AN INSTRUMENT FOR MEASUREMENT OF VIBRATION SENSATION IN MAN[1]

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MEASUREMENT of vibration sensation is commonly part of a clinical neurological examination, especially where particular attention is paid to possible nutritional disease. The method much used is application of a tuning fork to fingers and toes. In a nutrition survey which will be reported later (1) it was felt that a more quantitative method was desirable, one which would give thresholds, as amplitudes of the applied vibration, over a range of frequencies. An instrument for this purpose was devised and found to be useful in an examination of the thresholds, at the toes, of over 400 cases. This paper gives a description of that instrument, which is an electrically driven vibrator with amplitude and frequency independently controlled, together with some of the results obtained from its use. Similar apparatus has been described previously (2,3). The equipment may be assembled almost wholly from available, commercial, components.

A variable frequency audio oscillator generated the needed frequencies, the output from the oscillator was fed into an amplifier, the amplifier drove the vibrator unit which transformed the electrical oscillations into mechanical movements. A voltmeter was used to measure the strength of signal supplied to the vibrator unit and a cathode-ray oscilloscope was used as a check when necessary on the frequency of the oscillations by comparison with the frequency of the 115-volt 60 cycle supply to the apparatus.

The variable frequency oscillator was of the type in which the frequency is determined by a resistance-capacity network (4,5). This type of oscillator is very stable, the warming-up period is short,

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and there is little subsequent frequency drift. The frequency at which it operated was set by a potentiometer with a dial calibrated in terms of frequency. It provided, within limits, any possible frequency lying in its range of 20 to 20,000 cycles per second (C.P.S.), and from this wide range only certain frequencies were chosen. The ones used, from 50 C.P.S. up, are included in Table 1.

The amplifier was one covering the audio range, a Clarion Model A3. A volume control was used to regulate the output to the vibrator unit, and so the strength of the stimulus applied to the subject. The magnitude of the stimulus was recorded with the aid of a voltmeter in the output circuit of the amplifier. The voltage readings so obtained are proportional to the amplitude of the applied vibration. The sensitivity of the voltmeter was somewhat greater than necessary. For this reason and to make subsequent calculations simpler, the recorded voltages were grouped and converted into a series of arbitrary numbers and fractions ranging from 0, no movement of the vibrator, to 7, corresponding to the maximum stimulus which the apparatus could deliver. These numbers of course are also proportional to the amplitude of the applied vibration. The nature of the arrangement was such that each number represented a voltage and amplitude of vibration twice the size of the number below it, thus the amplitude 2 is twice as big as amplitude 1, 3 twice as big at 2, and so forth. The justification for using arbitrary numbers to record the magnitude of the vibration comes from the fact that even with the same apparatus used at the same level of input

Table 1. Amplitude of vibration at different frequencies with needle in place on a toe and constant input to vibrator.

	Frequency, Cycles Per Second												
	50	100	150	200	250	300	350	400	500	600	800	1,000	1,500
Amplitude (Relative)	14	14	8	8	7	8	8	8	9	8	5	4	3

to the vibrator, the response of the same subject will vary according to the effective area of the vibrating member applied to the skin, and the pressure with which it is applied; there are no standards for these two dimensions. These dimensions however were kept constant (*see* below).

The vibrator unit consisted of an Astatic M 41 magnetic cutting head which is designed for making phonograph records. The usual cutting stylus was replaced by a needle made of music wire 0.036″ in diameter and 1″ long with a flat brass button 0.08″ in diameter soldered to the end. The cutting head was mounted in a small holder attached to the end opposite the needle. The head can pivot freely in this holder in a vertical direction only, and the whole arrangement can be held conveniently. When in position for testing, the weight of the unit is divided between the pivot (supported by the operator) and the needle resting on the subject, *see* Figure 1. If the unit is kept horizontal the applied weight is constant; it amounted to 80 grams. The unit can be moved rapidly from one spot to another with one hand, leaving the other free to operate the volume control and to make records of the readings obtained.

It is a common feature of apparatus of this kind that its response as amplitude of vibration at different frequencies is not uniform. That is, even if what is controlled and measured, in this case the voltage applied to the vibrator unit, is kept uniform, the response of the effective part, the vibrating needle, may not remain constant if the frequency of vibration is independently varied. This variation of response as a function of frequency alone may also be affected by the resistance and impedance of the skin and tissue to the movement imposed on it by the vibrating part; this tissue resistance may be different at different frequencies. In order to assess the size of any such variations at the different frequencies used the following was done. A small mirror was cemented to the needle of the vibrator. With the vibrator in place on a subject's toe, the mirror was illuminated so as to reflect a spot of light on a screen some distance

away. Then the movements of this spot of light were measured, when the needle was vibrating with constant voltage input to the vibrator, and the frequency of vibration was changed. The results as relative amplitude of movement, at the different frequencies, with constant voltage input to the vibrator, are given in Table 1.

It can be seen that from 150 C.P.S. to 600 C.P.S. the amplitude of the applied vibrations is relatively constant when the input voltage is kept the same. At the lower frequencies the amplitude increases, and above 600 C.P.S. the amplitude decreases.

The apparatus was well grounded at all times. For testing the toes it was arranged along the front of a table of normal height, and the subject was seated on the table to one side. The feet were supported on a low stand; part of the top of the stand facing the subject sloped down, the rest was flat. The feet were placed so that the toes more or less curled over the break between the sloping and horizontal portions.

The vibrator was used on the skin over the nail bed. In nearly every case the fifth or small toe was not tested. In a great many people this toe is so curved that it was not possible to place the vibrator on the toe in the proper position.

The subject was first allowed to feel the vibrations of one or two of the lower frequencies on a finger. He was instructed to keep his eyes closed throughout the test. With the volume control turned down, and no signal in the vibrator, the vibrator was placed on one of the toes. Then, at the frequency which had been chosen, the volume control was turned up until the subject reported that he felt vibration by saying "Yes." The strength at this threshold was noted. This was repeated with the other toes of the foot at the various frequencies, choosing toes at random, and frequencies irregularly. The usual procedure was to quickly and rather roughly map out the higher frequency limits, then determine the limits more carefully and fill in the intermediate frequencies.

At the beginning of the tests the subjects were warned that at

times they would feel no vibration, only the pressure of the instrument. Throughout the test blank stimuli were given—that is, the vibrator was placed on a toe for the usual interval but the volume control was not turned up. Most subjects of course made no response to this procedure. There were, however, a number of people who persisted in giving a positive response to such a blank stimulus and one is forced to conclude that either they were lacking in vibration sense under the conditions of the test or they so easily confused the touch or pressure of the instrument with the sensation of vibration that they could not distinguish between the two. All such cases were marked unreliable and were rejected. This method we believe to have been effective in ruling out false responses.

There are one or two points of a general nature about precautions which were taken. One of these concerns adaptation.

Cohen and Lindley (6) have studied adaptation to vibratory stimulation. They found that a supra-liminal stimulus of 60 C.P.S. raised the threshold. Stimulation at or near threshold strength had little effect upon the threshold unless continued for some time.

Evidence has been obtained that adaptation may be excluded under the conditions, and with the methods, used in this work.

The vibrator, clamped by its holder in a stand, was placed on the right great toe of each of three subjects and the threshold determined at a frequency of 200 C.P.S. by means of three consistent readings. The vibrator was left on at a little above threshold strength. At intervals, without moving the vibrator, the input was shut off and the threshold at the same spot quickly redetermined with three consistent readings. The vibrator was then turned on again, usually with an increase of strength to take care of the increase in threshold which was found.

In all three cases, the threshold rose somewhat during the first fifteen or twenty minutes and then remained constant. The total time was about thirty minutes, which is about as long as anyone cares to stand the application of the vibrator to one spot. In two

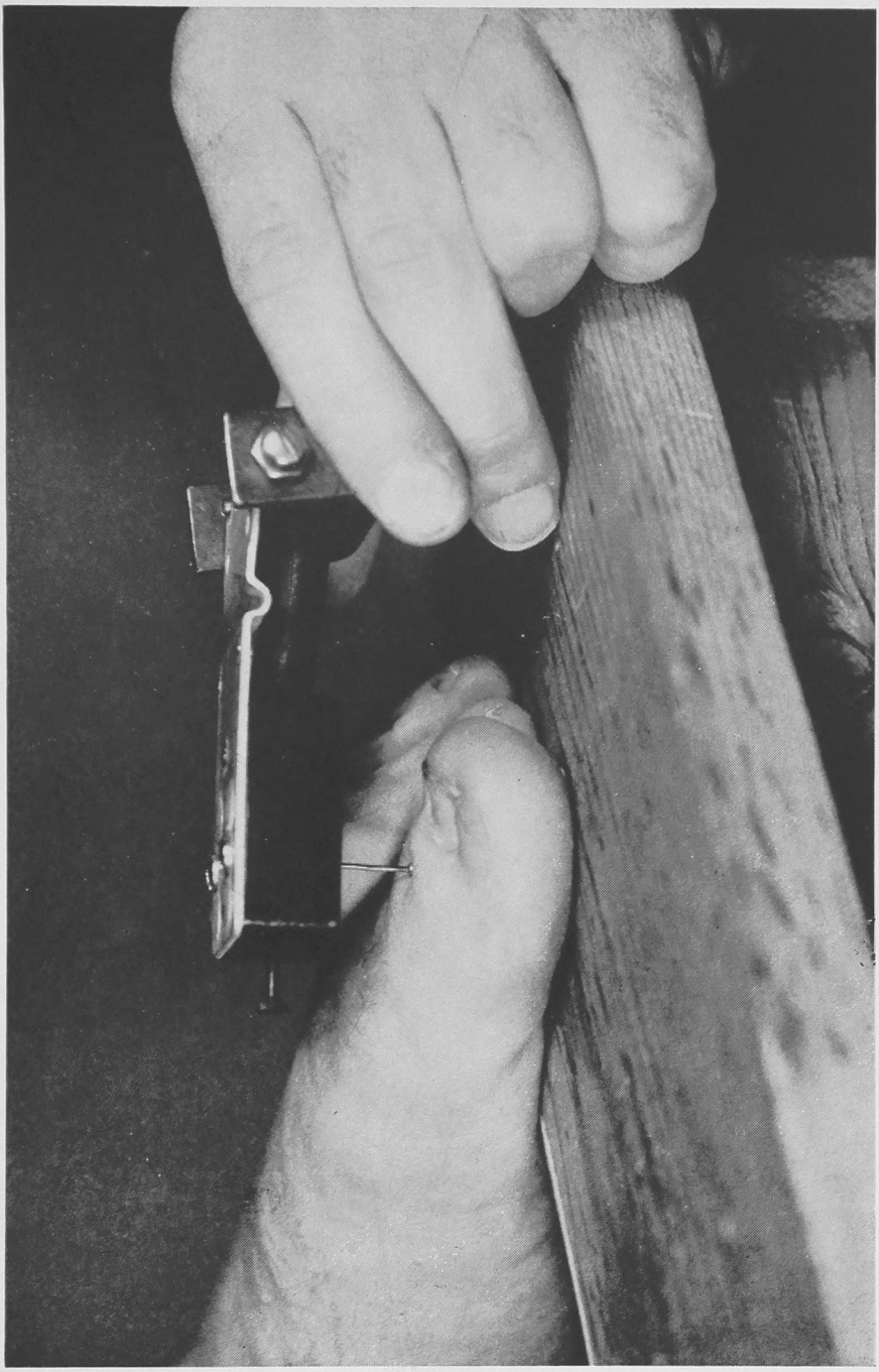

Fig. 1. Method of holding and applying vibrator unit.

cases the threshold was finally raised about 50 per cent and in one case about 100 per cent. At the end of the period of almost continuous stimulation, the vibrator was shut off. The threshold at the adapted spot returned to its original value in from four to eleven minutes. Although the threshold rose most in the first few minutes the rise in the first few seconds is too small to be determined with any certainty.

Thus, as continuous vibration, except for short intervals for testing the threshold, took several minutes to raise the threshold and as the return to normal was much quicker, it is unlikely that adaptation interfered in any way with the thresholds which have been determined. In the regular routine the vibrator was applied to any one toe for only a few seconds, after which there was a much longer interval while other toes were being tested. Moreover, the tests were done with the vibrator starting at rest, increasing the strength of the stimulation until the threshold was reached, so that the period during which vibration was appreciated was only a brief portion of the total time vibration was applied.

Many of the measurements were made during cold, rainy weather, and some on men who had been working outside. Although the room used was adequately heated the subject's bare feet were routinely warmed over a small electric heater for a short time before beginning. Feet which felt cold to the touch were found to give irregular, unreliable responses. It is very easy to show, by dipping the hand or foot into cold water and leaving it there until the skin feels somewhat cool to the touch, that this amount of chilling will raise the threshold considerably, see also Weitz (7). The need for precautions against chilling when vibration threshold measurements are to be taken cannot be over emphasized.

The group of over 400 men (1) who were tested with this apparatus were tested at the same time with tuning forks. Table 2 shows the relation between the tests with a tuning fork at 256 C.P.S. and with the electrically driven vibrator operated at 250 C.P.S. For the

	Total Tested	Both Positive	Both Negative	Vibrator Neg. and Tuning Fork Pos.	Vibrator Pos. and Tuning Fork Neg.
Number of Toes	1,692	1,323	47	10	312
Per Cent of Toes	100	78.2	2.8	0.6	18.4

Table 2. Comparison of positive and negative responses to tuning fork at 256 C.P.S. and to electric vibrator at 250 C.P.S. applied to four toes of each man tested.

purposes of this comparison the results from the electric vibrator have been used only to indicate whether the subject being tested did or did not respond. A response at any amplitude was considered positive. A negative response meant that he made no response to even the maximum stimulus which the instrument could give. The tests with the tuning fork and the electric vibrator were given by different persons. As the men were tested on four toes, rather than taking any arbitrary figure of, say, three toes positive, and calling such a case positive, or adopting any other measure of dividing positive from negative cases, tabulation has been made of the whole number of toes tested, which gives a figure four times the number of cases. As can be seen the agreement between the two tests is good, and in 81 per cent of the cases the results were the same. There is a small number of cases positive to 256 C.P.S. tuning fork and negative to 250 C.P.S. vibrator, and a larger number negative to 256 C.P.S. fork and positive to 250 C.P.S. vibrator. It should be noted that the electric vibrator, working at its full strength, is capable of giving a somewhat stronger stimulus than the tuning fork, so that this last result is to be expected.

Besides this positive or negative type of response, the thresholds at the various frequencies were found on over 200 men. Of the 400 men included in Table 2 some were excluded from this test because their response at some frequency or other was considered unreliable by the criterion given above for false responses. Of the remainder, the thresholds were obtained for the most sensitive toe of the least sensitive foot.

The thresholds are given in Table 3 in numbers ranging from 0 to 7, derived from the voltmeter on the instrument in the way described. All the readings so obtained at each of the frequencies used have been averaged. Values in Table 3 are mean thresholds. The results have been divided into three classes according to the age of the men. The table also gives the standard errors of the means, the number of men tested at each frequency, and the statistical significance of the differences between the means of the age groups is indicated by the ratio of a difference to the standard error of the difference.

The thresholds of each age group present a fairly regular varia-

Table 3. Mean vibration thresholds at various frequencies for employed men. Comparison by ages.

Age Group in Years	Frequency, Cycles Per Second									
	50	100	200	250	300	350	400	500	600	800
I 20-29										
Mean Thresholds	3.7	2.4	2.9	3.6	4.2	5.4	5.0	5.6	5.9	6.2
St. Error of Mean	.04	.06	.07	.06	.06	.04	.06	.05	.06	.07
Number Tested	276	277	276	273	273	90	267	237	177	82
II 30-39										
Mean Thresholds	4.0	2.8	3.4	4.1	4.6	5.5	5.3	5.8	6.1	6.3
St. Error of Mean	.08	.09	.11	.09	.10	.09	.09	.09	.09	.12
Number Tested	120	126	126	125	121	56	112	90	65	31
III 40+										
Mean Thresholds	4.4	3.4	4.0	4.7	5.1	5.7	5.6	5.8		
St. Error of Mean	.17	.24	.25	.18	.17	.18	.22	.22		
Number Tested	25	27	26	26	24	13	18	11		
Ratio of Difference to St. Error of Diff.										
I and II	2.91	3.18	4.13	4.76	3.83	1.49	2.78	2.04	1.55	.29
II and III	2.33	2.59	1.94	3.08	2.42	0.75	1.24			
I and III	3.90	4.12	4.08	5.87	5.00	1.58	2.58	1.14		

As stated in the text some men have been excluded because their responses were inconsistent and, therefore, unreliable. These men do not appear in the table. Variations in the numbers of men tested at different frequencies, other than tapering off at high frequencies caused by the approach of the threshold curve to the maximum stimulus curve, merely show that not every man was tested at all the frequencies listed. The upper and lower frequency limits of each man were always found, intermediate frequencies were not always completely covered.

tion with frequency. They are higher at the lowest and highest frequencies than in the neighborhood of 100-200 C.P.S. It should be pointed out that the characteristics of the vibrator unit are such (*see* Table 1), that the thresholds at 50 and 100 C.P.S. are higher than the figures show. The reason for the drop at 400 C.P.S. is undetermined.

This variation of threshold with frequency is similar to previously reported results, but in general is based on a larger number of cases. The shape of this curve has a bearing on the results at the upper frequencies. The output of the vibrator has an upper limit of strength, and as one extends the tests to the higher frequencies a point is reached where this curve of declining maximum strength is intersected by the rising curve of the threshold to sensation. At frequencies beyond this point there will be no response, though the subject might still be aware of a sensation if a stronger stimulus could be used.

The table shows that there is a rise in the threshold with increasing age. This is one of the most striking features, and was one of the first effects to be noticed. Newman and Corbin (8) seem to have been the first to measure this quantitatively, though it had been observed previously (9). They measured the threshold at one frequency, 60 C.P.S. The present work, based on a large number of men, shows increase of threshold with age in all three age groups, and at all frequencies used. The effect of age is to raise the whole threshold curve so that the point at which it intersects the curve of maximum signal strength falls at a lower frequency. It can be seen that the older men fail to respond to the higher frequencies. At the highest frequencies in each age group the means all tend to approach the same upper limit; so the differences are small. At 350 C.P.S. fewer men were tested. With these two exceptions nearly all the differences between mean thresholds of the different age groups are significant, that is the ratios of the differences of the means to the standard error of the differences are more than 2.

With this method a subject's vibration thresholds may be found readily over the whole range of frequencies. All that is necessary is to set the frequency control to the desired frequency, hold the vibrator unit in place, turn up the volume control till the subject responds and read the voltmeter at this point. This gives a number between 0 and 7, which is related to the amplitude as described above, and this number is the threshold. Some practice with normal young people whose responses are quick and definite is helpful. In older people the range of effective frequencies is generally limited and more care is needed to exclude false responses to stimuli outside this range, some of which must be given to establish the limits. Even within the effective range their responses are apt to be hesitant. Explanation at the start, together with several applications of frequencies in the 100 - 200 C.P.S. range, of sufficient strength to produce adequate stimulation, should be used.

It is not possible to state whether the ability to measure thresholds at several frequencies will prove to be of practical significance. The present evidence would suggest that determinations at two or three frequencies, corresponding to the frequencies of the commonly used tuning forks, would be sufficient, and would differentiate between the different vibratory sensitivities of individuals as well as a more extended series. All the men examined were employed and healthy enough to be at work. In cases of disease, in which changes in vibratory sensitivity might be expected, and particularly those in which subsequent recovery might follow, it might be of value to follow the thresholds at several frequencies. The shape of the curve relating the thresholds of vibration to frequency, is similar to the curve for the variation of the threshold of hearing with frequency, and in the latter case losses of hearing are not always uniform throughout the audible frequency range.

Summary

An electrically driven apparatus is described which is suitable

for measuring the responses in man to mechanical vibrations of different frequencies.

The apparatus was used in testing several hundred men, and the technique is described.

Results are given which show the variation of the thresholds with respect to the frequency of vibration, and their increase with increasing age.

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