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A Comparative Study on the Ability of Orthodontic Patients to Distinguish Differences in Forces Applied to the Maxillary Canine Tooth Before and During Prolonged Orthodontic Treatment

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A COMPARATIVE STUDY ON THE ABILITY OF ORTHODONTIC PATIENTS TO DISTINGUISH DIFFERENCES IN FORCES APPLIED TO THE MAXILLARY CANINE TOOTH BEFORE AND DURING PROLONGED ORTHODONTIC TREATMENT

BY

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TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION AND STATEMENT OF THE PROBLEM	1
II.	REVIEW OF THE LITERATURE	2
	Weber's Law Fechner's Law The Periodontal Ligament: Innervation Function	
III.	METHODS AND MATERIALS	29
	Introduction Force Producing Instrument Experimental Procedure Miscellaneous	
IV.	FINDINGS	40
V.	DISCUSSION	63
VI.	SUMMARY AND CONCLUSION	69
APPENDICES I AND II	. . . .	71
BIBLIOGRAPHY	. . . .	73

LIST OF ILLUSTRATIONS

FIGURE		PAGE
1	Torque Wrenches	31
2	Orthodontics Chair with Torque Wrench Assembly	35
3	Mean Weber Ratios Plotted Against Measurement Periods For the 100 Gram Force	52
4	Mean Weber Ratios Plotted Against Measurement Periods For the 200 Gram Force	53
5	Mean Weber Ratios Plotted Against Measurement Periods For the 500 Gram Force	54
6	Mean Weber Ratios Plotted Against Measurement Periods For the 1000 Gram Force	55
7	Mean Weber Ratios Plotted Against Measurement Periods For the 1500 Gram Force	56
8	Mean Weber Ratios Plotted Against Measurement Periods For the 2000 Gram Force	57
9	Semi-Logarithmic Graph of Mean Differential Thresholds Plotted Against Forces Applied 90° to the Long Axis of the Maxillary Canine	59
10	Semi-Logarithmic Graph of Mean Differential Thresholds Plotted Against Forces Applied Along the Long Axis of the Maxillary Canine	60
11	Logarithmic-Logarithmic Graph of Mean Differential Thresholds Plotted Against Forces Applied 90° to the Long Axis of the Maxillary Canine	61
12	Logarithmic-Logarithmic Graph of Mean Differential Thresholds Plotted Against Forces Applied Along the Long Axis of the Maxillary Canine	62

LIST OF TABLES

TABLE		PAGE
1	Mean Weber Ratios Determined for Extraction, Non-Extraction and Combination Groups at First, Second and Third Measurement Periods	41
2	Mean Weber Ratios Determined for Extraction, Non-Extraction and Combination Groups at Fourth Measurement Period	42
3	Statistical Comparisons of Mean Weber Ratios Between Various Force Application for Fourth Measurements	45
4	Statistical Comparisons of Mean Weber Ratios Between Non-Extraction and Extraction Cases At Fourth Measurement	47
5	Statistical Comparisons of Mean Weber Ratios For Dusza's Third Measurements (Four Days After Appliance Insertion) Versus Fourth Measurements (Approximately One Year After Appliance Insertion)	48
6	Statistical Comparisons of Mean Weber Ratios For Dusza's First Measurements (Four Days After Appliance Insertion) Versus Fourth Measurements (Approximately One Year After Appliance Insertion) . .	50

CHAPTER I

INTRODUCTION AND STATEMENT OF THE PROBLEM

Over the years investigators have been aware of the presence of proprioceptive end organs in the periodontal ligament of human teeth. Until recently the study of these receptors has been performed on mammalian laboratory animals by stimulating the teeth and observing the sensory output from the periodontal ligament measured along some aspect of the trigeminal nerve.

Recent clinical studies have been reported dealing with a subject's ability to consciously discriminate between various sensory stimuli applied to the teeth. During orthodontic treatment teeth are subjected to varying amounts of force in order to reposition the teeth into a more stable, functional and aesthetic configuration.

The purpose of this investigation is to do a comparative study on the ability of orthodontic patients to distinguish differences in forces applied to the maxillary canine tooth, before and during prolonged orthodontic treatment. The findings of this study will also be applied to the Weber-Fechner Law in an effort to test its validity.

CHAPTER II

REVIEW OF THE LITERATURE

1. Weber's Law:

Bouguer in 1760, (from Hecht 1924) made observations of his ability to discern differences in light intensity. He performed his experiment and tested this ability by casting shadows of one candle upon a screen which was simultaneously illuminated by another candle. One candle was moved away from the screen until the shadow it projected was only first noticeable against the background of the screen. This first noticeable difference can thus be expressed as the ratio between these two illuminations. Bouguer discovered that this ratio of the two intensities at the point on the screen was 1/64. In other words, the shadow was first noticeable when the far candle was eight times as far from the screen as the near candle. He found that this ratio did not change when the brightness of the candles was varied or for any pair of distances at which the two candles were adjusted.

Subsequent studies by different investigators found the fraction to vary. Fechner and Volkmann, in 1858, as described by Boring (1942) repeated the experiment by Bouguer and found the fraction to be 1/100; while Argo (1850) reported a fraction of 1/133.

Depending upon conditions, Mason, in 1845, (from Boring 1942) found that the sensitivity varied from 1/50 to 1/120.

Helmholtz, in 1845, (from Boring 1942) showed the fraction to vary from 1/167 to 1/117.

Boring (1950) wrote that Weber (1834) discovered for the sense of touch that one could discriminate between two weights if they differed by 1 or 2 parts in 30. It was made clear by Weber, that the smallest perceptible difference between two weights could be stated as a ratio that was independent of the magnitudes of the weights. Further experiments were carried out by Weber using other weight, visual and sound experiments.

Misiak and Sexton (1966) point out a particularly valuable study carried out by Weber (1850) which dealt with the perception of small differences between weights, and length of lines, and pitch of tones. Weber found that in order for a subject to notice a change in stimulus, the "just noticeable difference", this change must constitute a certain portion of the stimulus, a constant. Thus, it is not just any increase or decrease in the stimulus that is noticed, but only a change which is proportional to the stimulus already effecting the receptor. He found this ratio to be 1/30 for weight, 1/50 or 1/100 for lines, and 1/160 for tones.

From these findings Weber was able to state a general principle: "in comparing objects and observing the distinction between them, we perceive not the difference between objects, but the ratio of this difference to the magnitude of the objects compared."

Weber did not formulate a specific law. However, Weber's proposals led Fechner to the first understanding of the relation between the psychological world and the physical (Hecht 1924).

Fechner, in 1860, (from Woolworth and Schlosberg 1958) found that 1 gram was a sufficient addition to a 50 gram weight on the palm to be just noticeable and that we have to add 2 grams to a 100 gram weight before a difference is noticed. To a 200 gram weight 4 grams are added to perceive a difference. Based on his own observations and those of Bouguer and Weber, Fechner devised a ratio between the sensory stimulus and the change in this stimulus before a difference in the two could be detected. He assumed that the "just noticeable difference" of sensation always contains the same number of sensation units and that this ratio is maintained along the entire scale of sensory stimuli, and was, therefore, a constant.

Although he recognized the original work of Bouguer, Fechner (1860) referred to this ratio as Weber's Law.

This law stated that the ratio between the detectable change in intensity of a stimulus and the intensity of the stimulus equals a constant. It is expressed mathematically in the formula $dI/I=C$, where I is the stimulus, dI the just noticeable difference, and C the constant.

The study of psychophysics was started by Fechner in 1860 (Misiak and Sexton 1966). Fechner considered psychophysics to be a philosophical system concerned with functional relationships between body and mind. The main goal of psychophysics has been to find what the minimum intensity of a stimulus must be in order for the subject to recognize the difference (differential threshold).

Boring (1950) points out the fact that an equation in terms of

Weber's Law which related the body and the mind could be written, demonstrated to Fechner their identity and their fundamental psychic character.

Not all investigators agreed with Fechner's psychophysical studies. Urban (1933) experienced difficulty in understanding Fechner's proposition, since his equation connects different dimensions, putting a sensation equal to a physical quantity. Urban could not conceive of any constant producing equality between physical and psychial entities.

James (1890) felt that Weber's Law was an empirical generalization and that the Weber Ratio could be found for measurable senses. The ratios he gave were: light, 1/100; sound, 3/10; pressure and muscle sense, 1/40; and warmth and taste, 1/3. He felt that the Law had only a purely physiologic value and he could not agree with Fechner's psychological interpretation of Weber's Law.

James felt, based upon his survey of the facts, that it is not any fixed amount added to an impression that makes us notice an increase in the latter, but that the amount depends upon how large the impression already is. That is to say the amount is expressed as a certain fraction of the entire impression to which it is added.

Hecht (1924) expressed belief that sensory judgments were relative, not absolute. He felt that Weber's Law was true, but that it only applied to a narrow range of the intensity scale. He criticized the limits Fechner set at the extremes of the intensity scale. He agreed with Exner (1879) and Wundt (1900) that Weber's Ratio was a constant only within narrow limits.

Knight (1922) believed the Weber Law in theory but questioned its workability in practical cases. He based his beliefs on: (1) the limited range of the Weber Ratio, (2) that the physical and psychological condition of the subjects must be approximately constant, and (3) because it only applied to intensities.

Thurstone (1927) felt that Weber's and Fechner's Laws were independent of each other, and should not be referred to jointly as the Weber-Fechner Law. Thurstone points out that the law should be rewritten to read, "The stimulus increase which is correctly discriminated in 75 percent of the attempts, when only two judgments "higher" and "lower", or their equivalents, are allowed, is a constant fraction of the stimulus magnitude."

Culler (1926) showed Weber's Law to be a function of adaptation; it holds clearly and consistently for absolute limens (minima perceptibilia) but not at all for differential ones (minima distingibilia).

Steinhardt (1936) agreed with Hecht that as the intensity of a stimulus increased, the Weber Ratio showed a substantial decrease.

Holway et al (1937) working with the "method of constant stimuli", found that measurements of intensive discrimination revealed clearly that variation in the organism's discriminatory performance does occur. He felt because the organism tested had the capacity to vary its performance that significant properties of the organism could be established.

Crozier et al (1936) maintained that the organism's ability to vary its capacity to exhibit reactions is the reason for the variation of the magnitude of sensation to a stimulus and not "extraneous experimental error."

Van Leeuwen (1949), while working with the response of muscle spindles in the frog, reported that Weber's Law was a property of a single stretch receptor. However, a large number of results had to be taken into account because random fluctuations so invalidated single observations that the relation was not clear.

Pieron (1952) also felt that Weber's Law only applied to the intermediate range of intensities, and that near threshold or physiologically tolerable limits the ratio increased. He pointed out that Weber's Law assumes a discriminative capacity of the receptor organ requiring a difference threshold of a certain value before it is noticed and thereby representing a sensation step. He reasoned that if the discriminative capacity of the organ was increased, a corresponding decrease of the sensation step would occur without the fundamental relation being altered.

Fulton (1950) said that over a very limited range of intensities Weber's Law applied to most sensory modalities. He was critical of the generality that Fechner applied to Weber's Law.

Woolworth and Schlosberg (1958) point out that Weber's Law is fairly constant throughout the middle range of intensity for most of the senses. However, there is a difference from sense to sense, being as small as .016 for brightness and as large as .33 for loudness. The smaller the Weber fraction, the keener the discrimination. They believe that a terminal threshold, TL, exists for each sense. That is, every sense has its limit beyond which it yields no greater sensation. This terminal threshold varies for senses.

Kawamura and Watanabe (1960) determined the Weber Ratio for tactile sensations for human teeth. They compared the discriminatory ability of patients with natural and artificial dentitions by having the patients bite down on small diameter stainless steel wires placed between the teeth. They found the Weber Ratio in the human natural dentition to be 0.1 in both the incisor and molar areas. They could not confirm their findings in the tests with artificial dentitions. They believe that the periodontal membrane is necessary in both the maxillary and mandibular teeth in order to make correct judgments of the size of the material.

Treisman (1963 and 1964) agreed with previous investigators and held Weber's Law to be valid in middle ranges of intensity and to increase in low and high ranges of intensity for many stimuli.

Grossman and Hattis (1965) using the Semmes-Weinstein anesthesiometer studied the relative tactile sensitivity at several oral sites and on the hand. Applying the procedure of "just noticeable difference" they listed the areas of greatest oral tactile sensitivity in the following order: (1) upper lip; (2) tongue; (3) lower lip; and (4) incisive papilla. The finger and palm were less sensitive to tactile stimulation than all oral sites studied.

Bowman and Nakfoor (1968) studied the ability of subjects to discriminate intensity of forces applied to the maxillary central incisor of patients undergoing active orthodontic treatment. They found that the Weber ratio was a constant over the middle ranges of intensity, but increased at both the lower and higher ends of the scale. They established a Weber ratio for these teeth of 0.10 to 0.15 for 70 percent discrimination when force standards employed fell between 50 and 500 grams.

Soltis (1968) tested the maxillary central incisor of the same group of orthodontic patients as Bowman and Nakfoor (1968). HIs studies were initiated several months following prolonged active orthodontic treatment. He found that the Weber ratios increased during the early stages of treatment, but that they tended to return to the pretreatment levels after approximately one year of orthodontic treatment. He found the Weber ratios of the fifth measurement period compared significantly with those of Bowman and Nakfoor for the first measurement period.

Bonaguro (1968) testing the mandibular incisor, canine and premolar found that the Weber Ratio for the periodontal ligament of human adults ranged between .125 and .153 of the standard force values between 500 grams and 1500 grams on the central and lateral incisors, .117 and .153 of the standard force values between 500 grams and 2500 grams on the canine, and .137 and .165 of the standard force values between 500 grams and 2500 grams on the first premolar.

Dusza (1968) studied the maxillary canine tooth and found the optimal working range of the Psychophysical Law, for his experiment, was between 200 and 500 grams; the upper limit was not established. The Weber Ratio for the periodontal ligament of the subjects was found to range between 0.06 and 0.15 of the standard force values over the range.

2. Fechner's Law:

Fechner (1850) formulated the Psychophysical Law which stated that sensation increases as the logarithm of the intensity of stimulus increases. He expressed this mathematically as $S=A \log I + K$, where S equalled the intensity of the sensation in sensation units. On a logarithmic scale, I, the intensity of the stimulus increased in a straight line starting from K. The slope of this line was represented by the constant A.

When Fechner (from Woolworth and Schlosberg 1958) published his treatise of "Psychophysics", he was trying to work out in a scientific manner the relations between body and mind, or between the physical and psychical worlds. It was his goal to discover some definite quantitative relations between the physical stimulus and the resulting conscious sensation.

Fechner's Law showed that when stimulus strength I increases in geometric progression, something in sensation that we call its quality S increases in arithmetical progression.

Helmholtz (1866), Delbouef (1872) and Broca (1894), working with light, concluded that sensation increases proportionately to the logarithm of intensity. As the sensation increases, a variable intensity factor must be added as well as a constant.

James (1890) did not believe in the validity of Fechner's Law. He felt it had no basis in psychology even though the law was of mathematical and metaphysical interest. He disagreed sharply with Fechner's assumption that the "just noticeable difference" was a sensation unit, and that all of our sensations consisted of sums of these units. James felt that Fechner's attempts to measure sensations numerically were pure mathematical speculation.

Munsterberg (1894) believed in the validity of Fechner's Law. He studied the ability of subjects to visually estimate the differences in lengths of lines. However, in his experiments he used the psychometric method of measuring psychophysical phenomena rather than the method of "just noticeable difference" which he felt was theoretically questionable.

Waller (1895) relating responses of retina, muscle and nerve to electrical stimulation by the Weber-Fechner Law found that the logarithmic curve held only in the medium range of the sensation scale. However, he found that inflections occurred at law and high intensities and thus felt that an S-shaped (sigmoid) curve must be substituted for the logarithmic straight line.

Waller supported the belief that the excitatory processes of these tissues were controlled by Fechner's Law. He reasoned this must be true in everyday life because if the maximum increments of sensation equalled the increments of stimulation at the low end of the scale near threshold we would be in an intolerable state of hyperaesthesia, due to the multitude of minute stimuli which surround us.

Cowdrick (1917) following experiments with 89 cases over five intensities held that the formula of Cattell and Fullerton, S=C R+b, represents the actual results better than does the Weber-Fechner formula.

Cowdrick also found that with a limited range of intensities and after practice the approximation to both hypotheses greatly improves but the Weber-Fechner Law is more representative.

Thurstone (1929) found from his experiment concerning the assessment of the varying numbers of dots on cards that Fechner's Law was valid for his experiment.

Matthews (1931 and 1933) studying muscle spindles, single and organs and nerve endings in mammalian and frog muscle found that the rate of response of the receptors is roughly proportional to the logarithm of the tension on the muscle. This only occurred at moderate tensions. At higher tensions, the muscle spindle fell short of this proportionality.

Hartline and Graham (1932) studied the effect of light on the lateral eye of the horseshoe crab. Their results paralleled those of Matthews. They found in studying impulses from single receptors in the eye that when the frequency of discharge is plotted against the logarithm of the stimulating intensity, the result is a linear relation over a moderate range.

Guilford (1932) proposed a general psychophysical nth power law which was written $dS=Ks^n$ and which read as:

"The just noticeable increment in a stimulus is equal to a constant times the nth power of the stimulus."

In Weber's Law, n would be 1, whereas in the square root law, n would be 1/2.

Guilford suggested that this nth power law would take care of small values of S where Fechner's Law did not hold true. He stated that Fechner's Law was only true for the middle ranges of stimulus intensity.

Houstoun (1932) wrote that Helmholtz in his studies found Fechner's Law to apply to the medium ranges of illumination, but that its validity did not hold true at the upper and lower limits of intensity.

Pfaffman (1939) while investigating the mechanoreceptors of the maxillary teeth of the cat, found that the relationship between frequency of response and the stimulus was approximately logarithmic, within limited ranges the high and low forces utilized were 20 grams and 200 grams respectively.

Ness (1954) while studying the mechanoreceptors in the periodontal ligament of the rabbit mandibular incisor reported that the neural response obtained during mechanical stimulation with forces of less than 100 grams produced a linear relationship when plotted against the logarithm of the magnitude of the stimulus.

Over the years many investigators have challenged Fechner's Law on the grounds that the relation between sensory intensity and stimulus intensity could be expressed more accurately as a power function. Among the men who have opposed Fechner's Law on this basis are: Plateau (1850), Bretano (1874), Grotenfelt (1888), Guilford and Stevens (1957 and 1960).

Cobb (1932) contends that Fechnerian reasoning overlooks the fact that any two stimuli presented in conjunction will modify the effects of each other. With this in mind he suggests a formula where a factor (M) is considered to be a weighted mean of all stimuli acting at the time.

Newman (1933) concluded following attempts to correlate two sets of data concerning brightness and loudness that the "just noticeable difference" is not a very acceptable unit of measure.

Stevens (1957), undoubtedly one of the most outspoken critics of the Fechner Psychophysical Law, demonstrated on 14 class I or prothetic continua (those having to do with how much) that the psychological magnitude is a power function of the stimulus magnitude. He felt that the sensation was proportional to the stimulus raised to a power, and proposed the following equation: $dS=kI^{x}$. For these 14 continua he found the exponents to range from 0.33 for brightness to 3.5 for electric shocks applied to the finger. Experimentally, Stevens felt that Fechner's Law was not found to be true because the just noticeable difference (the indirect resolving power) was not constant in psychological units as Fechner had assumed, but was proportional to the psychological magnitude.

Treisman (1961) wrote that both Fechner's Logarithmic Law and Steven's Power Law were valid. However, it was his observation that a central neural response determining process as described by the Fechner logarithmic function was simpler and more useful than one using the power function.

Brett (1962) objected to Fechner's Law on the following basis:

(1) the laws and formulae of psychophysics lacked support of experimental evidence; (2) the law only had psysiologic value; (3) the mathematical expression of Fechner's was wrong; and (4) that mental processes were biological rather than mathematical as advocated by Fechner.

Luce, Bush and Galanter (1963) agreed with Stevens that the psychological magnitude is a power function of the stimulus magnitude. Also, that for continua involving changes of intensity, or prothetic ones, the magnitude scale is to a good approximation a power function of the physical energy of the stimulus. They listed some of Steven's power function exponents as ranging from 0.3 for loudness to 3.5 for electric shock through the finger.

Miller (1964) states that in order for sensitivity to be accurately measured it must be considered as a variable matter and not as a constant. Several factors should be determined: (1) its extreme, (2) its mean value, (3) the dependency of its change upon circumstances and (4) search for laws which hold throughout its variations.

Bowman and Nakfoor (1968), testing for proprioceptive discrimination in the periodontal ligament of the human maxillary central incisors, found that the power function of Stevens fit their data better than did Fechner's logarithmic equation. They found that the optimal working range for the psychophysical phenomenon to be between 50 and 500 grams.

Bowman and Nakfoor found that for forces applied to the incisal surface and directed along the long axis of the tooth, the results could best be described by the equation $dS=0.23I^{.861}$, and for the 90° axis,

$dS=0.24I^{0.865}$. The general formula used being: $dS=KI^{x}$, where I equals the applied force and dS equals the minimal difference in force that can be discerned at this force level.

They established that a near linear relationship existed in the range of forces between 50 and 500 grams, but that forces of 10 and 1000 grams fell outside the optimal limits of the Psychophysical Phenomenon.

Soltis (1968) tested the same group of patients that was utilized by Bowman and Nakfoor (1968). Soltis began his studies after approximately one year of orthodontic treatment. He found that a comparison of the Weber ratios for the five measurement periods including the three periods of Nakfoor and the two periods of his own reveals that the highest values recorded were for the third measurement period, while the fifth and final readings could be compared grossly to the starting values. The first measurement was done prior to any orthodontic treatment. The data for the second measurement period was recorded two to four days after removal of the maxillary premolar teeth in those patients requiring this type of treatment. The third measurements were recorded four days after insertion of the orthodontic appliances. The fourth measurements were made approximately six months after activation of the orthodontic appliances and the fifth measurements were made at approximately one year of treatment.

Of interest, is the fact that for the 1000 gram level at the fifth and final measurement period the Weber ratios were .074 for the 90° axis and .072 for the long axis, while at the first measurement period they were .195 for the 90° axis and .179 for the long axis.

Soltis felt that the accumulated data showed a definite trend indicating that a return to normal discrimination is to be expected upon completion of orthodontic treatment. He felt that the Weber ratios for the 1,000 gram force level will return to normal following the removal of orthodontic appliances.

Bonaguro (1968) studied the ability of young adults to quantitatively discriminate force stimuli applied to the mandibular central incisor, lateral incisor, canine, and premolar teeth. The data collected was obtained from readings of force applied to the labial surface and incisal edge of the central incisor, lateral incisor, and canine, and to the buccal surface of the first premolar. The forces used in this investigation varied between 50 grams and 2000 grams for the mandibular central and lateral incisors, and 100 grams to 2500 grams for the mandibular canine and first premolar.

Bonaguro found that the optimal working range of the Psychophysical Phenomenon varied for the different teeth tested.

The Weber Ratio for the periodontal ligament of human adults ranged between .125 and .153 of the standard force values between 500 grams and 1500 grams on the central and lateral incisors, .117 and .153 of the standard force values between 500 grams and 2500 grams on the canine, and .137 and .165 of the standard force values between 500 grams and 2500 grams on the first premolar.

Bonaguro also reported the power function equation of Stevens to be the better expression of the relationship between sensory intensity and stimulus intensity.

Dusza (1968) studied the initial effects of orthodontic forces applied to the maxillary canine tooth on the ability of patients to consciously discriminate between varying forces. The subjects studied were divided into two experimental groups. One group required the extraction of the first premolar teeth while the members of the other group did not require the extraction of teeth for the treatment of their malocclusion.

Dusza found that the ability of the patients to discriminate between forces applied to the surface of the canine significantly improved following the extraction of the first premolar teeth and further improved with the application of light orthodontic forces. He also found that the human periodontal ligament exhibited no greater directional sensitivity to forces applied along the long axis of the same tooth.

The optimal working range of the Psychophysical Law, for Dusza's experiment, was found to begin between 200 and 500 grams; the upper limit was not established. The Weber ratio was found to range between 0.06 and 0.15 of the standard force values.

Dusza also concluded that the differential threshold for this range is better expressed by the Steven's formula, $dS=KI^{X}$.

3. The Periodontal Ligament: Innervation and Function.

Peaslee in 1857, (from Brashear 1936) stated that teeth can detect pressure and have powers of localization. He felt that the teeth were most sensitive on their masticatory surfaces.

Noyes (1921) wrote that the sense of touch for the teeth rested entirely in the periodontal ligament, and the innervation of the periodontal ligament was only for proprioception.

Stewart (1927) conducted pressure experiments and found that pulpless teeth gave the same results as teeth with normal pulpal tissues. He felt transmission of pressure was not a function of the pulpal nerves, but was a function of the nerves of the periodontal ligament. He also found that the teeth had the ability to localize pressure stimuli. The canine was found to be the most sensitive tooth.

Van der Sprenkel (1935) described the innervation of the periodontal ligament as consisting of apical fibers following the path of the blood vessels, and alveolar fibers arising from the interdental areas. The alveolar fibers supplemented the apical fibers, and then both groups of fibers proceeded gingivally together. He found three types of endings for the myelinated nerves of the periodontal ligament. The first were small end rings which functioned in pressure perception and localization. The second were the terminal reticula, but he did not know the significance of these. Finally, he found unmyelinated fibers that penetrated the dentin and cementum of the teeth. It was his hypothesis that these fibers might be sensitive to changes in the shape of the teeth due to compression of the dentinal tubules during mastication.

Bradlaw (1936) in his description of the innervation of the teeth stated that the branches from the main trunk to the formed tooth divide into pulpal and paradental nerves before the apex is reached. The peridontal nerves pass upwards with blood vessels in a channel for protection from tooth movement and give off twigs, at intervals, to the surrounding alveolus. He further observed that, at times, they may enter the interdental septum for varying distances before entering the periodontal membrane. The nerves pass beyond the circular ligament, where they divide to supply the mucous membrane and to anastomose with the periodontal nerves of the adjoining teeth across the crest of the interdental septum. Bradlaw suggests that this may be a mechanism for the coordination and control of occlusion in the act of mastication.

Lewinsky and Stewart (1936) studied the periodontal ligament innervation of both the human and cat. They found as did Van der Sprenkel that the nerves of the periodontal ligament arose from the apical region, proceeded along the course of the blood vessels, and receive fasciculi which enter the periodontal membrane through the foramina in the alveolar process. They found that the nerves ended in fine arborizations, small round bodies and recurrent loops, as they approached the cementum. However, they were unable to trace any nerve fibers into the cementum of the teeth.

Lewinsky and Stewart (1936) following their studies of the periodontal ligament of the cat were able to show that the innervation of the periodontal membrane of the cat is from two sources; (1) fibers arising from the apical region and (2) fibers entering laterally from the alveolar plates. As they course apically and gingivally there is a division. There are two types of nerve fibers observed, (1) thick fibers confined to the periphery of the membrane with specialized end organ terminations, and

(2) finer fibers which pass deep into the membrane and end in arborizations. Lewinsky and Stewart suggest the function of the thick fibers with their end-organs to be associated with tactile and pressure sensations, while the function of the finer fibers is associated with pain. They were unable to trace nerve fibers into the cementum.

Bernick (1957) found it possible to clearly identify the nerves present in the pulp, periodontal membrane, and gingiva. He utilized proteolytic enzymes to remove the non-nervous fibers. He observed that the common pulpal nerve arises as a union of the branches of the various dental nerves which enter the apical periodontal membrane of all the surfaces surrounding the tooth. In the coronal portion of the pulp the nerve branches into cuspal nerves which terminate in the odontoblastic layer of the cuspal horns. The nerve supply of the periodontal membrane arises from the dental and interalveolar branches of the alveolar nerves. The dental nerve fibers supply the periapical region and pass gingivally to form a bundle with perforating branches of the interalveolar nerves.

Bernick found two types of nerve endings in the periodontal membrane.

(1) Nonmedullated nerve fibers may unite at their terminals to form an arborization or "free nerve endings."

(2) Medullated fibers may lose their myeling sheath, and the naked fibrils terminate into an elongated spindle-like structure.

The gingival innervation is derived from two sources; (1) fibers arising from the nerves of the periodontal membrane and (2) fibers originating from the labial or palatal nerves.

Kizior, et al (1968) studying the innervation of the periodontal ligament of the cat identified two types of receptors. One was ovoid and encapsulated and appeared in the apical 1/3 of the periodontal ligament. The second type of receptor observed was seen throughout the periodontal ligament as free nerve endings.

Cuozzo (1966) also studying the cat concluded, histologically, that the small fibers, (1-5m) in diameter, of the mandibular nerve mediate painful responses originating in the receptors of the periodontal ligament.

Different investigators have determined that the pulpal nerves are specific for the conduction of pain, while the nerves of the periodontal membrane are specific for pressure.

Stewart (1927) with the aid of an aethesiometer found that the minimal detectable pressure for incisors and canines of both the maxilla and the mandible varied between 7 and 50 gm/mm^2 for 260 feet tested. He found that pulpless teeth and teeth with normal pulpal tissues tested similarly and thus concluded that pressure must be transmitted along the nerves of the periodontal ligament.

Brashear (1936) felt that the large sized nerve fibers of the periodontal ligament were responsible for the transmission of pressure sensations to the teeth. These fibers measured 10-16 microns in diameter and represented 24 per cent of the total nerve fibers counted. He felt that temperature sensations were transmitted by the medium sized fibers 6-10 microns in diameter, and that pain was mediated along small myelinated and unmyelinated nerve fibers measuring less than 6 microns in diameter.

Pfaffman (1939) believes that many, if not most, of the tactile and pressure endings of the teeth are located in the periodontal membrane and receive their nerve supply through the alveolar bone, because negligible changes were noted upon stimulation of the tooth following removal of the pulp and destruction of the nerves at the apex of the tooth.

Pfaffman also found that when the full nerve trunk supplying the maxillary incisor, canine and premolar of the cat was placed on the sensory electrodes, pressure against any surface of the tooth elicited responses of approximately the same magnitude. A single fiber, however, was only affected by pressure against a particular surface of a tooth. He concluded that from the maximal position, the stimulating efficiency decreases until a position of 90° on either side is reached where the stimulus is no longer effective for the particular fiber.

Pfaffman also described two types of nerve fibers in the periodontal ligament. The first were large fibers of 10 to 14 microns in diameter, and consisted of 20 percent of all the fibers present. He felt these fibers carried impulses of pressure. He felt that the smaller nerve fibers of 2 to 9 microns in diameter carried painful impulses.

Orban (1944) felt that three types of nerve fibers could be found in the periodontal ligament. The first were free nerve endings responsible for the conduction of painful impulses. The second type were those that formed loops or rings around the bundles of principle fibers of the periodontal ligament to which Orban assigned no function. The third type were described as knob-like swellings responsible for proprioception and the localization of pressure stimuli.

Ness (1954) studied the mechanoreceptors of the rabbit mandibular incisor. He stated that the receptors responding to pressure applied to the crowns of the teeth were located in the periodontal ligament. He divided these mechanoreceptors into slow adapting, fast adapting, and spontaneously discharging depending upon the spike sizes of their nervous discharges. He observed that the slow adapting receptors had the greatest directional sensitivity. The most sensitive direction was found to be incisoapically. Ness felt that this could be due to the orientation of the individual receptors in the periodontal ligament.

Dockrill (1954) compared the innervation of hair follicles, whisker follicles and teeth and found that they all had the same basic nerve pattern consisting of thicker myelinated and thinner non-myelinated fibers. He speculated that this similarity of innervation might be due to the common ectodermal origin of these structures.

Loewenstein and Rathkamp (1955) studied pressure thresholds of vital teeth. Force was applied to the incisal edges of the anterior teeth and to the occlusal surfaces of the posterior teeth. Their findings showed an increasing threshold in both maxillary and mandibular teeth from incisors toward molars. They felt that the higher threshold observed in the posterior teeth was due to the greater surface area of the roots of these teeth. They noted that thresholds of pulpless teeth were significantly higher (57%) as compared to normal teeth. From this they concluded that there were intradental as well as periodontal pressoreceptors. This conclusion was in disagreement with the findings of Pfaffman and Stewart.

Kawamura and Watanabe (1960) after comparing the Weber ratios of natural and artificial dentitions determined that the periodontal ligament was necessary to make finite judgments in the size of materials placed between the upper and lower teeth.

Corbin and Harrison (1940) used a Horsley-Clark stereatoxic instrument and picked up action potentials from the homolateral mesencephalic root of the fifth cranial nerve. These came in response to opening of the jaw and the stretching of the masticatory muscles. Action potentials were also elicited from the caudal half of the mesencephalic root due to blunt pressure stimulation of the homolateral teeth and hard palate. They found that in the cat the canine teeth were the most responsive of the oral structures.

Jerge (1963) found three types of neurons in the mesencephalic trigeminal nucleus: (1) those innervating muscle spindles of the masseter, temporalis and medial pterygoid muscles, (2) those innervating dental pressure receptors of a single tooth (type I), and (3) those innervating dental pressoreceptors of two or more adjacent teeth and in some cases contiguous gingival areas (type II). The type II dental pressoreceptor units and over half of the type I units were found in the caudal half of the mesencephalic nucleus. The threshold for the type I units ranged from 1 to 3 grams while those of the type II units ranged from 2 to 6 grams. It was noted that as one progressed posteriorly from tooth to tooth the threshold increased.

Kruger and Michel (1962) studied 23 decerebrate cats and found that generally only one face of a tooth was sensitive to gentle stimulation. They also found the canines to have a richer representation of neurons in the trigeminal complex than any of the other teeth, and suggest this to reflect their richer innervation and greater usefulness as a tactile organ.

Kizior, et al (1968) observed marked increases in adaptation time with forces ranging from 4 to over 1700 grams. They noted that the increases in adaptation times indicate individual threshold levels and that the threshold levels may also be influenced by the location of the receptor in the ligament. This was shown by the differences in the potential amplitudes when the direction of the stimulus was varied. Forces applied to the incisal edge and directed along the long axis of the tooth evoked the highest potentials, indicating the greatest number of receptors were probably activated at this time. He correlated this with his finding of the ovoid encapsulated structures which were located only in the apical one third of the ligament, and thus accounted for the directional sensitivity of the periodontal ligament receptors.

Bowman and Nakfoor (1968) working with human maxillary central incisors noticed no directional sensitivity when applying pressure stimuli to the labial surface and incisal edge of these teeth. From this they concluded that the proprioceptive nerve endings were evenly distributed throughout the periodontal ligament. This is in contrast to the pattern reported for the cat canine.

Bowman and Nakfoor (1968) found that the periodontal ligament loses much of its ability to discriminate between forces applied to maxillary central incisors during treatment. He noted that the pain threshold is apparently lowered by the application of continuous light differential orthodontic forces to the teeth.

Dusza (1968) studying the human maxillary canine reports no significant difference in discrimination could be found between forces directed along the long axis as opposed to those directed 90° to the long axis. These findings agree with those of Bowman and Nakfoor and confirm the lack of conscious directional sensitivity in the human dentition. However, these findings stand in contrast to those of Pfaffman, Ness and Kizior each of whom observed directional sensitivity. The study by Dusza shows a significant improvement in the ability of patients to discriminate varying forces within four days after the removal of the maxillary first bicuspid teeth. Nakfoor's study showed that the ability of his subjects to discriminate between various force stimuli prior to treatment was not altered by the extraction of the maxillary first bicuspid teeth. The results of Dusza's study show that the ability of patients to consciously discriminate between forces applied to the maxillary canine tooth significantly improved after insertion of orthodontic appliances. The opposite was true for Nakfoor's study.

Bonaguro (1968) studied the mandibular central incisor, lateral incisor, canine, and premolar teeth and based on the results of this study the teeth tested did not exhibit directional sensitivity. In all cases, labially and incisally applied forces had nearly the same range of discrimination. This is in general agreement with the findings of Lewinsky and Stewart that the pressoreceptors are evenly distributed throughout the periodontal ligament. Of the teeth tested the canines showed the greatest sensitivity to this force stimulation. The first premolar showed the lowest sensitivity to tactile stimuli of any of the teeth tested.

Soltis (1968) studying the effects of prolonged orthodontic therapy upon periodontal proprioceptors found that although a patient's ability to consciously discriminate between varying force stimuli is altered, as reported by Bowman and Nakfoor (1968), the subject's ability to discriminate between comparable forces slowly returns as the forces of orthodontic appliances are diminished.

Soltis also found that after prolonged orthodontic treatment, the pain threshold rises to near its original level.

CHAPTER III

METHODS AND MATERIALS

1. Introduction:

The thirty subjects used in this study were the same subjects that Dusza (1968) selected for his investigation. These subjects were orthodontic patients undergoing treatment in the Department of Orthodontics at Loyola University, Chicago, and had worn appliances for a period of time that ranged from nine months to one year. Their ages ranged from twelve to eighteen years.

The subjects were divided into two groups. One group consisted of thirteen non-extraction patients and the other group consisted of seventeen patients that required the extraction of the four first premolar teeth.

All data were recorded for the maxillary canine teeth. The patients had all been wearing activated appliances for approximately nine months to one year when the experimental data was being gathered.

The initial stages of treatment were already completed, and at this time the patients were found to be in various phases of treatment. In the cases which required the extraction of the first premolar teeth the forces which had been directly applied to the maxillary canine teeth, for the purpose of retracting these teeth into the extraction sites, had been discontinued.

A pilot study was conducted by the author and Dr. G. Dusza on several graduate students within the Department of Orthodontics. Each investigator used the same technique in testing these subjects and recorded his own measurements. To verify the accuracy in duplicating the measurements by the author the measurements of the two investigators were statistically analyzed.

2. Force Producing Instrument:

The force producing instrument employed in this study was the identical one used by Dusza (1968) in his research (FIGURE 1). This torque wrench device was originally designed and manufactured for Kizior, et al (1968) by the P.A. Sturtevant Company, Elmhurst, Illinois.

The force producing instrument was constructed by employing torque. Torque is the resistance to a turning force, and a torque wrench is a device used to apply and measure the resistance to a turning force. The integral parts of this instrument are:

(a) drive square

(b) a flexible beam

(c) handle

(d) scale

(e) force indicator

This instrument allowed force to be applied to any surface of the tooth and to be directed along any plane. The versatility of the instrument was derived from the arrangement of its components, a torque wrench with its adaptor and the fixture on which it was mounted.

Flexing the beam by application of force on the handle produces torque at the drive square end. The magnitude of torque can be computed by

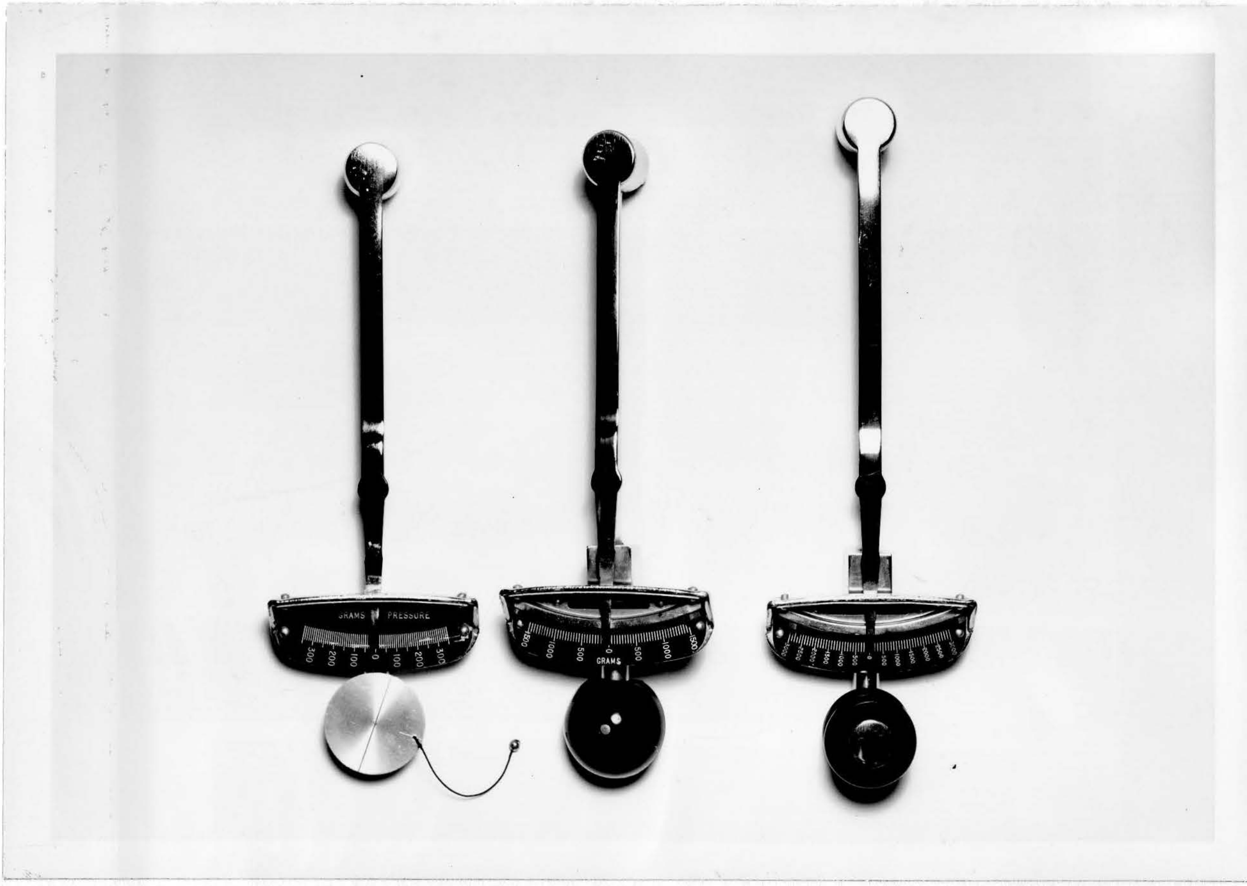


FIGURE 1

Torque Wrenches

the mathematical expression T = F x D, the Torque Law, where T expresses torque, F designates force, and D is the distance through which force is applied (beam length).

The Torque Law states that the moment or torque about a point equals the force multiplied by the distance. The lever length refers to the distance from the point on the handle where the pulling or pushing force is concentrated to the center of the drive square. This is always measured 90° to the direction of the force.

In this study, the torque wrench was modified by having its drive square coupled with a bearing and drive shaft assembly. This modification allowed for a nearly frictionless movement as the drive square rotated through 360°. This rotating drive shaft was coupled to a twelve inch level arm with an adjustable pointer and balanced at the opposite end by a counterweighted four inch lever arm. The relationship of the pointer to the long axis of the tooth determined the direction in which the force was applied to the tooth. Balancing the lever arms permitted any desired position of the pointer to the tooth.

To assure that the force application was perpendicular with the torque wrench beam, to satisfy the Torque Law, and to standardize the procedure, all forces were applied by using the index finger and thumb of the right hand of the examiner. The force was applied by pulling the disk or handle which was centered to concentrate all the force at one point. The use of the thumb and index finger to apply the needed force insured that the force would be 90° to the beam.

All torque wrench calibrations were certified with a maximal allowable error that did not exceed two per cent of the full scale readings. The force values used to stimulate the teeth during this experiment ranged from 0 to 3000 grams.

Three torque wrenches were used in this experiment. They were calibrated as follows:

(1) 0-350 grams calibrated in 10 gram increments

(2) 0-1500 grams calibrated in 50 gram increments

(3) 0-3000 grams calibrated in 100 gram increments

The above figures were the range of forces which would be delivered to the tooth, depending upon deflection, through the twelve inch lever extension from the drive shaft. The direct force readings can be explained by solving the Torque Law, $T = F \times D$, for F which reads $F = T/D$.

The torque force is produced at the drive square and transmitted through the drive shaft and ball bearing assembly. The new resulting torque force was called the "compressive" force and was delivered to the tooth through the fibre pointer attached to the lever arm. The force varies indirectly with the length of the lever arm. That is to say, a 50 inch gram torque wrench exhibits 50 grams "compressive" force 1 inch from the center of the drive shaft. At 12 inches from the center of the drive shaft a 50 inch gram torque wrench would exhibit 1/12 "compressive" force or 4.15 grams.

The calibrated scales were engraved to give direct readings of the "compressive" force expressed in grams when the twelve inch lever arm was used. The length of the lever arm remained constant throughout the experiment.

The tip of the pointer used on both the labial and incisal surfaces of the tooth was a solid cylindrical piece of vulcanized fibre 1/4 inch in diameter. The tooth contacting surface of the fiber rod was fashioned to conform to the various shapes of the maxillary canine tooth. It was attached to the metal tip of thepointer by means of a centered hole half way through the rod. National Vulcanized Fiber is a converted cotton cellulose with a tough, dense structure. This material was supplied through the courtesy of the National Vulcanized Fiber Company, Broadview, Illinois.

The fixture from which the torque wrench was suspended allowed additional versatility by means of adjustable parts, FIGURE 2. The iron base measured 48 inches by 18 inches and weighed approximately 300 pounds. Centrally located on the rear one-fifth of this base was an adjustable iron pipe which projected upward 90° to the base and measured 48 inches. A conventional dental head rest was attached to a post and was used as a "head restrainer".

An extension arm, 48 inches high, paralleled the fixed post. One arm was an iron extension and the second was welded; both were adjustable in a horizontal direction. The bottom brace was also adjustable in the vertical direction.

A 36 inch adjustable vertical arm ran perpendicular to the extension arm. The torque wrench assembly was securely fastened to this vertical arm.

The major horizontal and vertical adjustments were accomplished by

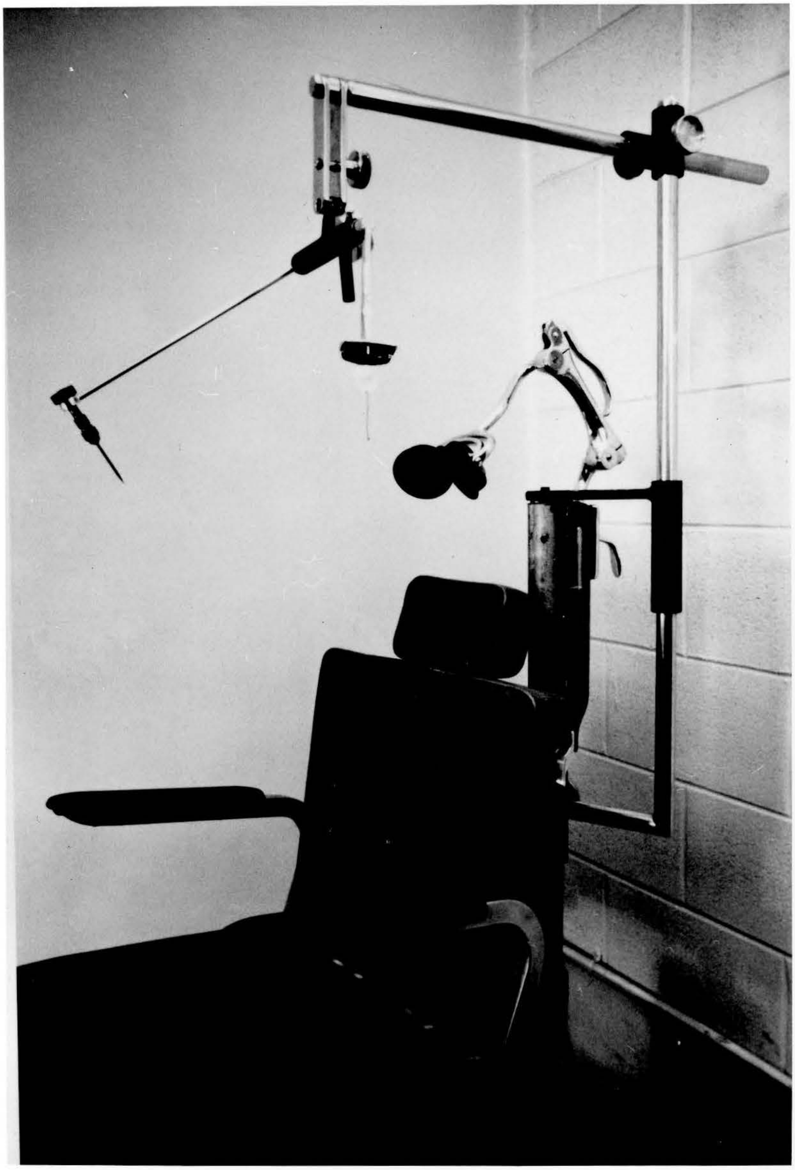


FIGURE 2

Orthodontics Chair With Torque Wrench Assembly a perpendicular adjustable assembly holding these arms. This was a welded couple with threaded screws to secure the desired position.

Any size patient or any desired position could be accomplished due to the versatility of the torque wrench assembly and numerous horizontal and vertical adjustments of the fixture.

3. Experimental Procedure:

The tests were made in a study room which was approximately seven feet square, quiet, well-lighted and air-conditioned. The testing device with its heavy metal base was positioned in the center of the room. On the base stood a dental chair with its back towards the fixed vertical post of the fixture. The chair had fixed arm rests, with a hydraulic pump and adjustable back and head rest. While testing subjects, the examiner sat at the side of the dental chair facing the torque wrench.

The subjects were asked to recall their first testing period and were informed that because of the changing position of their teeth, there were probably some changes in the "nerves" around these teeth. It was then explained that the examiner wanted to determine if any further changes had taken place. They were assured that the procedure would be exactly the same as that utilized at the first testing period. The entire testing procedure was then again reviewed with the patients to make sure they understood the method to be used.

With the patient seated in the dental chair and the torque wrench assembly adjusted to the selected tooth, the examiner than demonstrated two forces that were easily distinguishable. The patient was informed of the impending force by the comment: "This is the first and this is the second. Which one felt heavier?" The patient was then asked to concentrate very hard for it would now become slightly more difficult to identify the heavier force.

The two positions in which the instrument tip was to be placed were also explained to the subjects before the procedure continued. They were shown by means of finger pressure how the first six sets of forces would be along the biting edge of the tooth (the incisal edge directed along the long axis), and how the second set of six forces would be against the outside of the tooth (the labial surface, 90° to the long axis).

It was found that the question "Which one felt heavier?" could be dropped very shortly after the testing began, for the subjects anticipated the question and answered before it was asked. The examiner would then remind the patient occasionally to identify the heavier force and to concentrate very hard.

The length of time each stimulus was to be applied to the tooth was considered important. Since the forces were to be administrered by the hand of the examiner, it was necessary to develop a rhythm that permitted nearly equal time in applying each of these forces and the standard values and their respective differential thresholds. It was found that the use of a metronome greatly assisted in obtaining just such a needed rhythm. The metronome was not used in the experimental procedure, but practice sessions were held to help maintain this constant rhythm in force application.

The differential threshold, or the "just noticeable difference" between like forces, was determined for each subject at each of the standard force values of 100, 200, 500, 1000, 1500 and 2000 grams. These force ranges were applied along the long axis and 90° to the labial surface of the same tooth. With each torque wrench, a force differing by ± ten per cent from the standard force value was applied and then followed by the standard force value. The subject then judged which of the two forces was the heavier and the comparative forces were then accordingly increased or decreased as was necessary to establish the differential threshold. The validity of the resolved differential threshold was established by the subject's ability to correctly identify the heavier force at least seven out of ten times. These forces were administered in random fashion.

The differential threshold was determined above and below the standard force values. This was done to insure a true differential threshold because the threshold values above and below the standard force values were not always identical. In instances where the threshold values did vary, the two values were added and an average taken.

If the subject was unable to judge the heavier of the two forces at least seven out of ten times, it was felt that the differential threshold was too low. The force differential would then be gradually increased, in relation to the standard force value, until the subject could correctly identify the heavier of the two forces at least seventy per cent of the time. This was then considered the true differential threshold.

The differential threshold was considered too high if the subject correctly identified the heavier force ten times out of ten. The force differential would then be gradually decreased, in relation to the standard force value, until the subject could identify the heavier force, in random order, at least seven times out of ten, but less than ten times out of ten.

After each pair of forces were administered, the subject was asked which of the two forces felt heavier. If the pointer prevented him from verbalizing his reply, he would indicate his answer by using the first two fingers of either hand. The replies were recorded immediately after the subject identified the heavier force, under the force values used as the differential threshold for that particular standard force.

All subjects were tested as closely as possible by the described procedure. There was no significance attached to what axis of the tooth was to be tested first. The axis to be tested first was chosen at random.

The measurements obtained were recorded on semi-logarithmic and logarithmic graph paper. The differential thresholds established were plotted along the abscissa (x-axis) and the standard force values were plotted along the ordinate (y-axis) for uniformity.

The same procedure, as closely as possible, was followed for the subsequent readings on all subjects.

CHAPTER IV

FINDINGS

The standard force values used in this study were 100, 200, 500, 1000, 1500 and 2000 gram force stimuli, the same as those used by Dr. G.R. Dusza (1968). He found that the apparent optimal range of the Psychophysical Law for his experiment began somewhere between 200 and 500 grams, the upper limits of which were not established.

All data were recorded in terms of actual differential force values and percent of the standard force values used (Appendices I and II). The Weber ratios were changed to percent values to facilitate statistical analysis of the data by means of the Studentized "t" Tests.

TABLE 1 is a modified form of a table taken from Dusza (1968). It shows a comparison of the Weber ratios for the standard force values at the first three measurement periods. The first measurements were recorded before any definitive treatment was started. The second measurement involved only those subjects that required removal of their maxillary premolar teeth. The data for this measurement period was recorded two to four days after extraction of the maxillary premolar teeth. The third measurements were recorded four days after the orthodontic appliances were placed in the mouth.

TABLE 2 shows the mean Weber ratios for all groups for the fourth measurement period. The fourth series of measurements were made approximately nine months to one year after insertion of the appliances.

TABLE 1*

Mean Weber Ratios Determined For Extraction, Non Extraction And Combination Groups At First, Second And Third Measurement Periods

Non Extraction		First		Second		Third	
13 Subjects		L.A.***	90°	L.A.	90°	L.A.	90°
Grams	100	.350±.079	.369±.090**			.200±.061	.204±.069
	200	.211±.047	.212±.043			.129±.037	.133±.037
	500	.119±.025	.123±.039			.100±.020	.100±.020
	1000	.077±.022	.077±.023			.058±.016	.062±.026
	1500	.082±.023	.083±.023			.062±.015	.069±.020
	2000	.073±.019	.093±.020			.058±.012	.059±.013
Extraction							
17 Subjects							
Grams	100	.400±.083	.406±.107	.320±.059	.309±.051	.221±.090	.232±.125
	200	.241±.036	.244±.086	.184±.029	.185±.041	.129±.041	.143±.064
	500	.150±.047	.168±.097	.112±.028	.121±.044	.097±.012	.109±.026
	1000	.098±.046	.109±.068	.074±.024	.075±.027	.056±.011	.057±.012
	1500	.092±.037	.094±.033	.070±.017	.079±.029	.067±.010	.067±.011
	2000	.096±.031	.094±.034	.075±.018	.077±.027	.053±.008	.058±.012
Combined							
30 Subjects							
Grams	100	.378±.084	.390±.083			.212±.078	.220±.104
	200	.228±.043	.230±.071			.129±.038	.138±.053
	500	.137±.041	.148±.079			.098±.016	.105±.024
	1000	.089±.037	.095±.059			.057±.013	.059±.019
	1500	.087±.031	.089±.029			.065±.013	.068±.016
	2000	.086±.028	.094±.028			.056±.010	.059±.012

* Modified from Dusza, G.R., "An Evaluation of the Psychophysical Phenomenon on Sensory Stimuli to the Periodontal Ligament." M.S. Thesis, Loyola University, Chicago, Illinois, 1968.

** Mean ± One Standard Deviation

*** Long Axis

TABLE 2

Mean Weber Ratios Determined For Extraction, Non Extraction and Combination Groups At Fourth Measurement Period

		Fourth	
Non Extraction 13 Subjects		L.A.*	90°
Grams	100	.211+.044	.242+.080**
	200	.140+.039	.146+.030
	500	.131+.046	.125+.043
	1000	.084+.033	.072+.032
	1500	.074+.019	.084+.026
	2000	.071+.016	.079+.017
Extraction 17 Subjects			
Grams	100	.285+.083	.279+.116
	200	.173+.054	.170+.053
	500	.129+.030	.130+.037
	1000	.078+.017	.079+.017
	1500	.078+.016	.077+.015
	2000	.077+.019	.080+.012
Combined 30 Subjects			
Grams	100	.253+.070	.263+.104
	200	.159+.050	.160+.046
	500	.130+.037	.127+.040
	1000	.081+.255	.076+.025
	1500	.076+.017	.080+.020
	2000	.074+.018	.079+.017

* Long Axis

** Mean ± One Standard Deviation

In comparing the third measurement period and the fourth measurement period the Weber ratios are all higher for the fourth measurement period which would indicate that the ability of the subjects to discriminate between "similar" forces was better at the third measurement period.

A comparison of the first and fourth measurement periods shows that the Weber ratios are all generally higher for the first measurement period with the exception of the 500 and 1000 gram force levels for the non-extraction group. This group shows the Weber ratios for the 500 and 1000 gram force levels to be slightly higher at the fourth measurement period for readings taken parallel to the long axis. It would generally appear that at the fourth measurement the discriminatory ability of the orthodontics patients tested would be better than at the first recording.

As a point of interest it is noted that the Weber ratios for the first and third periods at each standard force value are all smaller for the long axis than the 90° readings. In the fourth measurement period the Weber ratios are generally smaller for the long axis than the 90° readings with some exceptions; in the non-extraction group of the fourth measurement period the Weber ratios at the 500 and 1000 gram levels are higher for the long axis readings; in the extraction group of the fourth period the Weber ratios at the 100, 200, and 1500 gram levels are higher for the long axis readings; and, for the combined group the 1000 and 1500 gram levels show higher Weber ratios for the long axis readings than the 90° readings.

Statistical comparisons of mean Weber ratios between force values at the fourth measurement period is presented in TABLE 3. The comparisons of the fourth reading show that there is no significant difference between the 1000 and 1500 gram range, between the 1000 and 2000 gram range and between the 1500 and 2000 gram range when comparing the mean Weber ratios. The lack of significant difference between the Weber ratios for these gram force values is noted both for the 90° and the long axis "t" values. The mean Weber ratios for the higher force values are the lowest for all force values indicating that discrimination at the higher force levels is better than discrimination at the lower force levels.

The comparisons of mean Weber ratios between the 100 and 500 gram range, the 200 and 1000 gram range and the 500 and 1000 gram range show that a significant difference ($P < .01$) exists for the 90° "t" values but not for the long axis "t" values. The comparison of mean Weber ratios between the 200 gram and 500 gram force values show a significant difference ($P < .01$) for 90° "t" values and a significant difference ($.05 > P > .01$) for the long axis "t" values. The mean Weber ratio comparisons made with the 100 gram force stimulus show the highest degree of significance; the "t" values ranged from 4.876 to 9.414 for the 90° axis and from 3.058 to 13.342 for the long axis. The mean Weber ratio comparisons involving the 2000 gram force stimulus at the 90° axis had significant "t" values that ranged from 5.945 to 9.400 and from 7.336 to 13.342 for the long axis.

TABLE 3

Statistical Comparisons of Mean Weber Ratios Between Various Force Application For Fourth Measurements

	90° "t" Values	Long Axis "t" Values
100 vs 200	4.876**	3.058**
100 vs 500	6.571**	1.516
100 vs 1000	9.414**	3.502**
100 vs 1500	9.313**	13.231**
100 vs 2000	9.400**	13.342**
200 vs 500	2.913**	2.510*
200 vs 1000	8.641**	1.720
200 vs 1500	8.582**	8.462**
200 vs 2000	8.885**	8.619**
500 vs 1000	5.829**	1.024
500 vs 1500	5.659**	7.137**
500 vs 2000	5.945**	7.336**
1000 vs 1500	.674	.105
1000 vs 2000	.536	.147
1500 vs 2000	.205	.436

* $.05 > P > .01$

** $P < .01$

The Studentized "t" test was also utilized to determine if a significant difference existed between the extraction and non-extraction groups for the fourth measurement period. TABLE 4 shows the results of the Weber ratio comparisons. The "t" values for the 100 gram force level show a significant difference ($P < .01$) for the long axis comparison, and at the 200 gram force level there was also a significant difference ($.05 > P > .01$) for the long axis comparison. This may be meaningful, but discrimination at these low force values is not as good as it is at the higher force values.

The results of the statistical comparison of mean Weber ratios between the third measurements (four days after appliance insertion) and the fourth measurements (approximately one year after appliance insertion) are presented in TABLE 5. As previously stated all of the Weber ratios for the third measurement period were lower than the Weber ratios for the fourth measurement period. The "t" values for the combined group of the third and fourth measurement period comparisons show that there was a statistical significance between the two measurements at all force levels with three exceptions; at the 100 gram 90° reading, the 200 gram 90° reading and at the 1000 gram long axis reading. For the non-extraction group a statistical significance existed for the Weber ratios between the two measurements at the 500 gram long axis reading, the 1000 gram long axis reading and at the 90° and long axis readings for the 2000 gram force. The extraction group showed a statistical significance for the Weber ratios between the two measurements for most force values with

TABLE 4

Statistical Comparisons of Mean Weber Ratios Between Non-extraction And Extraction Cases At Fourth Measurement

Force Values	90° "t" Values	Long Axis "t" Values
100 grams	.951	2.816**
200 grams	1.413	2.419*
500 grams	.330	-.138
1000 grams	.744	-.623
1500 grams	-.898	.602
2000 grams	.183	.884

* $.05 > P > .01$

** $P < .01$

TABLE 5

Statistical Comparisons of Mean Weber Ratios For Dusza's Third Measurements (Four Days After Appliance Insertion) Versus Fourth Measurements (Approximately One Year After Appliance Insertion)

	Force Values	90° "t" Values	Long Axis "t" Values
Combined Group	100	1.574	2.107*
	200	1.687	2.573*
	500	2.537*	4.268**
	1000	2.924**	1.582
	1500	2.515*	2.762**
	2000	5.195**	4.730**
Non-Extraction Group	100	1.246	.506
	200	.945	.708
	500	1.835	2.126*
	1000	1.524	2.457*
	1500	1.538	1.735
	2000	3.235**	2.254*
Extraction Group	100	1.102	2.091*
	200	1.299	2.596*
	500	1.855	3.978**
	1000	4.244**	4.355**
	1500	2.169*	2.327*
	2000	5.261**	4.683**

* $.05 > P > .01$

** $P < .01$

the exception of the 100 gram force 90° reading, the 200 gram force 90° reading and the 500 gram 90° reading. Generally, it can be stated that the trend is a return to the pretreatment levels. All levels are rising and tending to return to normal. Although the extremes have not returned the middle operating ranges are approaching pretreatment levels.

TABLE 6 presents the "t" values resulting from the comparison between the first measurement (prior to treatment) and fourth measurement (approximately one year after appliance insertion). Only one-third of the "t" Test comparisons made between these measurement periods were shown to be statistically significant. The 100 and 200 gram force values for all groups were statistically significant. For the combined group at the 2000 gram force level and the 90° axis a significant difference was found, and for the extraction group at the 2000 gram force level and the long axis comparison a significant difference was also noted. None of the middle force values (500, 1000, 1500) showed a significant difference for the "t" Test comparisons made between the first and fourth measurement periods. The significant "t" values for 90" axis ranged from 2.470 to 5.139 and for the long axis they ranged from 2.092 to 6.155. These values show that the middle operating ranges have all returned to normal, but the extremes (100, 200, 2000) have not returned to pretreatment levels. However, since the trend is a return to normal it would seem that the extremes would also return. Nevertheless, it is interesting to note that at the 100 and 200 gram levels at the fourth measurement the subjects are discriminating better than at the first period, and at the other extreme,

TABLE 6

Statistical Comparisons of Mean Weber Ratios For Dusza's First Measurements (Four Days After Appliance Insertion) Versus Fourth Measurements (Approximately One Year After Appliance Insertion)

	Force Values	90° "t" Values	Long Axis "t" Values
Combined Group	100	5.139**	6.155**
	200	4.455**	5.634**
	500	1.277	.683
	1000	1.598	.167
	1500	1.376	1.370
	2000	2.470*	1.948
Non-Extraction Group	100	3.654**	5.324**
	200	4.350**	4.027**
	500	.119	.788
	1000	.440	.661
	1500	.099	.928
	2000	1.848	.278
Extraction Group	100	3.219**	3.919**
	200	2.929**	4.187**
	500	1.465	1.506
	1000	1.483	1.629
	1500	1.879	1.387
	2000	1.553	2.092*

* $.05 > P > .01$

** $P < .01$

the 2000 gram level, the discriminatory ability may be less than at the beginning of treatment.

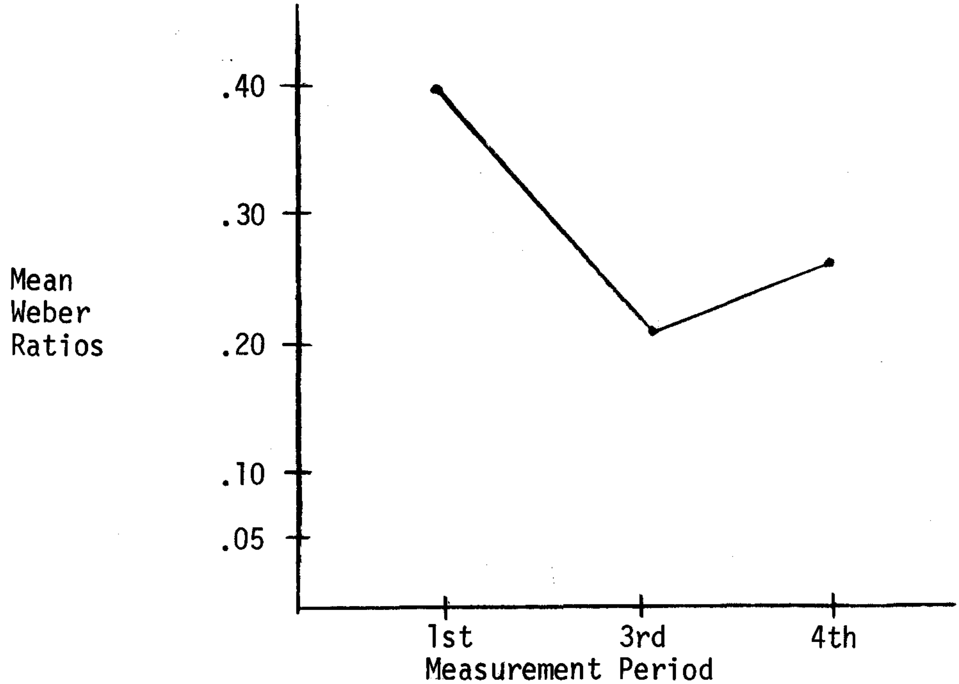
When comparing the mean Weber ratios of the fourth measurement period with the mean values from the other measurement periods the Weber ratios for the fourth measurement period are all higher than the third reading but lower than the first reading with the exception of the 500 gram and 1000 gram long axis readings and the 1500 gram 90° axis reading which were higher at the fourth period than at the first measurement. These findings substantiate the observation that the trend is to pre-treatment levels.

The Weber ratios were plotted against the first, third and fourth measurement periods for each standard Force stimulus employed. These were graphic representations of the changes in the Weber ratio between the measurement periods for each particular standard force value. The Weber ratios for each standard force stimulus are presented in FIGURES 3 through 8.

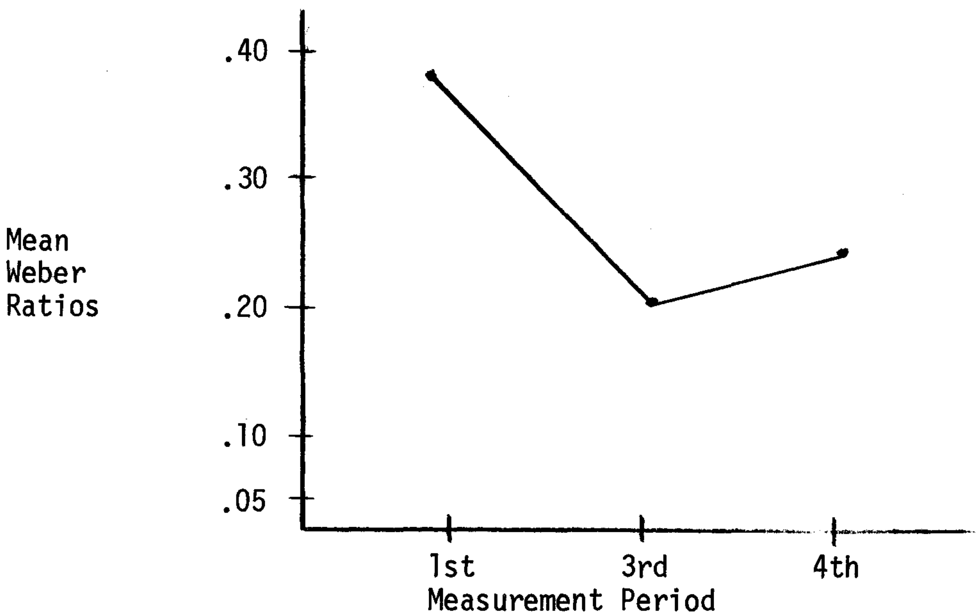
The plots of the Weber ratios for the 100 gram force are presented in FIGURE 3. The curves are very similar for both axes in that the plots for the first period are high followed by a drop at the third period and a linear return at the fourth period. The plot at the first period is higher than any subsequent period. The plots for the 200, 500, 1000, 1500 and 2000 gram values show curves which follow the same basic pattern (FIGURES 4 to 8). The curves show more linearity as the gram forces levels increase. The plots for 1500 gram force level show the most

FIGURE 3

Mean Weber Ratios Plotted Against Measurement Periods For the 100 Gram Force



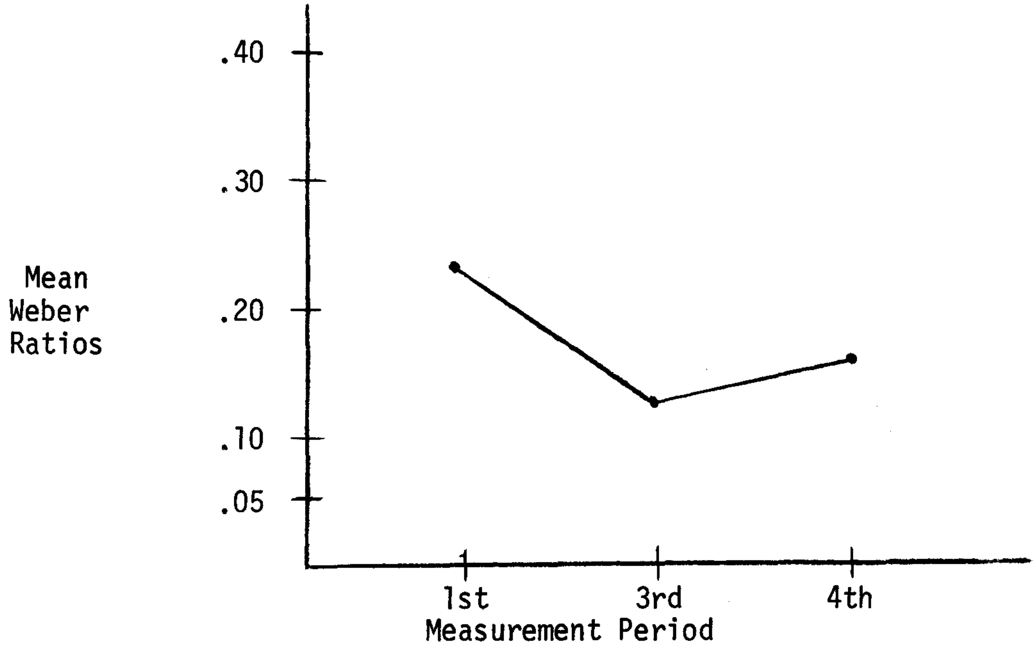
(a) Applied 90° To the Long Axis



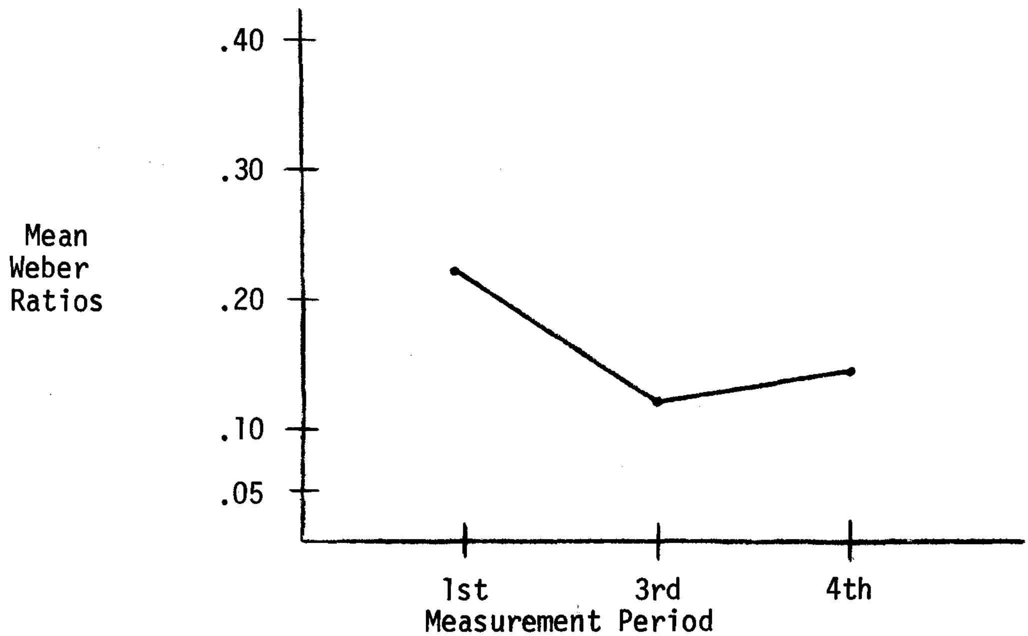
(b) Applied Along the Long Axis

FIGURE 4

Mean Weber Ratios Plotted Against Measurement Periods For the 200 Gram Force



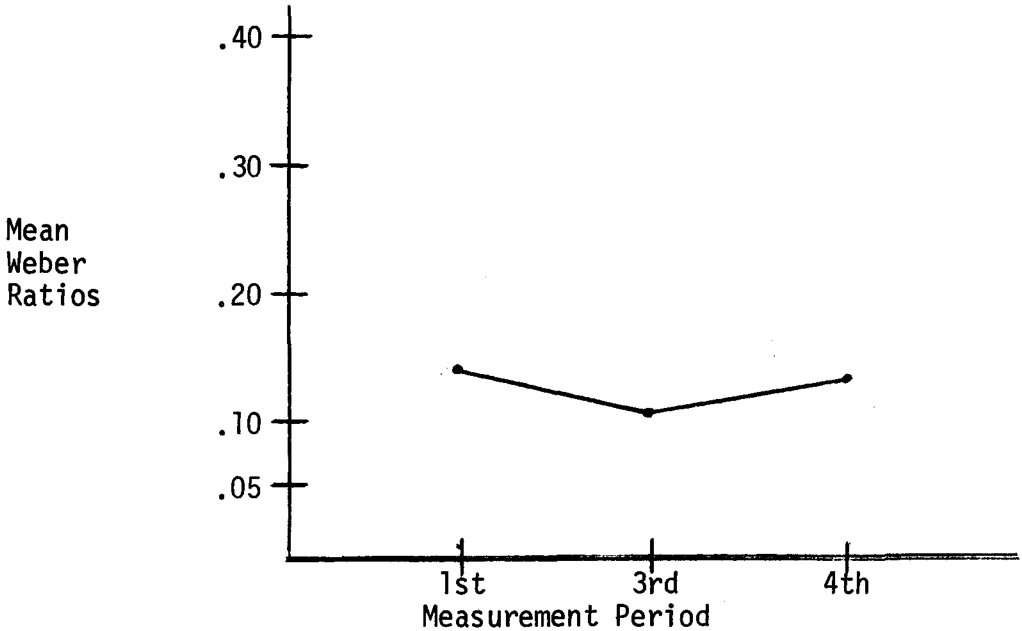
(a) Applied 90° to the Long Axis



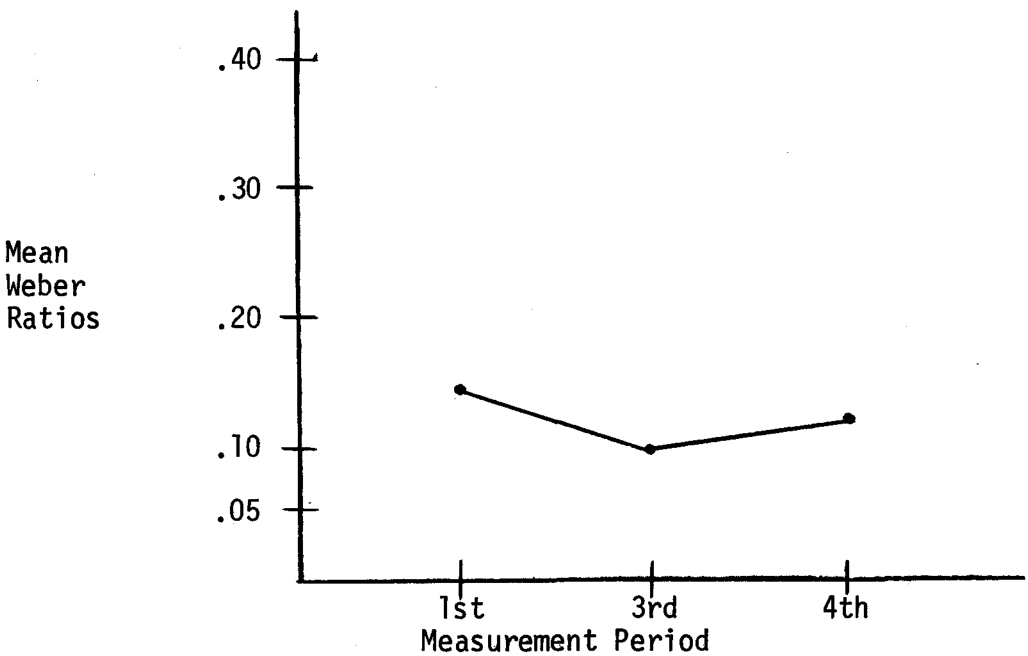
(b) Applied Along the Long Axis

FIGURE 5

Mean Weber Ratios Plotted Against Measurement Periods For the 500 Gram Force



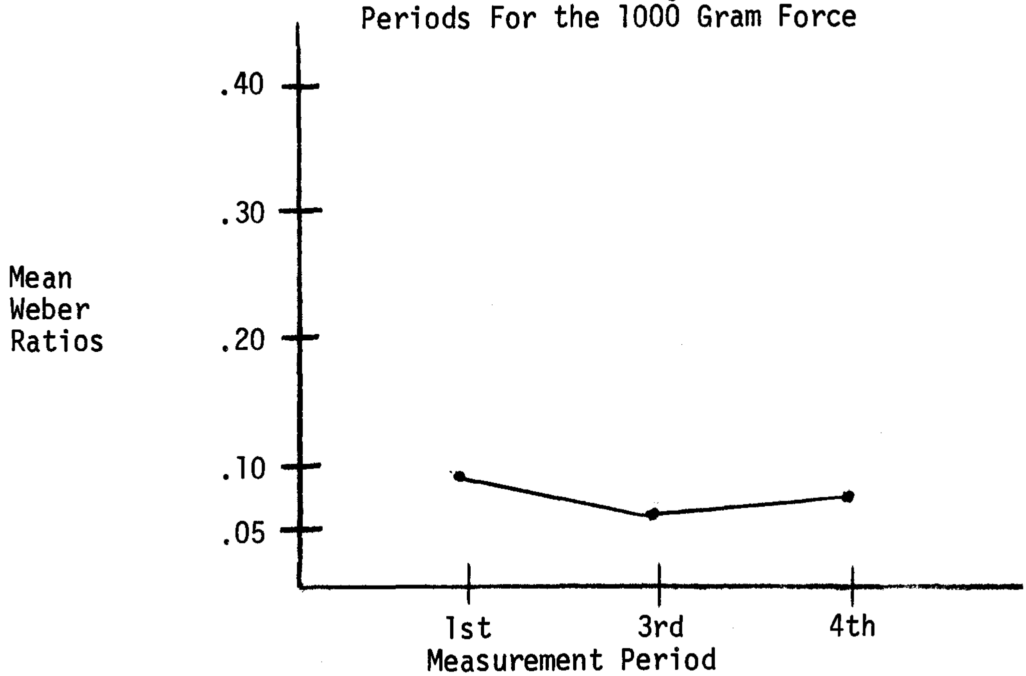
(a) Applied 90° to the Long Axis



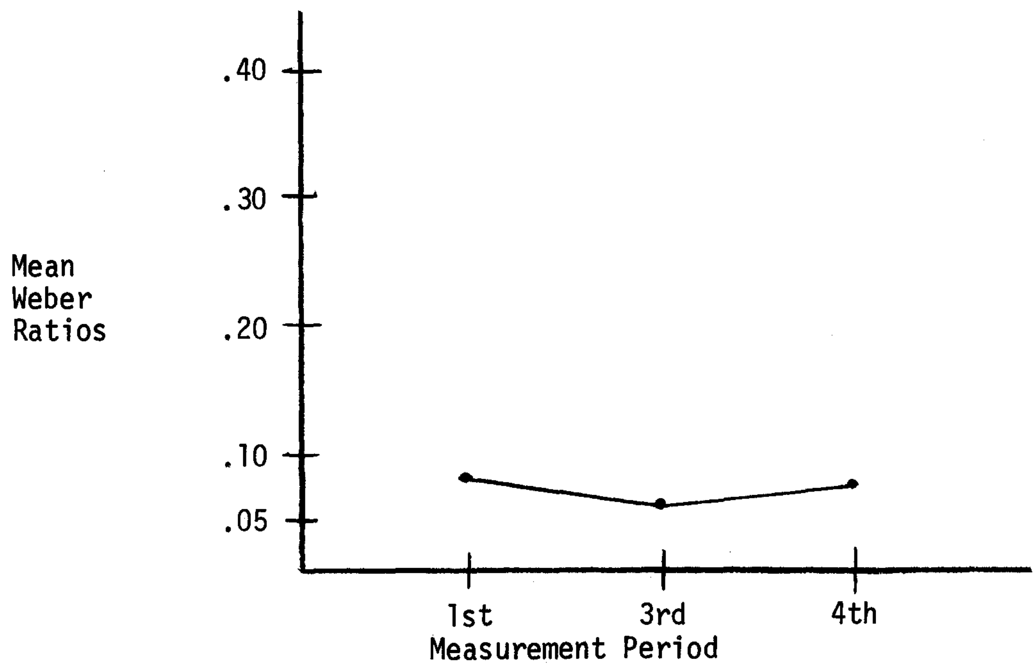
(b) Applied Along the Long Axis

FIGURE 6

Mean Weber Ratios Plotted Against Measurement Periods For the 1000 Gram Force



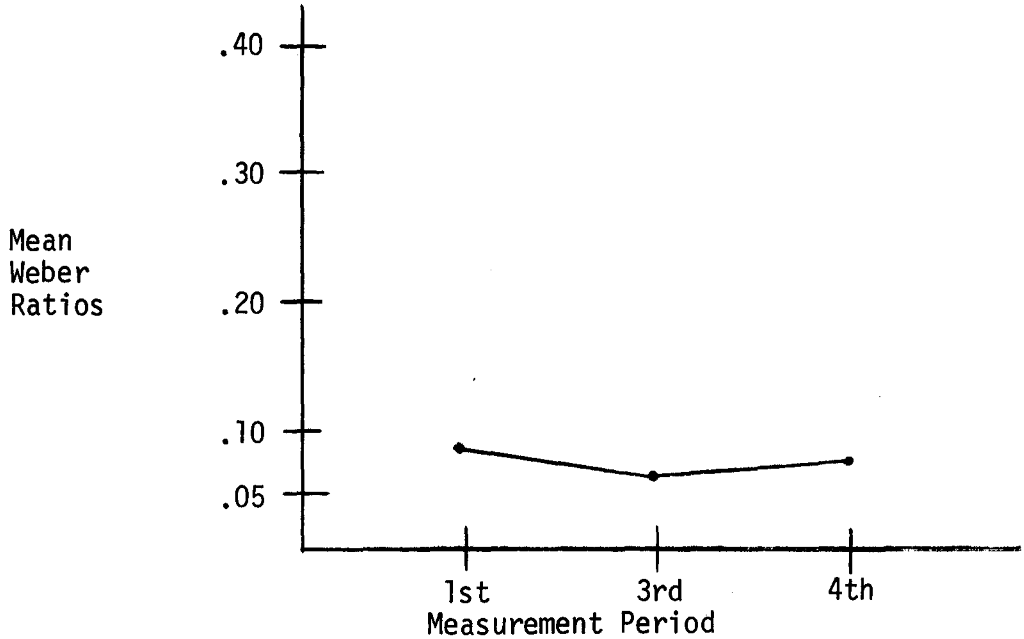
(a) Applied 90° to the Long Axis



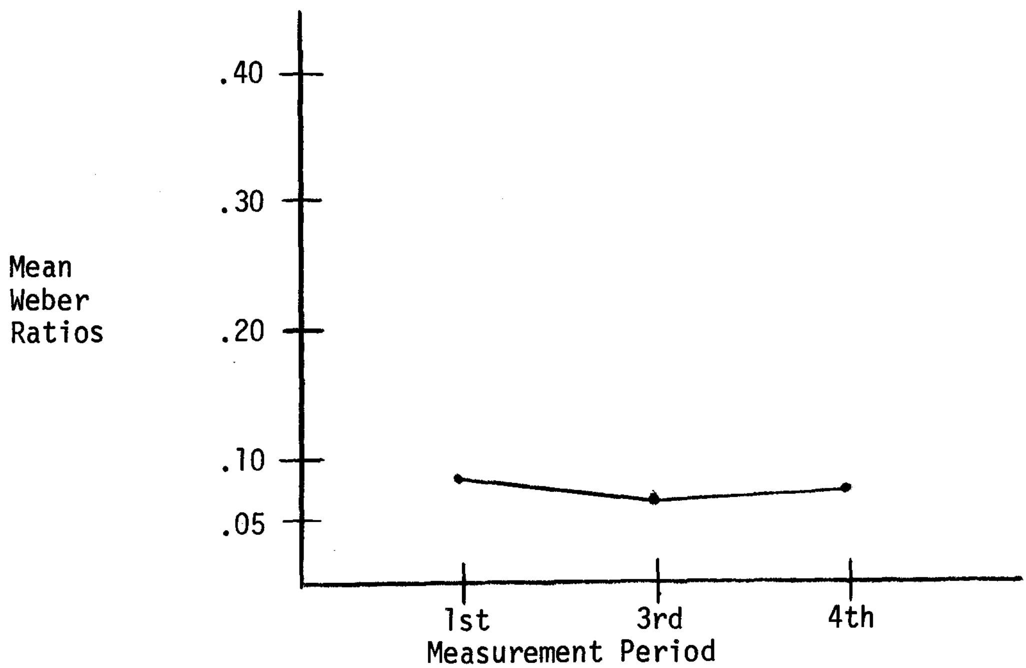
(b) Applied Along the Long Axis

FIGURE 7

Mean Weber Ratios Plotted Against Measurement Periods For the 1500 Gram Force



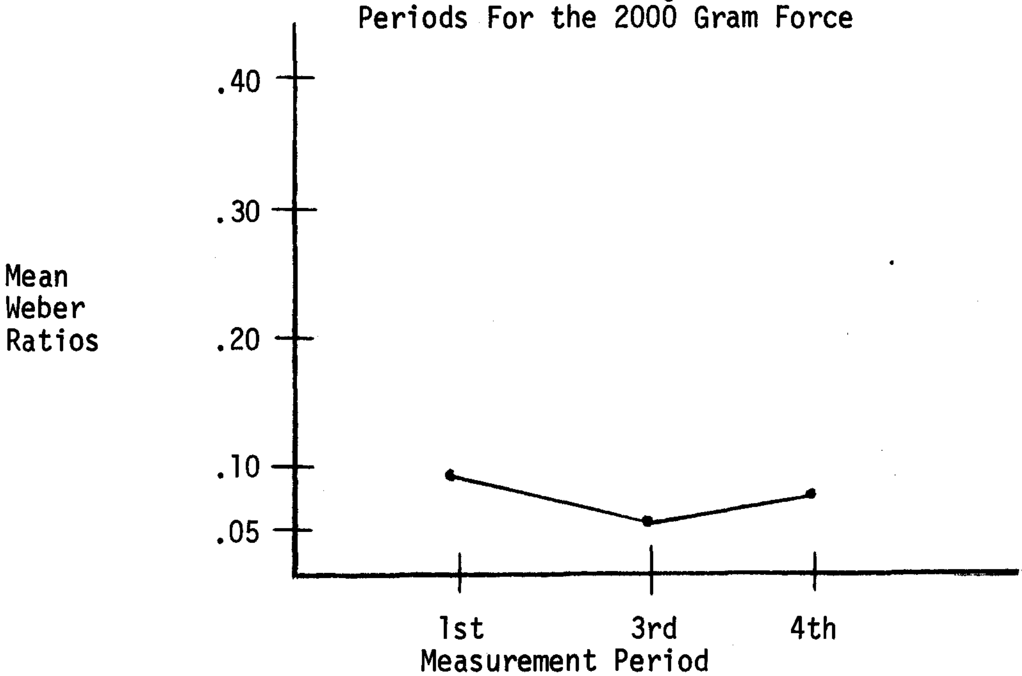
(a) Applied 90° to the Long Axis



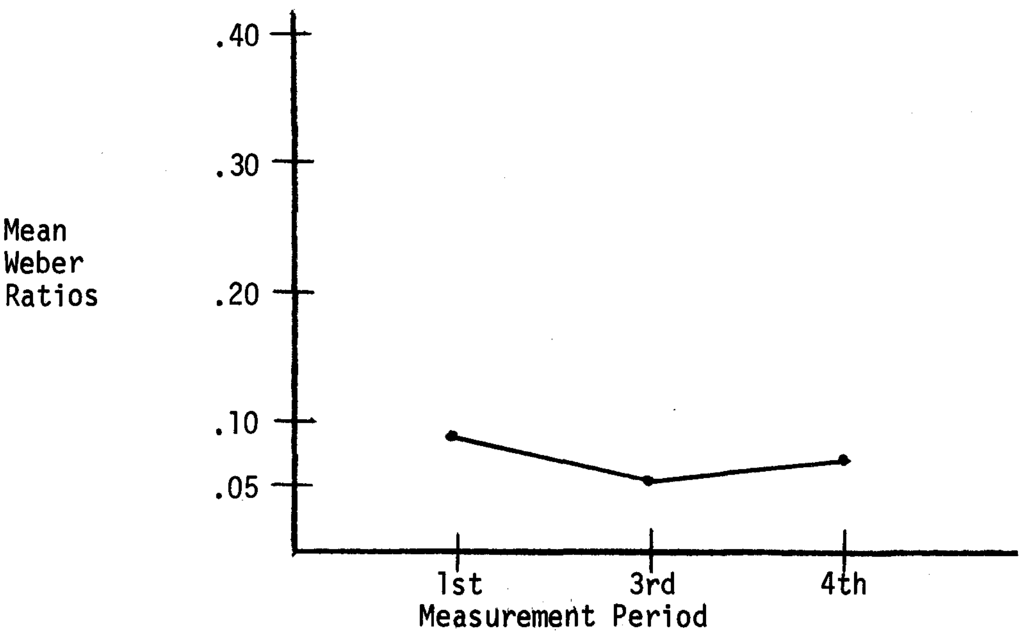
(b) Applied Along the Long Axis

FIGURE 8

Mean Weber Ratios Plotted Against Measurement Periods For the 2000 Gram Force



(a) Applied 90° to the Long Axis



(b) Applied Along the Long Axis

linearity. For each gram force the plots for the first period are higher than the subsequent periods, however, as the gram force increases the difference between the Weber ratios for the three periods decreases graphically and a more linear relationship occurs. The plots for the 500, 1000, 1500 and 2000 gram forces for the three measurement periods show curves which are almost identical.

Fechner believed that the Psychophysical Law is best represented by the general formula $S=A \text{ Log } I + K$, however, Stevens held that this phenomenon is best expressed as a power function represented by the general equation $dS=KI^X$. The validity of Fechner's formula was tested by plotting the mean discernible difference for each force used against the logarithm of the forces, FIGURES 9 and 10. The Stevens formula was tested by plotting the logarithm of the mean discernible difference for each force used against the logarithm of the forces, FIGURES 11 and 12.

A review of the graphs demonstrates that the log-log plot generally exhibits better linearity than the semi-log plot. Therefore, for this study, it is felt that the log-log plot represents the Psychophysical Law more closely than the semi-log plot. The semi-log graphs and the log-log graphs all indicate that the optimal force range begins somewhere between 200 and 500 grams, but the upper limits of the range are not determined. The log-log graphs exhibit a more linear relationship between 200 and 2000 grams. If the mean differential thresholds for the 1000 gram force were higher the semi-log graphs would exhibit a more linear relationship for the 500 to 2000 gram force range.

FIGURE 9

Semi-Logarithmic Graph of Mean Differential Thresholds Plotted Against Forces Applied 90° to the Long Axis of the Maxillary Canine

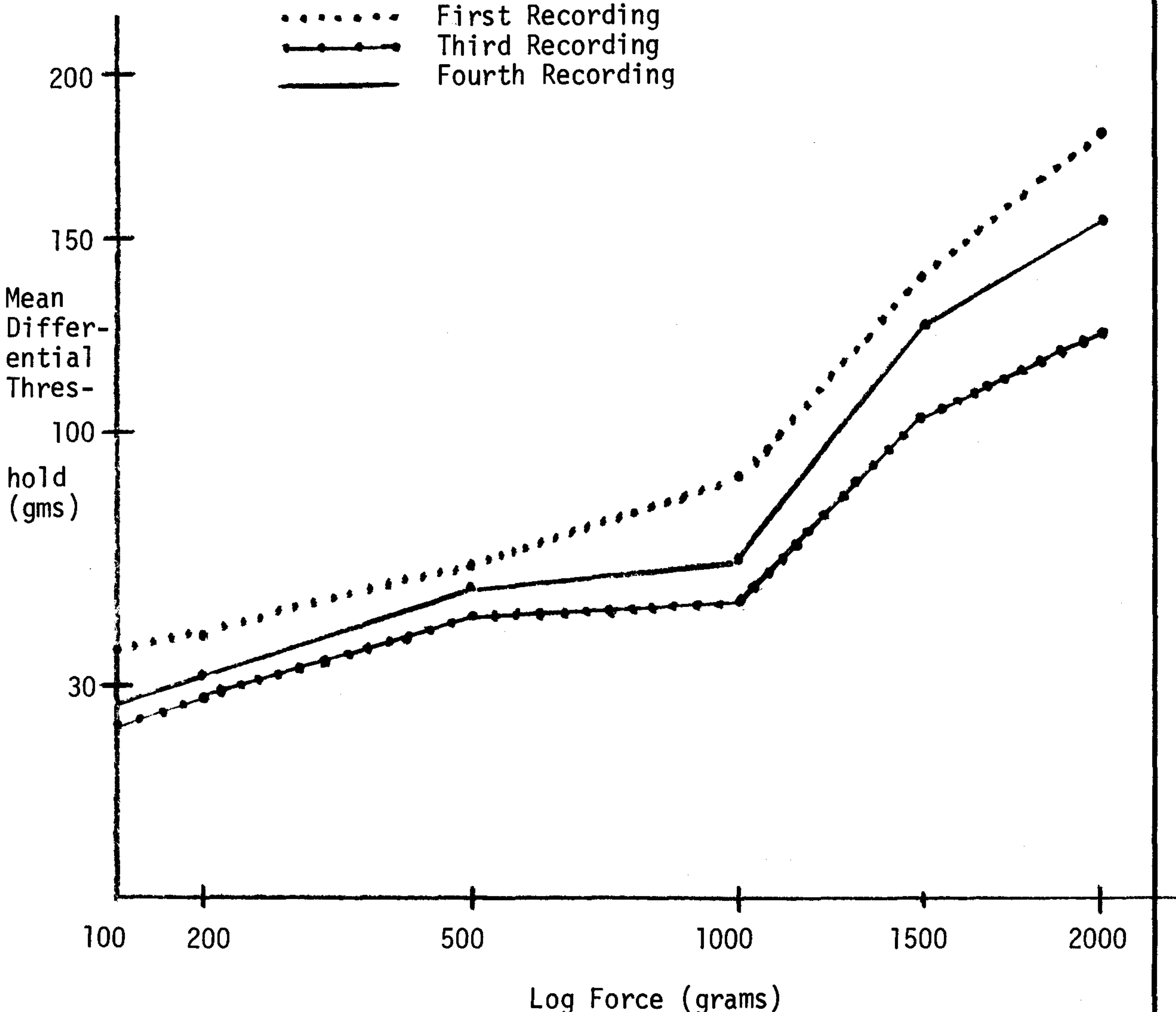


FIGURE 10

Semi-Logarithmic Graph of Mean Differential Thresholds Plotted Against Forces Applied Along the Long Axis of the Maxillary Canine

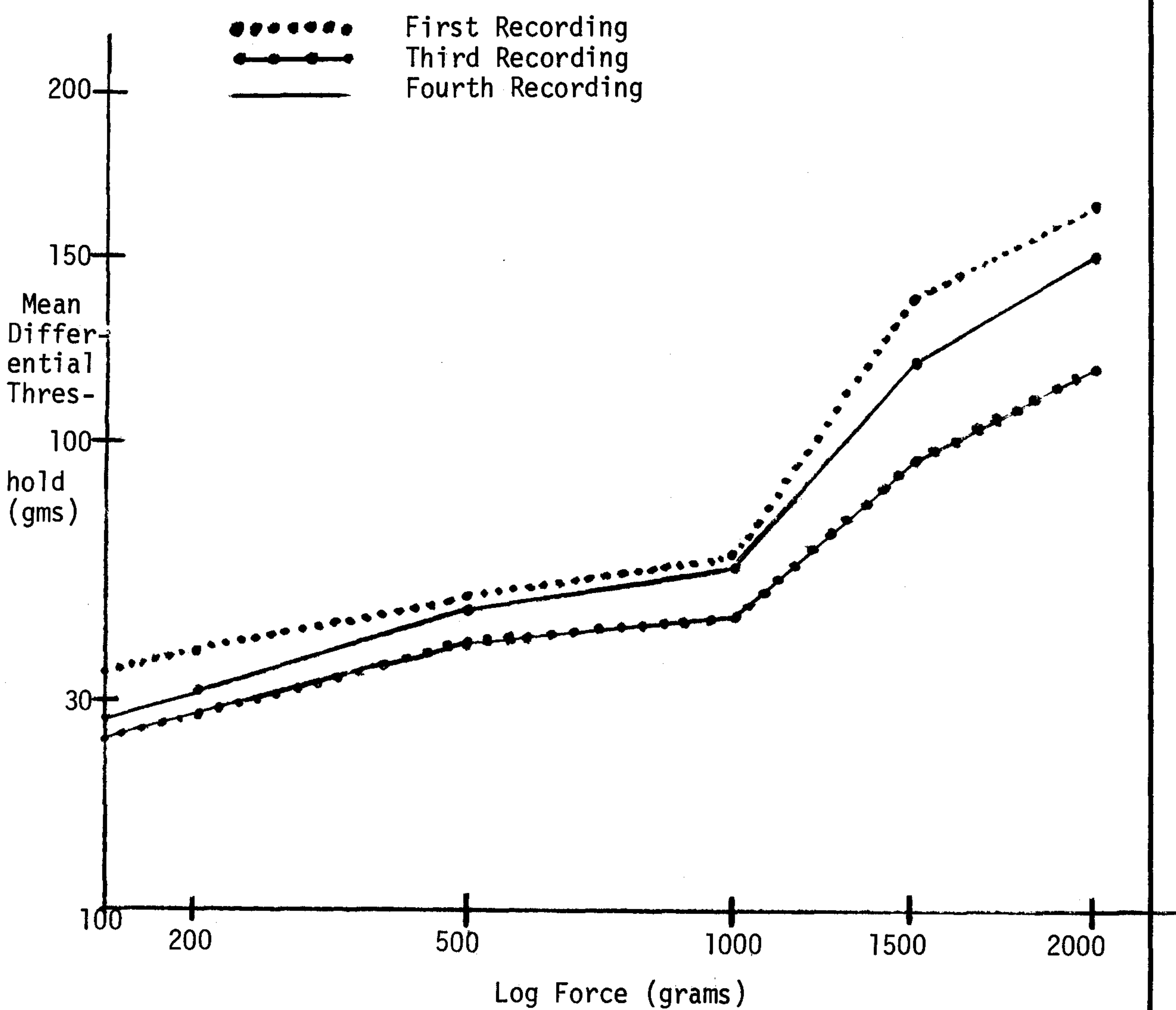


FIGURE 11

Logarithmic-Logarithmic Graph of Mean Differential Thresholds Plotted Against Forces Applied 90° to the Long Axis of the Maxillary Canine

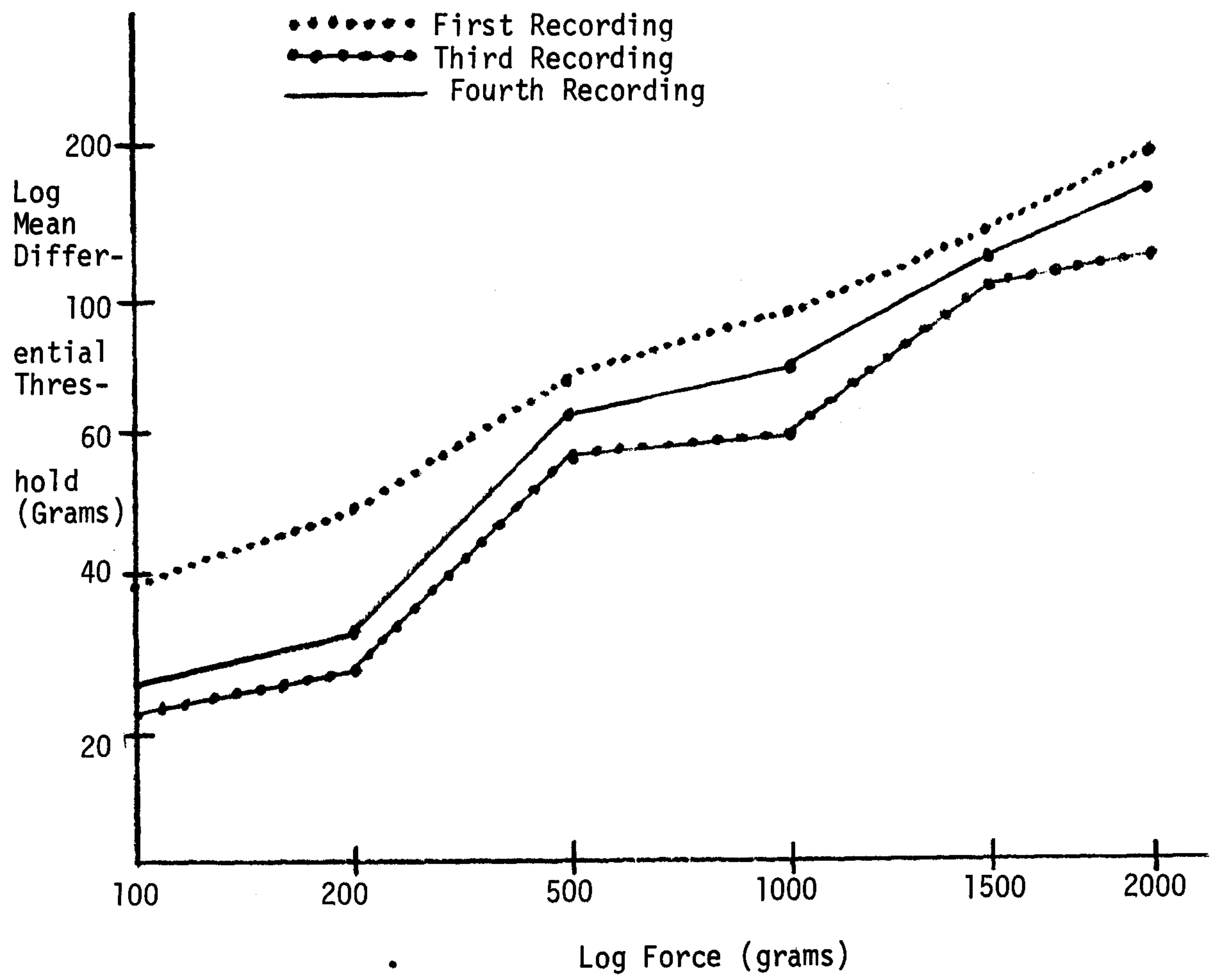
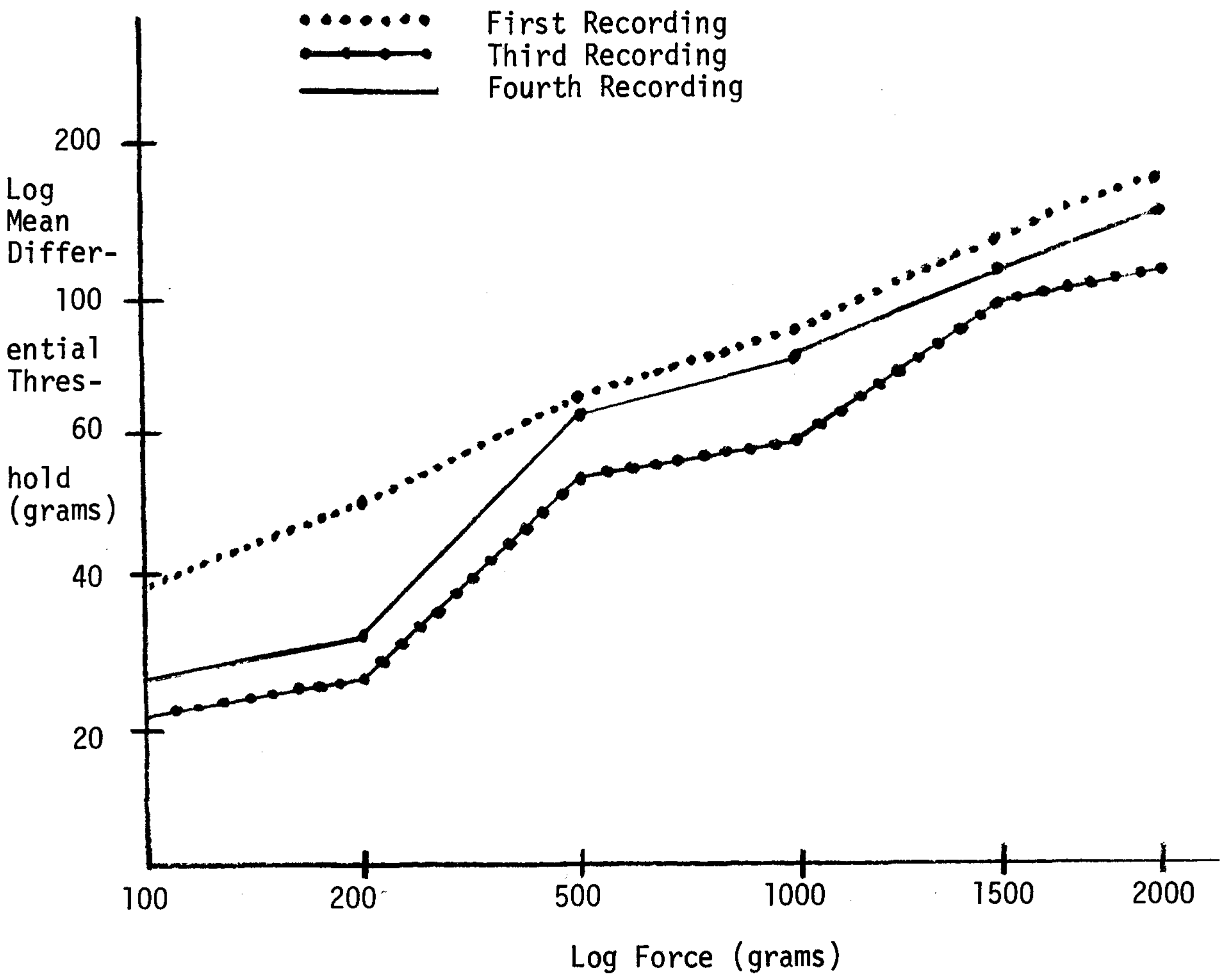


FIGURE 12

Logarithmic-Logarithmic Graph of Mean Differential Thresholds Plotted Against Forces Applied Along the Long Axis Of the Maxillary Canine



CHAPTER V

DISCUSSION

Fechner, whose work led to the formulation of the Psychophysical Law, assumed during his studies that the "just noticeable difference" of sensation always contained the same number of sensation units. Therefore, he believed the Weber Ratio, the ratio between the change in intensity of a stimulus and the intensity of a stimulus, remained a constant throughout the entire scale of sensory stimuli.

Since Fechner's time many investigators have challenged the validity of the Fechner stated Weber's Law. James, Hecht, Pieron, Guilford, Treisman, Bowman and Nakfoor, Soltis, Bonaguro and Dusza all generally agree that the Weber Ratio is a constant only over the intermediate ranges of intensity, and that near threshold or physiologically tolerable limits of intensity the ratio increases.

The results of this experiment are basically in agreement with the observations of these investigators. It was found that for the lower intensities (100 and 200 grams) the Weber Ratio did not show any constancy and discrimination was relatively poor. Around the 500 gram force level the Weber Ratio began to show constancy. The extreme upper limits of the optimal range were not determined, and the Weber Ratios from TABLE 2 show that the 2000 gram force stimuli were within the optimal range of the Psychophysical Law. A possible explanation for this could be that the lower force values were very close to the threshold limits of the maxillary canine tooth, whereas, the higher applied forces were still within the physiologically tolerable ranges.

The Japanese investigators, Kawamura and Watanabe, tested the discriminatory ability of test subjects by having them bit down on stainless steel wires of small diameter. Basing their findings on 100 percent discrimination Kawamura and Watanabe established the Weber Ratio for the natural human dentition to be 0.1 in both the incisor and molar areas. Subsequent studies by Bowman and Nakfoor, Soltis, Bonaguro and Dusza found Weber Ratios for selected teeth in the human dentition to compare favorably with the findings of Kawamura and Watanabe. However, the findings of Bowman and Nakfoor, Soltis, Bonaguro and Dusza were based upon 70 percent discrimination. If 100 percent discrimination had been required the Weber Ratios may have been higher.

This study demonstrated Weber Ratios ranging from .07 to 0.16 for 70 percent discrimination in the optimal range. As previously noted, if 100 percent discrimination had been required these may have been higher.

Fechner's Psychophysical Law states that sensation increases as the logarithm of the stimulus intensity increases and can be expressed by the general equation $S=A \text{ Log } I + K$. This Law has been challenged by numerous investigators, and most notably by Stevens. He believes that the Law is best expressed as a power function of the general form $dS=KI^{X}$.

If the Fechner equation provides the better fit for the data of this experiment a semi-logarithm plot should exhibit linearity for those forces that fall within the optimal limits of the Psychophysical Law. However, if the power function equation as proposed by Stevens better fits the data then a logarithmic-logarithmic plot will best exhibit the desired linearity for those forces that fall within the optimal functional limits of the Psychophysical Law. When comparing the two plots for this study a more linear relationship can be demonstrated for the functional range of the Psychophysical Phenomenon in the logarithmic-logarithmic graphs (FIGURES 11 and 12) than in the semi-logarithmic graphs (FIGURES 9 and 10). Based upon these findings the author feels that the power function of Stevens, $dS=KI^x$, fits the data of this study better than the Fechner logarithmic equation.

It can be concluded, based upon the results of this study, that the maxillary canine did not exhibit directional sensitivity to the extent reported for the cat canine in studies by Pfaffman, and for the rabbit incisor in Ness' study. In all cases, labially and incisally applied forces had nearly the same range of discrimination with regard to the actual values in grams employed. These findings were in general agreement with those of Bowman and Nakfoor, Soltis, Bonaguro and Dusza and would offer indirect evidence as to the location of the pressoreceptors in the human periodontal ligament. The lack of directional sensitivity lends support to the findings of Lewinsky and Stewart that the pressoreceptors are evenly distributed throughout the periodontal ligament, rather than being limited to the apical one-third of the root as reported by Kizior in his study of the cat.

It is interesting to note that Kruger and Michel describe the canine teeth of cats as having a richer representation of neurons than any other teeth. Corbin and Harrison found that in cats the canine teeth are the most responsive oral structures. Bonaguro found in his study that the mandibular canine showed the greatest sensitivity to the application of force stimuli and suggested his results may indicate an evolutionary retention of the canine tooth as a tactile organ, although these teeth do not function significantly as tactile organs in humans.

The forces effecting this study were derived from intrinsic and extrinsic sources. The intrinsic forces resulted from the various archwires, while the extrinsic forces were derived from orthodontic elastics, elastic thread and auxillary attachments. The forces generated by these appliances were calculated to be in the range of 60 grams to 170 grams.

The effect of these orthodontic forces on the ability of the individual to discriminate forces applied to the surface of the maxillary canine were initially reported by Dusza (1968). The results of his study showed that the ability of patients to consciously discriminate between forces applied to the maxillary canine tooth significantly improved after insertion of orthodontic appliances. His findings stand in contrast to those reported by Nakfoor for the maxillary central incisor. Nakfoor found that after insertion of the orthodontic appliances the discriminatory ability of the individual decreased.

The results of this study, based upon measurements made after approximately one year of orthodontic treatment (fourth measurement period), demonstrated that the discriminatory ability of the same subjects tested by Dusza (1968) was returning to the established pretreatment levels. The optimal range for the Psychophysical Law for this experiment was found to begin somewhere between 200 and 500 grams, the upper limits of which were not established.

The forces created by the orthodontic appliances and transmitted to the maxillary canine represented a continuous application of forces ranging from 60 to 170 grams. This continual stimulation to the periodontal proprioceptive mechanism effected the patient's ability to discriminate between similar forces. These relatively light, continuous forces may have served to lower the threshold of the pressoreceptors in the periodontal ligament to such a degree that the test forces generated by the torque wrench applied to the tooth allowed the optimal range to be reached more readily. This then facilitated the subject's ability to discriminate between the varying forces. However, because there was a sustained force on the maxillary canine during the early stages of treatment straight, long range neural adaption was to be expected. Thus, as the patient adapted to these continuous forces the discriminatory ability of the maxillary canine tended to return to pretreatment levels.

Another aspect to consider is the fact that as treatment time continues and the major tooth movements have been accomplished, the actual force delivered to the teeth by the archwire and its attachments is diminished. This allows the distorted sensory receptors in the periodontal ligament to attain a normal functional arrangement.

An analysis of the accumulated data reveals a definite trend indicating that a return to normal, pretreatment, discrimination is to be expected following completion of orthodontic treatment.

CHAPTER VI

SUMMARY AND CONCLUSION

A clinical method was described for testing dental proprioceptive discrimination in the human periodontal ligament. The reliability of this method has been statistically proven by Nakfoor (Masters Thesis, Loyola University, Chicago, 1967). This method was used to determine the effect of prolonged orthodontic treatment upon periodontal proprioceptors of the maxillary canine tooth.

Thirty orthodontic patients were utilized in this study. Seventeen patients required the removal of premolar teeth to facilitate orthodontic treatment. Thirteen patients could be treated without removal of teeth. Measurements made at approximately one year of treatment provide values comparable to those obtained before any treatment was initiated. No significant difference was found between the two groups in their ability to discriminate between the applied forces after one year of orthodontic treatment.

A recent study shows that the ability to consciously evaluate proprioception from the periodontal ligament of the maxillary canine is significantly improved with the application of light orthodontic forces. This study shows that following prolonged orthodontic therapy this discriminatory ability returns to pretreatment levels.

The optimal working range of the Weber-Fechner Psychophysical Law, for this study, was found to begin between 200 and 500 grams; the upper limit of which was not established. The Weber Ratio for the periodontal ligament of the subjects was found to range between 0.07 and 0.16 of the standard force values over this range.

The differential threshold for this range is best expressed by the Steven's formula, generally expressed as $dS=KI^{x}$.

The overall trend to normal proprioceptive discrimination is expected upon the completion of orthodontic treatment.

APPENDIX I

Fourth Measurement (All Subjects, Approximately One Year After Appliance Insertion) Along the Long Axis Expressed In Actual Values and Percent of Actual Values

Subj.	100 Gms.		200 Gms.		500 Gms.		1000 Gms.		1500 Gms.		2000 Gms.	
No.	%	Gm.	%	Gm.	%	Gm.	%	Gm.	%	Gm.	%	Gm.
1	25	25	15	30	10	50	7.5	75	10	150	10	200
2	25	25	15	30	15	75	7.5	75	6.6	100	7.5	150
3	25	25	15	30	15	75	7.5	75	10	150	10	200
4	20	20	10	20	10	50	5	50	6.6	100	5	100
5	35	35	20	40	15	75	10	100	10	150	10	200
6	20	20	15	30	15	75	7.5	75	6.6	100	5	100
7	15	15	10	20	10	50	5	50	6.6	100	5	100
8	20	20	15	30	10	50	5	50	6.6	100	5	100
9	50	50	25	50	15	75	7.5	75	6.6	100	7.5	150
10	25	25	12.5	25	10	50	7.5	75	6.6	100	8.75	175
11	30	30	25	50	15	75	10	100	10	150	10	200
12	40	40	22.5	45	10	50	7.5	75	6.6	100	7.5	150
13	30	30	25	50	15	75	10	100	6.6	100	7.5	150
14	35	35	15	30	10	50	7.5	75	6.6	100	6.25	125
15	30	30	20	40	20	100	10	100	6.6	100	5	100
16	25	25	15	30	10	50	5	50	6.6	100	7.5	150
17	20	20	10	20	10	50	10	100	6.6	100	5	100
18	20	20	10	20	10	50	10	100	10	150	8.75	175
19	15	15	10	20	10	50	5	50	6.6	100	5	100
20	20	20	12.5	25	10	50	7.5	75	6.6	100	7.5	150
21	25	25	25	50	15	75	7.5	75	6.6	100	7.5	150
22	35	35	25	50	15	75	10	100	10	150	10	200
23	30	30	15	30	15	75	7.5	75	10	150	10	200
24	25	25	15	30	10	50	5	50	6.6	100	7.5	150
25	20	20	15	30	10	50	10	100	6.6	100	7.5	150
26	20	20	15	30	20	100	10	100	6.6	100	5	100
27	15	15	10	20	10	50	5	50	6.6	100	7.5	150
28	15	15	10	20	10	50	7.5	75	6.6	100	7.5	150
29	25	25	15	30	15	75	10	100	6.6	100	7.5	150
30	25	25	15	30	25	125	17.5	175	13.2	200	10	200

APPENDIX II

Fourth Measurement (All Subjects, Approximately One Year After Appliance Insertion) 90° To the Long Axis Expressed In Actual Values and Percent of Actual Values

Subj. No.												
1	20	20	15	30	10	50	7.5	75	6.6	100	6.25	125
2	25	25	20	40	15	75	10	100	8.3	125	7.5	150
3	25	25	20	40	15	75	7.5	75	10	150	10	200
4	15	15	12.5	25	10	50	7.5	75	6.6	100	7.5	150
5	20	20	15	75	15	75	7.5	75	10	150	10	200
6	35	35	17.5	100	20	100	12.5	125	10	150	10	200
7	15	15	12.5	45	9	45	5	50	6.6	100	5	100
8	20	20	15	75	15	75	7.5	75	8.3	125	8.75	175
9	50	50	25	75	15	75	10	100	6.6	100	7.5	150
10	20	20	12.5	50	10	50	5	50	6.6	100	7.5	150
11	30	30	12.5	25	10	50	5	50	10	150	10	200
12	50	50	25	50	20	100	10	100	10	150	10	200
13	50	50	25	50	15	75	7.5	75	8.3	125	6.25	125
14	30	30	20	40	10	50	7.5	75	6.6	100	5	100
15	30	30	10	20	10	50	10	100	6.6	100	10	200
16	40	40	20	40	10	50	7.5	75	8.3	125	8.75	175
17	20	20	12.5	25	10	50	5	50	6.6	100	5	100
18	15	15	10	20	6	30	7.5	75	10	150	10	200
19	25	25	12.5	25	10	50	5	50	8.3	125	7.5	150
20	25	25	17.5	35	10	50	7.5	75	6.6	100	7.5	150
21	15	15	12.5	25	10	50	5	50	5	75	5	100
22	35	35	25	50	20	100	10	100	6.6	100	10	200
23	30	30	15	30	15	75	10	100	6.6	100	7.5	150
24	25	25	12.5	25	8	40	4	40	5	75	6.25	125
25	25	25	15	30	15	75	7.5	75	6.6	100	7.5	150
26	10	10	10	20	20	100	10	100	13.2	200	10	200
27	15	15	12.5	25	10	50	5	50	10	150	7.5	150
28	20	20	12.5	25	10	50	5	50	6.6	100	7.5	150
29	25	25	15	30	10	50	5	50	6.6	100	7.5	150
30	30	30	20	40	20	100	15	150	13.2	200	10	200

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APPROVAL SHEET

The thesis submitted by Dr. Peter C. Knudson has been read and approved by members of the Department of Oral Biology.

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.

5/23/69
Date

Douglas C. Bowman
Signature of Advisor