1968

A Psychophysical Analysis of the Discriminatory Ability of Orthodontic Patients to Forces Applied to the Maxillary Canine Tooth

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A PSYCHOPHYSICAL ANALYSIS OF THE DISCRIMINATORY ABILITY OF ORTHODONTIC PATIENTS TO FORCES APPLIED TO THE MAXILLARY CANINE TOOTH

BY

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A THESIS SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF LOYOLA UNIVERSITY IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

JUNE

1968

LIFE

Gerald Raymond Dusza was born on October 9, 1938 in Punxsutawney, Pennsylvania. Shortly after he was born his family moved to Warren, Ohio.

After his graduation from Warren G. Harding High School in June, 1956, he entered Youngstown University. He received his B.A. degree from Youngstown University in June, 1960. He entered Loyola University School of Dentistry in 1960, and received his degree of Doctor of Dental Surgery in 1964.

Following graduation from dental school, he was commissioned a Lieutenant in the Dental Corps of the U.S. Naval Reserve. He was assigned to active duty with the Fleet Marine Force, First Marine Division, Camp Pendleton, California, and later Okinawa.

Following his release from active duty in April, 1966, he began graduate studies in oral biology at Loyola University, Chicago, Illinois.

He is married to the former Mary Catherine Kostner of Chicago, Illinois. They have one child, Nancy Elizabeth.

ACKNOWLEDGEMENTS

I would like to extend my sincere appreciation to those patients who volunteered to participate in this study.

I would also like to thank Douglas C. Bowman, M.S., Ph.D., Professor of Physiology, Loyola University, my advisor, who inspired this research and contributed his invaluable assistance and supervision throughout the course of this work.

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CHAPTER I

INTRODUCTION AND STATEMENT OF THE PRØBLEM

Many studies have been reported on the sensory output from the periodontal ligament recorded along some aspect of the trigeminal nerve. However, a subject relatively unexplored in Dentistry is the assessment of the sensory perception of the periodontal ligament to stimuli transmitted through the teeth.

The purpose of this study is to determine the initial effects of orthodontic forces applied to the maxillary canine tooth upon the ability of patients to consciously discriminate between varying force stimuli. This study also entails a report of the Psychophysical Law (Weber-Fechner Law) in the initial stages of orthodontic treatment.

CHAPTER II

REVIEW OF THE LITERATURE

1. Weber's Law:

The initial research on differential sensitivity antedates Weber's Law. Bouguer, in 1760, (from Boring 1942) was the first to perform the shadow experiment. Two candles project shadows of a rod upon a white screen. One candle is moved away from the screen until the shadow that it projects is 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 is approximately constant for any pair of distances at which the two candles are adjusted. He set the ratio at "1/64"; that is to say, the shadow was first noticeable when the far candle was eight times as far from the screen as the near candle.

Fechner and Volkmann, in 1858, (from Boring 1942) repeating the experiment found the fraction to be 1/100; while Argo (1850) reported a fraction of 1/133.

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

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

Aubert, in 1865, (from Boring 1942) showed how great the ratio was when he obtained values from 1/3 at low intensities to 1/146 at high intensities.

Misiak and Sexton (1966) point out that Weber's experimentation on the just noticeable difference included not only visual, but also temperature, touch and auditory discrimination. Working on the perception of differences between weights, the length of lines, and the pitch of tones, Weber found that in order for a subject to notice a change in the stimulus, this change must constitute a certain portion of the stimulus. 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 acting on the sense organ. He found this proportion or ratio to be 1/30 for weight; 1/150 or even 1/100 for lines; and 1/160 for tones.

These findings led Weber 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."

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 was noticeable. Then to a 200 gram weight we should have to add 4 grams to perceive a difference. From his observations and Weber's results, Fechner derived a ratio between the sensory stimulus and the change in stimulus before a difference between the two can be noticed. 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, therefore, is a constant. Fechner called this ratio Weber's Law and expressed it in mathematical terms in the formula, $\Delta R/R=C$, where R is the stimulus, ΔR the just noticeable difference, and C the constant.

James (1890) cites some ratios for Weber's Law as: 1/100 for sensation of light, 1/17 for muscular sensation, and 1/3 for the feeling of pressure, warmth, and sound.

He describes his feelings as he surveys the facts in 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. The amount is expressible as a certain fraction of the entire impression to which it is added.

He describes Weber's Law as an empirical generalization of practical importance.

Hecht (1924) agreed with Exner (1879) and Wundt (1908) that Weber's Law holds over a very moderate range of intensities. He criticized the limits Fechner set for the intensity scale as being too extreme.

Thurstone (1927) wrote that Weber's Law is usually stated as the just noticeable increase of a stimulus is a constant fraction of the stimulus. He 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 judgements '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). He found the Weber ratios for warm and cold limens from 16° to 44° C. to range between .0035 to .0053.

Holway and Pratt (1936) in several special studies of the Weber function for different senses noted that as R increases, the Weber fraction for intensity discrimination decreases initially and approaches a finite minimal value. They also observed that in the majority of these instances, moreover, $\Delta R/R$ passes through a minimum and then tends to rise.

Van Leeuwen (1949) investigating the response of a frog's muscle spindle suggests that Weber's Law holds as a property of the single stretch receptor, but that the relation is clear only when a large number of results are taken into consideration.

Woolworth and Schlosberg (1958) point out that Weber's Law is fairly constant throughout the middle range of intensity for most of the senses. It differs widely 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 every sense has its limit beyond which it yields no greater sensation. This limit is the terminal threshold, TL. It varies for senses.

Kawamura and Watanabe (1960) confirmed the discriminative threshold of thickness of two wires when the material was held between the teeth of persons with natural and artificial dentition. They found that persons with natural dentition can discriminate 100% between two wires with a difference in diameter of a Weber ratio of 0.1 or more. This fact was recognized in both the incisors and molars. They could not confirm their findings in the tests with artificial dentitions. The authors believe that the existence of the periodontal "membrane" is necessary in both the maxillary and mandibular teeth to correctly discriminate material size.

Treisman (1964) states that Weber's Law holds approximately, for the midranges of many stimulus dimensions, but not for low and sometimes high values. He attempts to show that this response variance is due to three sources of noise which limit discrimination. These are the irreducible physical variance of the stimulus; the spontaneous "background" noise to which the stimulus can be considered to be added; and neural noise arising from variation in the response of the pathways transmitting the sensory message centrally.

Grossman and Hattis (1965) used the Semmes-Weinstein anesthesiometer to study relative tactile sensitivity at several oral sites and on the hand. They found the upper lip the most sensitive with the tongue and lower lip more sensitive than the incisive papilla. The finger and palm were less sensitive to tactile stimulation than all oral sites studied.

Boring (1942) points out that Weber's Law won belief because it is obvious that the just noticeable difference increases as the stimulus increases and that it represents more nearly a constant proportion of the stimulus than a constant absolute amount.

2. Fechner's Law

When Fechner, in 1860 (from Woolworth and Schlosberg 1958) published his treatise on "Psychophysics," he was trying to work out in a scientific manner the relations between body and mind, or between the psychical and physical worlds. He hoped to discover some definite quantitative relations between the physical stimulus and the resulting conscious sensation.

Fechner, (from Granit 1955) concluded that the increment threshold ΔR of the stimulus R was constant and carried out many experiments to establish the validity of this generalization $\Delta R/R$=constant. He regarded the constant as a minute sensory unit ΔS. He then defined as Weber's Law or the fundamental law:

1. $\Delta R/R=K\Delta S$ (where K is a factor of proportionality). He then suggested that ΔR and ΔS were true limiting values dR and dS (from calculus) and that he could rewrite (1) as an elementary differential equation,

(2) $dS/dR=1/KR$ (which gives)

(3) $S=a \log R+b$

in which the constant a also includes the coefficient for transformation into decadic logarithms and b is an integration constant. This then is Fechner's Law which he also derived in other ways. It states that something in sensation that one might call its quantity S is proportional to the logarithm of the stimulus R.

His law shows that when stimulus strength R increases in geometric progression, something in sensation that we call its quantity S increases in arithmetical progression.

Pieron (1952) relates that Helmholtz (1866) Delboeuf (1872) and Broca (1894) working with brightness steps demonstrated that the sensation increases proportionally to the logarithm of a ratio in which intensity is the variable balanced by the addition of constants.

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.

Cowdrick (1917) experimenting with 89 cases over 5 intensities showed that the formula of Fullerton and Cattell, $S=C\sqrt{R}+b$ represents the actual results much more adequately than does the Weber-Fechner formula.

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

Thurstone (1929), in an experiment concerning the assessment of the varying numbers of dots on cards showed that Fechner's Law was valid for his experiment. He pointed out a methodological error in the Sanford weight experiment and corrected this in his experiment by plotting S on R and ascertaining an S value for each of the 24 stimulus magnitudes.

Matthews (1931 and 1933) studying 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.

The results of Hartline and Grahm (1932) parallel 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.

Pfaffman (1939) demonstrated that the application of a vibrating stylus to the surface of the intact tooth (of cats) gave rise to an oscillatory discharge in the dental nerves which is synchronized with the frequency of the stimulus.

Ness (1954) reported that the neural response obtained during mechanical stimulation of a rabbit's incisor with forces of less than 100 grams produced a linear relationship when plotted against the logarithm of the magnitude of the stimulus.

Many investigators have challenged Fechner's Law on varying grounds.

Guilford (1932) suggests a generalized psychophysical law with a power function existing between stimulus and response.

Cobb (1932) concluded that Fechnerian reasoning begins with an oversight. He contends that the fact overlooked is that any two stimuli presented in conjunction will each modify the effect of the other. He suggests a formula where a factor (M) is assumed to be some sort of a weighted mean of all stimuli acting at the time.

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

Stevens (1957) working with Class I (prothetic) continua which deals with "how much" has shown that a power function exists between stimulus and response. The exponent, as measured on fourteen different continua, varies from 0.3 for loudness to about 2.0 for visual flash rate.

Luce, Bush and Galanter (1963) concur with Stevens and Galanter (1957) 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 cite some of Steven's power function exponents as ranging from .3 for loudness to 3.5 for electric shock through the finger.

Brett (1962) lists some objections to Fechner's Law as: (1) the laws and formulae of psychophysics are not supported by facts of experiment; (2) the law has only a psychological value; (3) that the mathematical expression of the formulae is wrong; (4) that Fechner ignores the real character of mental processes. He considers them to be mathematical rather than biological.

Miller (1964) relates sensitivity as a variable matter and that we should not measure it as we would a constant; but we should determine, (1) its extreme, (2) its mean value, (3) the dependency of its change upon circumstances and (4) make search for laws which hold throughout its variations.

He also points out that in 1958 Luce and Edwards, described flaws in Fechner's mathematics. They showed that Fechner's assumption that all "just noticeable differences" are subjectively equal is too weak to generate an interval scale for measuring sensation, and that a somewhat stronger assumption - that equally often noticed differences are equal unless always or never noticed - is actually required.

Nakfoor (1967) testing for proprioceptive discrimination in the human periodontal ligament found the optimal working range for the psychophysical phenomenon to be between 50 and 500 grams. In his experiment he utilized 50 orthodontic patients dividing them into two groups, (1) extraction, and (2) non-extraction. The maxillary central incisor was tested along its long axis and 90^o to its long axis.

Nakfoor found that the Weber ratios for determined proprioceptors of the periodontal ligaments of children ranged between 10 and 15 percent of the standard force values falling between 50 and 500 grams. He related that the differential threshold covering this range can be expressed best by the general formula:

$$dS = KI^x$$

He established the values for the K as .24 for 90^o to the long axis and .23 for the long axis. The values for x, 90^o to the long axis and along the long axis are .865 and .861 respectively.

3. The Periodontal Ligament: Innervation and Function

Peaslee, in 1857, (from Brashear 1936) stated that the teeth are able to detect various forms of pressure.

Black, in 1887, (from Brashear 1936) stated that the sense of touch resides wholly in the periodontal tissue, while the pulp always gives a painful response.

Bradlaw (1936) described the innervation of the teeth as follows: The branches from the main trunk to the formed tooth divide into pulpal and paradontal nerves before the apex is reached. The periodontal nerves enter the root membrane and pass upwards with blood vessels in a channel for protection from tooth movement and give off twigs, at intervals, to the surrounding alveolus. They may, at times, enter the interdental septum for varying distances before entering the periodontal membrane. The termination of these 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. He suggests that this may be a mechanism for the coordination and control of occlusion in the act of mastication.

Lewinsky and Stewart (1936) found that nerves entering the periodontal membrane come from the apical region of the tooth and course toward the gigiva along with the blood vessels. They receive fasciculi which enter the membrane through foramina in the aveolar process. They noted that the nerves ended in fine arborizations, small round bodies and recurrent loops, as they approach the cementum.

Lewinsky and Stewart (1936) showed 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. They divide and course apically and gingivally. The nerve fibers are of two types, (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. They suggest that the thick fibers with their end-organs are associated with tactile and pressure sensations, while the finer fibers are associated with pain. No fibers could be traced into the cementum.

Bernick (1957) using proteolytic enzymes to remove the non nervous fibers, found it possible to clearly identify the nerves present in the pulp, periodontal membrane, and gingiva. He found 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. Once 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 to the periodontal membrane arises from the dental and inter-alveolar branches of the alveolar nerves. The dental nerve fibers supply the periapical region and pass gingivally to form a bundle with the perforating branches of the interalveolar nerves.

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

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

b.) Medullated fibers may lose their myelin 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 (1966) identified two types of receptors in the periodontal ligament of the cat canine. One was ovoid and encapsulated and appeared in the apical 1/3 of the periodontal ligament. The other type observed throughout the periodontal ligament was free nerve endings.

Cuozzo (1966) working with cats concluded, histologically, that the small fibers (1-5u.) in diameter of the inferior alveolar nerve mediate painful responses originating in the receptors of the periodontal ligament.

Several investigators have shown that the nerves of the pulp are mainly responsible for the conduction of pain, and those of the periodontal membrane for pressure.

Stewart (1927) using an aethesiometer to find the minimal detectable pressure for incisors and canines in both jaws, found that the results varied between 7 and 50 gm/mm^2 for 260 teeth tested. He noted that the incisors gave similar results but the canines were higher than the average. He found that little difference was noticed between pulpless and normal teeth and that pressure must be transmitted along the nerves of the periodontal membrane.

Pfaffman (1939) contends that many, if not most, of the tactile and pressure endings are located in the periodontal membrane and receive their nerve supply through the alveolar bone, since little if any, change was noted upon stimulation of the tooth after removal of the pulp and destruction of the nerves in the apical canal by cautery.

Pfaffman also noted that when the electrodes covered the full nerve trunk, pressures against any surface of the tooth elicited responses of approximately the same magnitude. Single fibers, however, responded only to pressures against one particular surface. 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.

Loewenstein and Rathkamp (1955) using a spring esthesiometer studied the pressure threshold of 155 normal and pulpless teeth. Their findings showed an increasing threshold in both maxillary and mandibular teeth from incisors toward molars. They noted that the thresholds of pulpless teeth were significantly higher (57%) as compared to normal teeth. They suggest evidence for the existence of intradental as well as periodontal presso-receptors.

Brashear (1936) points out that the three varieties of sensations are mediated by different types of nerve fibers - touch by large myelinated fibers, temperature sensations by intermediate size fibers, and pain by fine myelinated and unmyelinated nerve fibers. He also suggests that through its supply of nerve fibers of all sizes, the peridental tissue of cat and human teeth becomes the organ of touch of the tooth and also responds to other sensations.

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

Jerge (1963) observed 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). He noted that all of the type II dental pressure receptor 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. In the units observed that innervated several teeth the threshold increased from tooth to tooth as one progresses posteriorly.

Kruger and Michel (1962) working with 23 decerebrate cats found that usually only one face of a tooth was sensitive to gentle touch. 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.

Ness (1954) reported three types of responses from the incisor nerve upon mechanical stimulation of the incisor crown: 1) slow-adapting, 2) fast-adapting, and 3) spontaneously discharging. He believes these responses emanate from three distinct groups of receptors and has proposed models which might show receptor directionality.

Nafe and Wagoner (1941) offer proof to show that adequate pressure stimulation consists only of movement due to the adjustment of tissues, in which endorgans are embedded, to a stimulating object. They show that adjustment requires time and that the time of stimulation and "adaptation time" coincide. They interpret this as showing that adaptation is due to loss of effectiveness of the stimulus rather than to any loss on the part of the end-organ.

Kizior (1966) working with the canine tooth of the cat observed marked increases in adaptation time with forces ranging from 4 to over 1700 grams. He observed 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 demonstrated by the differences in the potential amplitudes when the direction of the stimulus was varied. Forces along the long axis of the tooth evoked the highest potentials, indicating the greatest number of receptors were probably activated at this time. He explained this by the observance of the ovoid encapsulated structures only in the apical 1/3 of the ligament.

Nakfoor (1967) working with the maxillary central incisor of orthodontic patients has shown that the periodontal ligament loses much of its ability to discriminate between forces during treatment. He observed that the pain threshold is apparently lowered by the application of continuous light differential orthodontic forces to the teeth. His study shows a significant lowering of the pain threshold when forces from orthodontic appliances have been in effect for a period of four days.

Nakfoor further reported that no greater sensitivity existed for forces directed along the long axis than for those directed to the labial surface, 90^{o} to the long axis.

CHAPTER III

METHODS & MATERIALS

1. INTRODUCTION

This study utilized thirty patients who presented themselves for treatment in the Department of Orthodontics at Loyola University. Their ages ranged from eleven to seventeen years.

All data were taken from the maxillary canine teeth. Each subject had been previously examined and accepted as a "good teaching case" by the Loyola Graduate Orthodontic Department. Initial records were taken on each patient before any experimental data was collected. These records consisted of a set of plaster casts, full mouth radiographs, a panorex radiograph, three lateral and two postero-anterior radiographs, and color intraoral transparencies.

The subjects were divided into two groups: (1) extraction and (2) non-extraction.

The extraction group consisted of seventeen subjects whose first premolars were removed to facilitate correction of their malocclusion. These patients were examined three times. The first examination was after the initial records were taken but before any treatment had begun.

The second examination was two to four days after extraction of the maxillary first bicuspid teeth. The third examination was four days after the orthodontic appliances were placed.

The non-extraction group consisted of thirteen patients. They required two examinations. The first examination was after the initial records were taken but before any treatment had begun. The second examination was four days after the orthodontic appliances were placed.

The only subjects chosen were those whose maxillary canine teeth exhibited sufficient eruption and position so that the adjacent teeth did not interfere with the experimental equipment.

Previous to any subjects being tested, a pilot study was conducted on five orthodontic graduate students. Their ages ranged from twenty-six to forty-one years. The force values obtained from this pilot study were later used with the thirty orthodontic patients.

2. FORCE PRODUCING INSTRUMENT

The instrument used in this research was a specially designed torque wrench manufactured by the P.A. Sturtevant Company, Elmhurst, Illinois for Cuozzo and Kizior (1966), Figure 1.

A torque wrench is a device used to measure resistance to a turning force. The components:

FIGURE 1

TORQUE WRENCHES

a.) drive square
b.) a flexible beam
c.) handle
d.) scale
e.) force indicator

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 the mathematical expression $T = F \times D$, 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, fundamentally the Law of the Lever, governs the use of a torque wrench. The 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^o to the direction of the force.

A torque wrench must always function upon another object to measure torque, which is resistance to turning. A specific task can be accomplished by modifying a torque wrench with engaging devices.

Variability in the angle at which force could be applied to a tooth was achieved by adapting a bearing and drive shaft assembly to the torque wrench. This modification allowed nearly frictionless movement and the ability to rotate 360^o. This rotating drive shaft was coupled to a twelve inch lever 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 x 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 fibre rod was fashioned to conform to the various shapes of the maxillary canine tooth. It was attached to the metal tip of the pointer 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.

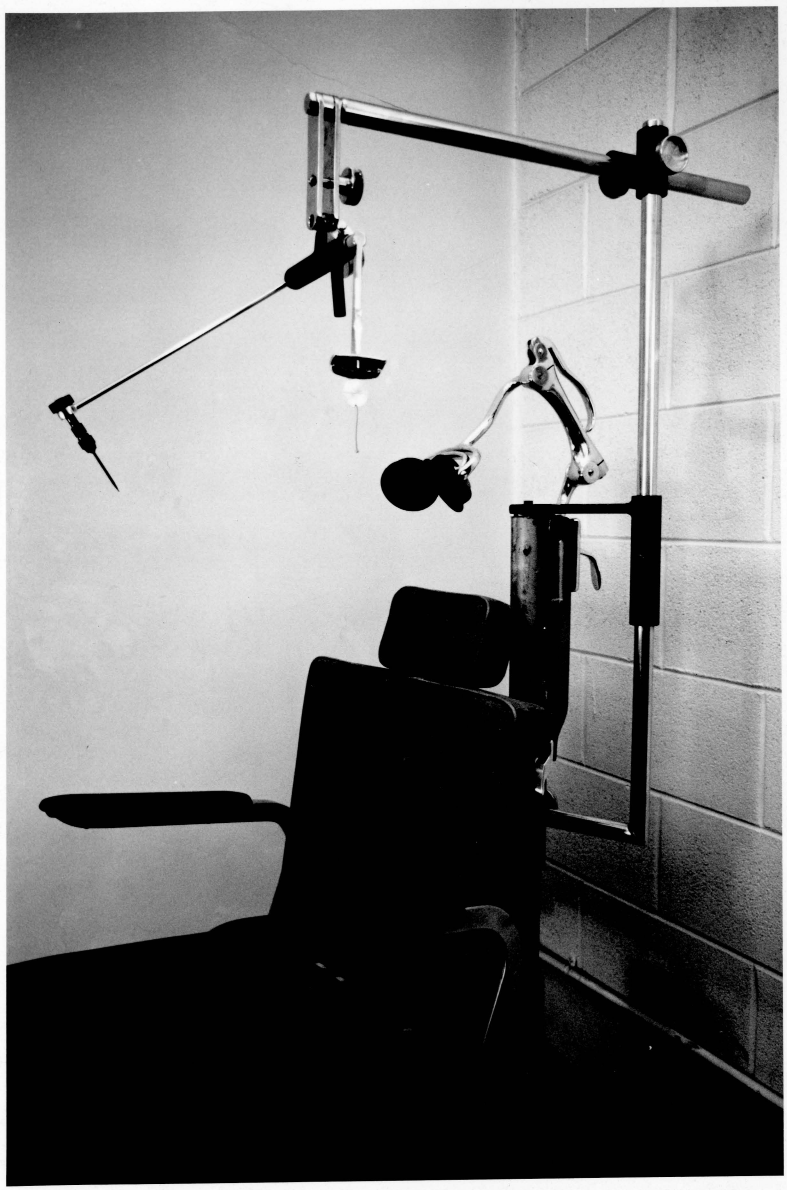
The fixture from which the torque wrench was suspended allowed additional versatility by means of adjustable parts, Figure 2. The iron base measured 48 inches by 18 inches and weighed approximately 300 pounds. Centrally located on the rear one-fifth of this base was an adjustable iron pipe which projected 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-holder".

An extension arm, 48 inches high, paralleled the fixed post. Two right-angled arms braced the extension arm to 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 a perpendicular adjustable assembly holding these arms. This was a welded couple with threaded screws to secure the desired position.

FIGURE 2



DENTAL CHAIR AND TORQUE WRENCH ASSEMBLY

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

3. EXPERIMENTAL PROCEDURE

The examining room was a seven foot square, well lighted, air conditioned study room in the orthodontic department. The metal base of the force producing instrument sat in the middle of the room with the examiner seated at the side of the patient.

The patients were seated in a dental chair which had an adjustable head rest, a foot rest, an adjustable back, stationary arms and a foot controlled hydraulic pump. The chair was placed on the metal base with the head rest against the fixed vertical post.

Before any testing was begun it was explained to the patient that not only will the position of their teeth change during orthodontic treatment but that the "nerves" around their teeth change too. They were then asked if they would help the examiner determine what some of the changes were by pushing on the canine tooth with various forces. They were assured that the procedure would not be painful.

The examiner then demonstrated two pushes against the arm of the patient and commented, "first force, second force; which of the two forces was heavier?"

Before the procedure continued the examiner explained the two positions of the instrument tip by placing his index finger on the patient's tooth. They were told during this demonstration that the first six series of pushes would be from the biting edge (along the long axis by way of the incisal edge) and that the next six series of pushes would be from the lip side of the tooth (90^{o} to the long axis of the tooth on the labial surface).

All forces were transmitted to the tooth through the vulcanized fiber tips. These tips exerted no force upon the tooth being investigated until the torque wrench was flexed.

The standard force values used were 100, 200, 500, 1000, 1500, and 2000 grams. The differential threshold was established for each of these force ranges for each subject. This was accomplished by first using a differential threshold of ± 10 percent of the standard values, and then increasing or decreasing these forces as was necessary for the individual.

The validity of the differential threshold was established by asking the subject to correctly identify the heavier of the two forces at least seven out of ten times. The forces were administered in random order.

If the subject could not correctly identify the heavier force 70 percent of the time, the differential threshold was considered too low and was then increased until the subject was able to identify the heavier force at least seven out of ten times.

If the subject correctly identified the heavier force ten out of ten times, the differential threshold was considered too high and was lowered in comparison to the standard force. The subject was then required to identify the heavier force, in random order, seven or more times out of ten but less than ten times out of ten.

The subject's replies were recorded immediately after the stimulus was placed on the tooth. A correct reply was recorded by a plus and a wrong reply by dash.

The results of the recordings, 90^{o} to the long axis and along the long axis, were then plotted on semilogarithmic and full logarithmic graph paper. The differential thresholds 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.

4. MISCELLANEOUS

During the actual recording the patient was instructed to close his eyes and concentrate on the tooth being tested. This prevented any distraction of the subject due to movements by the examiner. The subject then identified the heavier force by voice or by raising the first two fingers of his right hand, which ever was easier.

An important factor was the duration of tooth stimulation. Each subject was considered, individually, according to quickness of response and adaptation time. The duration of the stimulus was then adjusted to accommodate the rate of response of each subject.

CHAPTER IV

FINDINGS

In order to establish the approximate Weber Ratios to be anticipated in this study and the expected range over which the Psychophysical Law would be valid, a pilot study was conducted utilizing five subjects. The following table presents the mean Weber Ratios for each standard force employed in the pilot study.

TABLE 1

Means Weber Ratios From the Pilot Study

Grams Force	50	100	200	500	1000	1500	2000	2500
Weber Ratio Along Long Axis	.760	.430	.240	.100	.087	.086	.080	.065
Weber Ratio 90° to Long Axis	.465	.340	.225	.140	.090	.086	.080	.075

From these results it was decided to employ the 100, 200, 500, 1000, 1500, and 2000 gram force stimuli. It was felt that the 100 gram force would give measurements below the apparent optimal range of the Psychological Law. Although the 2,500 gram force appeared to be within the optimal range it was decided to use the 2,000 gram force as the upper limit. It was felt that this range (100 - 2000 gram) would be adequate in ascertaining whether or not the application of orthodontic forces altered the patient's conscious proprioceptive discrimination.

All data were converted from gram measurements to percent values. These percent values were then analyzed by means of the Student "t" Tests. Although the Weber-Fechner Phenomenon is not generally expressed in percent values, the statistical assessment of the data was facilitated by this conversion.

The conclusions of the Student "t" Tests, between the results of the first measurement and the results of the third measurement (four days after appliance insertion), are expressed in Table 2. These "t" Test results show all the comparisons to be significant at the .01 level for both the long axis and 90° to the long axis.

In reviewing the gram force tables for the first and third measurements we find that the ability of the subjects to discriminate between two "similar" forces was significantly improved with the placement of the archwires. It can be concluded that the conscious proprioceptive ability to discriminate forces applied to the maxillary canine tooth was significantly improved by orthodontic forces.

The "t" values were also determined for a comparison of the extraction and non-extraction groups. The determinations were made for both the first and third measurements along the long axis and 90° to the long axis. The "t" values demonstrate no significant difference in the differential thresholds between

TABLE 2

Statistical Evaluation of First Measurement (Prior To Treatment) Versus the Third Measurement (Four Days After Appliance Insertion)

First vs. Third	"t" Values Long Axis	90^{o}
100 vs. 100	7.816 **	6.869 **
200 vs. 200	9.213 **	5.556 **
500 vs. 500	4.657 **	2.814 **
1000 vs. 1000	4.410 **	3.087 **
1500 vs. 1500	3.431 **	3.158 **
2000 vs. 2000	4.847 **	5.532 **

* $P < .05$
** $P < .01$

the extraction and non-extraction group before orthodontic treatment or four days after orthodontic forces were applied to the teeth. The only exceptions were the 200, 500, and 2000 gram measurements along the long axis for the first measurement (Table 3). They were significant, however, only at the .05 level. The "t" values for Table 4 show that there was no significant difference in perception to forces applied along the long axis or 90° to the long axis for the first and third measurements. Although some investigators have found directional sensitivity to exist in the teeth of experimental animals these results support Nakfoor's findings of a lack of directional sensitivity in the human dentition.

In comparing the "t" values for the pre-extraction vs. post-extraction results in Table 5 there is a significant difference at the .01 level for the 100, 200, and 500 gram forces along the long axis and the 100 gram force 90° to the long axis. The 1000, 1500, and 2000 gram forces along the long axis and the 200, 500, and 1000 gram forces 90° to the long axis show a significant difference at the .05 level. There is no significant difference for the 1500, and 2000 gram forces 90° to the long axis.

The mean differential thresholds for all groups and all forces used are presented in Table 6. The statistical comparisons between the various standard force values for the first measurement and third measurement are presented in Tables 7 and 8.

TABLE 3

Statistical Evaluation of Extraction Versus Non-Extraction Cases At First Measurement (Prior to Treatment) And Third Measurement (Four Days After Appliance Insertion)

First Measurement	"t" Values Long Axis	90°
100 vs. 100	1.615	.959
200 vs. 200	1.872 *	1.217
500 vs. 500	2.074 *	1.516
1000 vs. 1000	1.532	1.497
1500 vs. 1500	.857	.882
2000 vs. 2000	2.231 *	.0488
Third Measurement	**Long Axis**	**90°**
100 vs. 100	.684	.716
200 vs. 200	.038	.486
500 vs. 500	.475	.964
1000 vs. 1000	.358	.566
1500 vs. 1500	.942	.220
2000 vs. 2000	1.182	.247

* $P < .05$
** $P < .01$

TABLE 4

Statistical Evaluation of Long Axis Versus 90° Values For the First Measurement (Prior to Treatment) And the Third Measurement (Four Days After Treatment)

First Measurements Long Axis vs. 90°			"t" Values
100	vs.	100	.533
200	vs.	200	.110
500	vs.	500	.698
1000	vs.	1000	.421
1500	vs.	1500	.199
2000	vs.	2000	1.009

Third Measurements Long Axis vs. 90°			"t" Values
100	vs.	100	.345
200	vs.	200	.752
500	vs.	500	1.242
1000	vs.	1000	.581
1500	vs.	1500	.786
2000	vs.	2000	.982

* $P < .05$
** $P < .01$

TABLE 5

Statistical Evaluation of Pre-Extraction Cases (First Measurement) Versus Post-Extraction Cases (Second Measurement - Within Four Days After Extraction of First Bicuspids)

Pre-Ext.	Vs.	Post-Ext.	"t" Values Long Axis	"t" Values 90^{o}
100	Vs.	100	3.123 **	3.268 **
200	Vs.	200	4.911 **	2.485 *
500	Vs.	500	2.802 **	1.774 *
1000	Vs.	1000	1.941 *	1.846 *
1500	Vs.	1500	2.090 *	1.304
2000	Vs.	2000	2.076 *	1.465

* $P < .05$
** $P < .01$

TABLE 6

Mean Percent Differential Threshold for Extraction, Non-Extraction and Combination Groups at First, Second and Third Measurement Periods

Non-Extraction 13 Subjects (Gram)	First L.A. **	First 90°	Second L.A.	Second 90°	Third L.A.	Third 90°
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 ± .02			.058 ± .012	.059 ± .015
Extraction 17 Subjects (Gm)						
100	.400 ± .083	.406 ± .107	.320 ± .059	.309 ± .051	.221 ± .090	.232 ± .12[illegible]
200	.241 ± .036	.244 ± .086	.184 ± .029	.185 ± .041	.129 ± .041	.143 ± .06[illegible]
500	.150 ± .047	.168 ± .097	.112 ± .028	.121 ± .044	.097 ± .012	.109 ± .02[illegible]
1000	.098 ± .046	.109 ± .068	.074 ± .024	.075 ± .027	.056 ± .011	.057 ± .01[illegible]
1500	.092 ± .037	.094 ± .033	.070 ± .017	.079 ± .029	.067 ± .010	.067 ± .01[illegible]
2000	.096 ± .031	.094 ± .034	.075 ± .018	.077 ± .027	.053 ± .008	.058 ± .01[illegible]
Combined 30 Subjects (Gm)						
100	.378 ± .084	.390 ± .083			.212 ± .078	.220 ± .104
200	.228 ± .043	.230 ± .071			.129 ± .038	.138 ± .05[illegible]
500	.137 ± .041	.148 ± .079			.098 ± .016	.105 ± .024
1000	.089 ± .037	.095 ± .059			.057 ± .013	.059 ± .01[illegible]
1500	.087 ± .031	.089 ± .029			.065 ± .013	.068 ± .01[illegible]
2000	.086 ± .028	.094 ± .028			.056 ± .010	.059 ± .01[illegible]

* Mean ± One Standard Deviation
** Long Axis

TABLE 7

Statistical Comparison Between Various Force Applications For the First Measurement

	"t" Values	
	Long Axis	90°
100 vs. 200	8.562 **	7.855 **
100 vs. 500	13.917 **	10.878 **
100 vs. 1000	16.968 **	15.399 **
100 vs. 1500	17.527 **	17.792 **
100 vs. 2000	17.899 **	17.328 **
200 vs. 500	8.223 **	4.128 **
200 vs. 1000	14.011 **	7.820 **
200 vs. 1500	14.208 **	9.601 **
200 vs. 2000	14.794 **	9.197 **
500 vs. 1000	4.583 **	2.894 **
500 vs. 1500	5.129 **	3.672 **
500 vs. 2000	5.458 **	3.353 **
1000 vs. 1500	.200	.451 **
1000 vs. 2000	.383	.884
1500 vs. 2000	.195	.579

* $P < .05$
** $P < .01$

TABLE 8

Statistical Comparison Between Various Force Applications For the Third Measurement

	"t" Values	
	Long Axis	90°
100 vs. 200	5.089 **	3.767 **
100 vs. 500	3.367 **	5.805 **
100 vs. 1000	10.494 **	8.197 **
100 vs. 1500	9.468 **	7.246 **
100 vs. 2000	9.497 **	7.573 **
200 vs. 500	4.000 **	3.072 **
200 vs. 1000	9.641 **	7.532 **
200 vs. 1500	8.174 **	6.360 **
200 vs. 2000	8.956 **	7.173 **
500 vs. 1000	10.877 **	8.040 **
500 vs. 1500	8.480 **	6.562 **
500 vs. 2000	11.065 **	8.534 **
1000 vs. 1500	2.350 *	1.849 *
1000 vs. 2000	.282	.038
1500 vs. 2000	2.711 **	2.241 *

* $P < .05$
** $P < .01$

In observing the "t" values from the first measurements in Table 7, it is evident that there is no significant difference between Weber Ratios for the 1000 to 2000 gram forces. In comparing the 100 and 200 gram forces to the 200, 500, 1000, 1500 and 2000 gram forces there is a significant difference at the .01 level. Although there is a significant difference at the .01 level when comparing the 500 gram force to the 1000, 1500, and 2000 gram forces, the "t" values are much lower. This would appear to make the 500 gram force more closely related to the higher forces than to the lower forces.

The "t" comparisons for the third measurements demonstrate the same level of significance (.01) for the lower forces. In the higher forces, 1000 vs. 1500 and 1500 vs. 2000 grams, although, the level of significance is not as closely related as for the first measurements.

Fechner has stated that the Psychophysical Law is best represented by the general formula $S=A \text{ Log. } I + K$, while Stevens believes that this phenomenon is best expressed as a power function represented by the general equation $dS=KI^x$. The validity of both the Fechner and Stevens formulae was tested by plotting the mean discernible difference for each force used against the logarithm of the force, Figures 3 and 4, and by plotting the logarithm of the mean discernible difference for each force used against the logarithm of the forces, Figures 5 and 6.

Semi-Logarithm Graphs of Mean Differential Thresholds Plotted Against the Gram Force Stimuli

Figure 3 First Measurement

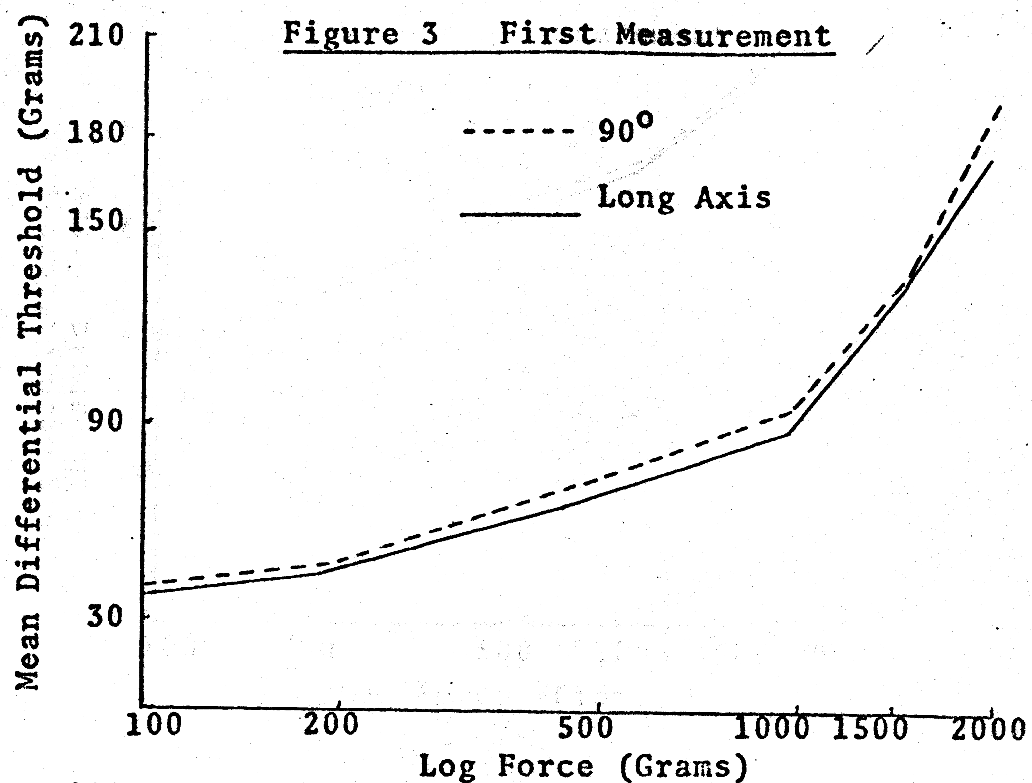
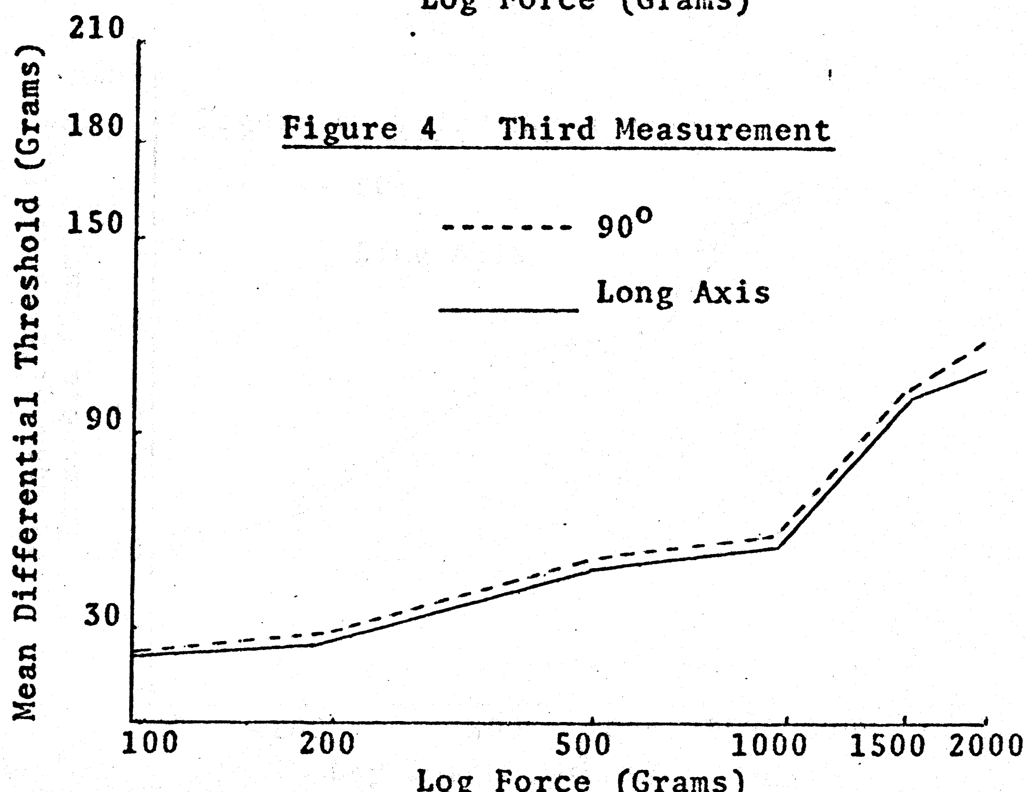
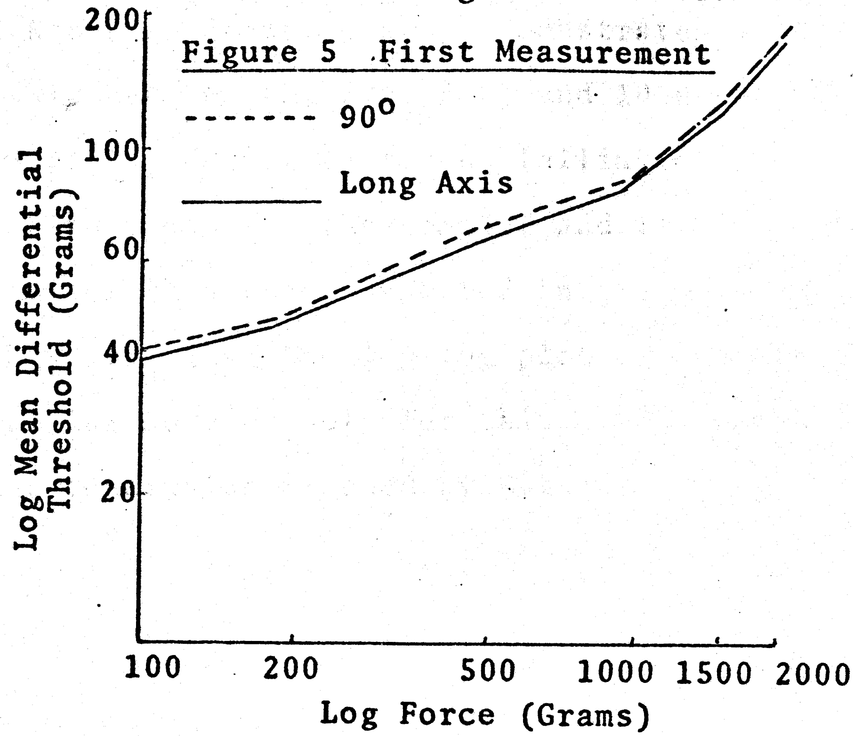
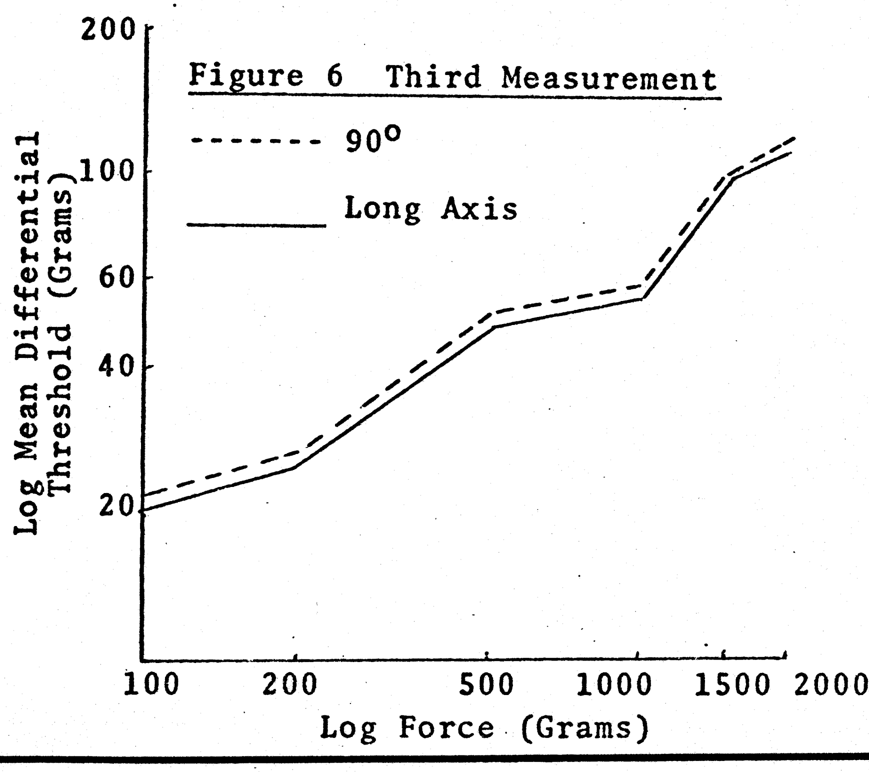


Figure 4 Third Measurement



Logarithmic-Logarithmic Graphs of Mean Differential Thresholds Plotted Against the Gram Force Stimuli





A review of the graphs demonstrates a close linear relationship between the 200, 500, and 1000 gram forces; with the 100, 1500, and 2000 gram forces falling outside the optimal force range. The plots for the semilog and log-log graphs appear much more similar than those reported in the Nakfoor study. It is felt, however, that the log-log plot represents the Psychophysical Law more closely for this study, which is in agreement with the conclusion reached by Nakfoor.

CHAPTER V

DISCUSSION

The validity of the assumption that the Fechner stated Weber's Law, the ratio between the change in intensity of a stimulus and the intensity of a stimulus being equal to a constant ($\Delta R/R=C$), has been repeatedly challenged.

Many investigators believe that the Weber Ratio is constant only over the midrange of intensity, and that it does not hold true for either the lower or higher ranges of intensity.

This experiment concurs in part with these investigators. The Weber Ratio did not show any constancy for the lower intensities of force application but did first evidence consistency around the 500 gram force stimuli. The mean Weber Ratios from the pilot study (Table 1) and from Table 6 show that the 2000 and 2500 gram force stimuli were both within the optimal range of the Psychophysical Law.

Kawamura and Watanabe tested the ability of persons to determine the thickness of two wires placed between the teeth. They established a Weber Ratio for tactile sensation of human teeth as 0.1 for 100 percent discrimination. Nakfoor, testing the ability of subjects to discriminate between various forces applied to the maxillary central incisor, showed Weber Ratios ranging from 0.1 to 0.15 for 70 percent discrimination. This project demonstrated Weber Ratios ranging from .06 to 0.15 for 70 percent discrimination in the optimal range. As Nakfoor points out, these may have been higher if 100 percent discrimination had been required.

Fechner's Law, which can be expressed by the general equation $S=A \text{ Log. } I + K$, has been challanged on many fronts. Stevens, one of the leading opponents, believes that the law is best expressed as a power function generally expressed as $dS=KI^x$.

If the Fechner equation provides the best fit for the data a semi-logarithmic plot should exhibit linearity for those forces that fall within the optimal functional limits of the Psychophysical Law. If the power function equation proposed by Stevens best fits the data a logarithmic-logarithmic plot should exhibit linearity for those forces that fall within the optimal functional limits of the Psychophysical Law. A more linear relationship between the 200, 500, and 1000 gram forces can be demonstrated in the logarithmic-logarithmic graphs (Figures 5 and 6) than in the semi-logarithmic graphs (Figures 3 and 4).

Although the differences between the plots are not as dramatic as those reported in the Nakfoor study, the author believes that the Stevens log-log plot gives the better graphic representation of the Psychophysical Law for this study.

A review of Table 4 shows that no significant difference 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 Nakfoor for the maxillary central incisor and confirm the lack of conscious directional sensitivity in the human dentition.

These results stand in contrast to Pfaffman who demonstrated directional sensitivity for single nerve fibers for the maxillary canine of the cat.

Ness, based on his studies, has even proposed models which might show receptor directionality.

Kizior found that the canine tooth of the cat was more sensitive to forces directed along its long axis than those directed 90° to the long axis. He accounted for this directional sensitivity by the discovery of pressoreceptors only in the apical one-third of the periodontal ligament.

Along this line 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, while Corbin and Harrison report that in cats, the canine teeth are the most responsive of oral structures.

One explanation was the possibility that the anatomical and/or functional innervation of the periodontal ligament of the maxillary canine is different than that of the maxillary incisor.

The results of this study, however, leads one to suspect that the more likely explanation is an actual variation in distribution of the pressoreceptors between the two species.

This study 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.

This stands in contrast to Nakfoor's study which 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. This difference can possibly be explained by the proximity of the canine to the extraction site and pressure due to inflammation in the extraction area. This pressure due to inflammatory swelling may have served to lower the threshold of the pressoreceptors in the area and thus, made the subject more aware of any slight changes in pressure applied to the canine.

Another possibility is the distribution of part of the applied force to the lateral incisor and first bicuspid through their contact with the canine. The loss of the contact with the bicuspid tooth may have served to direct forces to the canine which would normally have been transmitted via surface contact to the first bicuspid. The Nakfoor study evidenced an apparent lowering of the pain threshold by the application of continuous light differential orthodontic forces. His subjects showed a decreased ability to discriminate between forces within four days after the orthodontic appliances were inserted. He derived the forces from two sources. The intrinsic forces were derived from the archwires while the extrinsic forces were derived primarily from orthodontic elastics. He calculated forces to range from 40 to 150 grams.

The forces utilized in this study similarly were derived from two sources. The intrinsic forces were derived from the archwires, while the extrinsic forces were derived from orthodontic elastics, elastic thread and auxiliary wire loops. The calculated forces generated by these appliances ranged from 60 grams to 170 grams.

The effect of these orthodontic forces on the individual's ability to discriminate forces applied to the surface of the maxillary canine stand in contrast with those reported by Nakfoor for the maxillary central incisor. The results of this 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 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 ascertained. The forces generated by the orthodontic appliances to the canine tooth represented a constant application of forces ranging from 60 grams to 170 grams. These continuous orthodontic forces may have served to lower the threshold of the pressoreceptors in the periodontal ligament so that the test forces generated by the torque applied to the tooth allowed the optimal range to be reached more readily. This lowering of the effective threshold of the pressoreceptors in the periodontal ligament would then facilitate the subjects ability to discriminate between the varying forces.

The opposite then, must be true for Nakfoor's study, since he found the optimal range for the maxillary central incisor to be between 50 grams and 500 grams. Thus, the constant forces from the orthodontic appliances must have placed his subjects into the optimal range prior to any experimental force discriminations, and thereby complicate the central nervous system's interpretation of the comparative amount of forces being applied to the teeth.

CHAPTER VI

SUMMARY AND CONCLUSION

A previously described method of testing for conscious discrimination of proprioceptive imput from the periodontal ligament was utilized for this experiment. The reliability of this method has been statistically proven by Nakfoor (Masters Thesis, Loyola U., Chicago 1967). This procedure was used to determine 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 were divided into two experimental groups. One group required the extraction of first premolar teeth while the other group did not require the extraction of teeth for the treatment of their malocclusion. Tests made within four days after the extraction of the first bicuspid teeth showed that the ability of the patients to discriminate between the forces applied to the surface of the canine significantly improved.

This ability to consciously evaluate proprioception from the periodontal ligament of the maxillary canine is significantly improved with the application of light orthodontic forces. Within four days after these light orthodontic forces were applied to the maxillary canine tooth, the ability of the subjects to discriminate between "similar" forces was significantly improved.

The human periodontal ligament exhibited no greater directional sensitivity to forces applied along the long axis of a tooth than those applied 90^{o} to the long axis of the same tooth. This confirms the findings of Nakfoor in his study on the periodontal ligament of the maxillary central incisor.

The optimal working range of the Psychophysical Law, for this experiment, 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 0.06 and 0.15 of the standard force values over this range.

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

APPENDIX I

First Measurement (Prior to Any Treatment) 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.	%	Gms.
1	40	40	22.5	45	15	75	10	100	10	150	12.5	250
2	40	40	22.5	45	15	75	10	100	10	150	10	200
3	40	40	25	50	20	100	10	100	13.3	200	12.5	250
4	20	20	15	30	10	50	5	50	6.6	100	5	100
5	50	50	30	60	20	100	25	250	20	300	15	300
6	40	40	25	50	10	50	5	50	10	150	7.5	150
7	40	40	25	50	15	75	10	100	6.6	100	5	100
8	45	45	25	50	20	100	10	100	6.6	100	7.5	150
9	50	50	27.5	55	15	75	7.5	75	6.6	100	7.5	150
10	30	30	22.5	45	10	50	7.5	75	6.6	100	10	200
11	40	40	27.5	55	15	75	10	100	13.3	200	12.5	250
12	45	45	27.5	55	25	125	12.5	125	10	150	5	100
13	50	50	27.5	55	15	75	10	100	6.6	100	10	200
14	40	40	25	50	10	50	5	50	6.6	100	7.5	150
15	40	40	20	40	10	50	5	50	6.6	100	7.5	150
16	40	40	25	50	10	50	10	100	10	150	7.5	150
17	30	30	17.5	35	10	50	5	50	6.6	100	5	100
18	45	45	27.5	55	15	75	10	100	10	150	10	200
19	40	40	25	50	10	50	7.5	75	6.6	100	7.5	150
20	35	35	20	40	15	75	10	100	6.6	100	7.5	150
21	30	30	22.5	45	10	50	10	100	6.6	100	7.5	150
22	45	45	25	50	20	100	12.5	125	10	150	15	300
23	30	30	20	40	15	75	10	100	13.3	200	12.5	250
24	30	30	17.5	35	10	50	7.5	75	6.6	100	7.5	150
25	30	30	20	40	15	75	10	100	10	150	7.5	150
26	40	40	22.5	45	10	50	7.5	75	6.6	100	7.5	150
27	20	20	12.5	25	10	50	5	50	6.6	100	5	100
28	25	25	15	30	10	50	7.5	75	10	150	7.5	150
29	35	35	20	40	10	50	5	50	6.6	100	7.5	150
30	50	50	27.5	55	15	75	7.5	75	6.6	100	7.5	150

* Unable to determine
- Pain
+ Not tried

APPENDIX II

First Measurement (Prior to Any Treatment) 90° to 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.	%	Gms.
1	45	45	25	50	10	50	7.5	75	10	150	7.5	150
2	40	40	25	50	15	75	10	100	10	150	10	200
3	60	60	50	100	25	125	25	250	16.7	250	17.5	350
4	30	30	10	20	10	50	5	50	6.6	100	5	100
5	50	50	30	60	50	250	30	300	*	*	*	*
6	40	40	25	50	20	100	12.5	125	10	150	10	200
7	45	45	25	50	10	50	-	-	+	+	+	+
8	40	40	25	50	15	75	10	100	10	150	10	200
9	50	50	27.5	55	10	50	7.5	75	6.6	100	7.5	150
10	40	40	25	50	15	75	10	100	10	150	12.5	250
11	50	50	27.5	55	20	100	10	100	6.6	100	12.5	250
12	50	50	25	50	25	125	12.5	125	16.7	250	15	300
13	50	50	30	60	15	75	7.5	75	10	150	7.5	150
14	50	50	27.5	55	15	75	7.5	75	6.6	100	7.5	150
15	25	25	20	40	10	50	7.5	75	6.6	100	5	100
16	50	50	25	50	15	75	10	100	10	150	10	200
17	30	30	17.5	35	10	50	7.5	75	6.6	100	7.5	150
18	20	20	15	30	15	75	7.5	75	6.6	100	7.5	150
19	40	40	20	40	15	75	7.5	75	10	150	10	200
20	35	35	20	40	15	75	7.5	75	6.6	100	10	200
21	40	40	25	50	15	75	10	100	10	150	10	200
22	30	30	17.5	35	10	50	10	100	6.6	100	10	200
23	30	30	17.5	35	15	75	10	100	6.6	100	7.5	150
24	30	30	17.5	35	10	50	7.5	75	6.6	100	7.5	150
25	30	30	20	40	10	50	7.5	75	13.3	200	12.5	250
26	30	30	17.5	35	10	50	5	50	6.6	100	7.5	150
27	25	25	15	30	10	50	7.5	75	10	150	10	200
28	30	30	17.5	35	10	50	5	50	6.6	100	7.5	150
29	35	35	20	40	10	50	5	50	10	150	-	-
30	50	50	27.5	55	10	50	7.5	75	6.6	100	7.5	150

* Unable to determine
- Pain
+ Not tried

APPENDIX III

Second Measurement (Extraction Cases Only, Within Four Days After Extraction) 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.	%	Gms.
1	30	30	17.5	35	10	50	7.5	75	6.6	100	7.5	150
2	35	35	20	40	10	50	5	50	6.6	100	7.5	150
3	30	30	17.5	35	10	50	5	50	6.6	100	7.5	150
4	35	35	17.5	35	10	50	7.5	75	6.6	100	7.5	150
5	50	50	25	50	20	100	10	100	6.6	100	-	-
8	30	30	15	30	10	50	10	100	6.6	100	5	100
9	30	30	17.5	35	10	50	7.5	75	6.6	100	-	-
10	30	30	15	30	10	50	5	50	6.6	100	7.5	150
12	25	25	17.5	35	10	50	7.5	75	6.6	100	7.5	150
13	30	30	17.5	35	10	50	5	50	6.6	100	-	-
14	25	25	15	30	15	75	7.5	75	-	-	+	+
15	30	30	17.5	35	10	50	5	50	6.6	100	5	100
18	30	30	17.5	35	10	50	10	100	6.6	100	7.5	150
19	35	35	20	40	10	50	5	50	6.6	100	7.5	150
21	30	30	20	40	10	50	10	100	6.6	100	7.5	150
22	40	40	25	50	15	75	12.5	125	13.3	200	12.5	250
23	30	30	17.5	35	10	50	5	50	6.6	100	7.5	150

* Unable to determine
\- Pain
\+ Not tried

APPENDIX IV

Second Measurement (Extraction Cases Only Within Four Days After Extraction) 90° To 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	30	30	17.5	35	10	50	7.5	75	6.6	100	7.5	150
2	30	30	15	30	10	50	7.5	75	6.6	100	7.5	150
3	35	35	17.5	35	10	50	5	50	5	75	5	100
4	30	30	17.5	35	10	50	7.5	75	6.6	100	-	-
5	40	40	25	50	20	100	10	100	6.6	100	7.5	150
8	25	25	15	30	15	75	7.5	75	6.6	100	5	100
9	35	35	20	40	10	50	5	50	6.6	100	7.5	150
10	25	25	15	30	10	50	5	50	6.6	100	5	100
12	40	40	30	60	25	125	15	150	16.7	250	15	300
13	35	35	17.5	35	10	50	5	50	-	-	+	+
14	30	30	15	30	10	50	7.5	75	-	-	+	+
15	25	25	15	30	10	50	5	50	6.6	100	5	100
18	25	25	17.5	35	10	50	7.5	75	6.6	100	7.5	150
19	30	30	20	40	10	50	5	50	10	150	7.5	150
21	35	35	22.5	45	15	75	10	100	10	150	10	200
22	30	30	17.5	35	10	50	10	100	10	150	10	200
23	25	25	17.5	35	10	50	7.5	75	6.6	100	7.5	150

* Unable to determine
- Pain
+ Not tried

APPENDIX V

Third Measurement (All Cases, Four Days After Appliance Insertion) Along the Long Axis Expressed in Actual Values and Percent of Actual Values

Subj. No.	100 Gms. %	100 Gms. Gm.	200 Gms. %	200 Gms. Gm.	500 Gms. %	500 Gms. Gm.	1000 Gms. %	1000 Gms. Gm.	1500 Gms. %	1500 Gms. Gm.	2000 Gms. %	2000 Gms. Gm.
1	15	15	10	20	10	50	5	50	6.6	100	5	100
2	15	15	7.5	15	10	50	5	50	6.6	100	5	100
3	15	15	10	20	10	50	5	50	-	-	+	+
4	15	15	10	20	10	50	5	50	6.6	100	5	100
5	25	25	15	30	10	50	7.5	75	6.6	100	-	-
6	20	20	12.5	25	15	75	7.5	75	6.6	100	-	-
7	15	15	10	20	10	50	5	50	6.6	100	5	100
8	15	15	10	20	10	50	5	50	6.6	100	5	100
9	40	40	20	40	10	50	5	50	-	-	+	+
10	20	20	12.5	25	10	50	5	50	-	-	+	+
11	30	30	17.5	35	10	50	7.5	75	6.6	100	5	100
12	40	40	22.5	45	10	50	7.5	75	10	150	7.5	150
13	25	25	15	30	10	50	7.5	75	6.6	100	5	100
14	25	25	12.5	25	10	50	5	50	6.6	100	5	100
15	30	30	15	30	10	50	7.5	75	6.6	100	5	100
16	25	25	15	30	10	50	5	50	6.6	100	7.5	150
17	25	25	17.5	35	10	50	5	50	6.6	100	5	100
18	10	10	7.5	15	5	25	5	50	6.6	100	5	100
19	15	15	10	20	10	50	5	50	6.6	100	5	100
20	15	15	10	20	10	50	5	50	5	75	5	100
21	15	15	12.5	25	10	50	5	50	5	75	6.25	125
22	25	25	15	30	10	50	5	50	6.6	100	-	-
23	30	30	15	30	10	50	5	50	6.6	100	5	100
24	10	10	7.5	15	5	25	2.5	25	3.3	50	5	100
25	20	20	12.5	25	10	50	5	50	5	75	5	100
26	20	20	12.5	25	10	50	5	50	5	75	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	10	150	7.5	150
29	20	20	12.5	25	10	50	7.5	75	6.6	100	5	100
30	30	30	20	40	10	50	7.5	75	6.6	100	7.5	150

* Unable to determine
\- Pain
\+ Not tried

APPENDIX VI

Third Measurement (All Cases, Four Days After Appliance Insertion) 90° To 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	15	15	10	20	10	50	5	50	6.6	100	5	100
2	15	15	10	20	10	50	5	50	6.6	100	5	100
3	15	15	10	20	10	50	5	50	6.6	100	-	-
4	15	15	10	20	10	50	5	50	6.6	100	5	100
5	20	20	12.5	25	10	50	7.5	75	-	-	+	+
6	30	30	17.5	35	15	75	12.5	125	10	150	7.5	150
7	15	15	10	20	10	50	5	50	6.6	100	5	100
8	15	15	10	20	10	50	5	50	6.6	100	5	100
9	50	50	25	50	15	75	7.5	75	-	-	+	+
10	20	20	12.5	25	10	50	5	50	-	-	+	+
11	25	25	15	30	10	50	5	50	10	150	7.5	150
12	45	45	27.5	55	15	75	7.5	75	6.6	100	7.5	150
13	45	45	27.5	55	15	75	7.5	75	6.6	100	5	100
14	20	20	12.5	25	10	50	5	50	-	-	+	+
15	20	20	12.5	25	10	50	5	50	10	150	7.5	150
16	30	30	15	30	10	50	5	50	6.6	100	7.5	150
17	25	25	17.5	35	10	50	5	50	6.6	100	5	100
18	10	10	7.5	15	5	25	5	50	6.6	100	5	100
19	15	15	10	20	10	50	5	50	6.6	100	5	100
20	20	20	15	30	10	50	5	50	5	75	5	100
21	15	15	12.5	25	10	50	5	50	5	75	5	100
22	35	35	17.5	35	15	75	7.5	75	6.6	100	7.5	150
23	25	25	15	30	10	50	5	50	6.6	100	7.5	150
24	10	10	7.5	15	5	25	2.5	25	3.3	50	5	100
25	15	15	12.5	25	10	50	5	50	6.6	100	5	100
26	15	15	10	20	10	50	5	50	5	75	5	100
27	15	15	10	20	10	50	5	50	6.6	100	5	100
28	15	15	10	20	10	50	7.5	75	6.6	100	7.5	150
29	20	20	12.5	25	10	50	7.5	75	6.6	100	5	100
30	30	30	20	40	10	50	10	100	10	150	7.5	150

* Unable to determine
- Pain
+ Not tried

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APPROVAL SHEET

The thesis submitted by Dr. Gerald R. Dusza 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.

5/10/68
Date

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Signature of Advisor