THE SENSATION OF VIBRATION, WITH SPECIAL REFERENCE TO ITS CLINICAL SIGNIFICANCE*

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THE sensation of vibration is the subjective experience of an individual when a series of rapidly repeated stimuli are applied to certain of his sensory end-organs, probably those of touch, pressure and passive movement, the sensation being recognized by him as a continuous tremor. The sensation is evoked by applying a tuningfork to his skin, preferably just superficial to a bony prominence.

The study of the sensation of vibration, although it involves no instrument or technique that could not have been available for hundreds of years, has only been developed within the last fifty years, and even today little advantage is taken by the clinician of the exact and quantitative method of examination of the vibratory sensation which is now available.

BRIEF SUMMARY OF PREVIOUS WORK

Rumpf²⁹ was probably the first to make an exact study of the sensation. After a few preliminary experiments he used a series of 14 tuningforks with rates of vibration varying from 13 to 1,000 per second. He believed that the sensation was confined to the skin and transmitted by cutaneous nerves. Later Treitel,³⁴ using a fork of 128 vibrations per second, came to the conclusion that the sensation was distinct from pressure and touch, and that it arose in the soft tissues. He noticed the characteristic diminution of the sensation in tabes.

Gradenigo¹⁴ developed a tuningfork, later much used in otological work, bearing the 'Gradenigo triangle.' A small triangle was impressed on the lateral side of the prong of a tuningfork, and appeared double, the one image overlapping the other, when the fork was struck. This overlap increased with diminution of amplitude of the prongs, and could be measured by a series of black lines, as seen under a magnifying glass. Egger⁸ found that a tuningfork vibrating at a rate of 128 per second was the best felt, and that one of 2,048 per second was quite imperceptible. He called the sensation 'la sensibilité osseuse,' as he believed that it was perceived by end-organs in

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bone, periosteum, ligaments and joint capsules. He noted decrease in the sensation with age.

Dweitschenko⁷ noted that a thick layer of soft parts over the bone reduced sensibility. Rydel and Seiffer³⁰ came to the conclusion that the sensation was a function of deep sensibility and that all the superimposed tissues could take part in it. Sterling³¹ stated that vibratory sensibility depended on the relative densities of the vibrating body and the tissues that carry the sensation.

Goldscheider¹³ believed that vibratory sensation was not a special one, but the result of a peculiar stimulation of the end-organs responsible for pressure and touch. Knapp¹⁹ found that a rate of 512 vibrations per second was the greatest rate normally perceptible. An instrument firm has recently been sending to medical men as an advertisement a small fork, of a vibration rate of 512 per second. Accordingly practitioners, if they bother to use the fork at all, will find the vibration sensation of many of their patients incorrectly reduced.

Minor,²⁴ using the Gradenigo triangle, stated, among some other important facts, that (a) the continuity of the bone was not necessary for a normal appreciation of the sensation; (b) periostitis, caries and superficial thickenings of bone have no effect on the sensation; (c) the vibrations were felt on bare bones and on sequestra; (d) the vibration sensation was diminished when the peripheral nerves were injured.

These facts suggested that while the bone had an important rôle in appreciation of the sensation it was not the site of its reception.

Williamson,³⁵ in a series of papers from 1905 to 1922, showed himself to be the foremost student of the sensation of vibration, with regard to its clinical application. He mentions its loss as one of the earliest signs of disease; its use in separating off pure diseases of the motor tracts; and that the tuningfork may be used in mapping out the upper limit of spinal lesions. He lists a number of diseases in which there is no loss, others in which diminution is an early sign. He did not, however, use a quantitative method of measuring the sensation. He mentions that the tuningfork is occasionally of advantage in detecting hysteria and malingering. In hemianæsthesia, if the fork is felt on one side of the sternum and not on the other, the disease is probably 'functional,' as the whole sternum is made to vibrate. Stated otherwise, in a case of anæsthesia of a limb, should the vibration not be felt when the fork is applied to a bone in the anæsthetic area, but be felt when applied to the same bone outside the anæsthetic area, the disease is likely to be hysterical. If the sensation of vibration is the only sensation to be diminished the disease is probably organic. In Rombergism the sensation is almost certain to be diminished if the disease is organic.

Bing⁴ anæsthetized the skin with various substances, and found that vibratory sensation was slightly diminished, and distinguished it from that of touch.

Lewandowsky²⁰ and also Head¹⁷ developed a method of testing the sensation which might be called the 'alternate displacement' or 'fatigue' method. The tuningfork is applied to a bone, say the right radius, and when the patient states that he can no longer feel the vibration a stop-watch is started and the tuningfork immediately transferred to the radius of the other arm, when the sensation will again be felt. The time is then taken until the sensation ceases to be felt in the left radius. The tuningfork is struck again and reapplied, first to the left radius, then to the right. Any marked difference between the two readings was held to be pathological. There are, however, serious objections to this method which may be dealt with here.

(a) The vibratory sensibility of the two sides of the body is often different, some writers stating that the sensation on the right, others that the sensation on the left, is the more acute.

(b) When one side is known to be abnormal the normal side cannot be measured against it, and has to be measured against a different limb, i.e. arm against leg. Usually the leg has a smaller sensibility than the arm.

(c) No account is taken of the force with which the fork is struck, i.e. its amplitude, for if the fork is started with a large amplitude its vibrations will last longer.

Experiment 1.—Strike the fork so that the amplitude is small, i.e. apply it just when the large window disappears (see later section for method) and test by Head's alternate displacement method, from right radius to left radius. Then do the experiment again, this time striking the fork until it clicks and applying immediately, i.e. when it is at its maximum amplitude. This can be repeated four times.

Result: (a) Fork at minimum amplitude, average of four trials 8.9 seconds (10, 7, 10, 8.5 secs.).

(b) Fork at maximum amplitude, average of four trials 11.5 seconds (11, 11, 13.5, 10.5 secs.).

That is to say, with Head's method the tuningfork is felt longer if struck harder. Head did not take account quantitatively of the strength with which the fork was struck.

The main conclusions from Head's¹⁷ work on the nature of the sensation have been generally recognized. The tuningfork stimulates two aspects of sensation: (a) That of 'jarring contacts' which are appreciated by the thalamus (vibration is perceived, but differently, when the thalamus is cut off from the cortex); (b) That of rapidly repeated movements of small range. These are similar to the perception of passive movements, and are appreciated by the cortex.

Head emphasized the close correlation between the sensation of vibration and appreciation of measured movement and posture, and remarked on the similarity of their tracks in the cord. As no lesion above the thalamus can cause complete insensibility to vibration, except in neural shock, the test of the tuningfork is only useful as a sign of the integrity of the posterior columns. He points out that developmentally, in the lateral line of fish, sensations of posture and vibration are associated, and both sensations have

a temporal and spatial factor, the former stressed most in vibration, the latter in posture.

Symns³² developed what is undoubtedly the most useful advance in the use of the tuningfork. He used a large A fork with a vibration rate of 108·75 per second (supplied by Messrs. Down Bros.). The feature of this fork is the presence between the prong tips of three interlapping plates of metal (see fig. 1). One of these plates, which fits in between the two on the other prong, bears two notches, which are invisible when the fork is at rest, but visible when it is struck fairly hard. The fork is struck and applied to the body just when the notch, or window, is about to disappear, and a stop-watch is started at the same time. When the patient states that he can no longer feel the sensation the watch is stopped and the time taken. This method ensures that the fork is always applied at a given amplitude, and results are quantitatively comparable with results from other parts of the

FIG. 1.—Head of tuningfork as used by Symns.

body and results from other individuals. Unfortunately results are not necessarily comparable with different forks, for every worker since Symns, using a presumable identical fork made by the same firm, has agreed that Symns' results are far too high. The firm investigated that matter, and found that the discrepancy was probably due to differences in temper and weight of the prongs. To avoid this in future, all forks made by that firm are tested against a known normal member of its staff and its graph is delivered with every new fork. The results can be plotted on a graph.

Symns dealt with the results in diabetes, tabes and disseminated sclerosis (discussed farther on). In alcoholic neuritis the legs and arms were always affected, the sacrum sometimes. In plumbic neuritis the legs were commonly, the arms less commonly, involved. There was no loss in amyotrophic lateral sclerosis, paralysis agitans and progressive muscular atrophy. Among other general statements he declared that: (a) when vibration sensation over the sacrum is absent the cord is involved; (b) when present over the sacrum but absent over one other extremity the condition is a peripheral neuritis.

Symns believed that the stimulus is carried through the skin and soft parts, and transmitted along the bones, but is felt in the soft tissues. A small tuningfork may not be felt over anæsthetized skin, when a larger one will be, i.e. both light touch and deep pressure are involved.

Wood,³⁷ using 100 normal cases, established a limit of normality, which cases are the basis of the published charts. He found the same sacral dip in tabetics that was emphasized by Symns, and remarked on the frequency with which patients, being treated as cases of gastric and duodenal ulcers, were later shown to be tabetics with gastric crises, as a result of routine

FIG. 2.

testing with the tuningfork, followed up by examination of the cerebrospinal fluid.

Piercy²⁷ followed up the work of Symns and Wood, and agreed with them in the main. In most cases of syphilis confined to the upper motor neurone no marked changes could be found, as would be expected, the vibratory test being a sign of integrity of the posterior columns. He remarked also on the changes in old age and chronic alcoholism.

Ahrens² also worked out a series of 100 normal cases, and found the spread of his graphs to be slightly wider than those of Wood's (fig 2). He emphasized the influence of the intelligence of the patient, his state of mind, fatigue and extraneous distractions. He worked out the graphs of a series of cases of pernicious anæmia, diabetes and general paralysis. Most of the latter had tabetic curves, in contradistinction to the findings of Piercy.²⁷

Epstein ⁹ describes the route in the cord and brain that the nervous impulse takes. The neurones of the first order travel in the columns of Goll and Burdach and end in the nuclei gracilis and cuneatus. Neurones of the second order relayed from these nuclei decussate at the median lemniscus, and end in the optic thalamus, which is the subcortical station subserving primitive undifferentiated sensation. Thalamocortical paths of neurones

FIG. 3.—Adapted from Epstein.

(third order) traverse the posterior end of the posterior limb of the internal capsule, pass into the corona radiata and end in the sensory cortex, which organizes and analyses the perceptions (fig 3).

Epstein emphasizes the value of the fork in multiple neuritis due to lead, arsenic, etc., its use in hysteria and in diagnosing pure affections of the motor systems, such as progressive muscular atrophy.

McKinley ²² mentions the essential physiological error in the previous quantitative methods of testing, as developed by Symns. The latter applied

the fork at its maximum amplitude, which gradually decreased to a minimum when the patient ceased to feel the vibrations; the scientific method would be to begin from below and find the threshold. Also fatigue brings a big error into Symns' method. To show this I have devised a simple experiment.

Experiment 2.—The fork was applied to the right radius when vibrating at a known amplitude. It was felt for 23 seconds. It was reapplied vibrating at the same amplitude, but every five seconds was held away from the bone for five seconds' rest. Its vibrations were felt up to the 32nd second.

This shows that the patient ceases to feel the vibration long before the amplitude of the fork has fallen to its physiological threshold, his senses being dulled by fatigue; so we have been measuring two factors—threshold of amplitude, and fatigue.

To obviate this McKinley developed a method of applying the fork at

FIG. 4.—Schematic graph (after McKinley) to show relation between time and amplitude.

its minimum amplitude. Between the prong tips could be applied one of a series of rods of which he had 15, of differing lengths. The rod was withdrawn sharply and the fork vibrated at an amplitude depending on the length of the rod. This method is much inferior to the electrical one of Gray¹⁵ and not nearly so valuable clinically as the method of Symns. The graph of time plotted against amplitude shows that the fork runs down very rapidly at first (fig. 4).

Pearson²⁶ mentions the neglect of the age factor by most other authors, and discusses the diminution of the sensation decade by decade. To explain this he describes some early work by Williamson^{35(h)} on the vessels of the cord. The vessels of the cord arise from spinal arteries that are among the longest vessels in the body. In the lumbar cord they are less numerous than in other portions, and must pass upwards. Arterial changes are thus common in these vessels in old people, giving rise to degeneration of the

posterior columns, hence to changes in the sensation of vibration, more marked in the lower limbs.

Gray,¹⁵ reasoning from the same objections as McKinley, has developed the most accurate method of testing the sensation of vibration. A magnetic coil is set between the prongs of the fork and the desired amplitude set up by varying the amperage of current running through the apparatus. The fork is not struck, but its vibrations sustained electrically. Obviously the greater the amplitude of the threshold stimulus, the less is the acuity of the sensation. The lowest constant amplitude felt by normal persons was 2.34 mm.

His work was confined to normal cases and to cases of pernicious anæmia. He noted the loss of acuity in pernicious anæmia, and went into great detail in its distribution. He also noted the loss in old age. An interesting feature he revealed was that the threshold improved after repeated testing. The threshold value at one point on September 12, 1929, was 0.22 mm., and on the same point seven months later 0.018 mm. On another point it was 0.549 mm. and 0.031 mm. respectively on the same two dates.

My criticism of Gray's method is that although it is scientifically accurate it is (a) far too cumbersome and lengthy for clinical use; (b) his thresholds for one point have a much larger spread than the equivalent threshold-fatigue-time method of Symns; (c) his method shows nothing clinically that cannot be shown by the Symns' fork; (d) if it is insisted that the threshold be approached from below and not from above, as in Symns' method, and the element of fatigue be eliminated, there can be devised a method of using the Symns fork that fulfils these criteria, and is no more involved.

AN ORIGINAL METHOD OF TESTING THE SENSATION OF VIBRATION

The ideal method of testing the sensation of vibration should (a) approach the threshold from below, (b) give the result in millimetres of amplitude of the fork, (c) not be so cumbersome that it cannot be used in routine examinations, and (d) eliminate the factor of fatigue.

Symns' method does not fulfil (a), (b), and (d); Gray's and McKinley's method, (c).

If the fork as used by Symns be struck and the stop-watch started at a known amplitude, i.e. when the first window disappears, the amplitude decreases, with a decreasing rate which can be plotted against the time (fig. 4). The fork is kept vibrating for, say, 30 seconds, and then, and not until then, applied to the bone. The patient is asked to state whether he can feel the vibrations or not. If he can, the process is repeated, increasing the length of time that the fork is held away from the bone until a time is reached when the vibrations cannot be felt. The previous reading, expressed in seconds, is the threshold value for that bone. Similarly, if at first the vibrations cannot be felt, the time is reduced until they can be. In practice, as the amplitude decreases with time, it is not necessary to change the latter

units into the former, especially as a complicated apparatus is required to plot the required graph. Three, and not more than four, applications are necessary to find each threshold, and they may be reduced to two. In the present instance the time-intervals were increased or decreased by 2.5 seconds. Two graphs of a normal individual are compared (fig. 5).

The continuous line is the threshold-fatigue curve of Symns, the dotted line is the minimum-threshold method, as it might be termed. A striking parallel is seen between the two curves, which speaks much for the accuracy of both methods. A disadvantage, which is easily rectified, is the length of time one has to wait for each application, i.e. 25 to 40 seconds. This is because the fork is made to be applied at a relatively high amplitude. If it

FIG. 5.

were applied at a lower amplitude the delay would be much less. To lower the amplitude it would only be necessary to have a larger window made in the metal slot.

The great advantage of the method is the clear-cut 'yes or no' reply required from the patient, who either feels the vibration or does not—very different from the hesitant replies often obtained from the most intelligent patients by the method of Symns, when he or she has to say when a slowly disappearing sensation becomes imperceptible.

In the case of, say, the right radius, the vibrations are only felt for 25 seconds, starting from a given amplitude, if the fork is continuously kept applied to the bone. The true threshold value for the sensation is, however, only reached after 40 seconds. The difference, 15 seconds, is loss due to fatigue, and perhaps slightly to an inability to appreciate a correct end point when the threshold is approached from above.

THE NATURE OF THE SENSATION

There is unanimity among observers as to the route taken by the nervous impulse in the nervous system, and this was described before. Disagreement arises in the study of the site of reception of the stimulus.

Rumpf²⁹ believed that the sensation was confined to the skin. Treitel³⁴ thought that it was distinct from both pressure and touch, as opposed to Goldscheider,¹³ who maintained this relationship. Egger⁸ was the first to put forward the idea that the end-organs of the sensation lay in bone, periosteum, ligaments and capsules of bones and joints. Minor²⁴ in a reasoned paper showed that continuity of bone was not necessary for perfect reception of the stimulus; that periostitis, caries and superficial thickenings of the bone had little effect, and that the sensation could be felt on a dead sequestrum. All this pointed to the fact that the bone was probably not the site of reception. Bing⁴ differentiated the sensation from that of touch by excluding the latter with local anæsthesia. Head¹⁷ analysed the subjective sensation into the two factors of 'jarring contacts' appreciated by the thalamus, and rapidly repeated movements of small range, perceived by the cortex. He noted the relationship between the sensations of vibration and those of passive movement and posture. Symns³² agrees. Tilney,³³ Epstein⁹ and Gray¹⁵ believe that the sensation arises in bone.

A few facts should be noted. (a) The sensations from a small tuning-fork of 518 vibrations per second may be abolished by local anæsthesia, and not those of a larger fork. (b) Disease and injury of bone, however, have very little effect on the distinctness and duration of the sensation. Three cases were investigated, and may be cited. In one, the affected femur was the site of extensive chondromatosis. In another there was decalcification with a suggestion of fibrocystic disease, and in the third the affected limb, due to disease-atrophy, was considerably shorter than the other. In each case the sensation in the affected limb was as good as in the normal, except in the third case where it was better.

Experiment 3.—The vibratory sensation was estimated on the skin of the posterior aspect of the middle of the thigh, and found to be 7 seconds. A plaster cast about 7 inches wide was then made to fit around the middle of the thigh, and the fork applied to it after it had set. The sensibility was slightly increased to 11 seconds. The fork was next applied to the condyles of the femur, and the time of reception of the stimulus was found to be still longer, i.e. 17 seconds.

Thus the bone, as a sounding-board in the middle of the soft tissues of the thigh, gives better results than the plaster-cast, a sounding-board applied to the tactile organs of the skin.

The sum of the evidence points to the fact that bone, because of its structure, distributes its vibrations to the deep tissues, i.e. muscles, tendons, joints, fascial planes, perhaps periosteum, where the main part of the sensation is perceived. The skin, to a less extent, takes part in its reception.

SOME INTERESTING FEATURES

Fatigue.—The sensation of vibration can be dulled by fatigue. Of this there are two forms, which may be termed intrinsic and extrinsic fatigue, a distinction apparently not hitherto drawn. Intrinsic fatigue is the diminution of the acuity at the point tested due to the continued application of the fork. This has been discussed earlier. Extrinsic fatigue is due to fatigue of the organism as a whole.

Experiment 4.—The sensation was tested in an individual before and after a round of 18 holes of golf.

	Before	After
Right radius	22 seconds	16 seconds
Right ulna	22 ..	16 ..
Left radius	22 ..	17 ..
Left ulna	19 ..	16 ..

These results show a considerable diminution in the sensation.

Vocal Fremitus.—Various workers have remarked on the difference in vibratory acuity of the two sides of the body. Some have stated the sensation on the left side of the body to be the more acute, others, that on the right. In this study the difference was noted, but no special side was found to predominate. This proves the clinical importance of testing vocal fremitus with the same hand on each side of the chest.

CLINICAL APPLICATIONS

A series of approximately 100 cases was examined for this work. They include 25 cases of diabetes and 25 cases of pernicious anæmia. Although the numbers are rather small for statistical analysis, the results may be considered suggestive.

The technique adopted was that developed by Symns.³² The fork used is a large A fork, of 108.5 vibrations per second, and prongs just under 9½ in. long. Each fork supplied is tested against a normal individual in the employ of the manufacturers, and his graph delivered with the fork. The fork is struck, and when the first window just disappears a stop-watch is started, and the handle of the fork applied to the point to be examined. The patient should be at ease, not tired, and should, before beginning the real test, be made to understand just what he has to do. During the test the patient can be examined as to his reliability by applying the fork when the vibrations have been stopped. When the patient ceases to feel the sensation he says 'Yes,' and the watch is stopped. With a reasonably intelligent patient successive tests show considerable accuracy, and need not vary more than 10 per cent. on repeated testing. The points tested are the radius, ulna, sternum, sacrum, anterior superior spine, tibia, internal and external malleolus. Both sides are tested, and if there is any appreciable difference the two results are recorded on the same graph. The fork should be applied with

a constant pressure, firm, but not heavy, care being taken not to hurt the patient. Leading questions will of course be avoided.

Ten cases not suffering from disease of the nervous system were tested, not to set a standard of normality, but to check the tuningfork with the comprehensive series of normals already investigated by Wood³⁷ and Ahrens.² The spread of the curves is certainly wider than that which Wood described as normal, but except for one case, fits in with that described as normal by Ahrens. This exception, in which the diminution of sensibility was slight, was a neurasthenic.

The compound graph (fig. 6) shows clearly a feature that has been described by others, the tendency for the vibration sensation in the arms to

FIG. 6.—Normal cases (10).

be fairly high, and to approximate closely in different individuals, whereas the spread over the limbs is much wider.

Loss with Age.—The gradual loss of the sensation of vibration has been remarked upon by Egger,⁸ Rydel and Seiffer,³⁰ Piercy,²⁷ Pearson²⁶ and Gray.¹⁵ Pearson made the most complete study of it, and stated that in the legs there was a diminution decade by decade, but no change in the arms occurred until the fiftieth year. Gray noted the effect of age on the vertebrae and pelvis, where there was also a loss. The five cases presented (fig. 7) include two with fracture of the neck of the femur, one with cataract, one with eczema, one with cholecystitis. The ages varied from 71 to 84 years. One had a low normal graph, all the others were distinctly abnormal. The loss was in the pelvis and lower limbs, the sensation in the arms remaining normal but on the low side. The loss, as explained before, is most likely the result of arterial degeneration of the spinal vessels.

Sensation in the Blind.—There does not appear to have been any work done on the sensation of vibration in the blind. It is often loosely stated

FIG. 7.—Old age (5 cases).

that the sensitivity of blind individuals is increased, without either adequate quantitative proof or evidence that the apparent increase is not due to a

FIG. 8.—Blind individuals (5).

raising of the threshold for the sensation but to a better discrimination of what is felt. The sensation of vibration is a useful test for this problem,

as it can be quantitatively measured, and it is unlikely that the individual tested can have had much previous experience of the sensation, resulting in better discrimination.

Results show a considerable increase in the vibratory acuity in the blind. Of the five cases (fig. 8), two have high normal curves, two have curves distinctly above the normal, and the fifth has very high acuity in the limbs, but practically absent vibratory sensibility in the pelvis. On the whole in the five cases the increase tends to be in the limbs and not in the pelvis. There is very little difference between the upper and lower extremities.

It should be noted that all the individuals selected were between the ages of 21 and 41, healthy, and had been blind for more than 10 years, and

FIG. 9.—Syphilitic aortitis (5 cases).

were trained workers. No cases were included in which the blindness might have been due to lesions of the central nervous system. Gray¹⁵ notes that the normal individual in whom he tested the sensation of vibration over a period of months showed a marked increase of acuity. Apparently the training of the apparatus of sensation which takes place in the blind over a period of years increases the threshold for sensation both generally, and for specific sensations.

Syphilitic Aortitis.—This series of cases was examined to test an assertion by Symns³² that absence of the sensation of vibration at the sacrum denoted a lesion of the central nervous system, the lesion in this case being easily demonstrated by the examination of the cerebrospinal fluid. None of the patients showed obvious signs of a lesion of the central nervous system.

The first impression from the compound graph (fig. 9) is a lessening of the sensation in the pelvis and lower limbs. This general diminution is

probably due to the average age of the group, which is 56. The only patient below the age of 52 had the only normal curve. Two cases had absent vibratory sensation at the sacrum. The cerebrospinal fluid of one was normal, that of the other showed the following: W.B.C.—50 per c.mm.; globulin—excess; albumin—0.05 per cent.; Fehling's solution—reduced; colloidal gold test—1112100000.

This shows that absence of sensation of vibration at the sacrum cannot be taken as diagnostic of cord involvement, but is suggestive, and might be used as a method of weeding out patients. Piercy²⁷ suggests that absence of sensation of vibration at the sacrum in a patient in whom no cord lesion can be found is suggestive of a healed lesion. This would be difficult to prove.

Postencephalitic Parkinsonism.—In this condition both Williamson³⁵

FIG. 10.—Postencephalitic Parkinsonism (5 cases).

and Symns³² state that there is no change in the acuity of the sensation. This is of course the accepted view, as no change in sensation is usually described.

Worster-Drought and Hill,³⁸ however, come to a different conclusion, stating that there is a loss, worse with the severer forms of the disease, and on the more affected side. It appears, however, that although they used Symns' technique, they also accepted what Symns described as the normal. Since it has since been amply proven that Symns' results were too high, due to the mechanical features of the fork he used, their conclusions cannot be accepted. They give the mean graph from their cases in their paper, and it is seen that this falls entirely within the normal as described by Wood and Ahrens (see fig. 2).

The compound graph (fig. 10) of the case done for this work demonstrates

always be found in this disease where sensory disturbances are often hard to demonstrate.

FIG. 12.—Disseminated sclerosis (5 cases).

Microcytic Anæmia.—This series of cases (fig. 13) is presented as a contrast to pernicious anæmia. The average age is somewhat high, 55 years,

FIG. 13.—Microcytic anæmia (5 cases).

and a lowering of the curves must be expected. Two of the patients have normal curves for their ages. Three have absence of vibratory appreciation at the sacrum, but only one a diminution over the lower limbs. According

to Symns ³² these three should have cord lesions. One had other signs and symptoms suggestive of subacute combined sclerosis, the complication from which the patient would most likely have been suffering, but it was hardly likely that the other two could have been suffering from a nervous complication. At least one shows a vibration chart suggestive of tabes.

Diabetes.—Williamson,³⁵ Symns,³² Ahrens ² and others describe loss of the sensation of vibration in diabetes. Williamson states that the loss is often so slight that it can only be demonstrated with the tuningfork and that it is often worse on the side affected by gangrene or ulcers. Ahrens

FIG. 14.—Diabetes (25 cases).

agrees. I have not found that the presence of arterial changes in the limbs usually causes diminution on the affected side.

The following table shows the incidence of absent or deficient sensation of vibration in the 25 cases :—

	Sensation absent	Sensation deficient	Sensation absent or deficient
Ulna.	1	0	1
Radius	1	0	1
Sternum	0	5	5
Sacrum	9	5	14
Ant. sup. spine	5	2	7
Tibia	4	4	8
Ext. malleolus	5	5	10
Int. malleolus	4	5	9

It will be noted (fig. 14) there is derangement at the sacrum in 14 cases, or 64 per cent. Sensation was never absent at the sternum. In the 55 cases of derangement at the points tested, 26 showed only diminution and not loss. It is important to note that without some quantitative technique this would probably not have been noted.

According to Symns' theory two of the cases are pure peripheral neuritis, without cord involvement, and five cases show cord involvement without peripheral neuritis. This is hardly likely to be the true state of affairs, and it cannot be granted that absence of sensation of vibration at the sacrum is a sign of a cord lesion. Five further cases show a deficiency both in the limbs and in the pelvis. Twelve of the 25 cases, or 48 per cent., show changes that definitely point to a lesion of the nervous system, probably a peripheral neuritis, with a possibility of one or two cases having a cord lesion, probably subacute combined sclerosis.

Pernicious Anæmia.—The history of the description of nervous lesions in pernicious anæmia is interesting. Addison¹ did not describe lesions of the central nervous system in his original account of the disease. Biermer³ described weakness, giddiness and palpitation, and found capillary hæmorrhages in the brain. In the early days subacute combined degeneration of the cord was confused with tabes. Dejerine⁶ pointed out the loss of deep sensibility in subacute combined degeneration, and its relation to pernicious anæmia. He also described the symptoms as due to lesions of the long fibres in the columns of Goll and Burdach.

Woltmann³⁶ suggested that some of the nervous lesions might be the result of a peripheral neuritis. Hamilton and Nixon¹⁶ carried out this idea still further, and believed that the remissions in the nervous symptoms might be due to the healing of the neuritis, and not to cord involvement. They based their conclusions largely on pathological data. Bramwell,⁵ on the other hand, stated that absence of lesions of the peripheral nerves was a feature of the disease.

Hamilton and Nixon¹⁶ found that loss of vibration sense was the commonest sensory deficiency found in subacute degeneration of the cord, being commoner than loss of the sensations of position, touch, or superficial pain.

Various workers have estimated the percentage of lesions of the central nervous system in pernicious anæmia. Some estimates are as follows:—Bramwell⁵ 2·8 per cent.; Nonne²⁵ 11·7 per cent.; McCrae²¹ 25 per cent.; McPhedran²³ 40·9 per cent.; Henneberg¹⁸ 50 per cent.; Gray¹⁵ 66·6 per cent.; Hamilton and Nixon¹⁶ 80 per cent.; Woltmann³⁶ 80·6 per cent.

Symns,³² Williamson³⁵ and Friedman¹² emphasize the use of the tuningfork in subacute combined degeneration, the latter considering it to be one of the most efficient tests. Gray¹⁵ made a fairly complete examination of a series of pernicious anæmia cases with his special tuningfork, and found that the minimum amplitude felt showed an increase in pernicious anæmia

which was not sufficiently large to be diagnostic in the arms, but was so in the lower limbs.

The following table embodies the results of the examination of 25 cases of pernicious anæmia :—

	Sensation absent	Sensation diminished	Sensation absent or diminished
Ulna	0	6	6
Radius	2	3	5
Sternum	0	6	6
Sacrum	14	4	18
Ant. sup. spine	11	6	17
Tibia	7	8	15
Ext. malleolus	12	5	17
Int. malleolus	12	6	18

In no case (fig. 15) was the sensation absent at the sternum or ulna. At 102 points tested there was derangement of sensation, but diminution

FIG. 15.—Pernicious anæmia (25 cases).

only in 44 of them. There was derangement at the sacrum in 18 cases, or 72 per cent.

According to Symms' theory there are in my group four cases of pure peripheral neuritis, four cases of pure cord lesions, and ten cases where the lesion lies in both the cord and peripheral nerves. In view of the results discussed in diabetes it is difficult to accept this theory.

Eighteen of the series are shown by the tuningfork to have definite lesions of the nervous system. This is 72 per cent., and the percentage would doubtless be higher were other criteria used as well as the sense of vibration as a sign of nerve lesions, and would doubtless approach that given by Hamilton and Nixon, and Woltmann, of 80 per cent. Ahrens² stated that none of his cases had normal sensation of vibration. In this series four were normal and three doubtful. The average age of the normal cases was 40 years, and of the whole group 54 years.

Miscellaneous Cases.—A series of cases are shown to illustrate special points of interest, or to demonstrate the value of the use of the tuningfork, or even, occasionally, the added confusion to which its use might give rise.

FIG. 16.

Subdural Hæmorrhage.—A case, the result of a fall, was seen. It was diagnosed after lumbar puncture, adhesions having resulted, causing a block in the flow of cerebrospinal fluid. This gave rise to Froin's syndrome; lipiodol, by cisternal puncture, was held up above the adhesions. The vibration sense was normal (fig. 16), showing that there could not have been much damage to the posterior roots or columns, although the patient had a paresis with absence of reflexes in the lower limbs. This was proved by the clinical course of the disease, the patient making a perfect recovery with no surgical interference.

Here may be mentioned some conflicting views in the literature, Williamson³⁵ stating that there is no loss in cord tumours and hæmatomyelia, Epstein⁹ stating that there often is. On purely anatomical grounds it is obvious that the site and extent of the lesion will be the deciding factor.

Intracranial Tumour.—An interesting but isolated case of increased intracranial pressure, probably due to a tumour, is presented. The site was not definitely diagnosed, but a suboccipital decompression gave much relief. The interest lies in the marked sensory acuity of the patient, the highest that I have yet tested, the readings being in some places too high to plot on the graph. In addition, the patient was markedly sensitive to pain of all kinds, intravenous injections causing him much discomfort. Further speculation on one isolated case would be useless. A similar result was not obtainable in another case of intracranial neoplasm.

Syringomyelia.—Williamson³⁵ states that there is no change in the vibration sense in syringomyelia, and Epstein⁹ that there might be. The

FIG. 17.

only case in this series showed marked loss of the sensation in the lower extremities (fig. 16).

Hemichorea.—To illustrate the absence of changes of the sensation of vibration in lesions of the brain, a case of hemichorea, probably the result of encephalitis lethargica, is presented. The patient had choreiform movements confined to the left side of the body. In view of the sites known to be affected in both encephalitis lethargica and lesions giving rise to chorea, i.e. the basal ganglia and midbrain, it is interesting that the sensation of vibration should have escaped entirely (fig. 17).

Cerebrospinal Syphilis.—According to Piercy²⁷ lesions of the secondary neurones should not give rise to diminution of vibratory acuity, hence in a pure case of general paralysis there should be no change, while there is a loss in tabes. Ahrens² found that of his five cases of general paralysis

three had normal graphs and two tabetic ones. It is difficult to be dogmatic as so many cases are a mixture of the two. A case of cerebrospinal syphilis may give a graph suggestive of tabes, but the patient may be suffering from syphilitic meningomyelitis, as in the example presented here (fig. 17).

Amyotrophic Lateral Sclerosis.—This disease, being purely a lesion of the motor neurones, should display no diminution of the sensation of vibration. In one of the illustrative cases (*a*) this was the case, but the other (*b*) presents an interesting problem. This patient had all the signs and symptoms of a pure upper motor neurone lesion, but absent vibratory sensation at the sacrum and anterior superior spines. Should this be sufficient to change the diagnosis? In this case I believe not, as the individual was rather fat,

FIG. 18.—Amyotrophic lateral sclerosis.

and had thickened arteries, which if present in the lumbar cord would suffice to cause this deficiency.

Peripheral Neuritis.—All writers concur that vibratory sensation is diminished in peripheral neuritis. Symns³² states that the sensation is usually present in the sacrum, but absent in one or other of the extremities. In diabetic neuritis he declared that the arms were normal, but the legs affected. In alcoholic neuritis both arms and legs were affected, and in plumbic neuritis usually the legs and less so the arms. Of my 25 cases of diabetes, only one had diminution in the arms, but 15 in the legs.

Two cases of peripheral neuritis, both of unknown origin, one acute, are presented here. Both show typical curves (fig. 19), the sensation being present at the sacrum, but absent at the limbs. In both of them the tuning-fork was of help in coming to a diagnosis. In this disease the sensation of vibration is usually the first to disappear, and is often deficient before the

kneejerks are absent. This is well shown in case (a). The kneejerk was present on the left side, but the tuningfork, though felt in the middle of the

FIG. 19.—Peripheral neuritis.

shaft of the tibia, could not be felt at the malleoli. The kneejerk was absent on the right side, and the sensation of vibration lost in the whole tibia, as well as at the malleoli.

FIG. 20.—Hemiplegia.

Hemiplegia.—Head,¹⁷ Epstein⁹ and others have discussed the effect of cerebral lesions on the sensation of vibration. Usually there is little loss,

but if there is other sensory diminution there is often some deficiency of the sensation of vibration. It is never completely lost, however, except in cases of neural shock. The protopathic component of the sensation, or what Head calls the 'jarring,' is probably felt in the thalamus, and the epicritic in the cortex. In hæmorrhage in the internal capsule there is said often to be a diminution, or feeling of distance, in the sensation. On the other hand, when the thalamus is irritated, or divorced from the cortex, the sensation is often extremely unpleasant, or even painful, and may be felt more strongly than in the sound limb. This applies to other sensations as well as vibration, such as tickling or pin-pricking, and was described by Roussy ²⁸ under the name of 'syndrome thalamique.'

Of the two cases of hemiplegia presented (fig. 20), both aspects are involved. In case (*a*) the sensation in the paresed limb was felt as long as in the normal limb, in spite of the fact that the patient averred that the sensation was much weaker on the paralysed side. The other patient (*b*) showed clearly the 'syndrome thalamique,' as when the fork was applied to the external malleolus of the affected side he cried out with discomfort, and attempted to withdraw his foot. The sensation was felt there much longer than in the normal limb.

DISCUSSION

The sensation of vibration is the most delicate known test of the integrity of the posterior columns of the cord. The great advantage of testing according to Symns' technique, which is rarely carried out, is that a quantitative result is obtained, thereby providing an indication of small changes, and giving a graph, which can be compared with the results of testing the patient at some future date.

The sensation of vibration is definitely related to that of deep pressure and passive movement, and the sensation, especially at the sacrum, shows a correlation with the presence or absence of Rombergism. To a less extent the sensation can be felt in the skin, like the sensation of touch, and this small component of the sensation can be abolished by local anæsthesia.

The fork is conveniently applied to some bony prominence, as thereby the bone is made to vibrate and transmit the impulse through the soft tissues. Disease or fracture of bones has little effect on the duration of the sensation, and probably only a small part of the sensation, if any, is felt in the bony tissues themselves. The sensation is perceived in the cerebrum—a protopathic element in the thalamus, and an epicritic in the cortex.

With practice, in a normal individual, the acuity of the perception can be considerably increased, and is found to be so increased in healthy blind individuals. The sensation is diminished by fatigue, of which there are two forms—extrinsic fatigue, due to tiring of the organism as a whole, and intrinsic fatigue, due to overstimulation of the sensation of vibration itself. It is the neglect of this latter factor that is the chief error in testing by Symns' method, and a simple way of overcoming this has been devised.

It has been frequently stated in the literature that diminution of the sensation at the sacrum denotes a lesion of the cord, whereas diminution at the limbs and a normal sensation at the sacrum mean a peripheral neuritis. With the latter assertion I have no dispute, but it is impossible to accept the view that absence of the sensation at the sacrum necessarily means a cord lesion. Were it so five of my cases of diabetes would have pure cord lesions, and only two pure peripheral neuritis; three out of five cases of microcytic anæmia would have cord involvement, whereas only one had suggestive signs and symptoms; and a case of syphilitic aortic disease, with no signs of symptoms of nervous lesions, and a perfectly normal cerebrospinal fluid, would also be diagnosed as such. Nevertheless, absence of sensation of vibration at the sacrum is suggestive, and should lead to further investigation. It should not be forgotten that the presence of a large sacral pad of fat is an element in reducing sacral acuity.

Probably the greatest help which the tuningfork gives is in the diagnosis of pure motor lesions, such as acute anterior poliomyelitis, amyotrophic lateral sclerosis, progressive muscular atrophy, and their differentiation from combined lesions, such as multiple neuritis, transverse myelitis, disseminated sclerosis and subacute combined degeneration of the cord. But note must be taken of the diminution of the acuity with age.

SUMMARY

1. A brief résumé of the history of the study of the sensation is given.
2. A few physiological principles involved in the perception of the sensation and its course in the brain and cord are discussed.
3. Ten individuals without disease of the nervous system were examined to correlate the normal with the investigations of others.
4. Five people above the age of 70 were examined to demonstrate the loss of vibratory acuity with age.
5. Five blind but otherwise healthy individuals were examined, and their vibratory acuity found to be above the normal, especially in the limbs.
6. Five cases of syphilitic aortitis were examined; sensation at the sacrum was absent in two, and the central nervous system diseased in one of these.
7. Five sufferers from postencephalitic Parkinsonism were tested, and their curves found to be rather low, but well within the normal. The feature of the curves was their evenness.
8. Five tabetics were examined, and their curves found to agree with the typical curve as described by Symns, showing the 'sacral dip.' One of the individuals had the lowest sensibility yet tested.
9. In four out of five cases of disseminated sclerosis there was marked diminution of acuity. The sensation of vibration is often the only sensation disturbed in this disease.
10. Five cases of microcytic anæmia are discussed.

11. Of 25 cases of diabetes 48 per cent. showed lesions of the nervous system. Fourteen had deficient sensation of vibration at the sacrum, but this could not have meant a cord lesion. In about half the cases of diminution of the vibratory sensation the loss would never have been found had not Symms' technique been used.

12. A brief résumé of the history of nerve lesions in pernicious anæmia is given. In subacute combined degeneration of the cord the sensation of vibration is deranged more frequently than any other sensation. Of the 25 cases tested 72 per cent. showed nervous lesions. In two-fifths of the cases the loss was quantitative and would not have been disclosed had not a quantitative technique been used. Four cases, or 16 per cent., had peripheral neuritis without cord involvement.

13. A few miscellaneous cases to illustrate various points are presented. One of these, a case of intracranial neoplasm, had the highest vibratory acuity so far encountered.

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