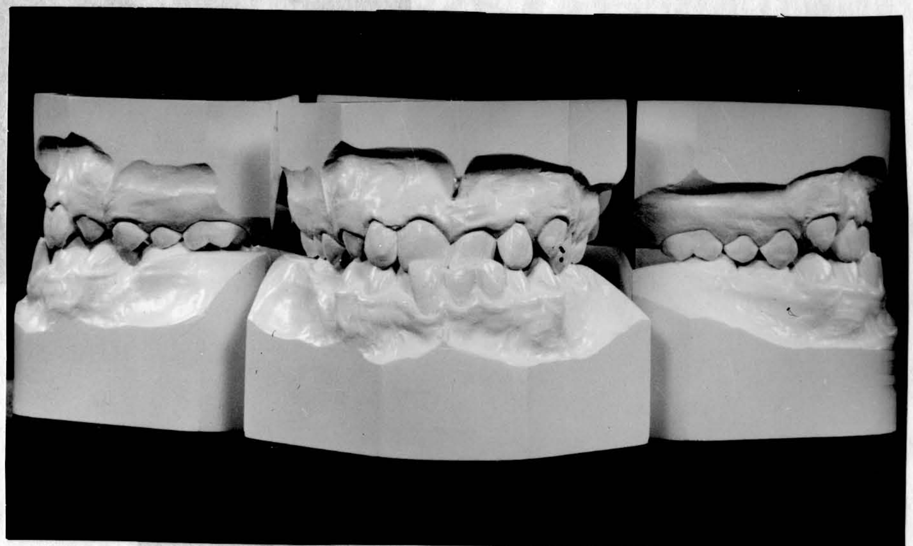
CHART 2. COMPARISON OF ONSET OF ACTIVITY BETWEEN EXPERIMENTS

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Masseter first	6	3	2	3	1	3
Masseter and middle temporal first	1	3	1	1	0	0
Masseter and posterior temporal first	1	0	1	0	0	0
Middle temporal first	0	0	1	0	0	1
Middle and posterior temporal first	1	1	1	2	3	4
Posterior temporal first	0	0	0	0	0	0
All together (Synchrony)	3	5	6	6	8	4
TOTAL NUMBER OF CHEWING STROKES	12	12	12	12	12	12

FINDINGS

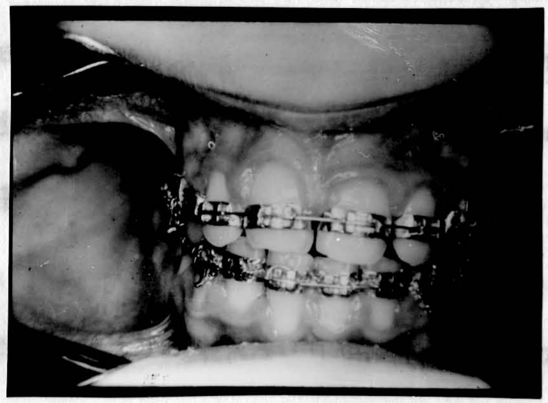
Subject #14 (D.T.) Age 12

Angle Classification of Malocclusion: Class I, Pseudo Class III



Subject #14 (D.T.)

Malocclusion After Completion of Anchorage Preparation



Subject #14

Treatment:

A. No teeth were extracted.

B. Appliance design. (See Methods and Materials page 35).

1. The maxillary archwire was a differential forces arch with only two loops, one mesial to each canine tooth.

2. The mandibular archwire was a straight (horizontal) arch with headgear attachments and headgear to the lower arch.

3. The elastics used were of type three mentioned in Methods and Materials (page 40). They were worn in a triangular fashion.

Chart 1

Bursts: Remained relatively the same (two to six) throughout all the experiments.

Amplitude: Ranged from moderate to minimum throughout all experiments.

Duration: Remained moderate throughout all experiments.

Noding: Remained maximal throughout all experiments except for a decrease to moderate in Experiment II.

Sustained low amplitude: Occurred in all experiments except Experiment IV.

Rate of onset: Moderate throughout all experiments.

Rate of ending: Moderate throughout all experiments.

Interim activity: Minimal in all experiments except Experiments III and IV, when it was moderate.

Chart 2

The masseters, which at first initiated activity one-half of the time, became less active in the role of initiating activity until, in Experiment VI, they only initiated activity once out of twelve times. Synchrony of all muscles, on the other hand, which at first played a very minor role in initiation of activity, became more predominant and in Experiment VI initiated activity one-half of the time. The temporals, also almost inactive in initiating activity at first, became more important in later experiments. In Experiment VI they were active in the onset of activity almost one-half of the time.

Conclusion

This subject adapted well to the orthodontic procedures.

THE BEHAVIOR OF THE MASSETER AND TEMPORAL MUSCLES

CHART 1. COMPARISON OF THE CHARACTERISTICS OF MYOGRAMS BETWEEN EXPERIMENTS

Subject #14 - D. T.

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Bursts	2 to 6	2 to 4	3 to 5	3 to 6	2 to 6	2 to 5
Amplitude	XX	X	XX	XX	X	X
Duration	XX	XX	XX	XX-XXX	XX	XX
Noding	XXX	XX	XXX	XXX	XXX	XXX
Sustained low amplitude	Mass. & Rt. Temp.	All Muscles	Rt. Mass. & Mid. Temp.	0	Mid. Temp. & Mass.	L. Mass.
Rate of onset	XX	XX	XX	XX	XX	XX
Rate of ending	XX	XX	XX	XX	XX	XX
Interim activity	X	X	XX	XX	X	X

LEGEND: xxx = maximum, xx = moderate, x = minimum, 0 = no obvious change

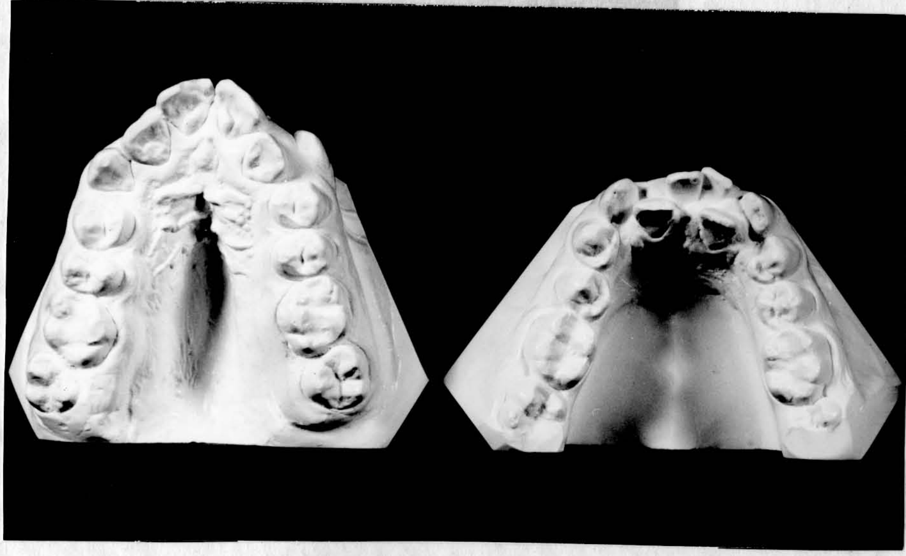
CHART 2. COMPARISON OF ONSET OF ACTIVITY BETWEEN EXPERIMENTS

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Masseter first	6	3	3	0	3	1
Masseter and middle temporal first	0	1	0	0	0	0
Masseter and posterior temporal first	1	0	1	0	0	0
Middle temporal first	1	0	0	0	0	0
Middle and posterior temporal first	2	2	3	2	6	4
Posterior temporal first	0	1	1	5	0	1
All together (Synchrony)	2	5	4	5	3	6
TOTAL NUMBER OF CHEWING STROKES	12	12	12	12	12	12

FINDINGS

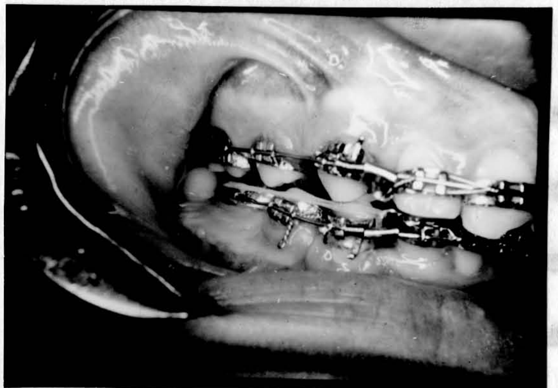
Subject #15 (J.V.) Age 14

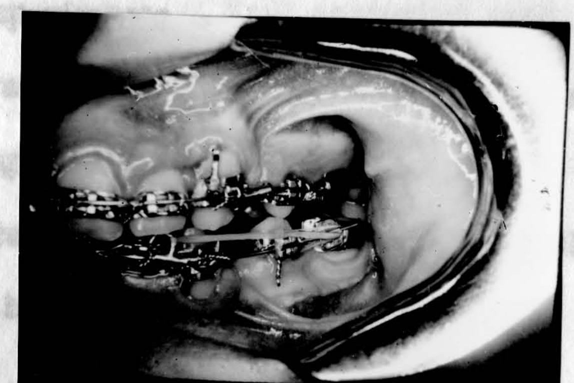
Angle Classification of Malocclusion: Class II - Division I



Subject #15 (J.V.)

Malocclusion After Completion of Anchorage Preparation





Subject #15

Treatment:

A. Extraction of the four first premolars.

B. Appliance design. (See Methods and Materials page 35).

1. The maxillary archwire was a typical differential forces arch.

2. The mandibular archwire was a differential forces arch with four loops. This is quite similar to the archwire in Figure 6 , except there is no loop between the central incisor teeth.

3. The elastics used were intramaxillary elastics in the mandibular arch, and between the arches, elastics were worn in a Class II and a triangular fashion.

Chart 1

Bursts: Moderate in Experiment I, but became "multi-bursts" in all of the following experiments.

Amplitude: Moderate in Experiments I and II and then became maximal in the remaining experiments.

Duration: Moderate in Experiments I and II, maximal in Experiments III and IV, and then between moderate and maximal in Experiments V and VI.

Noding: Moderate in Experiments I and II, then became maximal throughout the remaining experiments.

Sustained low amplitude: Minimal throughout all experiments.

Rate of onset: Moderate for the first five experiments and then became maximal in Experiment VI.

Rate of ending: Moderate throughout all experiments.

Interim activity: Minimal to moderate throughout all experiments.

Chart 2

Synchrony of all muscles, which initiated activity one-half of the time in the first two experiments, became more predominant in Experiments IV and V, when it initiated two-thirds of the chewing strokes. There was a marked decrease in synchronous initiation of the chewing stroke in Experiment VI. The masseters, at first somewhat active in initiating activity, failed to initiate activity in Experiments IV and V and initiated activity only once in Experiment VI. The middle and posterior temporals as a group, showed increased importance in initiating activity, doing so in one-half of the chewing strokes in Experiment VI.

Conclusion

This subject exhibited some difficulty in adapting to the orthodontic procedures.

THE BEHAVIOR OF THE MASSETER AND TEMPORAL MUSCLES

CHART 1. COMPARISON OF THE CHARACTERISTICS OF MYOGRAMS BETWEEN EXPERIMENTS

Subject #15 - J. V.

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Bursts	1 to 6	Multiple Sustained	Multiple "Searching	Multibursts	Multibursts	Multi-bursts
Amplitude	XX	XX	XX	XXX	XXX	XXX
Duration	XX	XX	XXX	XXX	XX-XXX	XX-XXX
Noding	XX	XX	XXX	XXX	XXX	XXX
Sustained low amplitude	Post. Temp. X	X	Post. Temp. X	Post. Temp. X	L. Mass. X	R. Mass. X
Rate of onset	XX	XX	XX	XX	XX	XXX
Rate of ending	XX	XX	XX	XX	XX	XX
Interim activity	X	XX	X	X-XX	X-XX	X-XX

LEGEND: xxx = maximum, xx = moderate, x = minimum, 0 = no obvious change

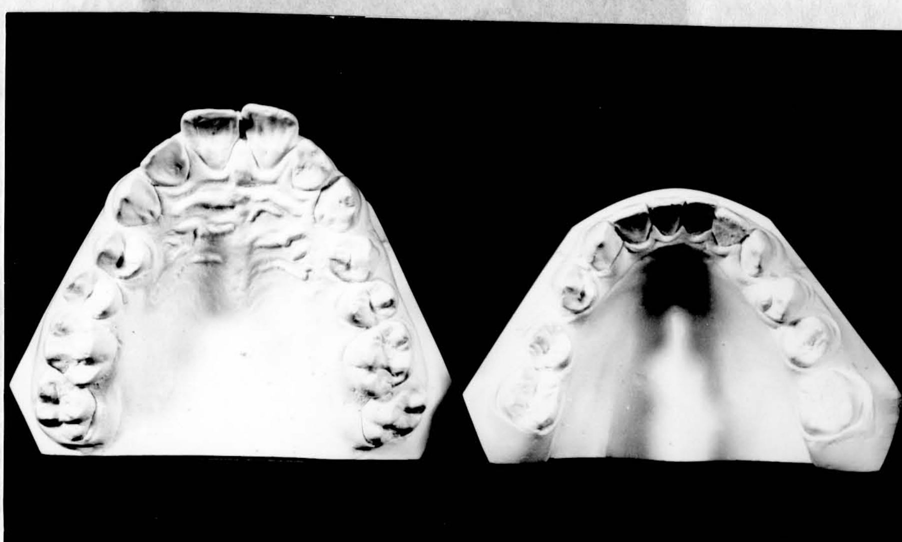
CHART 2. COMPARISON OF ONSET OF ACTIVITY BETWEEN EXPERIMENTS

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Masseter first	3	1	3	0	0	1
Masseter and middle temporal first	0	1	1	1	0	1
Masseter and posterior temporal first	0	0	0	0	0	0
Middle temporal first	1	0	1	0	0	0
Middle and posterior temporal first	1	4	3	1	4	6
Posterior temporal first	1	0	0	0	0	0
All together (Synchrony)	6	6	4	10	8	4
TOTAL NUMBER OF CHEWING STROKES	12	12	12	12	12	12

FINDINGS

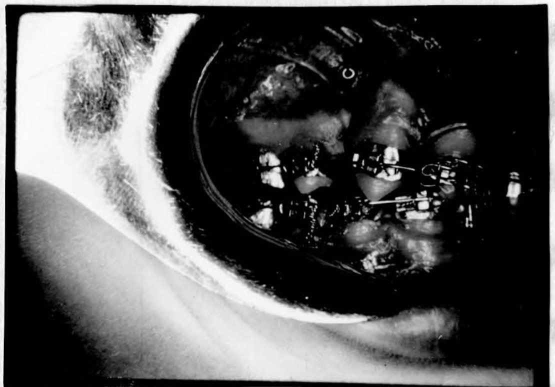
Subject #16 (J. W.) Age 12

Angle Classification of Malocclusion: Class II - Division I



Subject #16 (J. W.)

Malocclusion After Completion of Anchorage Preparation



Subject #16

Treatment:

A. Extraction of the maxillary first premolars (lower first permanent molars missing).

B. Appliance design. (See Methods and Materials page 35).

1. The maxillary archwire was a differential forces arch with only two loops, one mesial to each canine tooth.
2. The mandibular archwire was a straight (horizontal) arch with no attachments.
3. The elastics worn were of the three types mentioned in Methods and Materials (page 40). There were intramaxillary elastics in the mandibular arch, and between the arches elastics were worn in a Class II and a triangular fashion.

Chart 1

Bursts: Remained in the same range (two to six) throughout all experiments.

Amplitude: Remained minimal throughout all experiments.

Duration: Minimal at first, increased to maximal in Experiment IV and then decreased to moderate in Experiments V and VI.

Noding: Minimal in Experiments I and IV and moderate in all other experiments.

Sustained low amplitude: Showed moderate to maximal activity in Experiments I through V. In Experiment VI the sustained low amplitude became minimal.

Rate of onset: Minimal throughout all experiments.

Rate of ending: Minimal for the first four experiments and then became slightly increased in Experiments V and VI.

Interim activity: Remained minimal throughout all experiments except for an increase to moderate in Experiment VI.

Chart 2

The temporals were predominant in initiating the chewing stroke throughout the first five experiments. There was some synchronous initiation of activity at first, but this was reduced in Experiments IV and V. In experiment VI, synchrony of all muscles in initiating the chewing stroke occurred in nearly all of the chewing exercises.

Conclusion

This subject adapted well to the orthodontic procedures.

THE BEHAVIOR OF THE MASSETER AND TEMPORAL MUSCLES

CHART 1. COMPARISON OF THE CHARACTERISTICS OF MYOGRAMS BETWEEN EXPERIMENTS

Subject #16 - J. J.

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Bursts	2 to 6 Low Level	Multiple Sustained	2 to 6 Low Level	Low Sustained	2 to 6 Low Level	2 to 6 Low Level
Amplitude	X	X	X	X	X	X
Duration	X	X-XX	X	XXX	XX	XX
Noding	X	XX	XX	X	XX	XX
Sustained low amplitude	All Muscles XXX	XX	All Muscles XXX	All Muscles XXX Plus	Mass. & Mid. Temp. XX	[illegible]
Rate of onset	X	X	X	X	X	Searching
Rate of ending	X	X	X	X	X-XX	X-XX
Interim activity	X	XX	X	X	X	X

LEGEND: xxx = maximum, xx = moderate, x = minimum, 0 = no obvious change

CHART 2. COMPARISON OF ONSET OF ACTIVITY BETWEEN EXPERIMENTS

	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
Masseter first	1	2	0	1	0	1
Masseter and middle temporal first	1	0	1	0	1	0
Masseter and posterior temporal first	1	0	0	0	0	0
Middle temporal first	0	0	0	0	0	0
Middle and posterior temporal first	3	2	5	9	4	1
Posterior temporal first	3	4	0	0	5	1
All together (Synchrony)	3	4	6	2	2	9
TOTAL NUMBER OF CHEWING STROKES	12	12	12	12	12	12

C. Part II Combined Data from Sixteen Subjects

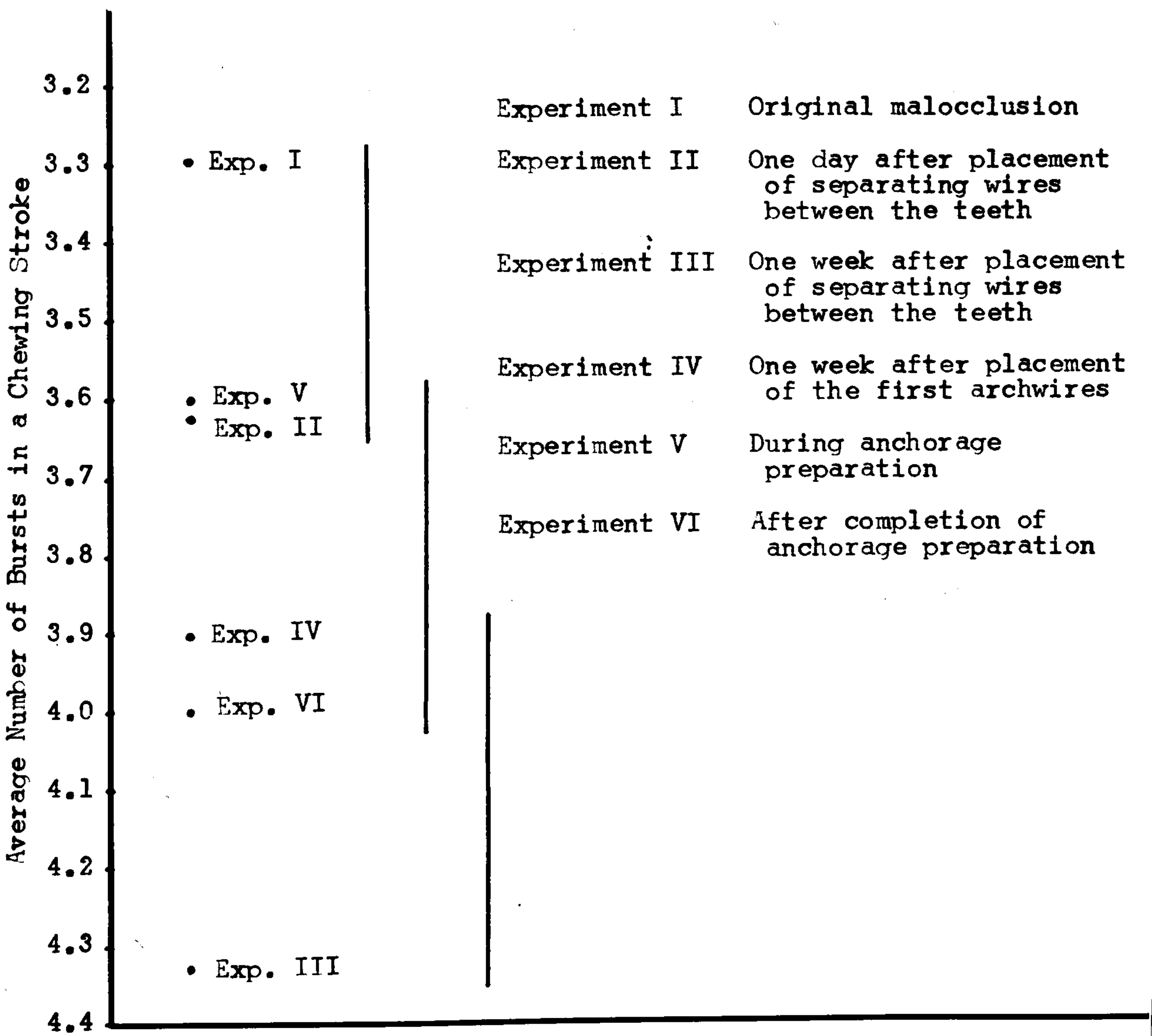
The Average Number of Bursts in a Chewing Stroke

From the total number of bursts in each of the chewing strokes for each of the three muscles being studied for all sixteen subjects in each of the six experiments, the average number of bursts in a chewing stroke was calculated for each of the six experiments. These averages were then submitted to Duncan's Multiple Range Test and the differences in the average number of bursts in a chewing stroke between the experiments were tested statistically at the .05 level of significance. Values found to be alike at this level of significance would have come from the same population ninety-five out of one hundred times. The vertical lines on Chart I, Part II, (page 148) represent the ranges of values within which the average number of bursts in a chewing stroke are alike at the .05 level of significance. Therefore, all average numbers of bursts in chewing strokes from the experiments connected by a vertical line in Chart I, Part II, are statistically similar at the .05 level of significance.

The average number of bursts in a chewing stroke in the original malocclusion (Experiment I) was the least of any of the six experiments.

CHART 1

THE AVERAGE NUMBER
OF BURSTS IN A CHEWING STROKE
(DUNCAN'S MULTIPLE RANGE TEST)



it was significantly less than the average number of bursts found one day after placement of separating wires between the teeth (Experiment II), one week after placement of the first archwires (Experiment IV), during anchorage preparation (Experiment V), and after the completion of anchorage preparation (Experiment VI). The average number of bursts found in all of the latter experiments was statistically alike.

The average number of bursts in a chewing stroke one week after the placement of separating wires between the teeth (Experiment III) was the greatest of all of the experiments. The results obtained from this experiment showed that the average number of bursts was significantly greater than that exhibited in all other experiments. This probably indicates that the subjects were having more difficulty masticating one week after the placement of separating wires between the teeth than at any other time this far in the orthodontic procedure.

Onset of Activity -- The Actual Number of Times a Muscle or Muscle Group Initiated the Chewing Cycle

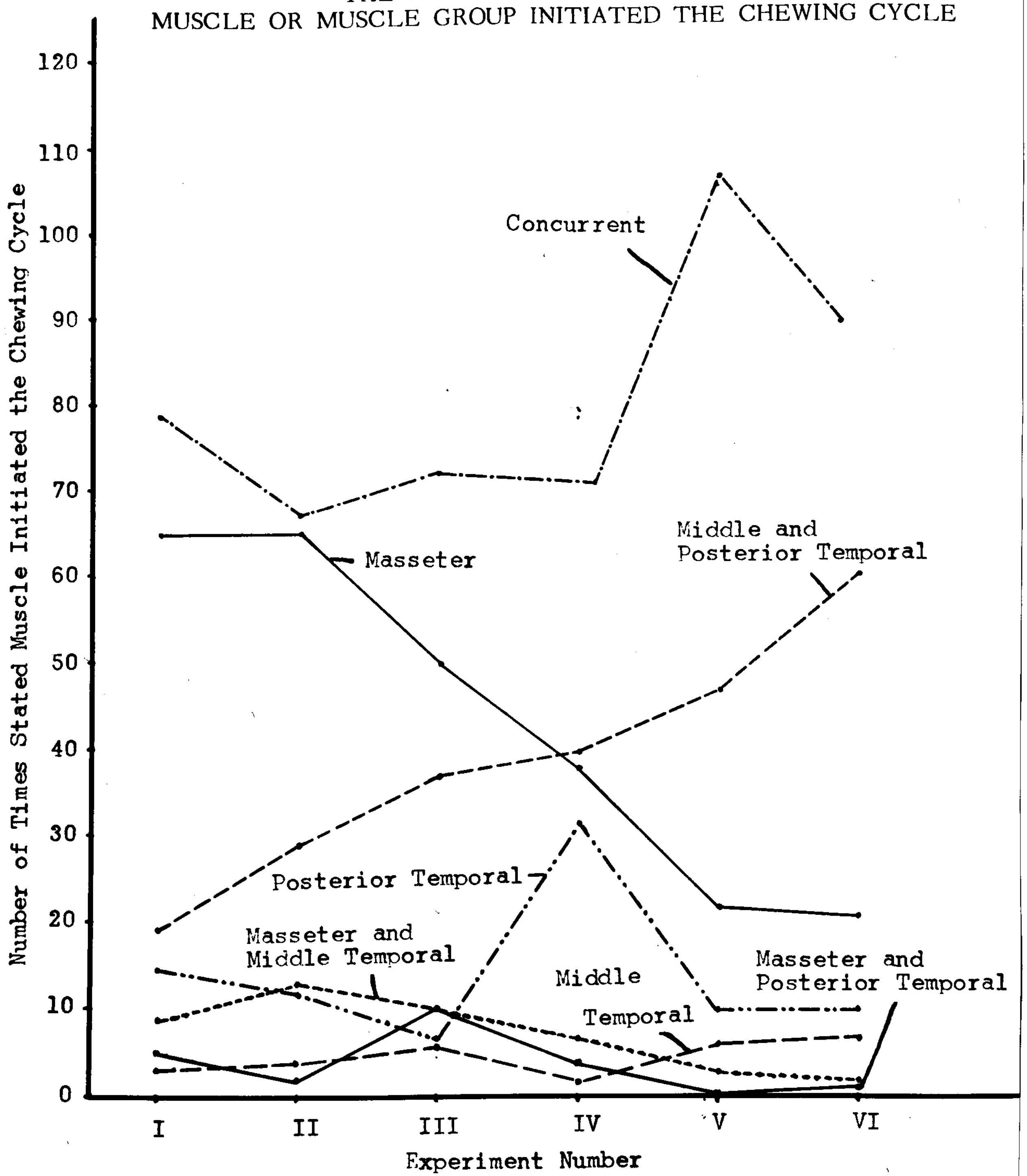
Among the various combinations of the three muscles being studied for onset of activity (chewing cycle), the combination most often noted in initiation of muscle activity in all six experiments was than when all

three muscles acted at the same time (concurrent). This is illustrated in Graph I (page 151). There was a large increase in the number of times with which concurrent muscle activity initiated the chewing cycle from one week after placement of the first archwires (Experiment IV - 36% of all chewing cycles) to during anchorage preparation (Experiment V - 55% of all chewing cycles). From during anchorage preparation (Experiment V) to after the completion of anchorage preparation (Experiment VI) there was a decrease in the number of times with which concurrent muscle activity initiated the chewing cycle to 47% of all chewing cycles. Concurrent muscle activity was noted in initiation of the chewing cycle more times after the completion of anchorage preparation (Experiment VI - 47%) than in the original malocclusion (Experiment I - 40%).

The second most frequently occurring muscle or muscle group to initiate the chewing cycle in the original malocclusion was the masseter muscle. These muscles showed their greatest activity in initiating the chewing cycle in the original malocclusion (Experiment I - 33% of all chewing cycles) with a progressive decrease in the number of times they initiated the chewing cycle through the completion of anchorage prepara-

GRAPH I

ONSET OF ACTIVITY
THE ACTUAL NUMBER OF TIMES A
MUSCLE OR MUSCLE GROUP INITIATED THE CHEWING CYCLE



tion (Experiment VI - 11% of all chewing cycles). After the completion of anchorage preparation they showed their least activity in initiating the chewing cycle and did so less often than the combination of the middle and posterior temporal muscles.

The combination of middle and posterior temporal muscles, acting together in initiating the chewing cycle, was third most active initiator in the original malocclusion (Experiment I - 10% of all chewing cycles). This combination showed a steady increase in the number of times it initiated the chewing cycle through the completion of anchorage preparation (Experiment VI - 32% of all chewing cycles). This combination was more active in initiating the chewing cycle at this time (Experiment VI) than the masseter muscles.

The posterior temporal muscles played a minor role in initiating the chewing cycle in all experiments with the exception of one week after placement of the first archwires (Experiment IV), when they participated in initiating the chewing cycle almost as frequently (17% of all chewing cycles) as the masseter muscles (20%) and the combination of the middle and posterior temporal muscles (21%).

The remainder of the muscles or muscle combinations studied in

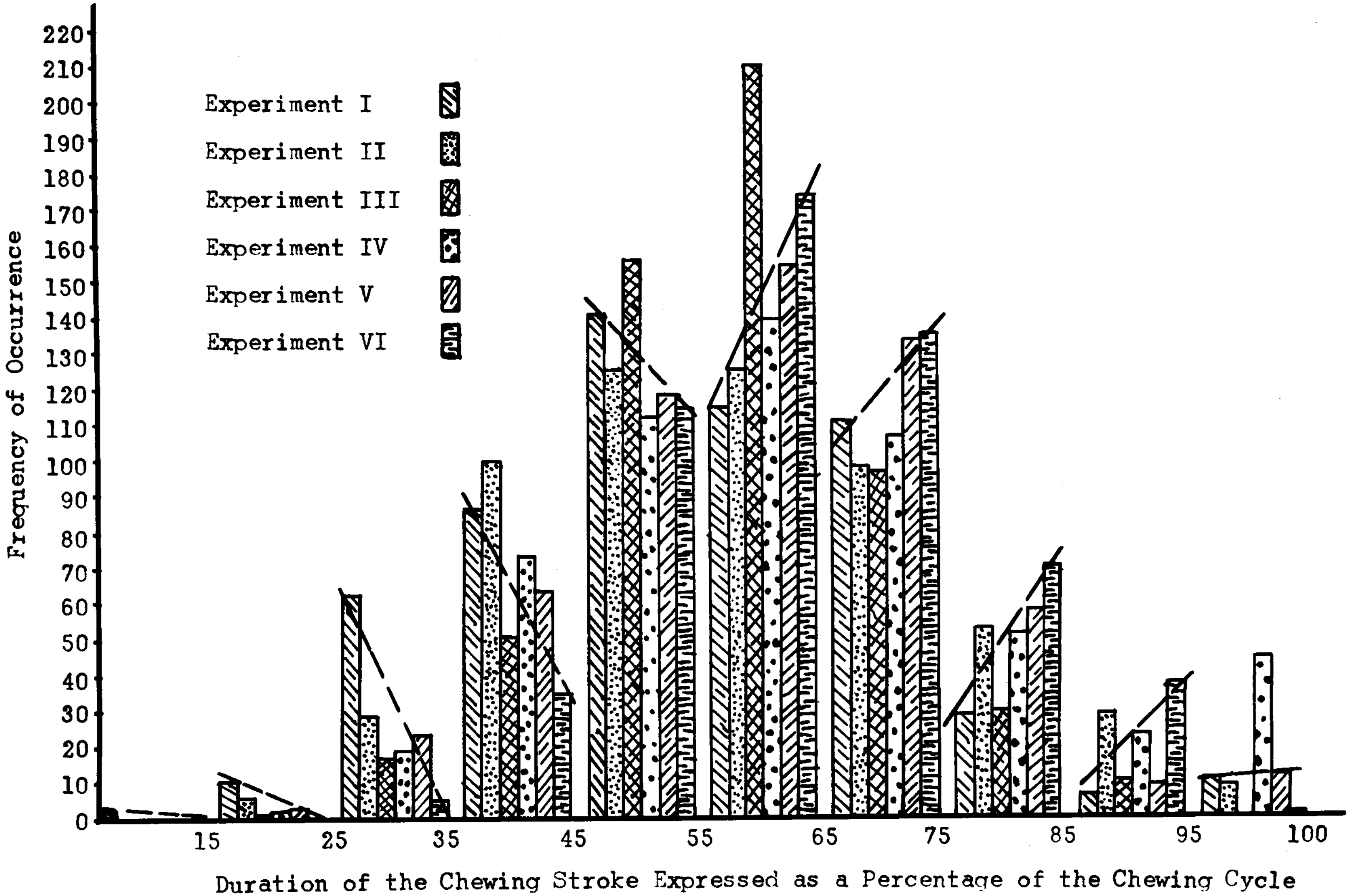
this experiment stayed relatively constant in the rate with which they initiated activity of the chewing cycle throughout the duration of this study. The tendency observed throughout the six experiments was one of decreasing participation on the part of the masseter muscles and of increasing participation on the part of the combination of middle and posterior temporal muscles in initiating the activity of the chewing cycle.

Duration of the Chewing Stroke Expressed as a Percentage of the Chewing Cycle

The changes that took place in the length of the chewing stroke (time necessary to complete the isotonic and isometric contractions of the muscles studied), when expressed as a percentage of the chewing cycle, are illustrated in Graph II (page 154). The rate of occurrence of the shorter chewing strokes (below fifty-five percent of the chewing cycle) decreased within each class interval (all experiments, from Experiment I through Experiment VI, in each percentage range) from the original malocclusion (Experiment I) through the completion of anchorage preparation (Experiment VI). Conversely, the rate of occurrence of the longer chewing strokes (at and above fifty-five percent of the chewing cycle) increased within each class interval (all experiments, from

GRAPH II

DURATION OF THE CHEWING STROKE EXPRESSED AS A PERCENTAGE OF THE CHEWING CYCLE



Experiment I through Experiment VI, in each percentage range) from the original malocclusion (Experiment I) through the completion of anchorage preparation (Experiment VI). Thus, the average duration of the chewing stroke, expressed as a percentage of the chewing cycle, became progressively longer from the original malocclusion (Experiment I - 53.93% through the completion of anchorage preparation (Experiment VI - 62.60%). This indicated that the subjects were actively closing their jaws (open to occlusion) for a progressively greater proportion of the chewing cycle as treatment progressed. This showed that the subjects were exhibiting more caution in mastication as treatment progressed.

To test the differences in the duration of the chewing stroke expressed as a percentage of the chewing cycle between the six experiments, the Chi-square test was applied to this data from all subjects in all experiments (see Methods and Materials page 49). The null hypothesis stated that the data were all drawn from one parent distribution, which would mean that there was no statistically significant difference in the duration of the chewing stroke expressed as a percentage of the chewing cycle between the experiments. The Chi-square value was calculated and found to be a highly significant difference

at the .001 probability level. This means that the null hypothesis is rejected and that there is a difference in the duration of the chewing stroke expressed as a percentage of the chewing cycle between the six experiments.

To further analyze the data, independent comparisons were made between the experiments to determine if there were differences in the chewing stroke expressed as a percentage of the chewing cycle between the various experiments. The chewing stroke expressed as a percentage of the chewing cycle displayed one day after the placement of separating wires between the teeth (Experiment II) was significantly greater than that shown in the original malocclusion (Experiment I). The chewing stroke expressed as a percentage of the chewing cycle exhibited one week after the placement of the first archwires (Experiment IV) was much greater than that seen one week after placement of separating wires between the teeth (Experiment III). The chewing stroke expressed as a percentage of the chewing cycle found at the completion of anchorage preparation (Experiment VI) was significantly greater than that displayed in the original malocclusion and during all previous periods of orthodontic treatment (Experiments I through V).

CHAPTER IV

DISCUSSION

A. General Considerations

Past studies on the reflex arc contribute much to the physiological literature on the behavior of muscles to stimuli. It is a well established fact that the sensory input from the environment governs, in a large measure, the motor output. In this study, it was sought to appraise the influence of changes in motor behavior of the masseter and temporal muscles when the sensory input from the highly arborized nerve endings in the periodontium were stimulated by axial changes of the teeth incident to orthodontic tooth movements. These axial changes altered the relations of the occlusal planes of the teeth to each other, and as a result of this there were alterations in the sensory input to the receptors located in the periodontal ligament, which in turn, it was believed, would modify the motor output.

The fibers of the mesencephalic root of the trigeminal nerve mediate primary proprioceptive impulses from the muscles of mastication and deep pressure impulses from the teeth. Some of these

afferent fibers which mediate sensory impulses from the area of the teeth are located in the periodontal ligament. The two main types are: those terminating in knob-like swellings (Lewinsky and Stewart), and those forming loops or rings around bundles of the principal fibers of the periodontal ligament (Lewinsky and Stewart). The afferent fibers from these specialized end-organs are myelinated, and they are confined to the peripheral part of the periodontal ligament. Still other afferent nerves (proprioceptors) mediating sensory impulses are located in the muscles of mastication (Herrick). The sensory nerve ending for proprioception located in the substance of the muscle is the neuromuscular spindle, which consists of small groups of attenuated muscle fibers around which the endings of the sensory nerve fibers are coiled in a corkscrew fashion. In addition to these, there are neurotendinous organs or organs of Golgi, located at the junction of muscles and tendons and in aponeuroses of muscles. These consist of small bundles of collagenic fibers. Finally, there are special proprioceptive nerve endings located in the capsule of the temporomandibular joint which mediate sensory impulses from the temporomandibular articulation.

The afferent proprioceptive impulses arising from the periodontal

ligament and muscles of mastication travel along special pathways to the mesencephalic root of the trigeminal nerve. They then go directly to the mesencephalic nucleus of the trigeminal nerve which is located in the lateral wall of the rostral portion of the fourth ventricle and in the lateral part of the gray matter surrounding the cerebral aqueduct. When the afferent impulses reach the mesencephalic nucleus, they follow one of two pathways. The first pathway is to form a reflex arc with the motor ganglion cells of the trigeminal motor nucleus, thus forming a two-neuron reflex arc of the masticatory muscles. The second pathway is to continue into the cerebellum where they spread out into a thin layer or sheet of fibers. They run through the base of the cerebellum and are lost in the region between the dentate and emboliform nuclei. The impulses that synapse to the motor nucleus of the trigeminal nerve are probably chiefly inhibitory, preventing damage to the teeth and gingivae.

The afferent fibers of the spinal nucleus of the trigeminal nerve mediate pain impulses from the periodontal ligament. The sensory receptors for pain, located in the periodontal ligament, are fine nerve fibers which pass to the deeper part of the periodontal ligament and

break up into fine arborizations without terminal organs. The afferent nerve fibers which conduct pain impulses from the periodontal ligament are principally unmyelinated, although there are a few small myelinated fibers also present. The pain impulses are conducted over these fibers to the spinal nucleus of the trigeminal nerve, which extends from the pons down to the upper-most cervical levels of the spinal cord. These impulses then ascend from the spinal cord level and are relayed to the cortex of the posterior central gyrus by fibers of the third order (third neuron from the spinal nucleus). The pain impulses, along with those of olfactory, auditory, visual, tactile and thermal, are correlated in the cerebral cortex. The motor cortex is then stimulated, and the musculature is activated through an efferent two-neuron pathway.

This study was undertaken as the fifth part of a longitudinal electromyographic study designed to investigate the influence of orthodontic manipulation of teeth on the motor behavior of the temporal and masseter muscles. Sixteen orthodontic subjects having dental malocclusions constituted the heterogeneous group from which the electromyographic data were taken. All subjects were free from any apparent temporomandibular joint disturbances or muscle spasms during

the course of treatment. Vicks cough drops were selected as the chewing medium to initiate a sensory input because of their uniform size and hardness. While the subject chewed on a cough drop, ipsilateral myograms were recorded of the masseter, middle, and posterior temporal muscles. The myograms of the first three chewing strokes of each chewing cycle were evaluated. The changes in motor behavior brought about by alterations in the sensory input to the receptors in the periodontal ligament were studied from before orthodontic treatment was begun until the completion of anchorage preparation (the uprighting and distal tipping of the mandibular posterior teeth to increase their ability to resist forward movements and to increase the occlusal vertical dimension).

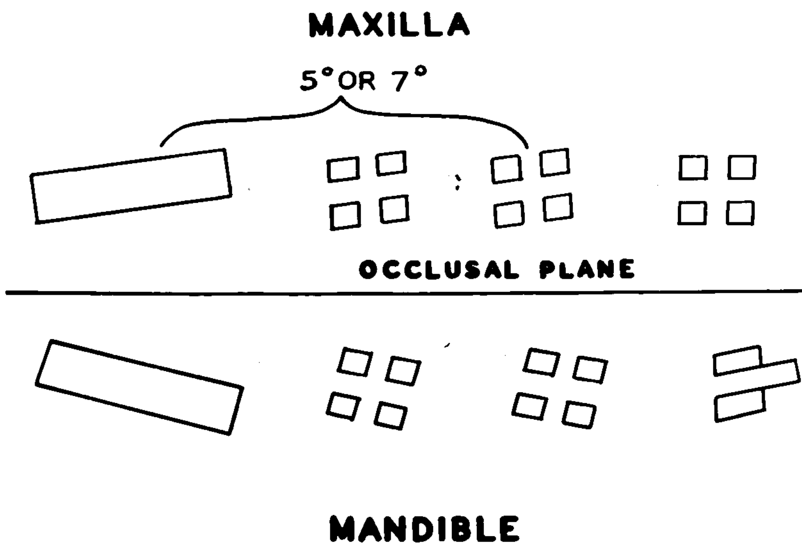
The previous investigators compared the electromyographic recordings from the original malocclusion with those obtained at certain times during the orthodontic treatment. The results of the study reported by Widen (1960), Part I, comparing the myograms of the original malocclusion with those taken one day after placement of separating wires between the teeth (Experiments I and II), showed that some change in the electromyographic behavior of muscles took place as a result of this phase of treatment. Asahino (1960) reported on Part II, comparing the

myograms of the original malocclusion with those taken one week after the placement of separating wires between the teeth (Experiments I and III). He found that the subjects, after initial changes in the electromyographic activity, resulting from these sensory input changes, seemingly adapted to the treatment procedure, and the records began to appear as they did before treatment was begun (Experiment I). Shanahan (1960), in Part III, comparing the myograms of the original malocclusion with those taken one week after the placement of the first archwires (Experiments I and IV), showed an increase in both the duration of the chewing stroke and the range of bursts of electrical activity. The temporal muscles, especially the posterior fibers, took a more active role in initiating activity of a chewing stroke at this time. When compared with the original malocclusion (Experiment I), the posterior temporal muscle initiated the chewing stroke more than twice as often one week after placement of archwires (Experiment IV). Zylinski (1961), Part IV, compared the myograms of the original malocclusion with those taken six to eight weeks after the placement of the first archwires (Experiments I and V). These myograms showed a small increase in the number of bursts, a definite increase in the duration of the chewing stroke

and a marked increase in occurrence of concurrent initiation of the chewing stroke. These three factors indicate that the musculature had adapted well to the stimuli from the orthodontic forces used at that time.

This part (Part V) of the study dealt with subjects who had an orthodontic appliance on their teeth for twelve to sixteen weeks. This fixed appliance consisted of small diameter, highly resilient archwires, latex elastics, and in some cases, extra-oral forces to effect tooth movements. At the completion of anchorage preparation (a clinical term meaning that the mandibular posterior teeth had been uprighted and tipped distally from their original positions), the relations of the mandibular posterior teeth to the maxillary posterior teeth had been altered from that present at the beginning of treatment. The maxillary posterior teeth, during this phase of treatment, had also been uprighted and tipped distally, but not as much as the mandibular posterior teeth (brackets on the maxillary teeth were angulated at five degrees to the horizontal, while brackets on the mandibular teeth were angulated at eight degrees to the horizontal). At this stage in treatment, the mandibular posterior teeth showed a greater distal relation to the maxillary posterior teeth than had been present at the beginning of

MESIO-DISTAL BRACKET ANGULATION



treatment. Those cases, in which extra-oral forces were applied to the mandibular arch (non-extraction cases), showed an even greater distal relation of the mandibular posterior teeth to the maxillary posterior teeth, because "traction" had not yet been placed on the maxillary teeth.

To determine which teeth were probably bearing the greatest occlusal forces during mastication, articulating (marking) paper was used to check which inclined planes were contacting in centric occlusion after the completion of anchorage preparation. In the extraction cases, the first permanent molars were the only teeth in occlusion in nearly all cases. In the non-extraction cases, the first permanent molars and either the second premolars alone or both the second premolars and the first premolars were in occlusion. This means that if these teeth exhibited tenderness and pain from masticatory pressures, the sensory input from the periodontal ligament of these teeth would most likely have a marked effect (inhibitory, protective) on the motor output of the temporal and masseter muscles.

In this study the electromyograms taken by Widen, Asahino, Shanahan, and Zylinski (original malocclusion, one day after placement of separating wires between the teeth, one week after placement of

separating wires between the teeth, one week after placement of the first archwires, and during anchorage preparation) were added to the electromyograms taken after the completion of anchorage preparation (Experiment VI). Some of the data obtained by the previous investigators were used and the corresponding data from after completion of anchorage preparation (Experiment VI) were added to their data. Those data were the characteristics of the myograms (bursts, amplitude, duration, noding, sustained low amplitude, rate of onset, rate of ending, and interim activity), onset of muscular activity of the chewing cycle, and duration of the chewing stroke expressed as a percentage of the chewing cycle. The electromyograms taken by the previous investigators were reappraised to obtain the actual number of bursts in each of the first three chewing strokes for each muscle studied in each of the experiments. Since they did not do this, it was done at this time to give a more exact picture of the changes in muscular behavior occurring during chewing activity.

The previous investigators had each compared their electromyograms with those taken from the original malocclusions for each of the sixteen subjects. It was felt that a more complete picture of the electromyographic changes could be obtained by comparing the findings of all six

experiments with each other. This would help in ascertaining trends of the electromyographic changes taking place during the six experiments from the original malocclusion through the completion of anchorage preparation. It would also help to detect any marked deviation from a trend that may have occurred at any of the stages in orthodontic treatment. In addition to this, it was believed that combining the data from all sixteen subjects in each of the experiments would help eliminate the variability that is seen in individual subjects. Therefore, in each of the six experiments, the data for each evaluation from all sixteen subjects were totaled.

The findings from the electromyographic recordings taken after completion of anchorage preparation (Experiment VI) were compared with the findings previously obtained by the other investigators (Widen, Experiments I and II; Asahino, Experiment III; Shanahan, Experiment IV; Zylinski, Experiment V). In addition to this, an overall appraisal of the electromyograms from the original malocclusion through the completion of anchorage preparation (Experiments I through VI) was made. The evaluations listed above were studied because it is known that orthodontic treatment alters the axial inclinations and the occlusal relations

of the inclined planes of the teeth. These axial changes in the teeth, it was believed by the author, and shown by Jarabak, Moyers, Perry and others, would alter the input to the sensory receptors (proprioception, touch and pain) in the periodontal ligament and since these regulate, in a large measure, the motor behavior of the temporal and masseter muscles, it was felt that changes in the electromyographic behavior of the muscles would occur. Thus, a comprehensive analysis of the electromyographic changes that had occurred from before orthodontic treatment was begun until after the completion of anchorage preparation is presented.

B. Interpretation and Evaluation of the Findings

The Average Number of Bursts in a Chewing Stroke

The number of bursts in a chewing stroke was studied to evaluate the amount of inhibition that occurred during chewing. Inhibition is expressed by "noding", a term in the experimental nomenclature which denotes diminished electrical activity or lack of electrical activity preceding and succeeding high amplitude activity. The high amplitude activity between "nodes" and the high amplitude activity occurring at the

beginning and end of a chewing stroke (before the first "node" and after the last "node") was called a burst. Thus, a large number of bursts is indicative of a large number of nodes, and this, in turn, indicates that a large amount of inhibition is taking place.

The number of bursts (see Chart I, page 148) in the original malocclusion (Experiment I) was the least for any of the periods of treatment through the completion of anchorage preparation. The number of bursts found after completion of anchorage preparation (Experiment VI) was similar to that found during most of the other phases of orthodontic treatment studied (one day after placement of separating wires between the teeth, Experiment II; one week after placement of the first archwires, Experiment IV; and during anchorage preparation, Experiment V). This would seem to indicate that during these phases of treatment the sensory input was not appreciably changed by the treatment. This indicates, therefore, that mastication or the behavior of these muscles during mastication, was not influenced appreciably by the orthodontic treatment for these particular experiments. The exception to this statement is given below when Experiment III is discussed.

On reappraisal of the data taken by the previous investigators it

was found that the myograms taken one week after placement of separating wires between the teeth (Experiment III) showed a greater number of bursts in a chewing stroke (a chewing stroke was considered to be that part of the chewing cycle during which isotonic and isometric contraction of the muscle were taking place) than at any other time during this study. This is a contradiction of the findings of Asahino, who evaluated the myograms in a different manner and found them to be similar to the original malocclusion. The greater number of bursts indicated that inhibition (as expressed by "noding") had occurred a greater number of times during this phase of the study. This increased inhibition demonstrated that the subjects were experiencing more difficulty masticating at this time than at any other time throughout the duration of this study. This very likely is due to the fact that the placement of separating wires between the teeth brought about two major environmental changes. First, the teeth were forcibly and suddenly moved in their alveoli as the separating wires were tightened. The second environmental change was the alteration of the relations of the inclined planes of the teeth. Let us consider first moving the teeth in their alveoli. In many cases the placement of separating wires

very likely caused the roots to be moved close to their bony sockets. This is predicated on the fact that most subjects complained of pain while the separating wires were being tightened. This was probably due to the stretching and breaking of the periodontal ligament fibers as well as the crushing of the structures within the periodontal space. In those instances in which the roots of the teeth came close to their alveoli it is very likely, as described by Reitan, that the contents of the periodontal space were crushed and the blood supply to the area was interrupted. As a result, the blood vessels were thrombosed, and the tissue became asphyxiated and eventually necrotic (Boyle). Since no blood could get into the area, the osteoclasts could not enter, and direct bone resorption could not take place. Undermining bone resorption, first described by Sandstedt in 1905, took place and the necrotic bone was finally removed.

Approximately one week after the placement of separating wires between the teeth, in those cases in which the tooth roots were moved close to their alveoli, undermining resorption and hyalinization of the periodontal ligament, as described by Reitan, were probably taking place. The looseness of the teeth, most likely partially a result of undermining

resorption, coupled with a lowered pain threshold brought about by the inflammatory condition of the periodontal ligament (Fulton), caused both the proprioceptive and pain nerve endings in the periodontal ligament to be more readily stimulated during mastication. The phenomenon of undermining resorption and the inflammatory condition of the periodontal ligament were not ascertained histologically in this study. Some of the clinical signs and symptoms of these conditions were present at this time (loose teeth, teeth extremely sensitive to touch and pressure). Thus, it was believed that these conditions were present one week after placement of separating wires between the teeth. The resultant of the two factors (looseness of the teeth and lowered pain threshold) was a greater amount of inhibition, both to protect the teeth and surrounding structures from damage (proprioceptive function), and to prevent the unpleasant experience of pain during mastication of the Vicks cough drops.

Placement of separating wires, it is believed, also changed the inclined plane relations of the teeth. This created areas of premature contact of the teeth. It is possible, and in the light of the electromyographical observations also probable, that this caused a change in the input to the sensory receptors in the periodontal ligament. The

proprioceptive nerve endings in the periodontal ligament were then stimulated to reflexly guide the mandible, through changes in the motor impulses to the masseter and temporal muscles, to the most non-traumatic path of closure.

Due to pain and the loose teeth, as well as teeth with premature occlusal interferences, the sensory input to the pain and proprioceptive receptors in the periodontal ligament modified the afferent impulses and caused muscular inhibition to take place during the masticating of Vicks cough drops. This inhibition of the jaw-closing muscles, according to Corbin (1940), served to control the force of the bite and thus prevented serious damage to the teeth and gums, as well as reflexly controlling mastication.

The Order of Onset of Muscular Activity of the Chewing Cycle

The onset of activity of the chewing cycle was studied to determine which muscle or muscle group (posterior temporal, middle temporal, masseter) was first to initiate the chewing cycle. Since the temporal and masseter muscles have different primary functions (positioning, power), it was believed that the changing occlusal relations of the teeth

during orthodontic treatment might possibly cause a change in the functional requirements of the mandibular musculature. For example, if more "power" is needed for the masticatory stroke, the masseter muscles will be the muscles "called upon" to provide the "power". Therefore, they would be expected to begin activity earlier than if their "power" function was not needed.

Initiation of the chewing cycle, identified by concurrent onset of muscle activity, occurred in 40% of the chewing cycles in the original malocclusion (Experiment I). Concurrent onset was when all three muscles being studied acted at the same time considering the ipsilateral side only. A chewing cycle was considered to be that period of time from the onset of one isotonic contraction of the muscle to the onset of the next isotonic contraction of that muscle, as determined from the electromyographic recording. This varied only slightly until during anchorage preparation (Experiment V) when concurrent activity initiated the chewing cycle 55% of the times studied (see Graph I, page 151). This meant that all of these muscles simultaneously initiated activity more often at this time than before orthodontic treatment was begun. After completion of anchorage preparation (Experiment VI) there was a

decrease in the number of times which concurrent activity initiated the chewing cycle to 47%. The sudden increase in the number of times concurrent activity of these muscles initiated the chewing cycle during anchorage preparation (Experiment V) was probably due to two factors. The first was that by this stage in orthodontic treatment the posterior teeth had been uprighted from their previously mesially inclined positions. (In almost all cases the mandibular posterior teeth exhibited an excessive mesial axial inclination before treatment had begun.) By uprighting the mandibular posterior teeth, the stimuli to the sensory receptors in the periodontal ligament which govern the proprioceptive reflex arc were altered. The uprighted teeth were more nearly parallel to the occlusal forces exerted upon them, with the result that these forces were distributed along the long axis of the teeth. Thus the sensory receptors interpret this as meaning that a more satisfactory axial inclination of the teeth had been attained. Second, the relation of the inclined planes of the maxillary and mandibular teeth to each other was improved in many cases at this phase of treatment (many of the original malocclusions exhibited cusp to cusp relations of the posterior teeth). These two factors, expressed by impulses from the sensory receptors in

the periodontal ligament and integrated by the mesencephalic root of the trigeminal nerve, reflexly controlled mastication by efferent impulses to the masseter and temporal muscles (Sherrington). This was expressed electromyographically by an increase in concurrent onset of muscular activity which seemed to indicate that there was a greater division of labor between the masseter and temporal muscles at this time (Experiment V) than at any other time during this study. The temporal muscles elevated and positioned the mandible. The masseter muscles provided the "power" to the masticatory stroke. More power could be used in the masticatory stroke at this time than previously because the more favorable axial inclinations of the teeth distributed the forces of mastication more equally over the teeth.

The decrease in number of times these muscles entered into activity simultaneously to initiate the chewing stroke from during anchorage preparation (Experiment V) to completion of anchorage preparation (Experiment VI) was probably the result of two factors. One was that the axial inclinations of the teeth were changed to a greater degree distally than when the muscles showed a greater division of labor. At the completion of anchorage preparation (Experiment VI) the

mandibular posterior teeth were tipped far more distally than at any other time in treatment and the occlusal forces were no longer distributed along similar axes of the teeth. The other factor was that the relation of the inclined planes of the maxillary and mandibular teeth to each other had been altered and as a result, areas of premature contact had been established. These two factors (abnormal axial inclination and premature contacts), it is believed, could change the sensory input from the receptors in the periodontal ligament. These could conceivably be the instrumental factors in the alterations in the impulses to the mesencephalic root of the trigeminal nerve, which in turn, would change the motor output of the masseter and temporal muscles.

Further breaking down of the records of these muscles revealed that the masseter muscle was the second to initiate activity of the chewing cycle (see Graph I, page 151) in the original malocclusion (33% of the time). The number of times which it initiated the chewing cycle decreased progressively in the succeeding experiments until it initiated the chewing cycle only 11% of the time after completion of the anchorage preparation (Experiment VI). In contrast to this, however, the middle and posterior temporal muscles showed a progressive increase

in the number of times which they initiated the activity of the chewing cycle. In the original malocclusion (Experiment I), the combination of the middle and posterior temporal muscles initiated activity 10% of the time. The number of times which they initiated the chewing cycle increased progressively in the succeeding experiments until they initiated the chewing cycle 32% of the time after completion of anchorage preparation (Experiment VI). The decrease in the number of times muscle activity was initiated by the masseter muscles and the concomitant increase in the number of times muscle activity was initiated by a combination of the posterior and middle temporal muscles from the original malocclusion (Experiment I) through the completion of anchorage preparation (Experiment VI) is most likely a result of the functions ascribed to the various muscles. Sicher described the masseter muscles as providing "power" for the masticatory stroke, while the temporal muscles acted as "positioners" of the mandible.

The stimuli to the sensory receptors in the periodontal ligament are altered through occlusion as the occlusal and axial relations of the teeth are changed by orthodontic treatment. It is very likely that masticating on hard substances (such as Vicks cough drops used in this

experiment) sufficiently changed the sensory input to bring about these muscle behaviors in activity onset. These pain impulses, mediated by the spinal nucleus of the trigeminal nerve and integrated with other afferent impulses in the cerebral cortex, caused the trigeminal motor nucleus to alter the efferent impulses to the masseter and temporal muscles. This was the manner in which the nervous system prevented the experience of additional painful stimuli. A similar inhibitory mechanism was operating over the two-neuron reflex arc mediated by the mesencephalic root of the trigeminal nerve. The inhibition mediated in the mesencephalic root was also a protective mechanism preventing damage to the teeth and their surrounding structures. Through the medium of these two pathways (pain and proprioceptive) the efferent stimuli to the masseter and temporal muscles were altered. This resulted in functional demand at the beginning of the chewing stroke for the temporal muscles to guid the mandible into a more comfortable path of closure, which caused the least pain and trauma to the teeth and supporting structures. Accompanying this was a decrease in the efferent stimuli to the masseter muscles since their "power" function was not needed at the beginning of the chewing stroke.

Initiation of the chewing cycle by the posterior temporal muscles occurred less than 8% of the time in each of the first three experiments (original malocclusion, one day after placement of separating wires between the teeth, and one week after placement of separating wires between the teeth). One week after placement of the first archwires (Experiment IV), however, the posterior temporal muscles initiated the chewing cycle 17% of the time. During anchorage preparation and after completion of anchorage preparation (Experiments V and VI) they initiated the chewing cycle only 5% of the time. The sudden increase in the number of times chewing activity was initiated by the posterior temporal muscles one week after placement of the first archwires (Experiment IV) may also be explained by the "positioning" function of the temporal muscles that expressed itself as expalined previously. An additional and very important factor here was one which applied to all subjects who had had teeth extracted (nine out of sixteen). Since the extraction of teeth had been performed just prior to the placement of the first archwires, the gingivae and alveolar processes of these subjects were still painful. This naturally resulted in the stimulation of the pain nerve endings in the gingivae as well as those located in the

periodontal ligaments. This caused an increased functional demand for more cautious positioning of the mandible by the posterior temporal muscles. The reflex control of mastication by the mesencephalic nucleus of the trigeminal nerve is well illustrated here as the reflex mechanism acts to carefully position the mandible to prevent pain from and trauma to the still unhealed extraction sites.

Duration of the Chewing Stroke Expressed as a Percentage of the Chewing Cycle

The duration of the chewing stroke expressed as a percentage of the chewing cycle was studied to determine if there was any change in the amount of the chewing cycle occupied by the chewing stroke (see Graph II, page 154). A chewing cycle was considered to be that period of time from the onset of one isotonic contraction of the muscle to the onset of the next isotonic contraction of that muscle, as determined from the electromyographic recording. A chewing stroke was considered to be that part of the chewing cycle during which isotonic and isometric contraction of the muscle were taking place. As mastication became more difficult the chewing stroke took longer, that is, it took more time to chew through the food bolus, or, as in this experiment, the

Vicks cough drop. This may be due to either or both of the following reasons. First, differences in the consistency of the chewing medium. It takes more time to chew through a hard object than a soft object. In this experiment this variable was eliminated by using the same chewing medium throughout all testing phases. The other reason for an increase in the time necessary to chew through a chewing medium is a result of changes in the ability of the masticatory apparatus to exert sufficient force to chew through the chewing medium. This is a result of the axial changes of the teeth during these phases of treatment. If teeth are tender to pressure the reflex mechanism or pain sensations will cause a more cautious, and therefore a longer, chewing stroke.

The data from the original malocclusion (Experiment I) showed that the length of the chewing stroke was shorter at this time than at any other time during this study. As treatment progressed (Experiments II through VI) there was a continuous increase in the length of the chewing stroke. After the completion of anchorage preparation (Experiment VI) the length of the chewing stroke was longer than at any other time during this study. The continuous increase in the portion of the chewing cycle occupied by the chewing stroke from the original

malocclusion (Experiment I) through the completion of anchorage preparation (Experiment VI) showed that it took longer to bite through the cough drop as treatment progressed. The significant factor governing these changes was that the subjects became more cautious in their chewing because the teeth and surrounding tissues were painful. This caution exhibited during mastication was expressed on the electromyogram by a longer chewing stroke.

Additional electromyographic recordings will be taken and analyzed by others to treatment completion in order to complete this longitudinal study. When this is done a more complete picture of the changes in the sensory input to the receptors in the periodontal ligament and the resultant changes in the motor behavior of the temporal and masseter muscles brought abuout by orthodontic treatment will be available. Analyzing the electromyographic changes throughout the entire treatment period will give a complete picture of the effects of orthodontic treatment upon the behavior of the temporal and masseter muscles.

CHAPTER V

SUMMARY AND CONCLUSIONS

A. Summary

This study is the fifth part of a longitudinal electromyographical investigation comparing the changes in the behavior of the masseter and temporal muscles before, during and after orthodontic treatment. The orthodontic methods used in this therapy are distinguished from other orthodontic procedures in that light forces generated from highly resilient, small diameter archwires and latex elastics were used. Sixteen subjects presenting varying types of malocclusions (three neutroclusion, thirteen distoclusion) constituted the heterogeneous experimental group. Only the first three chewing cycles of each of the chewing exercises on the ipsilateral side were studied and evaluated for certain characteristics. The chewing medium used was Vicks cough drops.

This part of the study concerned itself with the electromyographic readings taken after the completion of anchorage preparation (the uprighting and distal tipping of the mandibular posterior teeth to

increase their ability to resist forward movements and to increase the occlusal vertical dimension). The findings from this part of the study (after the completion of anchorage preparation) were compared with the findings previously obtained by the earlier investigators in this longitudinal study. Electromyographic recordings were taken this far in the longitudinal study during the following periods in the treatment of these malocclusions:

Experiment I	Original malocclusion.
Experiment II	One day after placement of separating wires between the teeth.
Experiment III	One week after placement of separating wires between the teeth.
Experiment IV	One week after placement of the first archwires.
Experiment V	During anchorage preparation.
Experiment VI	After completion of anchorage preparation.

The comparison between the present findings and those obtained previously was made in order to analyze the changes in muscle response (as detected electromyographically) to altered sensory input that had

taken place this far in the orthodontic procedure.

Additional electromyographic recordings will be taken and analyzed (by others) to treatment completion in order to complete this longitudinal study.

B. Conclusions

1. The greatest amount of inhibition, and therefore probably the greatest amount of difficulty and pain during mastication, that was found in this study occurred one week after the placement of separating wires between the teeth.

2. The decrease observed in the number of times which concurrent muscle activity initiated the chewing cycle from during anchorage preparation to the completion of anchorage preparation was attributed to the distal tipping of the previously uprighted mandibular posterior teeth.

3. From the original malocclusion through the completion of anchorage preparation the tendency exhibited in initiation of activity of the chewing cycle was one of decreasing participation on the part of the masseter muscles and of increasing participation on the part of the combination of middle and posterior temporal muscles. This suggested

a change in the division of labor between these muscles during orthodontic treatment.

4. The duration of the chewing stroke, expressed as a percentage of the chewing cycle, became progressively longer from the original malocclusion through the completion of anchorage preparation. This was partially attributed to painful experiences during mastication.

5. The number of bursts in a chewing stroke is a reasonably good indicator of the number of times inhibition has taken place in the muscle being studied.

BIBLIOGRAPHY

Ahlgren, J. An Electromyographic Investigation of the Response to Activator (Andressen) Therapy. American Journal of Orthodontics, 46: 57, 1960 (Abstract).

Allen, W. F. Application of the Marchi Method to the Study of the Radix Mesencephalica Trigemini in the Guinea Pig. Journal of Comparative Neurology, 30: 169-216, 1919.

Asahino, S. N. M. S. thesis, Loyola University School of Dentistry. Chicago, 1960.

Batson, H. C. An Introduction to Statistics in the Medical Sciences, Burgess Publishing Company, Minneapolis, 1956.

Begg, P. R. Light Arch Wire Technique. American Journal of Orthodontics, 47: 30-48, 1961.

Bernick, S. Innervation of Teeth and Periodontium after Enzymatic Removal of Collagenous Elements. Oral Surgery, Oral Medicine and Oral Pathology, 10: 323-332, 1957.

Bjorg, H. Electromyographic Analysis of the Temporal and Masseter Muscles During Function of Different Orthodontic Appliances. American Journal of Orthodontics, 46: 709, 1960 (Abstract).

Boyle, P. E. Kronfeld's Histopathology of the Teeth and Their Surrounding Structures. Lea and Febiger, Philadelphia, Fourth Edition, 1955.

Bradlaw, R. The Innervation of Teeth. Royal Society of Medicine Proceedings (Sect. Odont.), 29: 507-518, 1936.

Brashear, A. D. The Innervation of the Teeth, An Analysis of Nerve Fiber Components of the Pulp and Periodontal Tissues and Their Probable Significance. Journal of Comparative Neurology, 64: 169-185, 1936.

Brill, N. Reflexes, Registrations, and Prosthetic Therapy. Journal of Prosthetic Dentistry, 7: 341-360, 1957.

Buchanan, F. The Electrical Response of Muscle to Voluntary, Reflex, and Artificial Stimulation. Quarterly Journal of Experimental Physiology, I: 211-242, 1908.

Carlsoo, S. Nervous Co-ordination and Mechanical Function of the Mandibular Elevators, An Electromyographical Study of the Activity, and an Anatomic Analysis of the Mechanics of the Muscles. Acta Odontologica Scandinavia, 10: Supp. 11, Stockholm, 1952.

Cooper, S., Daniel, P. M., and Whitteridge, D. Nerve Impulses in the Brainstem of the Goat, Short Latency Responses Obtained by Stretching the Extrinsic Eye Muscles and the Jaw Muscles. Journal of Physiology 120: 471-490, 1953.

Corbin, K. B. Observations of the Peripheral Distribution of Fibers Arising in the Mesencephalic Nucleus of the Fifth Cranial Nerve. Journal of Comparative Neurology, 73: 153-177, 1940.

Corbin, K. B., and Harrison, F. Function of Mesencephalic Root of Fifth Cranial Nerve. Journal of Neurophysiology, 3: 423-435, 1940.

Creed, R. S., Denny-Brown, D., Eccles, J. C., Liddell, E. G. T., and Sherrington, C. S. Reflex Activity of the Spinal Cord, Oxford Press, 1932.

Denny-Brown, D. Interpretation of the Electromyogram. Archives of Neurology and Psychiatry, 61: 99-128, 1949.

Dependorff, L. Nerven Verteilung in der Zahnwurzelhaut des Menschens. Deutsch Monatschrift, Zahnheilkunde, 31: 853-864, 1913.

Fulton, J. F. Muscular Contraction and the Reflex Control of Movement. The Williams and Wilkins Company, Baltimore, 1926.

Fulton, J. F. Textbook of Physiology. 17th Edition, W. B. Saunders Company, Philadelphia and London , 1955.

Greenfield, B. E., and Timms, D. J. Electromyographic Studies in Orthodontics and Maxillo-Facial Surgery. International Dental Journal, 7: 572, 1957 (Abstract).

Greenfield, B. E. and Wyke, B. D. Electromyographic Study of Some Muscles of Mastication. British Dental Journal, 100: 129-143, 1956.

Hardy, J. D., Wolff, H. G., and Goodell, H. Pain Sensations and Reaction. Williams and Wilkins Company, 1952.

Herrick, C. J. The Proprioceptive Nervous System. Journal of Nervous and Mental Diseases, 106: 355-358, 1947.

Hickey, J. C., Woelfel, J. B., and Rinear, L. L. Influence of Overlapping Electrical Fields on the Interpretation of Electromyogram. Journal of Prosthetic Dentistry, 7: 273-281, 1957.

Jarabak, J. R. Adaptability of the Temporal and Masseter Muscles: An Electromyographical Study. Angle Orthodontist, 24: 193-213, 1954.

Jarabak, J. R. Electromyographical Analysis of Muscular and Temporomandibular Joint Disturbance Due to Imbalances in Occlusion. Angle Orthodontist, 26: 170-190, 1956.

Jarabak, J. R. Electromyographical Analysis of Muscular Behavior in Mandibular Movements from Rest Position. Journal of Prosthetic Dentistry, 7: 682-710, 1957.

Jarabak, J. R. Development of a Treatment Plan in the Light of One's Concept of Treatment Objectives. American Journal of Orthodontics, 46: 481-514, 1960.

Kadanoff, D. Nerven und Nerven Verteilung in der Zahnwurzelhaut Verhandlung. Physical Medicine, 54: 27-32, 1929.

Karau, R. E. Electromyographical Comparison of Temporal and Masseter Muscles of Orthodontically Treated and Untreated Malocclusions of the Teeth. American Journal of Orthodontics, 42: 792, 1956 (Abstract).

Latif, A. Electromyographic Study of Temporal Muscle in Normal Persons during Selected Positions and Movements of the Mandible. American Journal of Orthodontics, 43: 577-591, 1957.

Lewinsky, W. and Stewart, D. The Innervation of the Periodontal Membrane. Journal of Anatomy, 71: 98-102, 1936.

Lewinsky, W. and Stewart, D. The Innervation of the Periodontal Membrane of the Cat, with Some Observations on the Function of the End-Organs Found in that Structure. Journal of Anatomy, 71: 232-235, 1937.

Lewinsky, W. and Stewart, D. The Innervation of the Human Gum. Journal of Anatomy, 72: 531-534, 1938.

Licht, S. Electrodiagnosis and Electromyography. Volume One of the Physical Science Library.

Liebman, F. M., and Cosenza, F. An Evaluation of Electromyography in the Study of the Etiology of Malocclusion. Journal of Prosthetic Dentistry, 10: 1065-1077, 1960.

Lucas, K. The "All or None" Contraction of the Amphibian Skeletal Muscle Fiber. Journal of Physiology, 38: 113-133, 1909.

MacDougall, J. D. B., and Andrew, B. L. An Electromyographical Study of the Temporalis and Masseter Muscles. Journal of Anatomy, 87, Part I: 37-46, 1953.

Moyers, R. E. Temporomandibular Muscle Contraction Patterns in Angle Class II, Division I Malocclusions. American Journal of Orthodontics, 35: 837-857, 1949.

Moyers, R. E. Electromyographic Analysis of Certain Muscles Involved in Temporomandibular Movement. American Journal of Orthodontics, 36: 481-515, 1950.

Pearson, A. A. The Development and Connections of the Mesencephalic Root of the Trigeminal Nerve in Man. Journal of Comparative Neurology, 90: 1-46, 1949.

Pearson, A. A. Further Observations on the Mesencephalic Root of the Trigeminal Nerve. Journal of Comparative Neurology, 91: 147-194, 1949.

Perry, H. T. Jr., and Harris, S. C. Role of the Neuromuscular System in Functional Activity of the Mandible. Journal of the American Dental Association, 48: 665-673, 1954.

Perry, H. T., Jr., Functional Electromyography of Temporal and Masseter Muscles in Class II Division I Malocclusion and Excellent Occlusion. Angle Orthodontist, 25: 49-58, 1955.

Perry, H. T., Jr., Implications of Myographic Research. Angle Orthodontist, 25: 179-188, 1955.

Pfaffman, C. Different Impulses from Teeth due to Pressure and Noxious Stimulation. Journal of Physiology, 97: 207-219, 1939.

Porritt, J. E. An Electromyographic Study Involving Occlusal Interferences. American Journal of Orthodontics, 46: 57-58, 1960 (Abstract).

Pritchard, E. A. B. Central Mechanism of the Reflex Arc. Brain, 53: 431-448, 1931.

Pruzansky, S. Application of Electromyograph to Dental Research. Journal of the American Dental Association, 44: 49-68, 1952.

Rapp, R., Kirstine, W. D., and Avery, J. K. Study of Neural Endings in the Human Gingiva and Periodontal Membrane. Journal Canadian Dental Association, 23: 637-643, 1957.

Shanahan, R. J. M. S. thesis, Loyola University School of Dentistry, Chicago, 1960.

Sherrington, C. S. Integrative Action of the Nervous System. New Haven, Connecticut, Yale University Press, 1906.

Sherrington, C. S. Reflexes Elicitable in the Cat from Pinna Vibrissa and Jaws. Journal of Physiology, 51: 404-431, 1917.

Sicher, H. Positions and Movements of the Mandible. Journal of the American Dental Association 48: 620-625, 1954.

Sicher, H. Oral Anatomy, St. Louis, C. V. Mosby Company, Third Edition, 1960.

Stewart, D. Some Aspects of the Innervation of the Teeth. Proceedings of the Royal Society of Medicine, 20, Part 3: 1675-1686, 1927.

Stoner, M. M. Force Control in Clinical Practice. American Journal of Orthodontics, 46: 163-186, 1960.

Storey, E., and Smith, R. Force in Orthodontics and Its Relation to Tooth Movement. Australian Dental Journal, 56: 11, 1952.

Sutton, D. L. Electrode Comparison for Electromyographic Procedures. Journal of Dental Research, 39: 678-679, 1960 (Abstract).

Szentagothai, J. Anatomical Considerations of Monosynaptic Reflex Arcs. Journal of Neurophysiology 11: 445-454, 1948.

Urban, L. B., Beisler, E. H., and Skillen, W. G. Tissue Disturbances Caused by Mechanical Separation of the Teeth of the Dog. Journal of the American Dental Association, 18: 1943-1954, 1931.

Van der Sprenkel, H. B. Microscopical Investigation of the Innervation of the Tooth and its Surroundings. Journal of Anatomy, 70: 233-241, 1936.

Wentz, F. M., Jarabak, J. R. and Orban, B. Experimental Occlusal Trauma Initiating Cuspal Interference. Journal of Periodontology, 29: 117-127, 1958.

Widen, B. A. M. S. thesis, Loyola University School of Dentistry, Chicago, 1960.

Zwemer, T. An Electromyographic Study of the Temporal and Masseter Muscles in Cleft-palate Patients. M.S.D. Thesis, Northwestern University Dental School, 1954, also Angle Orthodontist 25: 99-112, 1955.

APPROVAL SHEET

The thesis submitted by Dr. Thomas W. Fleming has been read and approved by four members of the Departments of Anatomy and Oral Anatomy.

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.

5-19-61
DATE

Joseph R. Jasabek
Signature of Adviser