From: The Department of Prosthetic Dentistry (Head: Professor *W. Krogh-Poulsen*),
The Royal Dental College, Copenhagen, Denmark.

AN ASSESSMENT OF THE TACTILE SENSIBILITY IN HUMAN TEETH

AN EVALUATION OF A QUANTITATIVE METHOD

by

GERD TRYDE*)

OVE FRYDENBERG**)

NIELS BRILL***)

INTRODUCTION

As far as is known to the authors, *Theil* (1931) was the first to present a detailed study of tooth sensibility as determined by objects of varying thickness placed between occlusal or incisal surfaces of teeth. He wanted to determine the thickness of an object which could just be detected by a subject, when biting on it. He tested in all 150 subjects, 102 females and 48 males. The youngest subject was sixteen years old, the oldest forty years. All had natural teeth. Theil does not mention the occurrence of tooth replacements other than single crowns.

During the testing procedure the subjects were blindfolded. However, they knew that some object would be placed between their teeth. The objects used were platinum wires of fourteen

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*) Research fellow, Department of Prosthetic Dentistry, the Royal Dental College, Copenhagen, Denmark.

**) Associate professor of genetics and biological statistics, the Royal Dental College, Copenhagen, Denmark.

***) Associate professor, Department of Prosthetic Dentistry, the Royal Dental College, Copenhagen, Denmark.

different diameters, ranging from 0.5 to 0.015 mm. When a wire was inserted the subjects were told to search for it with the teeth and raise a hand if they detected anything. Light movements of the wire were thought to indicate contact between teeth and wire.

It was believed that the testing procedure might tire the subjects. As a preliminary measure, therefore, only a few wires were used to narrow down the range in which the thinnest detectable wire could be expected to appear. Within this critical range each subject was tested by applying wires with diameters increasing by steps of 0.01 mm.

Subjects might be unconsciously influenced by their knowledge of the purpose of the study. Theil reports that a colleague responded affirmatively in spite of the fact that no wire was placed between his teeth. In order to avoid distorted results arising from a study confined to dentists, he therefore included persons from other professions.

With the same investigation in mind *Hollstein* (1933) used Theil's method on 125 subjects, 57 females and 68 males. Their age varied from sixteen to seventy-one. Hollstein, however, introduced a few minor changes in the experimental method. He added some thicker wires to those used by Theil, thereby increasing the upper dimension studied from 0.5 mm to 0.9 mm.

Realising, that if the subjects are distracted or become tired during the experiment they may give unreliable answers, he discarded some of the initial procedures suggested by Theil, and by means of articulating paper Hollstein located occlusal contacts in order to spare the subjects a prolonged search for the wires. Moreover, during the testing Hollstein did not blindfold the subjects but merely told them to keep their eyes shut. Both Theil and Hollstein retracted the cheeks from the teeth; but Hollstein did not isolate the tongue as did Theil.

The present authors feel that the method used by Theil and Hollstein could be improved.

As stated by *Kawamura* (1960) the fine wires used are easily bent, and they may therefore be displaced during the experiment. Moreover, when teeth meet in occlusion the nature of the contact varies from points of contact to areas of contact depending on the degree of attrition. This means that when points of contacts occur, open spaces are found between the occlusal surfaces out-side the contact zone. This creates the problem of how one can be sure that a fine wire is placed inside the zone of contact. Furthermore, we feel that the concept of an upper threshold value might advantageously be replaced by a statistically more acceptable measure.

Hence the aims of the present work are: (1) to describe an improved clinical method, by which it is possible to obtain information concerning tactile sensibility in human teeth; and (2) to find a numerical term defining this sensibility.

EXPERIMENTAL METHOD

The essence of the method is that a person is asked to bite on a metal strip and to state whether or not he can feel anything between his teeth. It is required that two opposing teeth to be tested have attrition facets which are able to hold a metal strip of a thickness of 0.01 mm, when the teeth are closed against the strip and a pull is applied to the strip (Fig. 1).

The test strips: The test strips are made of rolled silver (Fig. 2). All strips are about five millimeters long and about one millimeter wide but they vary in thickness. The thickest strip is 0.1 mm and the thinnest is 0.01 mm. The difference between con-

Fig. 1. Opposing teeth closed against a metal strip held by means of tweezers.

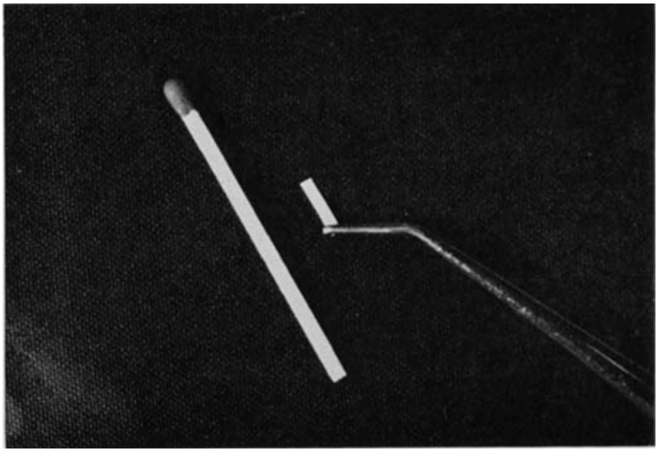

Fig. 2. Tweezers holding a test strip next to a match for comparison.

secutive strips is 0.01 mm. Hence altogether ten test dimensions are employed.

Conditions during the testing: The subject is seated comfortably in a dental chair with the head and back supported in a slightly reclining position. The examiner gently retracts the lips and inserts a metal strip between the two selected opposing teeth, by means of tweezers.

In order to familiarize himself with each new strip the subject goes through a few trials preceding the actual testing. During the actual testing the subject is asked to close his eyes in order to concentrate better upon sensations from the occlusal surfaces without being disturbed by visual impressions; for instance the slight movements of the examiner's hand. The subject is told that sometimes a strip will be placed between the teeth and sometimes not, and is then asked to close his teeth and state whether or not he can feel anything between them.

Trials per dimension: The subject is offered twenty trials at each of the ten dimensions. In some of the trials the strip is inserted between the teeth, in others it is left out.

The order of positive and negative trials is randomized. In practice this is ensured by means of special cards (Fig. 3), each

69.

\+ ÷ ÷ + +   + + + ÷ +

\+ ÷ ÷ ÷ ÷   + + + + ÷

Fig. 3. + and — signs entered at random on a card.

of which bears a sequence of plus-signs and minus-signs, twenty in all. A plus-sign signifies a *positive* trial, *i.e.* insertion of the test strip, and a minus-sign denotes a *negative* trial, *i.e.* a trial in which the test strip is actually not inserted between the teeth. The sequence of plus-signs and minus-signs on the individual card has been determined from a table of random sampling numbers (*Hald* 1960), in such a way that an even figure calls for a plus while an odd figure denotes a minus. It follows from this that not only the order of plus-signs and minus-signs varies from one card to the next but the total number of plus-signs on the individual card is also subject to random variation. One hundred such cards have been produced and for each new dimension tested a sequence card is picked at random.

Order of dimensions: The measurements with a set of strips are started with the thickest strip and carried through decreasing dimensions to the thinnest strip. All subjects go through all ten dimensions, each represented by twenty trials. Thus each person is offered altogether two hundred trials.

Recording the raw data: The answers, yes or no, to the question whether the subject feels anything or not are recorded accompanied by a plus or a minus to signify whether the answer is obtained in a positive or a negative trial.

The following combinations of answers and kinds of trials are obtainable: *yes*, +, *yes*, —, *no*, +, and *no*, —. The combination *yes*,+ indicates that the subject perceived a strip that was in fact inserted between his teeth or, to be strictly correct, it indicates that he was of the opinion that he did feel a strip. *Yes*, — denotes that the subject was of the same conviction in spite of the fact that no strip had been inserted. A failure to recognize the strip in a positive trial is recorded by *no,* +, and *no,* — stands for a negative answer in a negative trial.

Summarizing the raw data: The raw data constitute a confusing sequence of the four combinations of answers and trials but they are conveniently summarized by counting the number of each combination at each tested dimension. This is done in coloumns two to five of Table I for the results obtained with two different subjects, designated I and II. For the sake of illustration the measurements presented in Table I are selected from a collection of data not otherwise employed in this paper.

STATISTICAL ANALYSIS

The sensibility frequency: Assuming that there are no disturbing psychological effects, the frequency of yes-answers among positive trials, F(yes,+) is a measure of the subjects ability to recognize the tested dimension. A F(yes,+) equal to 100 per cent signifies that the subject recognized the strip every time it was inserted and a F(yes,+) equal to zero denotes that the subject failed to perceive the strip at all. Intermediate values indicate that the subject did sometimes recognize the strip but that he failed to do so in some cases. Thus, the higher the (F(yes,+) the greater the ability to perceive the tested dimension.

A moment's thought reveals, however, that we cannot accept the raw F(yes,+)-value as a dependable measure of the subject's ability to perceive the strip. In the extreme, an F(yes,+) equal to 100 per cent can be obtained for every strip by merely answering *yes* to all trials independent of whether the strip is actually inserted and perceived or if it is left out. If a subject has answered *yes* to all trials, he will score not only an F(yes,+) equal to 100 per cent but also an F(yes, —) of 100 per cent and it is obvious that he has not demonstrated any ability at all to recognize the strip. The same is true if a subject scores, say, an F(yes,+) = 75 per cent and simultaneously an F(yes, —) = 75 per cent. The essence of our test lies not in the frequency of correct answers among positive trials but rather in the difference in the frequencies of yes-answers among positive and negative trials.

Table I

Summarized raw data and calculation of Fd for two selected subjects.

Subject I

Dimension in mm	*Positive trials*[1]		*Negative trials*[2]		Frequency of yes-answers among		Sensibility frequency Fd per cent
	Number of yes-answers yes, +	Number of no-answers no, +	Number of yes-answers yes, −	Number of no-answers no, −	positive trials F (yes, +) %	negative trials F (yes, −) %	
0.10	10	0	0	10	100	0	100
0.09	10	1	0	9	91	0	91
0.08	6	0	0	14	100	0	100
0.07	9	0	0	11	100	0	100
0.06	8	0	0	12	100	0	100
0.05	10	1	0	9	91	0	91
0.04	8	1	0	11	89	0	89
0.03	2	4	0	14	33	0	33
0.02	0	7	1	12	0	8	—8
0.01	0	10	0	10	0	0	0

Subject II

Dimension in mm	*Positive trials*[1]		*Negative trials*[2]		Frequency of yes-answers among		Sensibility frequency Fd per cent
	Number of yes-answers yes, +	Number of no-answers no, +	Number of yes-answers yes, −	Number of no-answers no, −	positive trials F (yes, +) %	negative trials F (yes, −) %	
0.10	9	0	0	11	100	0	100
0.09	9	0	0	11	100	0	100
0.08	10	0	0	10	100	0	100
0.07	4	1	0	15	80	0	80
0.06	11	0	1	8	100	9	91
0.05	9	3	0	8	75	0	75
0.04	8	4	1	7	67	13	54
0.03	3	8	1	8	27	11	16
0.02	2	10	1	7	17	13	4
0.01	1	8	1	10	11	9	2

[1]) positive trials: trials in which the test-strip was actually inserted.

[2]) negative trials: trials in which the test-strip was not inserted.

As a single numerical expression of a person's ability to perceive a given dimension, d, we have therefore chosen a statistic, which we have named the sensibility frequency and which is designated by the symbol Fd. It is defined by the relation:

$$\text{Fd} = \text{F(yes, +)} - \text{F(yes, —)}.$$

Ideally Fd may vary from 0 per cent to 100 per cent. An Fd equal to 0 per cent denotes that the subject is unable to perceive strips of dimension d, and an Fd = 100 per cent means that the subject always perceives strips of this thickness. Intermediate values denote how frequently the strip is perceived by the subject.

The Fd at relatively great dimensions: Let us consider how the Fd measure works in two subjects whom we suppose to have an identical sensibility but who respond psychologically differently to the experimental situation. Let the two subjects A and B both be able to recognize perfectly the greatest dimension tested. Consequently they will answer *yes* in all positive trials and *no* in all negative trials. They will then score an F(yes, +) = 100 per cent and an F(yes, —) = 0 per cent and our measure becomes

$$\text{Fd} = 100\ \% - 0\ \% = 100\ \%$$

for both subjects, stating the fact that they have recognized the test strip every time it was inserted.

The Fd at relatively small dimensions: Now let us assume that the two subjects are entirely unable to perceive a strip of a certain small dimension. Subject A may actually realize and accept this fact and consequently he will answer *no* in every trial, whether the strip is inserted or not. He then scores an F(yes, +) = 0 per cent and an F(yes, —) = 0 per cent and consequently the Fd becomes

$$\text{Fd} = 0\ \% - 0\ \% = 0\ \%$$

which expresses satisfactorily the assumed fact that this subject cannot distinguish at all between positive and negative trials, *i.e.* that he has no perception whatever of the tested dimension. The data presented in Table I for subject I simulate this situation fairly closely.

Subject B may react differently when he is tested for a dimension he cannot recognize. He may, consciously or unconsciously, be unwilling to accept this fact and consequently he will continue to answer *yes* in some of the trials. Being, however, unable to distinguish between positive and negative trials, he is equally unable to favour either of them with his yes-answers. It follows that his yes-answers *on the average* will be equally frequent in the two categories of trials, *i.e.* subject B will score an F(yes, +) = a per cent and an F(yes, —) = a per cent and therefore

$$\text{Fd} = a\ \% - a\ \% = 0\ \%$$

which expresses satisfactorily the fact that he cannot recognize the test-strip at all. The actual frequencies of yes-answers in this situation will vary from person to person depending upon how able he believes himself to be. This variation is of course irrelevant to us but it must necessarily on the average cancel out in the calculation of the individual Fd. The factual data shown in Table I for subject II reflect a situation similar to that just described.

The Fd at intermediate dimensions: At an intermediate dimension the subjects may be able to recognize the strip with some uncertainty. In a "realistic" person like subject I (Table I) this may probably result in an intermediate F(yes, +) and an F(yes, —) equal to zero and in this case we have:

$$\text{Fd} = \text{F(yes, +)} - \text{F(yes, —)} = \text{F(yes, +)}.$$

Subject II may, however, also at this dimension believe himself more able than he actually is, resulting in an excess of yes-answers. The unjustified yes-answers offered gratuitously will on the average be distributed equally among positive and negative trials. The F(yes, +) will be too high by a value which must be, on an average, reflected in the value of F(yes, —). Consequently subtraction of the latter from the former gives us an Fd free from randomly occurring yes-answers.

In analogy with many other experimental situations the F(yes, —) can be said to measure the "background noise" for which the actual measurement, F(yes, +) has to be corrected.

The reliability of the measure: It follows from what has been said above that our measure of sensibility, Fd, is constructed in such a way that it is not possible for a subject systematically to score an Fd higher than he actually deserves: whenever for any reason he adds unjustified or gratuitous yes-answers these will be corrected for in the calculation of the sensibility frequency, Fd.

By mere chance he may of course succeed in offering more of his yes-answers in the positive trials resulting in an Fd which is too high. The same may happen when a subject's vision is tested by means of an eye testing chart. When asked about a letter that he cannot see he still has a chance of giving the right answer if he chooses at random among the letters of the alphabet. In the present case the subject has a fifty-fifty chance of answering correctly in the individual trial when he cannot perceive anything at all. This is a considerably higher chance than he would have in selecting the correct letter from the alphabet. This increase in error in the individual trial is partly compensated for by testing the subject twenty times at each dimension. It should be born in mind that gratuitous yes-answers will just as often result in too low as in too high Fds. The measured values of Fd will vary at random around the true value which would be obtained if the subject was offered an infinite number of trials.

The possible range of Fd-values: Being the difference between two observed frequencies the sensibility frequency, Fd, can never exceed 100 per cent. However, since both observed frequencies are subject to random variation sensibility frequencies may occasionally emerge which are negative.

Actually, in the range where a subject cannot perceive the strip at all one *expects* to get negative sensibility frequencies just as often as positive ones. As usual in measurements the actual measured values vary around the unknown true value that one would obtain as an average of an infinite number of measurements. When a subject cannot perceive the strip at all we expect an Fd equal to zero. The actual measured Fd based on a limited number of measurements may turn out bigger or smaller, *i.e.* positive or negative. Similarly, negative measured Fd-values may be obtained for expected values which are themselves positive, but close to zero.

The sensibility curve: We can get a comprehensive picture of a subject's response to the test by plotting the measured sensibility

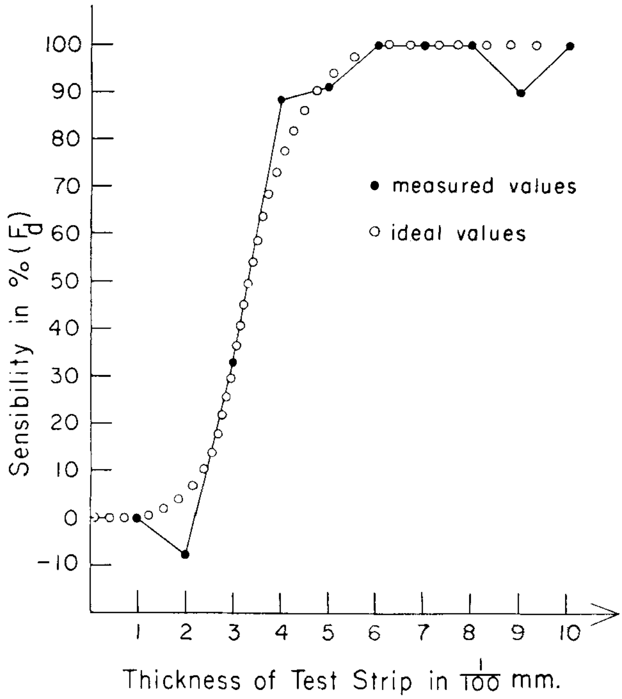

Fig. 4. The ideal curve and the observed curve of subject I.

frequencies as a function of the tested dimensions. This has been done in Fig. 4 with the data already given for subject I in Table I.

The general picture found is one of Fd-values equal to 100 per cent for the higher dimensions, then a region in which the Fds decrease with decreasing dimension and a final region in which the subject, apart from random variation, scores Fds equal to zero. Thus, providing we measure over a sufficiently wide range of dimensions, the sensibility curve appears sigmoid or S-shaped. In evaluating the individual curves it is important to remember that every measured point on the curve is potentially subject to an experimental error due to the fact that each dimension was tested only in a limited number of trials. The observed curve is but an imperfect picture of an ideal curve which would be approached closer and closer with an increasing number of trials for each dimension. This curve is indicated in Fig. 4 by white dots.

Properties of the sensibility curve: We do not know much about the exact shape of the ideal curve. A future analysis of a greater collection of data than we possess at the present time may confirm the impression that the curve is closely related to the normal Gaussian ogive.

In any case it is obvious that the individual curve has two important properties, *viz.* its position relative to the dimension axis and its slope.

Of these two properties, the position relative to the axis of dimension is of immediate interest to us as it indicates the subject's level of sensibility. The further to the left the dropping part of the curve is located the greater is the subject's sensibility. It would be desirable to express this in a single quantitative term.

Shortcomings of an upper treshold: It may appear reasonable to choose the point at which the curve starts to drop as a measure of the subject's sensibility. Coming from a higher dimension, where Fd-values equal to 100 per cent have been scored, the point where an Fd less than 100 per cent is obtained for the first time indicates the dimension at which the subject's sensibility begins to fail. For several reasons this is, however, undesirable.

Firstly, it is highly improbable that the ideal curve would have a point with the stated property of being the first point below 100 per cent going from higher to lower dimensions. This requires a discontinuity having a thoroughly unwarranted biological basis. If such a point does not exist theoretically it follows that it is unreasonable to try to estimate it from the data.

Secondly, such an estimate would depend almost entirely on a single observation, *viz.* the first observed point less than 100 per cent. Consequently the information obtained in measuring at all the other dimensions would hardly be utilized at all. This means great inaccuracy in the estimation. Perhaps this is illustrated best by considering once more Fig. 4. The first dimension giving an Fd less than 100 per cent is reached already at a dimension $d = 9 \times 10^{-2}$ mm. It is, however, rather obvious that this gives a false picture of the actual situation. The drop at 9×10^{-2} is caused by a single wrong answer which is probably due to a misunderstanding, as the subject scores 100 per cent at the next three tested dimensions. The next point below 100 per cent is first reached at 5×10^{-2} mm and again this is due to a single wrong answer. However, this time we are more willing to accept that at 5×10^{-2} mm the subject's sensibility is no longer perfect because the curve continues to drop. In the last sentence is embodied the fact that we prefer to utilize more than one point in obtaining our estimate. The inaccuracy inherent in the estimate of 5×10^{-2} mm becomes clear when we realize that mere chance could easily have resulted in an Fd = 100 per cent for this dimension. A different answer in only one trial would alter the estimate to 4×10^{-2} mm.

Shortcomings of a lower treshold: The kind of argument presented in the latter section is equally applicable to an estimate of the first dimension at which all sensibility is gone, *i.e.* at the dimension where Fd = 0 is scored for the first time. Theoretically one cannot conceive such a point without requiring some kind of discontinuity which would be biologically incomprehensible. Consequently, estimation of this point is meaningless.

The 50 per cent sensibility treshold: Though we can conceive no point being the first below 100 per cent, and no point where the true curve reaches zero for the first time, there must certainly be a point where the ideal curve passes through a sensibility frequency equal to any specified value between zero and 100 per cent. We therefore propose to use as a single numerical measurement of a person's sensibility the dimension at which the sensibility frequency is 50 per cent. This value we denote *the 50 per cent sensibility treshold* and it is designated by the symbol S_{50}.

Estimation of the 50 per cent treshold: The S_{50}-value is estimated from the observed data by simple linear interpolation between the lowest dimension giving an Fd just above 50 per cent and the greatest dimension yielding an Fd just below 50 per cent. This is the same as saying that the S_{50} is estimated as the dimension at which the observed curve intersects the 50 per cent level.

In case the empirical curve passes through 50 per cent more than once the interpolation is made between the last dimension before the first passage and the first dimension after the last passage of 50 per cent.

Our estimate utilizes all the information embodied in the two points just above and below 50 per cent plus part of the information embodied in the measurements made at the remaining dimensions, namely the fact that they have yielded Fd-values which are either greater or smaller than those of the two points on either side of 50 per cent.

Limitations of S_{50} concept: We believe that an essential property of a person's sensibility is conveniently characterized by an estimate of his 50 per cent sensibility treshold. However, it should be stressed that the S_{50}-value does not by any means contain all the information available from the measurement of a given person. A considerable amount of additional information is embodied in the sensibility curve, *e.g.* the slope of the curve tells something of how rapidly the subject's sensibility decreases with decreasing dimensions of the strips.

APPLICATION OF THE METHOD

Subjects tested: The method has been applied to an investigation concerning ten subjects. Seven females and three males were tested. Their ages varied from thirty to forty-nine, the mean age being thirty-seven. Only mentally well balanced persons were tested. The subjects belonged to the staff of the Royal Dental College; seven were teachers and three were dental nurses. Their qualifications thus made it easy to instruct them in the necessary procedure.

The number of teeth in the subjects varied from twenty-four to thirty-two. The teeth used were vital and surrounded by clinically healthy gingival margins. Moreover, it was assessed clinically that the teeth were not loose. Persons with occlusal fillings were admitted, whereas those with multiple restorations such as removable dentures, or crowns and bridgework were rejected. The teeth selected for study were premolars and molars with attrition facets capable of holding a strip of minimum thickness required by the method. In each subject only one pair of teeth were tested.

Results: Table II gives the sensibility frequencies and the derived 50 per cent sensibility thresholds obtained from the ten subjects. To illustrate the variation found from subject to subject four

Table II

Sensibility frequencies and 50 per cent sensibility thresholds for ten subjects.

Subject / Age and Sex / Dimensions in mm	1 43 y. ♂	2 32 y. ♀	3 35 y. ♀	4 35 y. ♀	5 49 y. ♂	6 30 y. ♀	7 42 y. ♀	8 39 y. ♂	9 36 y. ♀	10 37 y. ♀
0.10	100	100	100	100	100	100	100	100	100	100
0.09	100	100	100	100	100	100	100	100	100	100
0.08	100	100	100	100	100	100	100	100	100	100
0.07	100	100	100	100	100	100	100	100	100	100
0.06	100	100	100	100	100	100	100	100	100	100
0.05	100	100	100	100	100	100	100	100	100	100
0.04	82	80	100	100	100	100	100	100	100	100
0.03	21	54	90	80	100	91	89	53	88	100
0.02	— 8	33	79	20	100	70	71	80	89	60
0.01	29	40	18	0	20	50	58	70	0	20
S_{50} in mm	0.035	0.028	0.015	0.025	0.014	0.010	<0.010	<0.010	0.016	0.017

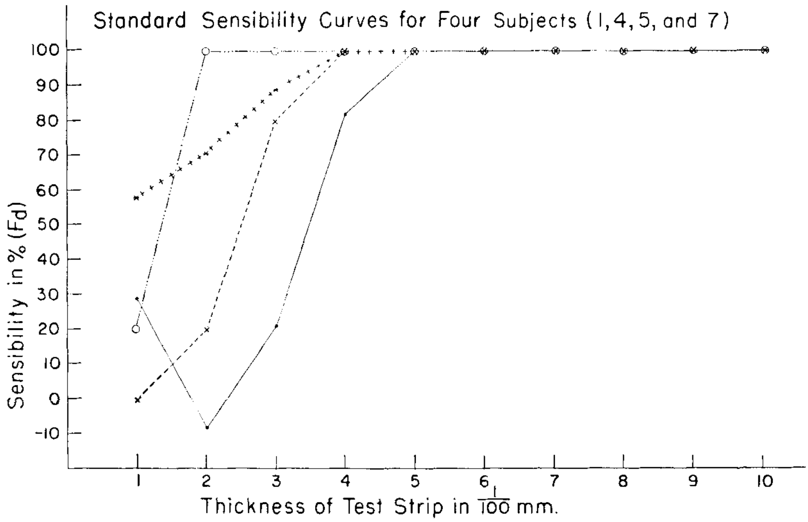

Fig. 5. Sensibility frequencies from Table II converted into curves.

selected sensibility curves, *viz.* those for the subjects 1, 4, 5, and 7, are shown in fig. 5.

In Table II the 50 per cent sensibility thresholds are found at the bottom of the columns. In two cases, *viz.* subjects 7 and 8, they even fall below the lowest dimension tested. Consequently, we cannot obtain an estimate of the 50 per cent threshold for these two subjects but have to confine ourselves to the statement that the 50 per cent sensibility thresholds for subjects 7 and 8 are less than 0.01 mm.

The range of 50 per cent thresholds found for the ten subjects extends from 0.035 mm to less than 0.010 mm, the average value being less than 0.018 mm.

EVALUATION OF THE METHOD

In evaluating the validity of the sensibility curves obtained it is necessary to investigate whether the curve for a given person is, to a measurable degree, dependent upon (a) the number of dimensions tested and (b) the order in which the individual dimensions are tested. This problem has been approached by comparing sensibility curves obtained by three different procedures in each of the ten subjects entered in Table II.

Table III

Sensibility frequencies for ten subjects. Series A measured from 0.10 mm downwards to 0.01 mm. Series B measured from 0.01 mm upwards to 0.10 mm. Series C measured from 1.0 mm downwards through 20 dimensions to 0.01 mm.

Subject Age and Sex	1 43 y. ♂			2 32 y. ♀			3 35 y. ♀			4 35 y. ♀			5 49 y. ♂			6 30 y. ♀			7 42 y. ♀			8 39 y. ♂			9 36 y. ♀			10 37 y. ♀		
Series	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1—0.2 mm	—	—	100	—	—	100	—	—	100	—	—	100	—	—	100	—	—	100	—	—	100	—	—	100	—	—	100	—	—	100
0.10 mm	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.09 mm	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.08 mm	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.07 mm	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.06 mm	100	100	91	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.05 mm	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.04 mm	82	92	56	80	100	91	100	100	100	100	82	100	100	100	100	100	100	100	100	100	100	100	83	92	100	100	100	100	100	85
0.03 mm	21	33	80	54	89	93	90	100	100	80	92	100	100	100	100	91	91	100	89	7	100	53	86	50	88	83	90	100	100	47
0.02 mm	-8	-15	34	33	70	71	79	89	100	20	33	64	100	91	100	70	90	100	71	69	70	80	100	51	89	35	70	60	92	35
0.01 mm	29	0	4	40	13	38	18	40	25	0	0	7	20	0	-19	50	64	30	58	0	24	70	38	23	0	40	0	20	0	27
S_{50} in mm	.035	.033	.023	.028	.017	.014	.015	.012	.013	.025	.023	.018	.014	.015	.016	.010	<.010	.013	<.010	.025	.016	<.010	.012	.022	.016	.023	.017	.017	.015	.031

Three different series: The results obtained by the three different procedures are given in Table III. The sensibility frequencies in series A have been collected following the standard procedure described above, *i.e.* by measuring through *decreasing* dimensions from 0.1 mm to 0.01 mm. Actually the data in series A in Table III are the same as those reported in Table II.

Series B involves the same dimensions as series A but the measurements have been carried out in reverse order, *i.e.* through *increasing* dimensions from 0.01 mm to 0.1 mm.

In series C the number of dimensions tested was extended from the usual ten to twenty by applying an additional set of ten strips of dimensions from 1.0 mm through steps of 0.1 mm downwards to 0.2 mm. The measurements in series C were started at 1.0 mm and carried downwards through all twenty dimensions. In this case the subject underwent 200 trials before the range of dimensions comparable to that used in series A and B was reached. All measurements at dimensions greater than 0.1 mm obtained in series C yielded sensibility frequencies equal to 100 per cent.

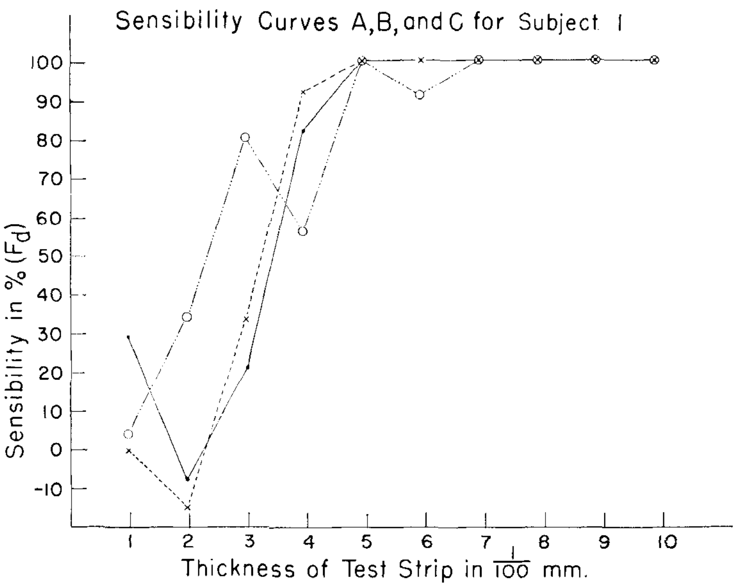

Fig. 6. Three different curves obtained in subject 1 by the standard method and two different control methods.

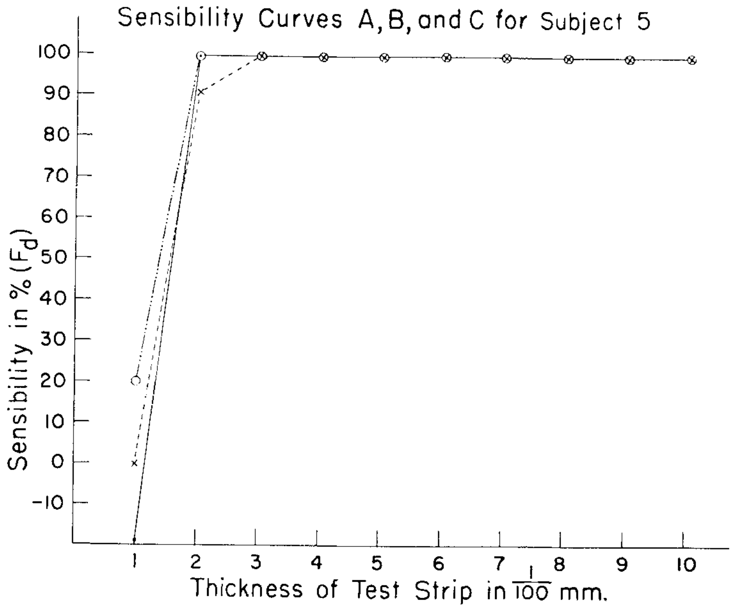

Fig. 7. Three different curves obtained in subject 5 by the standard method and two different control methods.

Figs. 6 and 7 show the three sensibility curves for subject 1 and subject 5, respectively.

Comparisons of the series: When considering the sensibility frequencies in the different series in Table III one is left with the impression that no consistent differences occur between the three series. This is further substantiated by comparing the S_{50}-values derived from the data and represented in Table IV.

A comparison between series A and C reveals that in four cases the S_{50}-value derived from the C series are less than those from the A series and in the remaining six cases they are greater. This distribution does not differ significantly from that expected if the series of values were pairwise identical. The average difference between the two series, excluding subjects 7 and 8, for whom no estimate of S_{50} can be obtained in series A, is 0.002 mm with a standard error of approximately 0.003 mm. *Thus we have not been able to demonstrate any influence on the position of the*

Table IV

S_{50}-values (in mm) from ten subjects.

Subject	A	B	C
1	0.035	0.033	0.023
2	0.028	0.017	0.014
3	0.015	0.012	0.013
4	0.025	0.023	0.018
5	0.014	0.015	0.016
6	0.010	(<0.010)	0.013
7	(<0.010)	0.025	0.016
8	(<0.010)	0.012	0.022
9	0.016	0.023	0.017
10	0.017	0.015	0.031
mean	0.0180	0.0185	0.0183

sensibility curve of testing the person with ten additional dimensions each consisting of twenty trials.

Nor does the B series of sensibility curves reveal any consistent difference from the A curves. In this case, six of the S_{50}-values from series A exceed those from series B which again is not significant. It should be noticed that in five cases of the seven, which allow an exact comparison, the numerical difference between the S_{50}-values is 0.003 mm or less. Though no absolute estimate of S_{50} can be derived from one series of three persons, it can be demonstrated from the data that 0.003 mm is a *maximum* estimate of the average difference and that 0.002 mm is a *minimum* estimate of the standard error of the average difference. As the maximal estimate of the average difference is less than twice the minimal estimate of the standard error, we can demonstrate no difference between the two series of sensibility curves.

Conclusions: We feel safe in concluding that the sensibility curves are to a surprisingly large degree independent both of the number of measurements carried out before the critical region is reached, and of the order in which the different dimensions are tested.

The standard error of an S_{50}: It remains to estimate the standard error of the individual S_{50}-values. As no consistent differences have been demonstrated among series A, B, and C an estimate of the variance of the S_{50}-values can be calculated for each subject.

For subjects 6, 7, and 8 only minimum estimates can be derived because only an upper limit for the S_{50} can be derived in one of the series. The variance estimates vary from 1×10^{-6} mm to 76×10^{-6} mm corresponding to a range in standard deviations from 0.0010 mm to 0.0087 mm, all estimates being based on two degrees of freedom. There is a rather strong indication that the variance increases considerably with S_{50} even within the narrow range of S_{50}-values observed in this investigation. However, the figures are too few to give a more exact impression of the relation between S_{50} and its variance.

For the time being the best we can do is to calculate the average variance in the observed range and in this way we obtain a minimum estimate of the variance equal to 30.45×10^{-6} mm corresponding to a standard deviation of 0.0055 mm. Paying due tribute to the unpretentious nature of this estimate we conclude that the true value of a person's S_{50} is probably to be found within a range of $\pm$ 0.015 mm on both sides of the observed S_{50}.

DISCUSSION

The experimental conditions of the method described require that the subject is presented with the task of distinguishing between two sensations: (1) the usual sensation of his teeth when he occludes, and (2) the sensation arising when he bites upon the strip.

Selection of subjects: Considering that the aim of this investigation has primarily been to scrutinize our experimental method, we have found it suitable to select subjects whose intelligence ensured cooperation and who had good natural dentitions in order that our method could be checked at low sensibility levels.

Experimental situation: In Theil's method a test person is not subjected to an unambigous experimental situation. He may be subjected to different conditions: (1) at any one moment he may feel contact between teeth and wire, (2) he may feel a continuous contact produced by grinding the teeth on the wire and (3) if he bites more than once on the wire he may feel a succession of contacts. These varying experimental conditions are liable to produce different thresholds. It is well known from studies of cutaneous tactile sensibility that momentary stimulation has a higher threshold than succssive stimulation (*Frey & Metzner*, 1902).

The method as modified by Hollstein spared the subject the search for the wire and thus seemed to give the possibility of a momentary stimulation only. However, as stated by Kawamura the fine wires are easily bent. Furthermore we would point out that a wire with a circular cross section, placed between two curved surfaces may easily tilt or roll, thus making it impossible to establish whether momentary or successive stimulation has taken place. A flat strip, placed between well defined attritional facets, is thought to minimize the risk of successive stimulation due to tilting or rolling, and thus provide a more reliable source of stimulus.

SUMMARY

Previous methods of studying tactile sensibility of human teeth such as those of *Theil* (1931) and *Hollstein* (1932) belong to the category of "Methods of Least Noticeable Stimuli" (*Woodworth & Schlosberg*, 1960 a). The principle of these methods is that the least noticeable stimulus is regarded a threshold value.

The present paper is a report of an investigation based on one of the so-called "Frequency Methods" (*Woodworth & Schlosberg*, 1960 b). Instead of applying the concepts of upper and lower absolute thresholds as defined in the text, a subject is characterized by his 50 per cent sensibility threshold.

The method has been applied to ten selected subjects yielding 50 per cent sensibility thresholds varying from less than 0.010 mm to 0.035 mm. It is demonstrated that the sensibility thresholds obtained by the method are largely independent of the total number of stimuli, and also of the order (ascending or descending) in which these are presented to the subjects.

RÉSUMÉ

MESURE DE LA SENSIBILITÉ TACTILE DE LA DENT HUMAINE. VALEUR D'UNE MÉTHODE QUANTITATIVE.

Les méthodes antérieures pour étudier la sensibilité tactile de la dent humaine, tels que celles de *Theil* (1931) et *Hollstein*

(1932) appartiennent à la catégorie des "Méthodes du plus petit stimulus perceptible" (*Woodworth & Schlosberg,* 1960 a). Le principe de ces méthodes est que le plus petit stimulus perceptible représente une valeur de seuil.

Le présent article rend compte d'une étude basée sur une des méthodes appelées "Méthodes des fréquences" (*Woodworth & Schlosberg,* 1960 b). Au lieu d'employer la conception de seuils supérieurs et inférieurs absolus tels qu'ils sont définis dans le texte, on caractérise un sujet par son seuil de sensibilité à 50 pour cent.

Cette méthode a été appliquée à dix sujets sélectionnés présentant des seuils de sensibilité à 50 pour cent allant de moins de 0,010 mm à 0,035 mm. Il est mis en évidence que les seuils de sensibilité obtenus par cette méthode sont dans l'ensemble indépendants du nombre total de stimuli, ainsi que de l'ordre (ascendant ou descendant) dans lequel is sont présentés aux sujets.

ZUSAMMENFASSUNG

EINE BEURTEILUNG DES TASTVERMÖGENS DER MENSCHLICHEN ZÄHNE. BEWERTUNG EINER QUANTITATIVEN METHODE.

Frühere Methoden zur Untersuchung des Tastvermögens der menschlichen Zähne wie diejenigen von *Theil* (1931) und *Hollstein* (1932) gehören der Kategorie von "Methoden zur Feststellung von eben merklichen Reizen" an (*Woodworth & Schlosberg,* 1960 a). Bei diesen Methoden wird dem eben merklichen Reiz ein Schwellenwert zugeschrieben.

Die vorliegende Untersuchung gründet sich auf eine sogenannte "Frequenz-Methode" (*Woodworth & Schlosberg,* 1960 b). Eine Person wird nicht durch absolute obere oder untere Schwellenwerte, die im Text besprochen sind, charakterisiert, sondern durch einen Reizschwellenwert von 50 prozent. Der Wert wird S_{50} genannt.

Zehn Versuchspersonen, die nach dieser Methode untersucht wurden, ergaben obigem Prozentsatz entsprechende Schwellenwerte, die zwischen 0,010 mm und 0,035 mm lagen. Es wird nachgewiesen, dass die nach dieser Methode gefundenen Schwellen-

werte sowohl von der totalen Anzahl der Reize als auch von der Art ihrer Verabfolgung bei auf- und absteigender Stärke völlig unabhängig sind.

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Address: *Københavns Tandlægehøjskole*
Universitetsparken 4
København Ø
Denmark