1967

# An Evaluation of the Psychophysical Phenomenon on Sensory Stimuli to the Periodontal Ligament

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# AN EVALUATION OF THE PSYCHOPHYSICAL PHENOMENON ON SENSORY STIMULI TO THE PERIODONTAL LIGAMENT

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

1967

AUTOBIOGRAPHY

Patrick R. Nakfoor was born in Lansing, Michigan, July 27, 1934. He graduated from Lansing St. Mary High School, in June 1952. He received his Bachelor of Science degree, June, 1956, from Notre Dame University. In June, 1960, he received his Doctor of Dental Surgery degree from the University of Michigan. He served as a Captain in the United States Air Force Dental Corps from August, 1960, until April, 1962, at Ernest Harmon Air Force Base, Stefenville, Newfoundland. Following his separation from the service, he practiced General Dentistry until May, 1965. He was married June, 1965 to the former Carol Ann Macksood. He was accepted into Loyola University Graduate School of Dentistry, Department of Orthodontics, in July, 1965. He has two daughters Cheryl Ann and Kara Elise.

# ACKNOWLEDGMENTS

My sincere appreciation and gratitude is extended to all those who have aided in making this study possible, particularly to the following:

To Dr. Douglas C. Bowman, Professor of Physiology, my advisor, who inspired this research and provided invaluable guidance, supervision and assistance throughout the course of this investigation.

To Dr. Joseph R. Jarabak, Professor of Orthodontics, to whom I shall always be indebted for his excellent instruction, inspiration and dedication throughout the past two years.

To Dr. Vincent J. Sawinski, Assistant Professor of Chemistry, for his technical advice in preparing this thesis.

To my classmates and to the students in the Orthodontic Class of 1968 for their assistance in the project.

To my parents for their confidence, encouragement, inspiration and guidance throughout the course of my endeavors.

To my wife, Carol, for help and encouragement during the past two years. To Cheryl Ann and Kara Elise, my daughters who brought joy when it was needed the most.

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# CHAPTER I

## INTRODUCTION AND STATEMENT OF THE PROBLEM

Quantitative assessment of the sensory perception of stimuli through the teeth to the periodontal ligament is a subject yet unexplored in Dentistry. Numerous studies have been reported on sensory output from periodontal ligament recorded along some aspects of the trigeminal nerve. Yet only one study has been published on the ability of the individual to recognize differences in the magnitude of sensory stimuli applied to teeth.

The purpose of this study is to determine if early orthodontic procedures alter the ability of individuals to quantitatively discriminate sensory stimuli applied to teeth being moved orthodontically. This study 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:

Krohn (1894), reported that Weber (1850), working on cutaneous areas of the human body, established the distances required on various parts of the body before two simultaneous stimuli were distinguishable as separate entities. The top of the tongue required a distance of only 0.04 inches while the middle of the back, the upper arm and the thigh required 2.75 inches. The remaining cutaneous areas of sensitivity were between these distances.

Fechner (1854), working with lifted weights, recognized that there must be a large enough difference between two weights before they can be distinquished as separate. Based on his observations and the results of Weber, Fechner derived a ratio between the sensory stimulus used and the change in this stimulus before a difference between the two can be detected. He assumed that the "just noticeable difference" of sensation always contains the same number of sensation units. This ratio is maintained along the entire scale of sensory stimuli and, therefore, is a constant.

This ratio is referred to as Weber's Law and states that the ratio between the change in intensity of a stimulus and the intensity of a stimulus equals a constant. Mathematically this is stated as $dI/I = C$.

James (1890) stated that Weber's Law was a fair empirical generalization and that the Weber Ratio could easily be found for measurable senses. The ratios he gave for weight, pressure and warmth were 1/3, light 1/100, feeling of muscular sensation 1/17, and sound 3/10.

Helmholtz (1924), reported the Bourger (1760), findings for fractional discernible differences for light as 1/64, the Fechner and Volkman findings (1858) as 1/100, and the Arago (1858) and Mason findings (1845) as 1/50 to 1/120 depending on vision. Helmholtz detected differences of 1/117 to 1/167 depending on condition.

Hecht (1924) held the Weber Law to be true but criticized the limits Fechner set at the extremes of the intensity scale. Hecht expressed belief that sensory judgments were relative not absolute. 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 to be theoretically interesting but not practically workable. He based this belief 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 applies only to intensity.

Thurstone (1927) wrote that Weber's Law usually states that the "just noticeable increase" of a stimulus is a constant fraction of the stimulus. The increase, which was correctly discriminated 75 per cent of the time, when two judgments were allowed, was a constant fraction of the stimulus magnitude.

Van Leeuwan (1949), working with the response of muscle spindles of a frog, reported that his results suggest that the Weber Law holds as a property of the single stretch receptors. Random fluctuation of the response required observations to be of a large number of results before a clear picture could be seen of this property.

Fulton (1955) stated Weber's Law applied to most sensory modalities over a very limited range of intensity. Treisman (1964) 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.

Kawamura and Wanatabe (1960) determined the Weber Ratio for tactile sensations for human teeth, by discriminating small differences in the diameter of two wires when the wires were placed between the teeth and force as in biting was used. They established a differential threshold of 0.1 for 100 per cent discrimination. They concluded that the periodontal ligament was necessary in order to make correct judgments of the size of the material.

Grossman (1965), using the method of "just noticeable differences" reported the oral areas of greatest tactile sensitivity were as follows: (1) upper lip; (2) tongue; (3) lower lip; (4) incisive pappilla; (5) finger; and (6) palm of the hand.

## 2. Fechner's Law:

Fechner (1850) formulated the Psychophysical Law which stated that sensation increases as the logarithm of the intensity of stimulus increases. Mathematically this was expressed as $S = A \log I + K$: on a logarithmic scale I, intensity of stimulus, increases in a straight line starting from K, the slope of which is the constant A. S equals intensity of sensation.

Helmholtz (1866), Delboeuf (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.

Preyer (1874) reported that shortening of muscle varies as the logarithm of electrical excitation increases.

Waller (1895), working on responses of the retina, muscles and nerves, maintained that Fechner's Law controlled the excitatory processes of these tissues. He reasoned this because the electrical responses effectively increased in the middle ranges as did the logarithm of stimulation intensities for the three tissues studied.

Matthew (1931 and 1933), studying muscle spindles, single end organs and nerve endings, proved the Fechner Law, as it is related to muscle, by concluding that the frequency of response of these receptors, to moderate range of intensity, was roughly proportional to the logarithm of the tension on the muscle.

Hartline and Graham (1933), working with nerve impulses from single receptors in the eye, paralled the findings of Matthew. They found a linear relationship between the frequency of discharge and the logarithm of intensity. This relationship was expressed throughout the moderate range of intensities.

Pfaffman (1932), investigating the mechanoreceptors of the maxillary teeth of the cat, concluded that the relationship between frequency of response and the stimulus was approximately logarithmic, within limited ranges. The forces utilized were between 20 grams and 200 grams.

Ness (1954), studying the mechanoreceptors of the rabbit incisor, reported that mechanical stimulation produced a response that was linearly related to the logarithm of the magnitude of stimulus and their discharges. This was only for forces below 100 grams.

The Fechner Law has been opposed by many investigators on psychological grounds. Plateau (1850), Brentano (1874), Grotenfelt (1888), Guilford (1932), and Stevens (1957) have all stated their belief that a power function exists between stimulus and perceptual response.

Stevens, the most ardent critic of the Fechner Psychophysical Law, has shown on twelve continua that apparent subjective magnitudes grow as a power function of stimulus intensity. The exponents range from 0.33 for brightness, to about 3.5 for electric shock to the finger.

Brett (1962) lists the reasons for objecting to Fechner's Law as: (1) lack of experimental evidence; (2) the law has only physiologic value; (3) the mathematical expression of the law is incorrect; and (4) mental processes were considered by Fechner to be mathematical rather than biological.

### 3. Innervation and Function of the Periodontal Ligament:

Peaslee (1857) stated that teeth can detect pressure and have powers of localization. Frankel (1871) attributed the ability to localize sensation to the periodontal ligament and states that this power remains after removal of the pulpal tissues. Black (1887) stated that the sense of touch resides solely in the periodontal ligament. Noyes (1921) wrote that light touch can be localized by teeth because of slight movements of the teeth which stimulates the periodontal ligament.

Steward (1927), using an aesthasiometer, measured the thresholds for teeth between 7 $gm/mm^2$ and 50 $gm/mm^2$, with little difference between pulpless and innervated teeth. He concluded that the response of teeth to light touch was an acute response; and that the pulpal nerve had nothing to do with pressure which must be transmitted along the nerves of the periodontal ligament.

Lewinski and Steward (1936) described the periodontal innervation as starting at the apical region of the tooth and longitudinally proceeding gingivally with the blood vessels. The nerves were supplemented but do not fuse with additional fibers that enter foramen through the alveolar process. The endings of the periodontal nerves appear as terminal knob-like bodies.

Brasher (1936) stated the nerve fibers that respond to pressure were myelinated fibers and that 20 per cent of the periodontal nerve fibers of the cat were ten microns or larger. He suggested that the periodontal ligament of the cat and human were the organs of touch for their teeth.

Bernick (1957) agreed with Lewinski and Steward on the location and the direction of periodontal nerve fibers. The nerve fibers terminate in spindle-like structures mainly in the lower 1/3 of the periodontal connective tissue.

Kizior (1966) stated that the fibers in the apical region had a large diameter and were found in the center of the ligament with the blood vessels. The nerve endings were encapsulated, highly organized and completely surround the apical 1/3.

Cuozzo (1966) reported the largest myelinated nerve fiber of the inferior dental nerve of the cat to be 16 microns. He concluded that the large fibers conduct action potentials of light forces to the mesencephalic nucleous of the trigeminal nerve. These messages of proprioceptive activity were transmitted along nerves 14 microns to 16 microns in size; and they account for two per cent to three per cent of the fibers of the inferior alveolar nerve.

Corbin and Harris (1940) showed a response to tapping of the maxillary teeth, to be located in the caudal half of the mesencephalic root of the trigeminal nerve, on the homolateral side. Pressure in any direction on the teeth gave large bursts of potential in the mesencephalic root through the duration of the stimulus.

Jerge (1963) reported two types of dental pressoreceptors. Type I response was from individually stimulated teeth. Type II response was from two or more teeth and adjacent gingival areas. All Type II and one-half of the Type I receptors were directed to the caudal half of the mesencephalic nucleous of the trigeminal nerve. These receptors were arranged about the tooth in such a manner that pressure from any direction elicits a response. These threshold vary from one gram to three grams depending upon the direction of force.

Kruger and Michel (1962), working with decerebrate cats, report only one surface of a tooth to be sensitive to light touch and compared it to the excellent directional sensitivity of the vibrissae. These receptors, sensitive to light touch, were fast-adapting receptors.

Pfaffman reported that when an electrode was attached to the inferior dental nerve trunk, a touch in any direction on a tooth elicited the same response. Single nerve endings, however, showed the greatest response to be from forces directed incisoapically and a diminishing response from other angles up to $90^{o}$. There was no response at $90^{o}$ because the isolated fiber did not respond to force in that direction.

Ness reported a rapid application of stimulus to a tooth yielded asynchronous spikes composed of many individual receptor responses, which vary with the magnitude of force. The most sensitive direction of teeth were incisoapically. He also classified mechanoreceptors according to speed of adaption.

Lowenstein and Rathkamp (1955), using a spring aesthasiometer, established absolute thresholds for 155 vital teeth. These thresholds varied from 0.948 grams to 4.533 grams. Twenty-one pulpless teeth showed 57 per cent higher threshold than teeth with pulps. They concluded that their findings supported belief that intradental and periodontal pressoreceptors exist.

Kizior and Cuozzo reported action potentials of varying heights, obtained from forces of the same magnitude from different directions. This indicated that differential sensitivity was dependent on the strength of stimulus and the direction from which the stimulus was applied to the tooth. Responses to incisal tappings were greater than responses to tapping of labial or lingual surfaces.

# CHAPTER III

# METHODS AND MATERIALS

## 1. Introduction:

The fifty subjects used in this study were selected from patients about to receive orthodontic treatment in the Department of Orthodontics at Loyola University. They ranged from age eleven to age seventeen.

The subjects were divided into two groups. Premolar teeth were extracted in the first group to facilitate treatment of their malocculsions, while the second group did not require extractions. The group requiring extractions consisted of thirty-one subjects. The non-extraction group had only nineteen subjects.

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 color intraoral transparencies, black and white polaroid photographs of the face, full mouth radiographs, lateral cephalograms and alginate impression for plaster casts of the teeth. Two weeks after the clinical records were taken the first experimental records were obtained. Subsequent data for twelve of these subjects were taken within two weeks to verify the reliability of the method employed.

All data were taken from maxillary central incisors.

The subjects that required extraction of premolar teeth, for the treatment of their malocclusions, were examined three times. The first examination was before any tooth movement took place. The second examination was two to four days after extraction of the maxillary premolar on the side the subject was previously tested. The third examination was four days after the orthodontic appliances were placed.

Previous to any subjects being tested, a pilot study was conducted on seven second year graduate orthodontic students. Their ages ranged from twenty-six years of age to thirty-eight years. The force values to be used later were attained from the pilot study.

All subjects used in this study had little or no spacing of the maxillary incisor teeth. The subjects were chosen so that the incisal edges of the maxillary incisor teeth exhibited an overjet relationship to the mandibular anterior teeth on the side tested.

## 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).

A torque wrench is a device used to measure resistance to a turning force. The components are: (Figure 1 and 2)

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. 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 $90^{\circ}$ to the direction of the force.

A torque wrench must always function upon another object to measure torque, which is resistance to turning. A

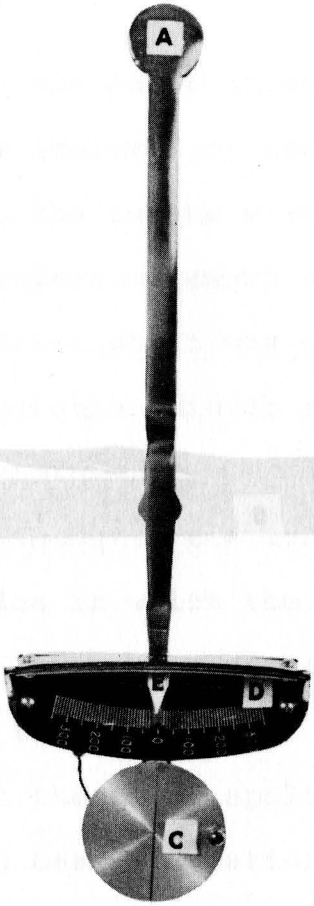



Fig. 1.--Torque Wrench

A. Drive Square
B. Flexible Beam
C. Handle
D. Scale
E. Force Indicator

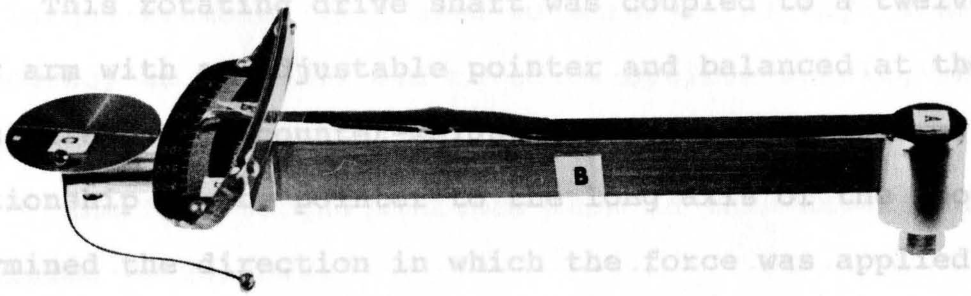



Fig. 2.--Torque Wrench

A. Drive Square
B. Flexible Beam
C. Handle
D. Scale
E. Force Indicator

specific task can be accomplished by modifying a torque wrench by 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 counter-weighter 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.

Assurance 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 force at one point. The thumb and index finger were used to apply the needed force. This insured that the applied force would be $90^{o}$ to the beam. If any additional force was required, as when applying 1000 grams or more, the left hand was used to push the right wrist, thus applying the additional force through the centered handle (Figure 3).

All torque wrench calibrations were certified with a maximal allowable error that did not exceed two per cent of the full scale readings. Force values ranged from 0 to 1300 grams were used to stimulate the teeth during this experiment. Four torque wrenches were used to maintain as high a degree of accuracy as possible and to allow optimal spacing of the increments on the various scales.

The four torque wrenches used in this experiment were calibrated as follows:

1) 0-16 grams calibrated in 0.5 gram increments
2) 0-70 grams calibrated in 2 gram increments
3) 0-350 grams calibrated in 5 gram increments
4) 0-1500 grams calibrated in 50 gram increments.

The above figures were the range of forces which would be delivered to the tooth, depending on deflection, through the twelve inch lever extension from the drive shaft. The direct force readings can be explained by the aforementioned Torque Law, T = F x D. When solved for F, the equation 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 plastic

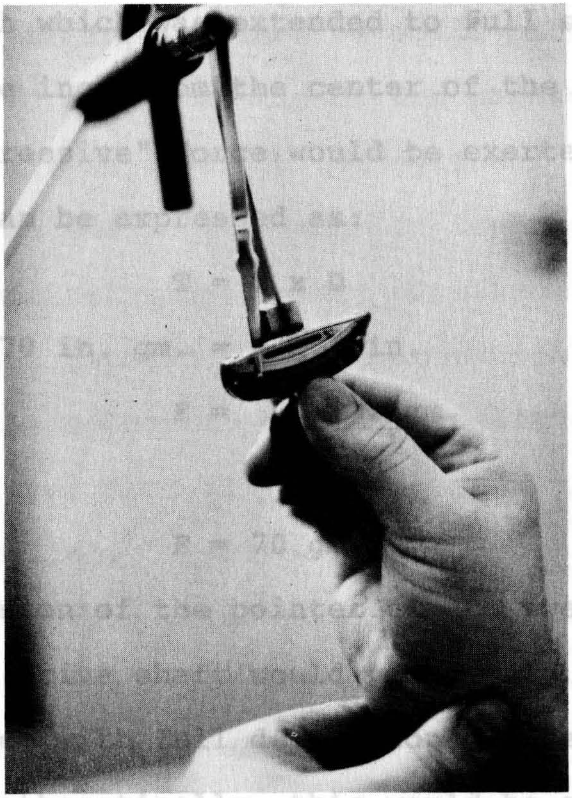


**Fig. 3.--Method of Force Application for 1000 Grams or More**

pointer attached to the lever arm. The force varies indirectly with the length of the lever arm: for example, if a 70 inch gram torque wrench which was extended to full scale range with a lever arm of one inch from the center of the drive shaft, 70 grams of "compressive" force would be exerted. Mathematically, this can be expressed as:

$$T = F \times D$$

$$70 \text{ in. gm.} = F \times 1 \text{ in.}$$

$$F = \frac{70 \text{ in. gm.}}{1 \text{ in.}}$$

$$F = 70 \text{ gm.}$$

The extension of the pointer tip to twelve inches from the center of the drive shaft would yield only 5.67 grams of "compressive" force with full deflection of the 70 inch grams torque wrench. Mathematically, this would be stated as:

$$T = F \times D$$

$$70 \text{ in. gm.} = F \times 12 \text{ in.}$$

$$F = \frac{70 \text{ in. gm.}}{12 \text{ in.}}$$

$$F = 5.67 \text{ gm.}$$

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 did not change during the experiment.

The tip of the pointer used on the labial surface of the tooth was a cylindrical piece of solid polyethylene vinyl plastic attached to the metal tip of the pointer by means of a centered hole half-way through the cylinder. The tip of the pointer used on the incisal edge of the tooth was a piece of the same cylindrical shaped vinyl plastic imbedded in methylmethacrolate, tapered oval configuration with a rectangular cut on the opposite end of the cylinder. This cut prevented the pointer from slipping from the incisal edge when force was applied. (Figure 4).

The fixture from which the torque wrench was suspended allowed additional versatility by means of adjustable parts (Figure 5). The iron base measured 48 inches by 18 inches and weighed approximately 300 pounds. Located centrally 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; and both were adjustable in a horizontal direction.

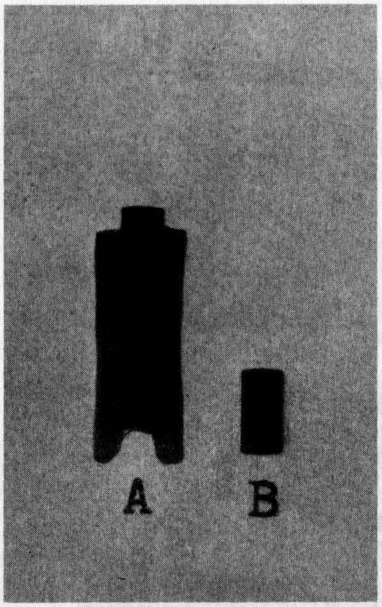



Fig. 4.--Stimulating Tips

A. Along Long Axis
B. 90° to Long Axis (Labial Surface)

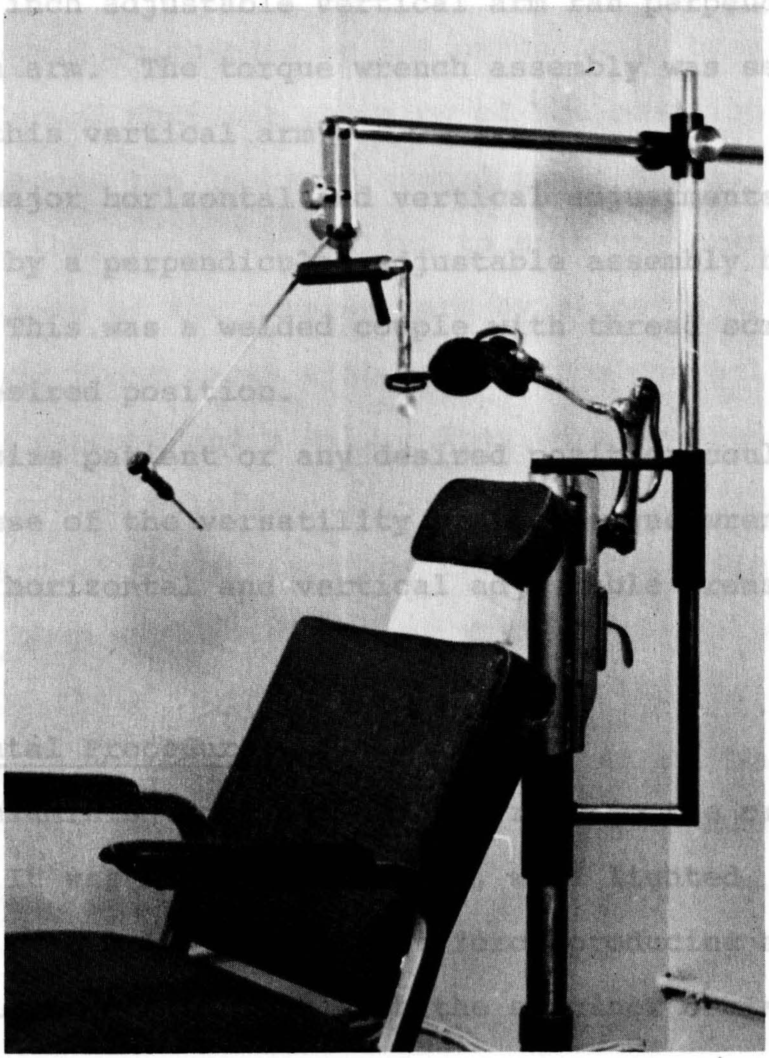


Fig. 5.--Torque Wrench Assembly and Dental Chair

The bottom brace was also adjustable in the vertical direction. (Figure 5).

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 thread screws to secure the desired position.

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

### 3. Experimental Procedure:

The examining room was a study room in the orthodontic department. It was seven feet square, well lighted, and air-conditioned. The metal base of the force producing apparatus sat in the middle of the room with the examiner seated at the side of the subject.

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

The subjects were reminded that the position of their front teeth would be changed by the orthodontic treatment; and they were informed that the changing of the position of the teeth also changes the "nerves" around these teeth. They were then asked if they would be willing to help the examiner determine what some of the changes were by allowing him to push on one of their front teeth with forces from one-half ounce to approximately a pound and a half. They were assured the procedure would not be painful.

The arm of the subject was then used to demonstrate to them what they would feel. They would feel two pushes and hear a comment "This is the first force and this is the second force" (at the time of each force application). "Can you tell which was the heavier force?" These two forces were always distinguishable by the subject. They were then informed that their "tooth" would feel the remaining forces. The procedure was repeated using the torque wrench on the selected tooth with forces that were easily distinguishable.

The subjects were informed that, henceforth, it would be slightly harder to identify the heavier force, but if they concentrated only on doing this, it would be possible. They were also requested to help the examiner to the best of their ability.

The two positions in which the instrument tip would be placed were explained to the subject before the procedure continued. They were told that the first six series of pushes would be from the outside of the tooth ($90^{\circ}$ to the long axis of the tooth on the labial surface). The biting edge (along the long axis by way of the incisal edge) would then be used for the remaining six series of pushes. These areas were demonstrated by pressure from the index finger of the examiner.

The forces directed $90^{\circ}$ to the long axis of the tooth were transmitted to the tooth through the cylindrical plastic tip placed on the labial surface of the tooth. The forces directed along the long axis of the tooth were transmitted through the methylmethacrolate tip placed on the incisal edge of the incisor. These tips exerted no force upon the tooth being investigated until the torque wrench was flexed.

The standard force values used were 10, 50, 100, 200, 500 and 1000 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 $\pm$ 10 per cent of the standard values, and then increasing or decreasing these forces as was necessary for the individual, when comparing it to the standard values. The validity of the differential threshold was established after it was determined. This was done by asking the individual to correctly identify the heavier of the two forces, at least seven out of ten times. These forces were administered in random order.

If the subject could not correctly identify the heavier force 70 per cent of the time, the differential threshold was considered too low and was then increased for the subject. The differential threshold was increased above the previously determined differential threshold until the subject could identify the heavier of two forces at least seven out of ten times. This value was then considered as the differential threshold for that subject.

If the subject correctly identified the heavier force ten times out of ten times, the determined differential threshold was considered too high and a new lower differential threshold was established. This was accomplished by decreasing the force differential compared 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 differential threshold was checked above and below the standard force values because the sensation of these two segments were not always the same. (Example: at 50 gm., 46 gm. may be distinguishable, but 56 gm. or 58 gm. may be required before it was distinguishable from 50 gm.)

The subjects correct replies were recorded by checks and the wrong replies by dashes. The replies were recorded immediately after the stimulus was placed on the tooth and the subject identified the heavier force.

The results of both the 90° to the long axis and the long axis recording were then plotted on semi-logarithmic and full logarithmic graph paper. The established differential thresholds were plotted along the abscissa (~~y~~X-axis) and the standard force values were plotted along the ordinate (~~x~~Y-axis), for uniformity.

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

<u>4. Miscellaneous:</u>

The records were made by the examiner after each pair of forces were administered. The person was asked which force was the heavier of the two forces. The subject then identified the heavier force by voice or by indicating with the first two fingers of his right hand if the pointer prevented him from verbalizing the answer. The answers were then recorded under the force values used as the differential threshold.

The duration of tooth stimulation was considered important. It was possible to develop a rhythm that permitted nearly equal time intervals for each of the standard forces and their respective differential thresholds by practicing the development of various force ranges to be used with the aid of a metronome set at two beats per second.

The constant tic-toc of the metronome was considered distracting by most pilot study subjects and was, therefore, not used in the experimental procedure. Practice sessions were frequently held to insure, as much as possible, a uniform time for the duration of stimulus for each of the force ranges.

## CHAPTER IV

## FINDINGS

The pilot study, which preceded the actual experiment, allowed the establishment of approximate Weber Ratios to be anticipated in this study. It further indicated the expected range over which the Psychophysical Law, for a subject, would be valid. The following table presents the mean Weber Ratios at each standard force employed in the pilot study.

TABLE 1

Mean Weber Ratios From the Pilot Study

| Grams Force | 10 | 20 | 50 | 100 | 200 | 300 | 500 | 750 | 1000 |
|---|---|---|---|---|---|---|---|---|---|
| Weber Ratio $90^{\circ}$ to Long Axis | .2 | .2 | .2 | .15 | .15 | .13 | .15 | .17 | .23 |
| Weber Ratio Along Long Axis | — | .5 | .1 | .14 | .14 | .13 | .1 | .14 | .25 |

It was decided from these results to use the 10, 50, 100, 200, 500 and 1000 gram force stimuli. It was felt that the Weber Ratio would probably be uniform between 50 and 500 grams. The 10 and 1000 gram forces would give one measurement below and one measurement above the apparent optimal range of the Psychophysical Law.

The reliability of the method utilized in the experiment was established by repeating the first test measurements on twelve of the fifty subjects. The results of these two determinations were then compared statistically. The Studentized "t" Test was employed to determine if there was any significant difference between the two measurements. The following table summarizes these results:

TABLE 2

"t" Comparison Between First and Repeat Measurements

| Grams Force | 10 | 50 | 100 | 200 | 500 | 1000 |
|---|---|---|---|---|---|---|
| Forces Applied 90° to the Long Axis | 1.5 | .45 | 1.42 | .67 | .99 | .32 |
| Forces Applied Along Long Axis | .99 | .89 | .08 | 0 | 1.46 | 1.43 |

The largest "t" value was only 1.50 ($p > .20$), from this it was concluded that no significant difference existed between the two measurements on the same subject. The method was, consequently, considered to be statistically reliable.

All data were converted from gram measurements to per cent values (Appendixes I through VI). These per cent values were then analyzed by means of Studentized "t" Tests. The Weber-Fechner Phenomenon is not generally expressed in per cent values, however, the statistical assessment of the data was facilitated by this conversion.

The conclusions of the Studentized "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 3. These "t" Test results show a highly significant difference ($P < .001$) between the two measurements, with the exception of one series, the ten gram values along the long axis ($.01 > P > .001$).

These results offer convincing proof that the ability of the subjects to discriminate between two "similar" forces was significantly altered. The cause of the decreased ability to distinguish between different forces must be attributed to the early effects of orthodontic force application. It can be concluded from this that this proprioceptive discriminatory ability was significantly altered by the orthodontically produced movement of the central incisor.

It should be noted that only the 10, 50, 100, and 200 gram comparisons were made. These forces were the only ones employed for all subjects at the third measurement because the majority of subjects experienced pain upon application of force above 200 grams. The number of subjects who experienced pain were as follows:

TABLE 3

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

| Force Values | $90^{o}$ "t" Values | Long Axis "t" Values |
|---|---|---|
| 10 grams | 3.51*** | 2.39** |
| 50 grams | 6.54*** | 6.35*** |
| 100 grams | 6.81*** | 6.62*** |
| 200 grams | 6.69*** | 6.64*** |

* $.05 > P > .01$

** $.01 > P > .001$

*** $P < .001$

1) $90^{\circ}$ to the long axis, 34 subjects at 500 grams and 7 additional subjects at 1000 grams.

2) Along the long axis, 30 subjects at 500 grams and 12 additional subjects at 1000 grams.

The forces between 10 grams and 200 grams caused no pain, except to one subject. This subject reported pain at the 200 gram force, for both directions.

Those subjects who experienced pain when a 500 gram force was applied to incisor teeth were not tested with a 1000 gram force. The one subject who experienced pain with 200 gram force was not tested with the 500 gram or the 1000 gram forces.

A comparison of the extraction and non-extraction groups was also determined by the use of Studentized "t" Tests. These determinations were made for both the first and third measurements. The "t" values evidence no significant difference in the differential thresholds between the extraction and non-extraction group prior to orthodontic treatment or four days after continuous light orthodontic forces were applied to the teeth. The only exception was for the 10 gram measurement at $90^{\circ}$ to the long axis, for the third measurement ( $.05 > P > .01$). (Table 4).

TABLE 4

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

| | $90^{\circ}$ "t" Values | Long Axis "t" Values |
|---|---|---|
| 10 grams | | |
| First | 0.16 | 0.14 |
| Third | 2.36* | 0 |
| 50 grams | | |
| First | 0.66 | 1.06 |
| Third | 0.59 | 0.58 |
| 100 grams | | |
| First | 0.4 | 0.7 |
| Third | 0.56 | 0.01 |
| 200 grams | | |
| First | 0.44 | 1.03 |
| Third | 0.59 | 0.53 |

* $.05 > P > .01$

** $.01 > P > .001$

*** $P < .001$

The mean per cent differential threshold for all groups and all forces used are presented in Table 5. The statistical comparison between the various standard force values at each of these measurement times is presented in Table 6. The much higher "t" values in evidence are of particular interest; when comparisons are made between 10 and 1000 gram force stimuli and the 50, 100, 200 and 500 gram forces, than between those comparisons involving only the 50, 100, 200 and 500 gram forces.

Those "t" comparisons, for the first measurements, involving the 10 gram force ranged from 6.00 to 7.77 for the 90$^{\circ}$ axis and from 5.76 to 6.22 for the long axis. The comparisons involving the 100 gram force stimulus had "t" values that ranged from 5.95 to 7.84 for the 90$^{\circ}$ axis and from 5.00 to 6.32 for the long axis. The "t" comparisons between the 50, 100, 200 and 500 gram forces all fell between 0.44 and 3.67 for the 90$^{\circ}$ axis and 0.21 and 4.18 for the long axis. These "t" values are all lower than the "t" comparisons involving the 10 and 1000 gram forces. The same observation is evident with those values obtained for the second test (in the extraction group two to four days after premolar extraction). Here the "t" comparisons involving the 10 gram force ranged from 5.35 to 7.66 for the 90$^{\circ}$ axis and from 4.95 to 6.31 for the long axis. The comparisons involving the 1000 gram force gave "t" values ranging from

## TABLE 5

### MEAN PER CENT DIFFERENTIAL THRESHOLD FOR EXTRACTION, NON-EXTRACTION AND COMBINATION GROUPS AT FIRST, SECOND AND THIRD MEASUREMENT PERIODS

| | | FIRST | | SECOND | | THIRD | |
|---|---|---|---|---|---|---|---|
| NON-EXTRACTION | | $90^{o}$ | L.A.** | $90^{o}$ | L.A. | $90^{o}$ | L.A. |
| 19 SUBJECTS | | | | | | | |
| GRAMS | 10 | 45.5±17.9* | 47.5±17.3 | | | 50.5± 4.3 | 56.5±8.6 |
| | 50 | 13.0± 3.1 | 12.9± 3.9 | | | 29.9± 4.3 | 26.4±5.4 |
| | 100 | 13.3± 3.9 | 15.0± 4.9 | | | 40.0± 8.6 | 39.5±5.4 |
| | 200 | 12.4± 3.5 | 13.0± 3.5 | | | 34.3± 6.1 | 32.2±6.5 |
| | 500 | 11.1± 3.0 | 9.9± 2.9 | | | | |
| | 1000 | 19.9± 4.0 | 16.2± 4.1 | | | | |
| EXTRACTION | | | | | | | |
| 31 SUBJECTS | | | | | | | |
| GRAMS | 10 | 45.2±16.7 | 53.2±17.8 | 45.5±13.6 | 48.5±17.3 | 55.6±10.7 | 56.5±9.3 |
| | 50 | 13.7± 3.5 | 14.0± 3.3 | 14.5± 2.9 | 13.8± 3.3 | 31.0± 3.3 | 29.1±6.7 |
| | 100 | 13.7± 3.1 | 14.2± 3.6 | 14.0± 3.0 | 14.9± 3.7 | 41.3± 6.4 | 39.2±6.7 |
| | 200 | 12.8± 3.8 | 12.1± 2.6 | 13.1± 2.8 | 13.2± 2.8 | 33.3± 6.9 | 33.4±9.2 |
| | 500 | 10.1± 3.3 | 11.3± 3.3 | 11.3± 2.9 | 11.6± 2.9 | | |
| | 1000 | 19.3± 3.8 | 18.8± 4.4 | 18.0± 1.2 | 18.0± 3.2 | | |
| COMBINED | | | | | | | |
| 50 SUBJECTS | | | | | | | |
| GRAMS | 10 | 45.3±16.8 | 46.7± 5.3 | 45.5±13.6 | 48.5±17.3 | 53.6±11.6 | 54.9±10.1 |
| | 50 | 13.3± 3.2 | 13.2± 3.6 | 14.5± 2.9 | 13.8± 3.3 | 30.4± 6.1 | 31.1±5.9 |
| | 100 | 13.5± 3.7 | 14.7± 4.1 | 14.0± 3.0 | 14.9± 3.7 | 40.6± 7.6 | 40.0±7.4 |
| | 200 | 12.6± 3.1 | 12.4± 3.0 | 13.1± 2.8 | 13.2± 2.8 | 33.6± 6.6 | 32.8±8.1 |
| | 500 | 10.5± 3.2 | 10.8± 3.1 | 11.3± 2.9 | 11.6± 2.9 | | |
| | 1000 | 19.5± 3.5 | 17.9± 4.3 | 18.0± 1.2 | 18.0± 3.2 | | |

* Mean ± One Standard Deviation
** Long Axis

TABLE 6

Statistical Comparison Between Various Force Application for First, Second and Third Measurements

| First Measurement Comparisons (Number of Subjects = 50) | "t" Values 90° | Long Axis |
|---|---|---|
| 10 grams vs 50 grams | 6.39*** | 5.95*** |
| 10 grams vs 100 grams | 6.41*** | 6.22*** |
| 10 grams vs 200 grams | 7.77*** | 6.04*** |
| 10 grams vs 500 grams | 6.41*** | 5.93*** |
| 10 grams vs 1000 grams | 6.00*** | 5.76*** |
| 50 grams vs 100 grams | 0.44 | 2.39** |
| 50 grams vs 200 grams | 1.42 | 0.21 |
| 50 grams vs 500 grams | 2.76** | 3.11** |
| 100 grams vs 200 grams | 1.67 | 3.95*** |
| 100 grams vs 500 grams | 3.67*** | 4.18*** |
| 200 grams vs 500 grams | 2.77** | 2.49** |
| 50 grams vs 1000 grams | 7.84*** | 6.32*** |
| 100 grams vs 1000 grams | 6.38*** | 5.00*** |
| 200 grams vs 1000 grams | 5.95*** | 5.48*** |
| 500 grams vs 1000 grams | 6.55*** | 5.55*** |

TABLE 6 Con't.

| Second Measurement Comparisons (Number of Subjects = 31) | "t" Values | |
|---|---|---|
| | $90^{o}$ | Long Axis |
| 10 grams vs 50 grams | 5.35*** | 4.95*** |
| 10 grams vs 100 grams | 6.21*** | 6.12*** |
| 10 grams vs 200 grams | 7.66*** | 6.31*** |
| 10 grams vs 500 grams | 6.14*** | 6.03*** |
| 10 grams vs 1000 grams | 5.87*** | 5.61*** |
| 50 grams vs 100 grams | 0.75 | 2.09* |
| 50 grams vs 200 grams | 1.93* | 1.19* |
| 50 grams vs 500 grams | 3.26*** | 2.94** |
| 100 grams vs 200 grams | 2.37** | 3.62*** |
| 100 grams vs 500 grams | 3.72*** | 2.97** |
| 200 grams vs 500 grams | 3.01*** | 2.98*** |
| 50 grams vs 1000 grams | 6.88*** | 6.59*** |
| 100 grams vs 1000 grams | 12.81*** | 8.31*** |
| 200 grams vs 1000 grams | 6.59*** | 5.88*** |
| 500 grams vs 1000 grams | 5.89*** | 5.62*** |

| Third Measurement Comparisons (Number of Subjects = 50) | "t" Values | |
|---|---|---|
| | $90^{o}$ | Long Axis |
| 10 grams vs 50 grams | 5.98*** | 6.28*** |
| 10 grams vs 100 grams | 6.04*** | 5.98*** |
| 10 grams vs 200 grams | 6.11*** | 6.02*** |
| 50 grams vs 100 grams | 5.69*** | 5.36*** |
| 50 grams vs 200 grams | 2.03* | 2.74* |
| 100 grams vs 200 grams | 5.71*** | 5.67*** |

* $.05 > P > .01$
** $.01 > P > .001$
*** $P < .001$

5.89 to 12.81 for the 90$^{\circ}$ axis and from 5.62 to 8.91 for the long axis. The "t" comparisons between the 50, 100, 200 and 500 gram forces ranged from 0.75 to 3.72 for the 90$^{\circ}$ axis and from 1.19 to 3.62 for the long axis, again all lower than those comparisons involving either the 10 or 1000 gram forces.

Several of the comparisons between the 50, 100, 200 and 500 gram forces were shown to be significantly different ($.01 > P > .001$) by normal statistical interpretation, however, it was still believed that these forces were within the functional limits ascribed to the Psychophysical Law. Fechner and subsequent investigators have stated that the phenomenon is best represented by the general equation $S = A \log I + K$. The validity of this mathematical expression of the data was tested by plotting the mean discernible difference for each force used against the logarithm of the force. The results for force application 90$^{\circ}$ to the long axis are plotted for each measurement period in Figure 6. The results for forces along the long axis are presented in Figure 7.

It can be seen from the plots of these Fechnerian expressions that the range between 50 grams and 200 grams, and between 100 grams and 500 grams were nearly linear, before orthodontic appliance placement. The range between 50 grams and 500 grams can generally be considered as approaching

FIGURE 6

Semi-Logarithmic Graph of Differential Thresholds Plotted Against Forces Applied 90$^{\circ}$ to Long Axis of the Maxillary Central Incisors

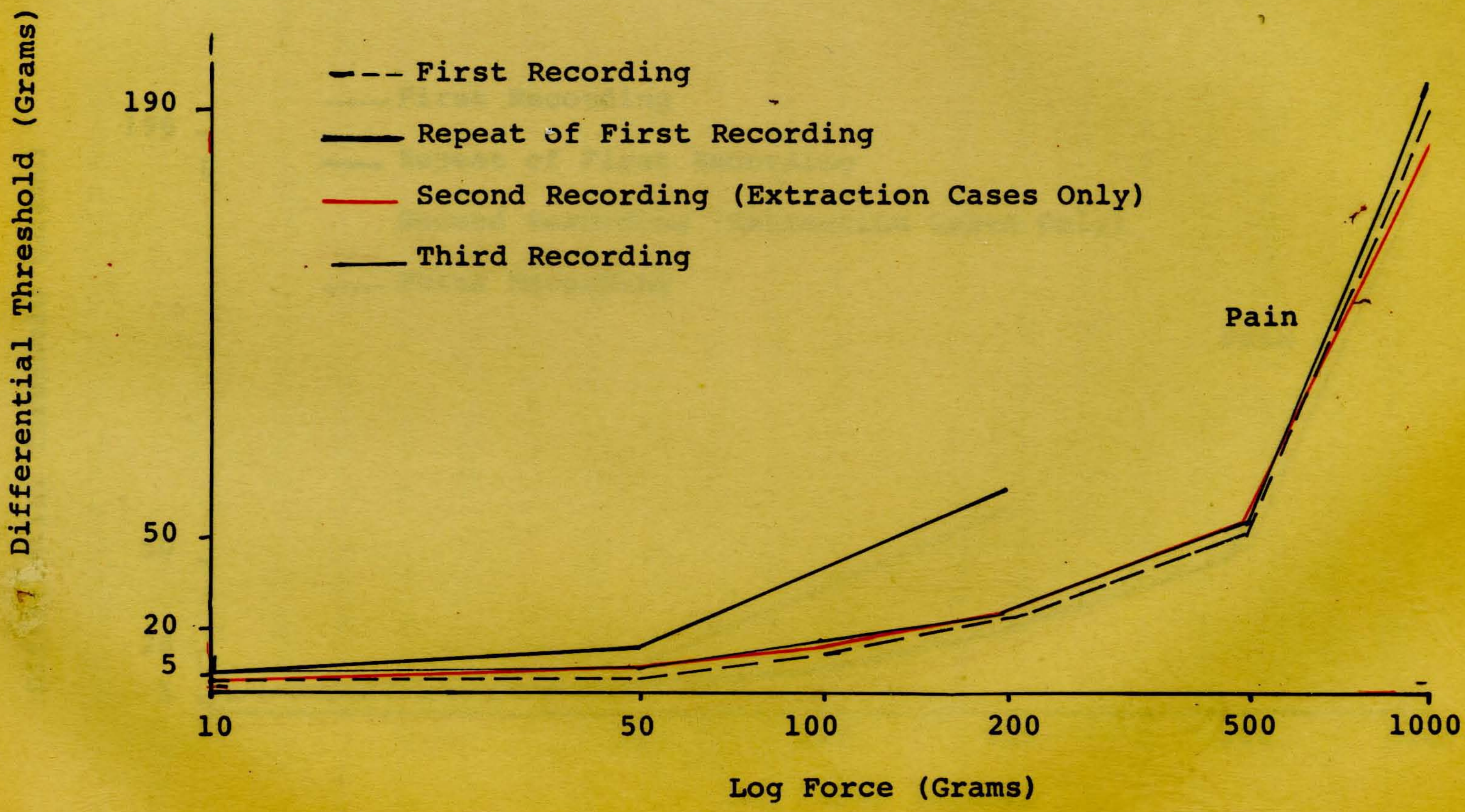
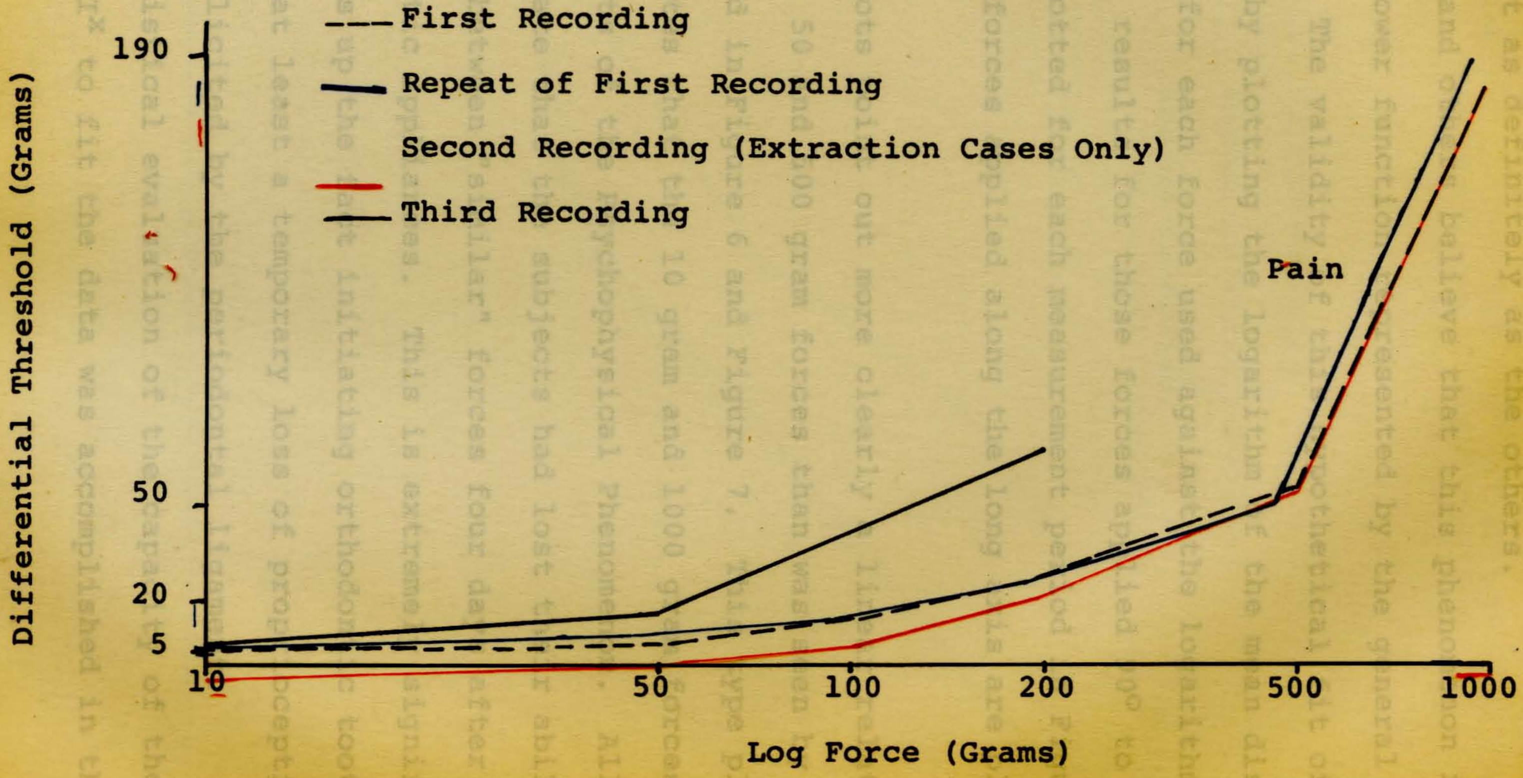


FIGURE 7

Semi-Logarithmic Graph of Differential Thresholds Plotted Against Forces Along the Long Axis of the Maxillary Central Incisor



linearity but not as definitely as the others.

Stevens and others believe that this phenomenon is best expressed as a power function represented by the general equation $dS = k\ I^x$. The validity of this hypothetical fit of the data was tested by plotting the logarithm of the mean discernible difference for each force used against the logarithm of the forces. The results for those forces applied $90^o$ to the long axis are plotted for each measurement period in Figure 8. The results for forces applied along the long axis are plotted in Figure 9.

These plots point out more clearly a linear relationship between the 50 and 500 gram forces than was seen by the type of plot used in Figure 6 and Figure 7. This type plot further illustrates that the 10 gram and 1000 gram forces fall outside the limits of the Psychophysical Phenomenon. All of the graphs indicate that the subjects had lost their ability to discriminate between "similar" forces four days after placement of orthodontic appliances. This is extremely significant because it points up the fact initiating orthodontic tooth movement causes at least a temporary loss of proprioceptive discrimination elicited by the periodontal ligament.

The statistical evaluation of the capacity of the equation $dS = k\ I^x$ to fit the data was accomplished in the

FIGURE 8

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

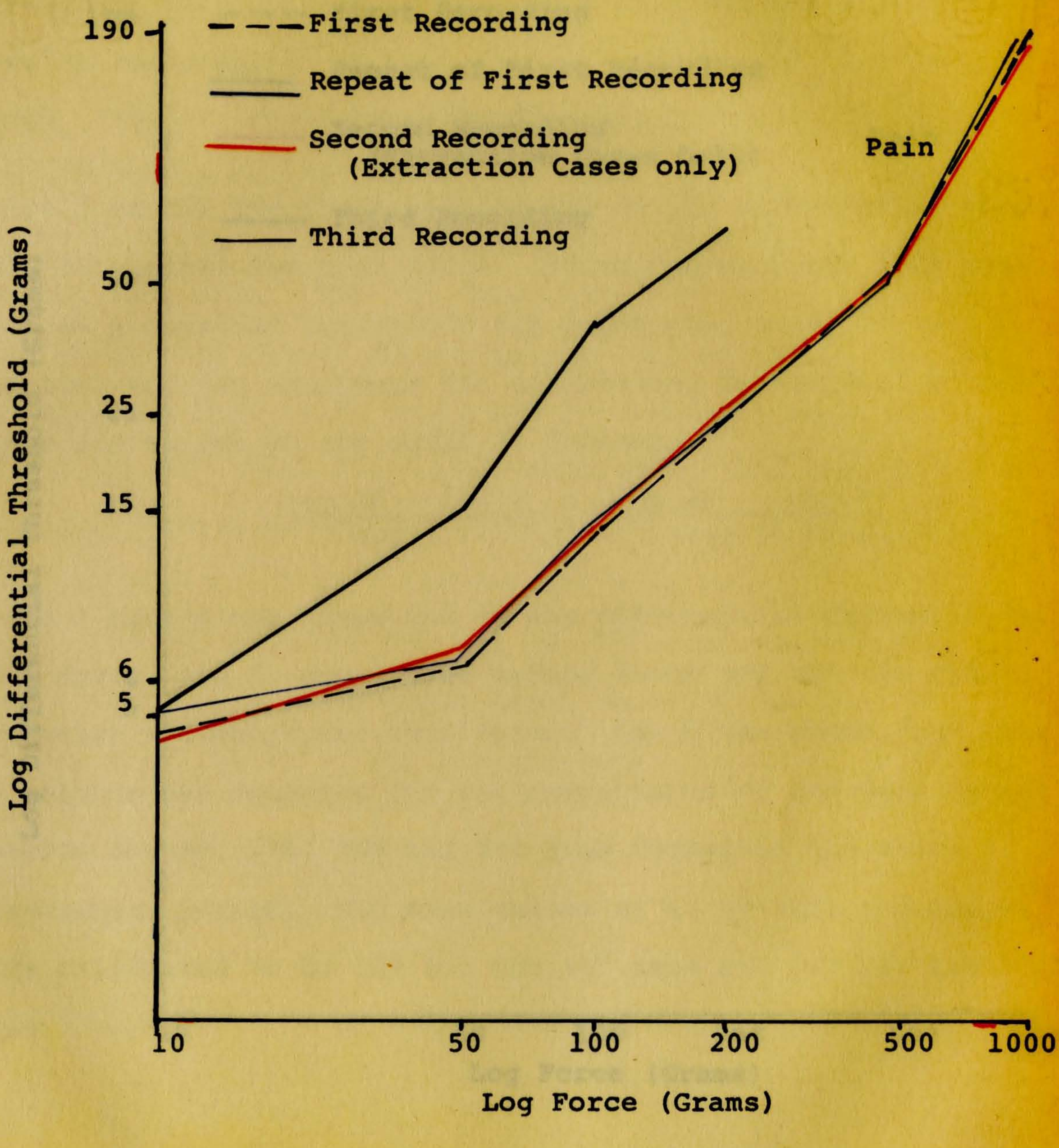
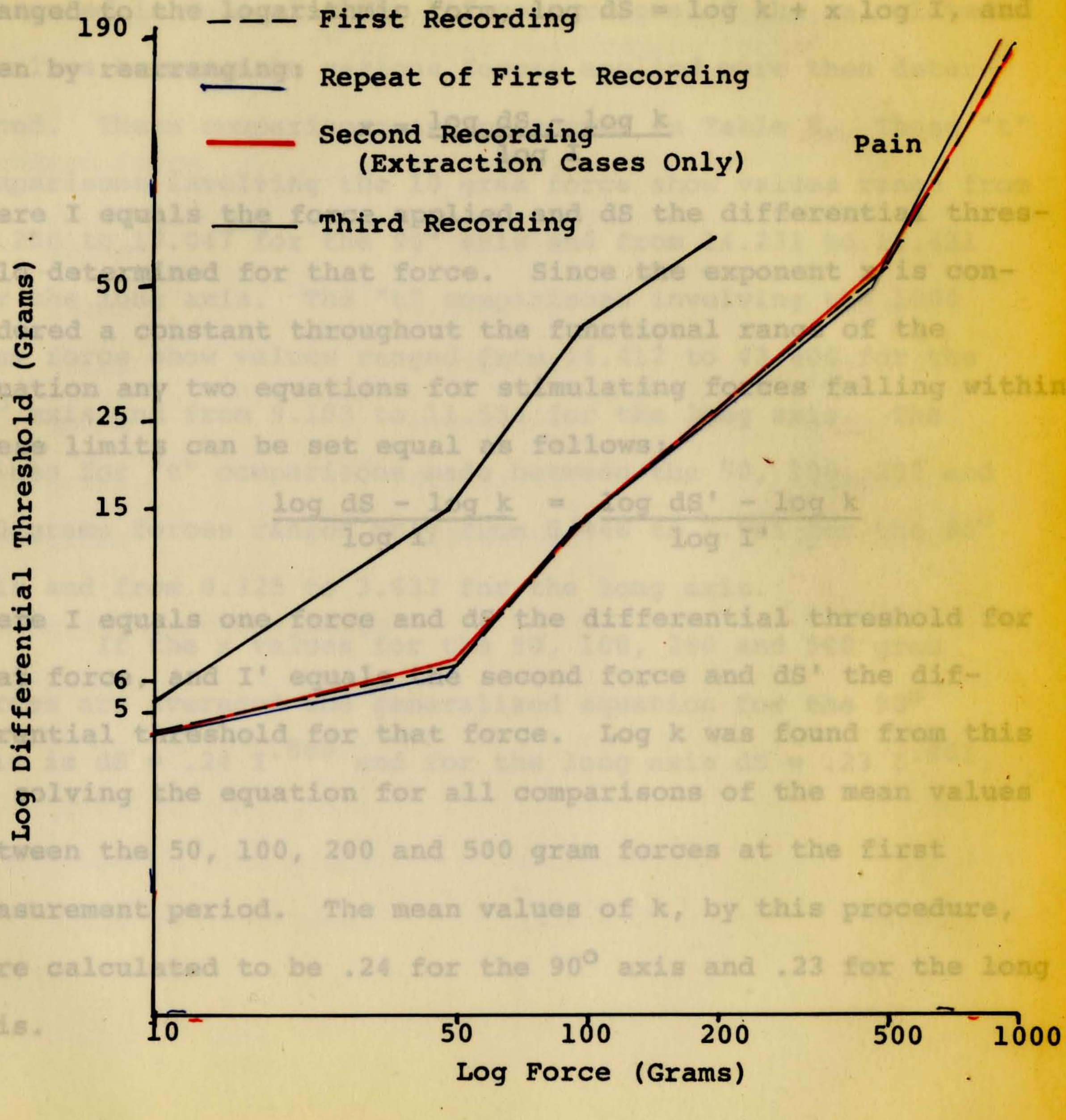


FIGURE 9

Logarithmic-Logarithmic Graph of Differential Thresholds Plotted Against Forces Applied Along the Long Axis of the Maxillary Central Incisor



following manner; it was first assumed that only the 50, 100, 200 and 500 gram forces fell within the optimal functional limits of the Psychophysical Phenomenon. The equation was changed to the logarithmic form, log dS = log k + x log I, and then by rearranging:

$$x = \frac{\log dS - \log k}{\log I}$$

where I equals the force applied and dS the differential threshold determined for that force. Since the exponent x is considered a constant throughout the functional range of the equation any two equations for stimulating forces falling within these limits can be set equal as follows:

$$\frac{\log dS - \log k}{\log I} = \frac{\log dS' - \log k}{\log I'}$$

where I equals one force and dS the differential threshold for that force, and I' equals the second force and dS' the differential threshold for that force. Log k was found from this by solving the equation for all comparisons of the mean values between the 50, 100, 200 and 500 gram forces at the first measurement period. The mean values of k, by this procedure, were calculated to be .24 for the $90^{\circ}$ axis and .23 for the long axis.

The x values were then calculated next for all subjects at each force application for the first test period. These mean exponential values and their standard deviations are presented in Table 7. The "t" comparisons of the calculated x values between the various forces applied were then determined. These comparisons are presented in Table 8. Those "t" comparisons involving the 10 gram force show values range from 12.256 to 17.047 for the $90^{o}$ axis and from 14.231 to 18.431 for the long axis. The "t" comparisons involving the 1000 gram force show values ranged from 14.412 to 43.400 for the $90^{o}$ axis and from 9.183 to 11.534 for the long axis. The values for "t" comparisons made between the 50, 100, 200 and 500 grams forces ranged only from 0.446 to 2.985 for the $90^{o}$ axis and from 0.325 to 3.637 for the long axis.

If the x values for the 50, 100, 200 and 500 gram forces are averaged the generalized equation for the $90^{o}$ axis is $dS = .24\ I^{.865}$ and for the long axis $dS = .23\ I^{.861}$.

TABLE 7

Mean Values of x Determined for the Equation
$dS = k\ I^x$ at First Measurement Period

| Standard Force | 90° x | Long Axis x |
|---|---|---|
| 10 grams | 1.251±.155* | 1.308±.150 |
| 50 grams | 0.847±.059 | 0.838±.067 |
| 100 grams | 0.871±.063 | 0.862±.062 |
| 200 grams | 0.866±.048 | 0.878±.054 |
| 500 grams | 0.876±.037 | 0.866±.050 |
| 1000 grams | 0.974±.029 | 0.966±.030 |

* ±One Standard Deviation

TABLE 8

x Values From Equation $dS = k\ I^x$ For First Measurement Period

| Comparisons (Number of Subjects = 50) | "t" Values 90° | Long Axis |
|---|---|---|
| 10 grams vs 50 grams | 17.047*** | 18.431*** |
| 10 grams vs 100 grams | 15.899*** | 17.773*** |
| 10 grams vs 200 grams | 16.642*** | 17.490*** |
| 10 grams vs 500 grams | 16.985*** | 18.414*** |
| 10 grams vs 1000 grams | 12.256*** | 14.231*** |
| 50 grams vs 100 grams | 1.951 | 1.655 |
| 50 grams vs 200 grams | 1.743 | 3.637*** |
| 50 grams vs 500 grams | 2.895** | 2.054** |
| 100 grams vs 200 grams | 0.446 | 1.262 |
| 100 grams vs 500 grams | 1.088 | 0.325 |
| 200 grams vs 500 grams | 1.149 | 1.053 |
| 50 grams vs 1000 grams | 18.529*** | 11.034*** |
| 100 grams vs 1000 grams | 33.260*** | 11.532*** |
| 200 grams vs 1000 grams | 43.400*** | 9.183*** |
| 500 grams vs 1000 grams | 14.412*** | 10.638*** |

* $.05 > P > .01$
** $.01 > P > .001$
*** $P < .001$

CHAPTER V

DISCUSSION

The validity of the Weber Ratio being expressed as a constant has been repeatedly questioned. Most authors expressed the belief that this ratio is valid within very narrow limits.

Fechner assumed that the "just noticeable difference" of sensation always contained the same number of sensation units and was maintained along the entire scale of sensory stimuli. He considered this ratio to be constant.

Hect, Exner, Wundt, Fulton and Treisman believe that the Weber Ratio is constant only over the middle range of intensity and that it increases in both the lower and the higher ranges of intensity.

The results of this experiment confirm the observations of these investigators. The "just noticeable difference" was found to be nearly constant only in the middle range of stimulus intensity. The extreme limits of stimulus intensity employed in this study had higher Weber Ratios.

Kawamura and Wanatabe established a Weber Ratio for tactile sensation of human teeth as 0.1 for 100 per cent discrimination. A small sample was used in their study. The subjects determined the differences in wire diameter by biting upon wires of different diameter and comparing them to another wire, the standard. The receptors that apprise the central nervous system with information from which the value judgments are made in determining the comparative thickness of these wires emenate from three sources. These sources are the periodontal ligament, the temperomandibular joint and the muscles of mastication.

It is believed that only the proprioceptive receptors of the periodontal ligament were receiving stimulation in this study. The Weber Ratios, ranging from 0.10 to 0.15 determined from this project, compare favorably with the Kawamura and Wanatabe value of 0.1. One significant difference is that these ratios were based on 70 per cent correct discriminations. The ratios would probably have been higher for 100 per cent discrimination.

Since its inception over 100 years ago, Fechner's Law has been put to many tests. The law which can be expressed by the general equation $S = A \log I + K$ has many advocates and many opponents. Leading the opposition in dispute of this concept has been Stevens. He believes that the law is best expressed as a power function of the general form $dS = k\ I^x$.

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 functional limits of the phenomenon. If the power function equation best fits the data a logarithmic-logarithmic plot should exhibit linearity for those forces that fall within the functional limits of the phenomenon. When the two plots are compared it can readily be seen that the logarithmic-logarithmic plot (Figures 8 and 9) exhibit better linearity between the 50 gram and 500 gram force ranges than does the semilogarithmic plot (Figures 6 and 7). This then demonstrates that the power equation, proposed by Stevens, provides better fit for the data of this study than does the Fechner logarithmic expression. It is felt, from this, that these results are best expressed by the general formula $dS = k\ I^x$.

The values for k were determined as .24 for the 90° axis, and .23 for the long axis, while the exponent x was determined as .865 for the 90° axis and .861 for the long axis. These exponential values were within the values ranging from 0.33 to 3.5 that Stevens has listed for other forms of stimulation.

The location of the pressoreceptors of the periodontal ligament has been investigated repeatedly. This study, however, cannot prove their location, it does offer indirect evidence as to their location for the central incisor teeth of man.

Pfaffman, Ness, Cuozzo and Kizior have all reported greater sensitivity to forces directed along the long axis of the cat canine than in other directions. Kizior accounted for this directional sensitivity by the observation that he could find pressoreceptors only in the apical one-third of the periodontal ligament. The confinement of these pressoreceptors to the apical one-third has also been reported in monkeys by Bernick. Lewinski and Steward, on the other hand, describe the periodontal receptors as starting in the apical region and proceeding gingivally in a longitudinal manner in both humans and cats.

No greater sensitivity was noted for forces directed along the long axis than on the labial surface, $90^{\circ}$ from the long axis. This is shown by the nearly identical equations derived to express the Psychophysical Law within its functional limits, $dS = .24\ I^{.865}$ for the $90^{\circ}$ axis and $dS = .23\ I^{.861}$ for the long axis.

If the Kizior explanation for directional sensitivity based on the confinement of the receptors to the apical one-third in the cat is valid, then the apparent lack of this directional sensitivity for the human incisor would tend to support the distribution reported by Lewinski and Steward.

No documented evidence existed, until the present time, on the discriminatory capacity of teeth prior to and after orthodontic treatment had begun. It had been repeatedly stated, in clinical circles, that the teeth were "more sensitive" until the periodontal proprioceptive mechanism can adapt to this new continual stimulation received from the forces stored in the appliances. This study has proved that the periodontal ligament does lose much of its ability to discriminate light forces. Four days after orthodontic treatment began the periodontal ligament was less able to differentiate tactile sensations than before orthodontic treatment began.

Clinically, it has been observed that the pain threshold is apparently lowered by the application of continuous light differential orthodontic forces to teeth. This study clearly documents a significant lowering of the pain threshold when forces from appliances involved in orthodontic treatment have been in effect for a period of four days.

Those subjects for whom differential thresholds were recorded at the 500 and 1000 gram force stimuli are of particular interest (Appendixes V and VI). Eight of the subjects were able to make these discriminations for both the 500 and 1000 gram forces applied to the $90^{\circ}$ axis. Seven of the subjects showed the ability to make these discriminations for 500 and 1000 gram forces applied to the long axis. All of these subjects showed differential thresholds of 25 grams at the 500 gram force stimulations. This yields a Weber Ratio of .05 compared to the mean value before treatment for the entire group of a Weber Ratio of .11. Some of the subjects had a differential threshold of 50 grams at the 1000 gram force interval. This also yields a Weber Ratio of .05 compared to the mean value of .19 for the entire group prior to treatment.

It is unlikely that these subjects experienced an actual improvement in discrimination for these force applications, especially since prior to treatment the 1000 gram force fell outside the normal range of this psychophysical phenomenon. The more logical explanation, in light of the fact that the remaining subjects reported pain for these forces, is that these discriminations were made by comparing differences in the degrees of pain sensation. It would seem that either these children were more stoic towards pain or that the input from the periodontal ligament in these subjects was below their conscious awareness of pain. It can, therefore, be speculated that orthodontic patients may respond to higher forces by discriminating between slight differences of pain sensation rather than by the normal proprioceptive discrimination used before the orthodontic treatment started.

The patients tested in this project were subjected to two types of forces. Most of the forces were developed from the orthodontic appliances attached to the teeth. These forces were continually applied to the teeth during the four day period. The remaining forces that were applied to the teeth were developed by the torque wrench. These were intermittent forces that were used to establish the working limits of the Psychophysical Law. The magnitudes used have been previously stated.

The continuous forces used can be classified as light orthodontic forces. They ranged from 40 grams to 150 grams. Their magnitudes varied and were dependent upon the intrinsic and extrinsic forces used. All forces derived from the orthodontic wire are considered intrinsic forces. The magnitude of these intrinsic forces is dependent upon the configuration, modulus of elasticity, deflection and cross sectional area of the orthodontic wire used. The extrinsic forces are classified as forces other than those inherent in the orthodontic wire that increase the magnitude of the forces applied to a tooth or a group of teeth. These forces are most commonly developed by orthodontic rubber bands.

The forces developed from the orthodontic appliances probably disrupted the proprioceptive mechanism of the periodontal ligament by causing the roots of the maxillary central incisor to constantly impinge upon some of the pressoreceptors of the periodontal ligament. The individuals were in the process of adjusting to this new environment of continuous sensory input arising from the pressoreceptors of the periodontal ligament. These individuals responded in a different manner to tactile stimulation applied to their teeth during the third measurement period than they did in either the first or the second measurement periods. The subjects were less effective in differentiating between the "similar" force magnitudes developed from the torque wrenches used to test the discriminatory ability of these individuals.

Three other possible causes may in part account for this loss in discriminatory ability. They are:

1. separation of the teeth for band placement
2. process of band placement
3. possible trauma to the periodontal ligament during the banding process.

These procedures, in some cases, were carried out on the same day as appliance placement. They could also contribute to the alteration of the proprioceptive mechanism. It is believed, however, that these causes would be of minor significance when compared to the continuous forces generated by the orthodontic appliances.

A return to normal discrimination is expected as the orthodontic treatment is continued. It is believed, that even with sustained force application, that this will occur in one or both of the following manners: first, the individual may be expected to show neural adaptation to these forces. This may occur peripherally as a property of the receptor and/or within the central nervous system as central accommodation to this continuous input which is caused by the effect of orthodontic forces upon the maxillary central incisor. Second, over an extended period of time bone resorbtion occurs on the pressure side of the alveolus and bone deposition occurs upon the tension side of the alveolus. This process will return the normal biological relationship between the root, the alveolus and the periodontal ligament. This then would allow the distorted receptor to return to their normal and thus more functional configuration.

## CHAPTER VI

## SUMMARY AND CONCLUSION

A method of testing for proprioceptive discrimination in the human periodontal ligament was described. The reliability of this procedure was statistically proved. This method was used to determine if the initial phase of orthodontic treatment alters the ability of the patients to differentiate between "similar" forces.

The proprioceptive ability of the periodontal ligament is significantly altered with the application of light orthodontic forces. Four days after these light orthodontic forces were applied to the maxillary central incisor the ability of the subjects to differentiate between forces of "similar" force magnitude was significantly decreased.

The subjects were divided into two groups before the experiment started. One group required the extraction of first premolar teeth in the treatment of their malocclusion. The second group did not require the extraction of teeth in their treatment. No difference was found in the two groups in their ability to discriminate between the forces used either before treatment or four days after appliance placement.

The working range of this psychophysical phenomenon, as applied to the human periodontal ligament, was found to be between 50 grams and 500 grams. Statistically the lower limit appears to be near 50 grams, while the upper limit probably exceeds 500 grams but does not approach 1000 grams.

The Weber Ratio for the periodontal ligament of children was found to range between 10 and 15 per cent of the standard force values between 50 grams and 500 grams.

The differential threshold covering this range can best be expressed by the general formula:

$$dS = k\ I^{x}$$

The constant k was established at .24 for the axis $90^{\circ}$ to the long axis of the maxillary central incisor, on the labial surface, while x was established at .865. The values for the constant k, for the long axis determinations, was .23 and the x value was .861.

The human periodontal ligament exhibited no greater directional sensitivity along the long axis than along the axis $90^{\circ}$ to the long axis, as had been reported for some experimental animals. It may be concluded from this that the proprioceptors of the periodontal ligament of the human present a different configuration or arrangement than that reported for experimental animals.

There was a significant reduction in the pain threshold to force application in 84 per cent of the patients four days after insertion of orthodontic appliances.

# APPENDIX I

First Measurement (Prior to any Treatment)
90° to the Long Axis Expressed in Actual
Values and Per cent of Actual Values

| Sub-ject No. | 10 gm. Gm. | 10 gm. % | 50 gm. Gm. | 50 gm. % | 100 gm. Gm. | 100 gm. % | 200 gm. Gm. | 200 gm. % | 500 gm. Gm. | 500 gm. % | 1000 gm. Gm. | 1000 gm. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 30 | 7.5 | 15 | 15 | 15 | 30 | 15 | 75 | 15 | 150 | 15 |
| 2 | 5 | 50 | 6 | 12 | 15 | 15 | 30 | 15 | 75 | 15 | 300 | 30 |
| 3 | 3 | 30 | 5 | 10 | 10 | 10 | 25 | 13 | 75 | 15 | 250 | 25 |
| 4 | 2 | 20 | 4 | 8 | 5 | 5 | 10 | 5 | 25 | 5 | 200 | 20 |
| 5 | 3 | 30 | 5 | 10 | 10 | 10 | 20 | 10 | 50 | 10 | 150 | 15 |
| 6 | 6 | 60 | 6 | 12 | 10 | 10 | 17.5 | 9 | 50 | 10 | 225 | 23 |
| 7 | 4.5 | 45 | 5 | 10 | 10 | 10 | 20 | 10 | 50 | 10 | 200 | 20 |
| 8 | 4.5 | 45 | 6 | 12 | 15 | 15 | 25 | 13 | 50 | 10 | 200 | 20 |
| 9 | 8 | 80 | 7 | 14 | 12.5 | 13 | 22.5 | 11 | 87.5 | 18 | 200 | 20 |
| 10 | 5.5 | 55 | 6 | 12 | 10 | 10 | 20 | 10 | 50 | 10 | 200 | 20 |
| 11 | 3 | 30 | 6 | 12 | 10 | 10 | 20 | 10 | 50 | 10 | 225 | 23 |
| 12 | 3 | 30 | 8 | 16 | 10 | 10 | 20 | 10 | 50 | 10 | 200 | 20 |
| 13 | 3.5 | 35 | 5 | 10 | 10 | 10 | 20 | 10 | 50 | 10 | 175 | 18 |
| 14 | 8 | 80 | 10 | 20 | 25 | 25 | 50 | 25 | 112.5 | 23 | 250 | 25 |
| 15 | 4 | 40 | 4 | 8 | 10 | 10 | 15 | 7.5 | 50 | 10 | 150 | 15 |
| 16 | 3 | 30 | 8 | 16 | 10 | 10 | 20 | 10 | 50 | 10 | 200 | 20 |
| 17 | 4 | 40 | 6 | 12 | 10 | 10 | 20 | 10 | 50 | 10 | 225 | 23 |
| 18 | 4 | 40 | 6 | 12 | 10 | 10 | 22.5 | 11 | 50 | 10 | 200 | 20 |
| 19 | 6 | 60 | 8 | 16 | 10 | 10 | 20 | 10 | 50 | 10 | 200 | 20 |
| 20 | 6 | 60 | 7 | 14 | 10 | 10 | 20 | 10 | 50 | 10 | 250 | 25 |
| 21 | 3 | 30 | 6 | 12 | 15 | 15 | 30 | 15 | 75 | 15 | 200 | 20 |
| 22 | 4 | 40 | 6 | 12 | 15 | 15 | 30 | 15 | 50 | 10 | 175 | 18 |
| 23 | 4 | 40 | 6 | 12 | 12.5 | 13 | 25 | 13 | 50 | 10 | 150 | 15 |
| 24 | 4.5 | 45 | 6 | 12 | 15 | 15 | 35 | 18 | 75 | 15 | 200 | 20 |
| 25 | 4 | 40 | 6 | 12 | 12.5 | 13 | 30 | 15 | 75 | 15 | 200 | 20 |
| 26 | 4 | 40 | 6 | 12 | 15 | 15 | 30 | 15 | 75 | 15 | 200 | 20 |
| 27 | 8.5 | 85 | 10 | 20 | 15 | 15 | 40 | 20 | 50 | 10 | 200 | 20 |
| 28 | 8 | 80 | 8 | 16 | 20 | 20 | 30 | 15 | 75 | 15 | 250 | 25 |
| 29 | 8 | 80 | 6 | 12 | 15 | 15 | 30 | 15 | 50 | 10 | 200 | 20 |
| 30 | 5 | 50 | 10 | 20 | 20 | 20 | 30 | 15 | 50 | 10 | 150 | 15 |
| 31 | 3 | 30 | 6 | 12 | 10 | 10 | 20 | 10 | 50 | 10 | 150 | 15 |
| 32 | 3 | 30 | 5 | 10 | 10 | 10 | 20 | 10 | 75 | 15 | 200 | 20 |
| 33 | 5.5 | 55 | 10 | 20 | 15 | 15 | 25 | 13 | 50 | 10 | 150 | 15 |
| 34 | 3 | 30 | 5 | 10 | 15 | 15 | 30 | 15 | 50 | 10 | 150 | 15 |
| 35 | 3 | 30 | 6 | 12 | 10 | 10 | 20 | 10 | 50 | 10 | 150 | 15 |
| 36 | 4 | 40 | 5 | 10 | 12.5 | 13 | 25 | 13 | 50 | 10 | 250 | 25 |

APPENDIX I (CONT'D)

| Subject No. | 10 gm. | | 50 gm. | | 100 gm. | | 200 gm. | | 500 gm. | | 1000 gm. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Gm. | % | Gm. | % | Gm. | % | Gm. | % | Gm. | % | Gm. | % |
| 37 | 6 | 60 | 7 | 14 | 15 | 15 | 25 | 13 | 75 | 15 | 200 | 20 |
| 38 | 3 | 30 | 6 | 12 | 15 | 15 | 25 | 13 | 50 | 10 | 200 | 20 |
| 39 | 3 | 30 | 6 | 12 | 12.5 | 13 | 25 | 13 | 50 | 10 | 200 | 20 |
| 40 | 4 | 40 | 5 | 10 | 15 | 15 | 25 | 13 | 50 | 10 | 150 | 15 |
| 41 | 5 | 50 | 6 | 12 | 20 | 20 | 30 | 15 | 75 | 15 | 200 | 20 |
| 42 | 6 | 60 | 9 | 18 | 15 | 15 | 30 | 15 | 50 | 10 | 250 | 25 |
| 43 | 6 | 60 | 6 | 12 | 15 | 15 | 20 | 10 | 50 | 10 | 200 | 20 |
| 44 | 3 | 30 | 6 | 12 | 15 | 15 | 25 | 13 | 50 | 10 | 150 | 15 |
| 45 | 4 | 40 | 7 | 14 | 15 | 15 | 25 | 13 | 50 | 10 | 150 | 15 |
| 46 | 2 | 20 | 5 | 10 | 10 | 10 | 15 | 7.5 | 50 | 10 | 200 | 20 |
| 47 | 3 | 30 | 10 | 20 | 20 | 20 | 25 | 13 | 50 | 10 | 200 | 20 |
| 48 | 6 | 60 | 8 | 16 | 17.5 | 18 | 25 | 13 | 50 | 10 | 200 | 20 |
| 49 | 6 | 60 | 8 | 16 | 15 | 15 | 20 | 10 | 50 | 10 | 150 | 15 |
| 50 | 6 | 60 | 10 | 20 | 15 | 15 | 30 | 15 | 50 | 10 | 150 | 15 |

APPENDIX II

First Measurement (Prior to any Treatment) Along the Long Axis Expressed in Actual Values and Per Cent of Actual Values

| Subject No. | 10 gm. Gm. | 10 gm. % | 50 gm. Gm. | 50 gm. % | 100 gm. Gm. | 100 gm. % | 200 gm. Gm. | 200 gm. % | 500 gm. Gm. | 500 gm. % | 1000 gm. Gm. | 1000 gm. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7 | 70 | 8 | 16 | 15 | 15 | 30 | 15 | 50 | 10 | 150 | 15 |
| 2 | 4.5 | 45 | 7 | 14 | 15.5 | 18 | 30 | 15 | 75 | 15 | 300 | 30 |
| 3 | 4.5 | 45 | 6 | 12 | 12.5 | 13 | 22.5 | 11 | 62.5 | 13 | 250 | 25 |
| 4 | 2 | 20 | 3 | 6 | 5 | 10 | 10 | 5 | 25 | 5 | 250 | 25 |
| 5 | 5 | 10 | 5 | 10 | 10 | 10 | 15.5 | 9 | 75 | 15 | 225 | 23 |
| 6 | 7 | 70 | 7 | 14 | 12.5 | 13 | 17.5 | 9 | 50 | 10 | 125 | 13 |
| 7 | 4.5 | 45 | 5 | 10 | 10 | 10 | 17.5 | 9 | 50 | 10 | 175 | 18 |
| 8 | U.T.D.* | | 5 | 10 | 25 | 25 | 40 | 20 | 75 | 15 | 150 | 15 |
| 9 | U.T.D.* | | 5.5 | 11 | 15 | 15 | 25 | 13 | 50 | 10 | 200 | 20 |
| 10 | 8.5 | 85 | 6 | 12 | 10 | 10 | 20 | 10 | 50 | 10 | 100 | 10 |
| 11 | 5 | 50 | 5 | 10 | 12.5 | 13 | 22.5 | 11 | 62.5 | 13 | 250 | 25 |
| 12 | 5 | 50 | 5 | 10 | 10 | 10 | 20 | 10 | 50 | 10 | 200 | 20 |
| 13 | 8 | 80 | 6 | 12 | 10 | 10 | 22.5 | 11 | 50 | 10 | 125 | 13 |
| 14 | 8 | 80 | 14 | 28 | 27.5 | 28 | 40 | 20 | 100 | 20 | 225 | 23 |
| 15 | 5 | 50 | 6 | 12 | 15 | 15 | 30 | 15 | 75 | 15 | 100 | 10 |
| 16 | 6 | 60 | 5 | 10 | 10 | 10 | 20 | 10 | 50 | 10 | 200 | 20 |
| 17 | 3 | 30 | 5 | 10 | 12.5 | 13 | 25 | 13 | 75 | 15 | 200 | 20 |
| 18 | 3 | 30 | 6 | 12 | 10 | 10 | 20 | 10 | 75 | 15 | 250 | 25 |
| 19 | 3 | 30 | 5 | 10 | 10 | 10 | 20 | 10 | 50 | 10 | 200 | 20 |
| 20 | 3 | 30 | 6 | 12 | 10 | 10 | 20 | 10 | 50 | 10 | 150 | 15 |
| 21 | 4 | 40 | 6 | 12 | 15 | 15 | 30 | 15 | 75 | 15 | 125 | 13 |
| 22 | 5 | 50 | 7.5 | 15 | 15 | 15 | 30 | 15 | 50 | 10 | 150 | 15 |
| 23 | 5 | 50 | 8 | 16 | 12.5 | 13 | 22.5 | 11 | 50 | 10 | 175 | 18 |
| 24 | 4 | 40 | 6 | 12 | 15 | 15 | 30 | 15 | 75 | 15 | 200 | 20 |
| 25 | 5 | 50 | 6 | 12 | 15 | 15 | 30 | 15 | 50 | 10 | 200 | 20 |
| 26 | 3 | 30 | 7 | 14 | 17.5 | 18 | 35 | 18 | 87.5 | 18 | 200 | 20 |
| 27 | U.T.D.* | | 10 | 20 | 20 | 20 | 30 | 15 | 50 | 10 | 200 | 20 |
| 28 | 8 | 80 | 8 | 16 | 20 | 20 | 30 | 15 | 75 | 15 | 200 | 20 |
| 29 | 5 | 10 | 6 | 12 | 15 | 15 | 30 | 15 | 50 | 10 | 200 | 20 |
| 30 | 8 | 80 | 6 | 12 | 15 | 15 | 30 | 15 | 50 | 10 | 200 | 20 |
| 31 | U.T.D.* | | 8 | 16 | 15 | 15 | 30 | 15 | 50 | 10 | 200 | 20 |
| 32 | 5 | 50 | 8 | 16 | 15 | 15 | 30 | 15 | 50 | 10 | 200 | 20 |

* Unable to Determine

## APPENDIX II (CONT'D)

| Subject No. | 10 gm. Gm. | 10 gm. % | 50 gm. Gm. | 50 gm. % | 100 gm. Gm. | 100 gm. % | 200 gm. Gm. | 200 gm. % | 500 gm. Gm. | 500 gm. % | 1000 gm. Gm. | 1000 gm. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 4 | 40 | 8 | 16 | 15 | 15 | 25 | 13 | 50 | 10 | 200 | 20 |
| 34 | U.T.D.* | | 8 | 16 | 15 | 15 | 30 | 15 | 50 | 10 | 150 | 15 |
| 35 | 3 | 30 | 7 | 14 | 15 | 15 | 20 | 10 | 50 | 10 | 150 | 15 |
| 36 | 6 | 60 | 5 | 10 | 10 | 10 | 15 | 8 | 25 | 5 | 150 | 15 |
| 37 | 8 | 80 | 8 | 16 | 20 | 20 | 30 | 15 | 75 | 15 | 200 | 20 |
| 38 | 3 | 30 | 8 | 16 | 15 | 15 | 25 | 13 | 50 | 10 | 200 | 20 |
| 39 | 3 | 30 | 5 | 10 | 10 | 10 | 15 | 8 | 25 | 5 | 150 | 15 |
| 40 | 5 | 50 | 5 | 10 | 15 | 15 | 25 | 13 | 50 | 10 | 150 | 15 |
| 41 | 4 | 40 | 7 | 14 | 15 | 15 | 25 | 13 | 75 | 15 | 200 | 20 |
| 42 | 4 | 40 | 7 | 14 | 20 | 20 | 30 | 15 | 50 | 10 | 200 | 20 |
| 43 | U.T.D.* | | 6 | 12 | 15 | 15 | 20 | 10 | 50 | 10 | 150 | 15 |
| 44 | 4 | 40 | 9 | 18 | 17.5 | 18 | 25 | 13 | 50 | 10 | 150 | 15 |
| 45 | 5 | 50 | 6 | 12 | 15 | 15 | 25 | 13 | 50 | 10 | 150 | 15 |
| 46 | 4 | 40 | 5 | 10 | 10 | 10 | 15 | 8 | 50 | 10 | 200 | 20 |
| 47 | 6 | 60 | 8 | 16 | 15 | 15 | 20 | 10 | 50 | 10 | 200 | 20 |
| 48 | U.T.D.* | | 6 | 12 | 15 | 15 | 25 | 13 | 50 | 10 | 200 | 20 |
| 49 | 5 | 50 | 8 | 16 | 15 | 15 | 25 | 13 | 50 | 10 | 150 | 15 |
| 50 | 6 | 60 | 10 | 20 | 20 | 20 | 30 | 15 | 50 | 10 | 150 | 15 |

* Unable to Determine

## APPENDIX III

Second Measurement (Extraction Cases Only, Two to Four Days After Extraction) 90° to the Long Axis Expressed in Actual Values and Per Cent of Actual Values

| Subject No. | 10 gm. Gm. | 10 gm. % | 50 gm. Gm. | 50 gm. % | 100 gm. Gm. | 100 gm. % | 200 gm. Gm. | 200 gm. % | 500 gm. Gm. | 500 gm. % | 1000 gm. Gm. | 1000 gm. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 5 | 50 | 8 | 16 | 15 | 15 | 30 | 15 | 75 | 15 | 300 | 30 |
| 3 | 4 | 40 | 6 | 12 | 15 | 15 | 30 | 15 | 75 | 15 | 200 | 20 |
| 4 | 3 | 30 | 5 | 10 | 10 | 10 | 15 | 8 | 25 | 5 | 200 | 20 |
| 7 | 4 | 40 | 5 | 10 | 15 | 15 | 25 | 13 | 50 | 10 | 150 | 15 |
| 8 | 5 | 50 | 8 | 16 | 15 | 15 | 25 | 13 | 50 | 10 | 200 | 20 |
| 9 | 5 | 50 | 8 | 16 | 15 | 15 | 25 | 13 | 75 | 15 | 200 | 20 |
| 11 | 3 | 30 | 6 | 12 | 10 | 10 | 20 | 10 | 50 | 10 | 200 | 20 |
| 12 | 3 | 30 | 8 | 16 | 10 | 10 | 25 | 13 | 50 | 10 | 175 | 18 |
| 14 | 6 | 60 | 9 | 18 | 20 | 20 | 45 | 23 | 100 | 20 | 200 | 20 |
| 15 | 5 | 50 | 6 | 12 | 10 | 10 | 15 | 8 | 50 | 10 | 150 | 15 |
| 18 | 4 | 40 | 6 | 12 | 10 | 10 | 25 | 13 | 50 | 10 | 100 | 10 |
| 19 | 4 | 40 | 8 | 16 | 12 | 12 | 20 | 10 | 50 | 10 | 200 | 20 |
| 20 | 6 | 60 | 8 | 16 | 10 | 10 | 20 | 10 | 50 | 10 | 250 | 25 |
| 21 | 3 | 30 | 6 | 12 | 15 | 15 | 25 | 13 | 75 | 15 | 200 | 20 |
| 22 | 5 | 50 | 8 | 16 | 15 | 15 | 30 | 15 | 50 | 10 | 150 | 15 |
| 23 | 4 | 40 | 8 | 16 | 15 | 15 | 30 | 15 | 50 | 10 | 150 | 15 |
| 24 | 4 | 40 | 6 | 12 | 17.5 | 18 | 30 | 15 | 75 | 15 | 200 | 20 |
| 25 | 4 | 40 | 8 | 16 | 15 | 15 | 25 | 13 | 75 | 15 | 200 | 20 |
| 26 | 5 | 50 | 6 | 12 | 15 | 15 | 30 | 15 | 75 | 15 | 200 | 20 |
| 28 | 6 | 60 | 8 | 16 | 20 | 20 | 30 | 15 | 75 | 15 | 200 | 20 |
| 30 | 5 | 50 | 12 | 24 | 20 | 20 | 30 | 15 | 50 | 10 | 150 | 15 |
| 31 | 3 | 30 | 7 | 14 | 10 | 10 | 20 | 10 | 50 | 10 | 150 | 15 |
| 32 | 3 | 30 | 5 | 10 | 10 | 10 | 20 | 10 | 50 | 10 | 200 | 20 |
| 33 | 5 | 50 | 8 | 16 | 15 | 15 | 25 | 13 | 50 | 10 | 150 | 15 |
| 35 | 3 | 30 | 6 | 12 | 10 | 10 | 25 | 13 | 50 | 10 | 150 | 15 |
| 37 | 6 | 60 | 7 | 14 | 15 | 15 | 25 | 13 | 75 | 15 | 200 | 20 |
| 40 | 5 | 50 | 7 | 14 | 15 | 15 | 25 | 13 | 50 | 10 | 150 | 15 |
| 43 | 6 | 60 | 8 | 16 | 15 | 15 | 30 | 15 | 50 | 10 | 200 | 20 |
| 45 | 5 | 50 | 7 | 14 | 15 | 15 | 20 | 10 | 50 | 10 | 150 | 15 |
| 46 | 6 | 60 | 10 | 20 | 15 | 15 | 30 | 15 | 50 | 10 | 150 | 15 |
| 48 | 6 | 60 | 8 | 16 | 15 | 15 | 25 | 13 | 50 | 10 | 200 | 20 |

APPENDIX IV

Second Measurement (Extraction Cases Only, Two to Four Days After Extraction) Along the Long Axis, Expressed in Actual Values and Per Cent of Actual Values

| Sub-ject No. | 10 gm. Gm. | 10 gm. % | 50 gm. Gm. | 50 gm. % | 100 gm. Gm. | 100 gm. % | 200 gm. Gm. | 200 gm. % | 500 gm. Gm. | 500 gm. % | 1000 gm. Gm. | 1000 gm. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 4.5 | 45 | 7 | 14 | 17.5 | 18 | 30 | 15 | 75 | 15 | 200 | 20 |
| 3 | 5 | 50 | 6 | 12 | 15 | 15 | 30 | 15 | 75 | 15 | 175 | 18 |
| 4 | 2 | 20 | 4 | 8 | 5 | 5 | 10 | 5 | 25 | 5 | 200 | 20 |
| 7 | 5 | 50 | 8 | 16 | 15 | 15 | 20 | 10 | 50 | 10 | 150 | 15 |
| 8 | 6 | 60 | 5 | 10 | 15 | 15 | 25 | 13 | 75 | 15 | 150 | 15 |
| 9 | 8 | 80 | 6 | 12 | 15 | 15 | 25 | 13 | 50 | 10 | 200 | 20 |
| 11 | 4 | 40 | 5 | 10 | 10 | 10 | 20 | 10 | 50 | 10 | 200 | 20 |
| 12 | 3 | 30 | 7 | 14 | 10 | 10 | 17.5 | 9 | 50 | 10 | 200 | 20 |
| 14 | 7.5 | 75 | 12 | 24 | 25 | 25 | 40 | 20 | 100 | 20 | 250 | 25 |
| 15 | 5 | 50 | 8 | 16 | 15 | 15 | 30 | 10 | 50 | 10 | 100 | 10 |
| 18 | 3 | 30 | 8 | 16 | 10 | 10 | 20 | 10 | 50 | 10 | 200 | 20 |
| 19 | 4 | 40 | 5 | 10 | 10 | 10 | 20 | 10 | 50 | 10 | 200 | 20 |
| 20 | 4 | 40 | 6 | 12 | 15 | 15 | 20 | 10 | 50 | 10 | 150 | 15 |
| 21 | 4 | 40 | 6 | 12 | 15 | 15 | 25 | 13 | 75 | 15 | 150 | 15 |
| 22 | 4 | 40 | 6 | 12 | 15 | 15 | 30 | 15 | 50 | 10 | 175 | 18 |
| 23 | 5 | 50 | 8 | 16 | 15 | 15 | 25 | 13 | 50 | 10 | 175 | 18 |
| 24 | 4 | 40 | 6 | 12 | 15 | 15 | 25 | 13 | 75 | 15 | 200 | 20 |
| 25 | 5 | 50 | 7 | 14 | 15 | 15 | 30 | 15 | 50 | 10 | 200 | 20 |
| 26 | 4 | 40 | 7 | 14 | 15 | 15 | 30 | 15 | 75 | 15 | 200 | 20 |
| 28 | 8 | 80 | 8 | 16 | 20 | 20 | 30 | 10 | 75 | 15 | 200 | 20 |
| 30 | 8 | 80 | 7 | 14 | 15 | 15 | 30 | 10 | 50 | 10 | 150 | 15 |
| 31 | U.T.D.* | | 8 | 16 | 15 | 15 | 30 | 15 | 50 | 10 | 150 | 15 |
| 32 | 5 | 50 | 8 | 16 | 15 | 15 | 25 | 13 | 50 | 10 | 200 | 20 |
| 33 | 4 | 40 | 5 | 10 | 15 | 15 | 30 | 15 | 50 | 10 | 200 | 20 |
| 35 | 3 | 30 | 7 | 14 | 15 | 15 | 25 | 13 | 50 | 10 | 200 | 20 |
| 37 | 8 | 80 | 8 | 16 | 20 | 20 | 30 | 15 | 75 | 15 | 200 | 20 |
| 40 | 5 | 50 | 5 | 10 | 15 | 15 | 30 | 15 | 50 | 10 | 150 | 15 |
| 43 | 8 | 80 | 8 | 16 | 15 | 15 | 30 | 15 | 50 | 10 | 150 | 15 |
| 45 | 5 | 50 | 7 | 14 | 15 | 15 | 25 | 13 | 50 | 10 | 150 | 15 |
| 46 | 6 | 60 | 10 | 20 | 20 | 20 | 30 | 15 | 50 | 10 | 150 | 15 |
| 48 | U.T.D.* | | 6 | 12 | 15 | 15 | 25 | 13 | 50 | 10 | 200 | 20 |

* Unable to Determine

APPENDIX V

Third Measurement (All Cases, Four Days After Appliance Insertion) 90° to the Long Axis Expressed in Actual Values and Per Cent of Actual Values

| Subject No. | 10 gm. Gm. | 10 gm. % | 50 gm. Gm. | 50 gm. % | 100 gm. Gm. | 100 gm. % | 200 gm. Gm. | 200 gm. % | 500 gm. Gm. | 500 gm. % | 1000 gm. Gm. | 1000 gm. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 30 | 12 | 24 | 30 | 30 | 60 | 30 | 25 | 5 | 75 | 7.5 |
| 2 | 6 | 60 | 6 | 12 | 30 | 30 | 50 | 25 | 25 | 5 | 25 | 2.5 |
| 3 | 8.5 | 85 | 10 | 20 | 30 | 30 | 50 | 25 | -- | -- | + | + |
| 4 | 4 | 40 | 20 | 40 | 40 | 40 | 50 | 25 | -- | -- | + | + |
| 5 | 4 | 40 | 15 | 30 | 25 | 25 | 50 | 25 | 25 | 5 | - | - |
| 6 | 6 | 60 | 10 | 20 | 25 | 25 | 50 | 25 | -- | -- | + | + |
| 7 | 6 | 60 | 12 | 24 | 30 | 30 | 50 | 25 | -- | -- | + | + |
| 8 | 5 | 50 | 18 | 36 | 40 | 40 | 70 | 35 | -- | -- | + | + |
| 9 | 6 | 60 | 16 | 32 | 50 | 50 | 70 | 35 | 25 | 5 | - | - |
| 10 | 3 | 30 | 20 | 40 | 50 | 50 | 80 | 40 | -- | -- | + | + |
| 11 | 6 | 60 | 15 | 30 | 40 | 40 | 55 | 28 | -- | -- | + | + |
| 12 | 5 | 50 | 20 | 40 | 40 | 40 | 80 | 40 | -- | -- | + | + |
| 13 | 4 | 40 | 15 | 30 | 50 | 50 | 80 | 40 | -- | -- | + | + |
| 14 | 6 | 60 | 20 | 40 | 50 | 50 | 100 | 50 | 25 | 5 | 25 | 2.5 |
| 15 | 6 | 60 | 16 | 32 | 40 | 40 | 70 | 35 | 100 | 20 | - | - |
| 16 | 6 | 60 | 20 | 40 | 50 | 50 | 80 | 40 | 25 | 5 | 50 | 5 |
| 17 | 5 | 50 | 16 | 32 | 50 | 50 | 75 | 35 | 25 | 5 | 50 | 5 |
| 18 | 5 | 50 | 12 | 24 | 40 | 40 | 60 | 30 | -- | -- | + | + |
| 19 | 2 | 20 | 12 | 24 | 30 | 30 | 50 | 25 | -- | -- | + | + |
| 20 | 6 | 60 | 14 | 28 | 40 | 40 | 80 | 40 | -- | -- | + | + |
| 21 | 6 | 60 | 20 | 40 | 50 | 50 | -- | -- | + | + | + | + |
| 22 | 6 | 60 | 18 | 36 | 50 | 50 | 70 | 35 | -- | -- | + | + |
| 23 | 6 | 60 | 18 | 36 | 45 | 45 | 70 | 35 | -- | -- | + | + |
| 24 | 6 | 60 | 20 | 40 | 45 | 45 | 70 | 35 | -- | -- | - | - |
| 25 | 4 | 40 | 18 | 36 | 50 | 50 | 100 | 50 | 25 | 5 | 75 | 7.5 |
| 26 | 5 | 50 | 16 | 32 | 45 | 45 | 65 | 33 | -- | -- | + | + |
| 27 | 8 | 80 | 18 | 36 | 40 | 40 | 70 | 35 | 100 | 20 | - | - |
| 28 | 6 | 60 | 12 | 24 | 40 | 40 | 60 | 30 | 25 | 5 | - | - |
| 29 | 5 | 50 | 12 | 24 | 30 | 30 | 50 | 25 | 25 | 5 | - | - |
| 30 | 5 | 50 | 12 | 24 | 40 | 40 | 60 | 30 | -- | -- | + | + |
| 31 | 6 | 60 | 18 | 36 | 45 | 45 | 70 | 35 | -- | -- | + | + |
| 32 | 4 | 40 | 20 | 40 | 40 | 40 | 60 | 30 | 25 | 5 | 50 | 5 |
| 33 | 6 | 60 | 18 | 36 | 40 | 40 | 70 | 35 | -- | -- | + | + |

## APPENDIX V (CONT'D)

| Sub-ject No. | 10 gm. Gm. | % | 50 gm. Gm. | % | 100 gm. Gm. | % | 200 gm. Gm. | % | 500 gm. Gm. | % | 1000 gm. Gm. | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 34 | 4 | 40 | 14 | 28 | 45 | 45 | 65 | 33 | -- | -- | + | + |
| 35 | 6 | 60 | 14 | 28 | 40 | 40 | 70 | 35 | -- | -- | + | + |
| 36 | 6 | 60 | 18 | 36 | 50 | 50 | 90 | 45 | -- | -- | + | + |
| 37 | 6 | 60 | 12 | 24 | 30 | 30 | 40 | 20 | -- | -- | + | + |
| 38 | 5 | 50 | 16 | 32 | 30 | 30 | 60 | 30 | -- | -- | + | + |
| 39 | 6 | 60 | 14 | 28 | 40 | 40 | 70 | 35 | -- | -- | + | + |
| 40 | 6 | 60 | 14 | 28 | 40 | 40 | 70 | 35 | -- | -- | + | + |
| 41 | 6 | 60 | 14 | 28 | 40 | 40 | 80 | 40 | -- | -- | + | + |
| 42 | 6 | 60 | 12 | 24 | 40 | 40 | 70 | 35 | -- | -- | + | + |
| 43 | 6 | 60 | 16 | 32 | 40 | 40 | 60 | 30 | 75 | 15 | - | - |
| 44 | 3 | 30 | 14 | 28 | 40 | 40 | 70 | 35 | -- | -- | + | + |
| 45 | 5 | 50 | 16 | 32 | 50 | 50 | 80 | 40 | -- | -- | + | + |
| 46 | 6 | 60 | 12 | 24 | 50 | 50 | 70 | 35 | -- | -- | + | + |
| 47 | 6 | 60 | 18 | 36 | 40 | 40 | 80 | 40 | -- | -- | + | + |
| 48 | 6 | 60 | 15 | 30 | 40 | 40 | 70 | 35 | -- | -- | + | + |
| 49 | 4 | 40 | 14 | 28 | 35 | 35 | 50 | 25 | 25 | 5 | 50 | 5 |
| 50 | 6 | 60 | 12 | 24 | 50 | 50 | 70 | 35 | -- | -- | + | + |

\- Pain
\+ Not Tried

APPENDIX VI

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

| Subject No. | 10 gm. Gm. | 10 gm. % | 50 gm. Gm. | 50 gm. % | 100 gm. Gm. | 100 gm. % | 200 gm. Gm. | 200 gm. % | 500 gm. Gm. | 500 gm. % | 1000 gm. Gm. | 1000 gm. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6 | 60 | 16 | 32 | 40 | 40 | 60 | 30 | -- | -- | + | + |
| 2 | U.T.D.* | | 20 | 40 | 40 | 40 | 40 | 20 | 25 | 5 | - | - |
| 3 | 6 | 60 | 20 | 40 | 45 | 45 | 100 | 50 | -- | -- | + | + |
| 4 | 5 | 50 | 12 | 24 | 30 | 30 | 50 | 25 | 100 | 20 | - | - |
| 5 | U.T.D.* | | 10 | 20 | 30 | 30 | 50 | 25 | 50 | 10 | - | - |
| 6 | 6 | 60 | 12 | 24 | 25 | 25 | 40 | 40 | -- | -- | + | + |
| 7 | 6 | 60 | 20 | 40 | 50 | 50 | 80 | 40 | -- | -- | + | + |
| 8 | 6 | 60 | 14 | 28 | 45 | 45 | 70 | 35 | -- | -- | + | + |
| 9 | 6 | 60 | 16 | 32 | 40 | 40 | 60 | 30 | -- | -- | + | + |
| 10 | U.T.D. | | 20 | 40 | 50 | 50 | 75 | 38 | -- | -- | + | + |
| 11 | 4 | 40 | 15 | 30 | 40 | 40 | 60 | 30 | 100 | 20 | - | - |
| 12 | 3 | 30 | 18 | 36 | 40 | 40 | 70 | 35 | 50 | 10 | - | - |
| 13 | 4 | 40 | 17 | 34 | 45 | 45 | 80 | 40 | 25 | 5 | 50 | 5 |
| 14 | U.T.D.* | | 20 | 40 | 45 | 45 | 110 | 55 | 25 | 5 | 50 | 5 |
| 15 | 6 | 60 | 20 | 40 | 50 | 50 | 80 | 40 | 25 | 5 | 50 | 5 |
| 16 | 6 | 60 | 15 | 30 | 50 | 50 | 75 | 38 | 25 | 5 | 75 | 7.5 |
| 17 | 5 | 50 | 20 | 40 | 50 | 50 | 70 | 35 | -- | -- | + | + |
| 18 | 4 | 40 | 15 | 30 | 40 | 40 | 70 | 35 | 75 | 15 | - | - |
| 19 | 4 | 40 | 15 | 30 | 40 | 40 | 70 | 35 | 25 | 5 | 25 | 2 |
| 20 | 6 | 60 | 16 | 32 | 30 | 30 | 70 | 35 | -- | -- | + | + |
| 21 | 7 | 70 | 18 | 36 | 40 | 40 | -- | -- | + | + | + | + |
| 22 | 6 | 60 | 14 | 28 | 30 | 30 | 50 | 25 | -- | -- | + | + |
| 23 | 6 | 60 | 18 | 36 | 40 | 40 | 80 | 40 | -- | -- | + | + |
| 24 | 5 | 50 | 16 | 32 | 50 | 50 | 70 | 35 | -- | -- | + | + |
| 25 | 5 | 50 | 15 | 30 | 40 | 40 | 90 | 45 | 25 | 5 | 75 | 7.5 |
| 26 | 6 | 60 | 20 | 40 | 50 | 50 | 100 | 50 | -- | -- | + | + |
| 27 | 8 | 80 | 20 | 40 | 40 | 40 | 60 | 30 | 100 | 20 | - | - |
| 28 | 6 | 60 | 20 | 40 | 40 | 40 | 70 | 35 | 100 | 20 | - | - |
| 29 | 5 | 50 | 15 | 30 | 40 | 40 | 60 | 30 | 100 | 20 | - | - |
| 30 | 6 | 60 | 12 | 24 | 35 | 35 | 55 | 28 | -- | -- | + | + |
| 31 | 6 | 60 | 14 | 28 | 30 | 30 | 55 | 28 | -- | -- | + | + |
| 32 | 5 | 50 | 12 | 24 | 25 | 25 | 50 | 25 | 25 | 5 | 25 | 2.5 |
| 33 | 6 | 60 | 20 | 40 | 40 | 40 | 70 | 35 | 25 | 5 | - | - |

* Unable to Determine
\- Pain
\+ Not Tried

APPENDIX VI (CONT'D)

| Subject No. | 10 gm. Gm. | % | 50 gm. Gm. | % | 100 gm. Gm. | % | 200 gm. Gm. | % | 500 gm. Gm. | % | 1000 gm. Gm. | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 34 | 6 | 60 | 16 | 32 | 45 | 45 | 80 | 40 | -- | -- | + | + |
| 35 | 6 | 60 | 14 | 28 | 30 | 30 | 50 | 25 | -- | -- | + | + |
| 36 | 6 | 60 | 16 | 32 | 45 | 45 | 80 | 40 | -- | -- | + | + |
| 37 | 8 | 80 | 20 | 40 | 40 | 40 | 50 | 25 | -- | -- | + | + |
| 38 | 5 | 50 | 12 | 24 | 30 | 30 | 50 | 25 | -- | -- | + | + |
| 39 | 6 | 60 | 12 | 24 | 25 | 25 | 50 | 25 | -- | -- | + | + |
| 40 | 6 | 60 | 14 | 28 | 40 | 40 | 60 | 30 | -- | -- | + | + |
| 41 | 6 | 60 | 18 | 36 | 40 | 40 | 60 | 30 | -- | -- | + | + |
| 42 | 5 | 50 | 16 | 32 | 40 | 40 | 80 | 40 | -- | -- | + | + |
| 43 | 6 | 60 | 14 | 28 | 30 | 30 | 60 | 30 | 75 | 15 | - | - |
| 44 | 5 | 50 | 14 | 28 | 50 | 50 | 80 | 40 | -- | -- | + | + |
| 45 | 5 | 50 | 14 | 28 | 45 | 45 | 65 | 33 | -- | -- | + | + |
| 46 | 6 | 60 | 10 | 20 | 40 | 40 | 60 | 30 | -- | -- | + | + |
| 47 | 6 | 60 | 12 | 24 | 25 | 25 | 45 | 23 | -- | -- | + | + |
| 48 | 6 | 60 | 12 | 24 | 35 | 35 | 50 | 25 | -- | -- | + | + |
| 49 | 5 | 50 | 18 | 36 | 40 | 40 | 70 | 35 | 25 | 5 | - | - |
| 50 | 6 | 60 | 10 | 20 | 40 | 40 | 60 | 30 | -- | -- | + | + |

* Unable to Determine
\- Pain
\+ Not Tried

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# APPROVAL SHEET

The thesis submitted by Dr. Patrick R. Nakfoor 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.

5/22/67 — Date

Douglas C. Bowman — Signature of Adviser