THE BRADSHAW LECTURE ON SUBJECTIVE SENSATIONS OF SOUND.

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MR. PRESIDENT AND GENTLEMEN,—I am little likely to be misunderstood if I say that I approach the task of delivering the Bradshaw Lecture with a deep sense of sadness. It is a task, Sir, that was committed to me by your predecessor in words of personal desire which must have had for anyone, and for many reasons had for me, the force of a command. The keen pleasure with which I looked forward to its execution before him, as President, who was then my oldest medical friend, has left me only the melancholy satisfaction of thereby fulfilling the last official request he gave as occupant of the highest and most honoured post in our profession. His was a mind that could not even know a thought that was inconsistent with the highest honour of our profession, a disposition ever ready to give without a thought of return, with the pure benevolence in which self-interest can have no motive place—ever ready to aid by the sympathy that helps others to endure or to strive, and by the wise counsel that only such sympathy can make effective—a man from whose lips I believe there never fell one unkind word, yet stern to condemn and firm to resist the wrong, a personification of that which is to us the highest and the best, fitly manifested by an outward grace still fresh in all our memories. That he has passed from us, that we enjoyed his personal influence as our head for so brief a time, is felt, I feel sure, by no one, Sir, more than by you, whose esteem for him was exceeded by that of no one, and who shared so equally with him the esteem of this College, as was once strikingly demonstrated within its walls.

I propose to ask you to consider some features of the sounds that are heard when no external cause for them exists—subjective auditory sensations. Not long ago I took advantage of another opportunity to consider the visual sensations which are of similar character, and the analogy of those of hearing, together with an extensive collection of observations, suggested my choice of a subject.

The time at my disposal makes it impossible even to attempt a general account of the subject. All that I propose to do is to present to you some of the more salient facts that have come under my notice regarding the two chief forms of these sensations, those of labyrinthine and of central origin, to endeavour to do this in such a way as may bring out those features and relations which seem to me to be of most importance. Especially I desire to indicate the points to be attended to in future observations in the hope that I may enable these to increase definitely our useful knowledge. No orderly arrangement is indeed possible. The facts themselves not only are so various and varied as to baffle adequate classification, but they present so tangled a skein, or rather network, that their separation is not possible except by force. To tear asunder that which is interwoven is an easy means of distinction. But we must be content with a less effective way and try to trace where we cannot disentangle, and to perceive where the interlacing strands are chiefly gathered together. While such limitation of the subject has the advantage of giving a greater insight into a series of symptoms it has the disadvantage of restricting the range of observation. The cases in which the subjective sounds depend upon diseases of the middle ear have come very little under my notice. They are seen chiefly by the aural surgeon. This is, however, less important, because such causes are effective through their action on the labyrinth and the study of sounds of labyrinthine and central origin are of chief importance. I should add that the rare sounds that can be heard by another person, usually the effect of an intracranial aneurysm, are also not considered. Curious they are, but without relation to my subject, and, as I shall explain, those

auditory sensations which are associated with insanity also transcend its scope. I should also state that the limits and character of the sketch I have to offer you preclude any assumption of originality on my part, as they also preclude reference to the work of others. I mention this because I doubt not that many things I have to say have been said before, and to those by whom they have been said I offer this explanation.

Among the facts that I shall have to mention are some relating to the power of hearing certain musical notes. Little information would be gained by the simple mention of these notes, either as a letter numbered according to the corresponding octave, as C², or by the number of vibrations per second which constitute the sound. I have, therefore, asked Mr. Hawksley kindly to give me his help. He will make each sound a definite conception by means either of a tuning-fork or of that most useful aid to clinical observation, a Galton's whistle, by which high notes can be produced with precision, ranging from 4,000 vibrations, two octaves above the treble clef, to the utmost capacity of the human ear, 18,000 or 20,000 vibrations a second, and, indeed, far higher, when a cat will start, though there is absolute silence to us. Although age lessens the power of hearing these high notes, the significance of early and one-sided loss renders the service of this instrument in diagnosis very great.

VISUAL AND AUDITORY SENSATIONS.

The resemblance which exists between the subjective sensations of vision and those of sound is superficial; the difference is profound, and it is also instructive. Subjective visual sensations are chiefly of central origin, and in themselves chiefly of physiological interest, while those of hearing are to a large extent produced in the sensory organ itself. They are often so obtrusive, and even distressing, that by the sinister dignity of a special name, the symptom has almost come to be looked upon as a disease. A definite designation is, however, at least a testimony to the frequency and reality of the suffering that is caused. It would be harmless were it not that names, once called into existence as our servants, are never long content with servitude. Too often we find ourselves controlled by them, and that which is only a symptom, when it has been named tends to be looked on as a disease, sometimes so definite that the investigation of its cause is hindered.

SIGHT AND HEARING.

The frequency with which the ear, and the rarity with which the eye, is the cause of subjective sensations is also of indirect significance. We are apt to place these two senses much too near together in our thought. Both are, indeed, excited by energy in the form of motion and of wave motion. Hence they present points of resemblance which may attract more attention than does the difference, and, indeed, distance, between them. Consider—for the question is of importance for us—consider the difference involved in the frequency of the vibrations that act on each organ. If we take a colour about the middle of the visible spectrum and a musical note below the middle of the treble clef we shall find that, in the interval of time between two successive waves of sound, there occur about one million million waves of light. It is not surprising, therefore, to find that, whereas the waves of sound occur only in media so definitely material that they can be weighed, the waves of light occur in a medium which is not only imponderable, but in which that quality is carried up to the hypothetical. Further, the waves of light can be traced upwards until they vanish to our direct perception, though beyond them, and their actinic successors, there seem to be almost ultra-etheral waves of such a nature that they can be only designated by the algebraic symbol for that which is unknown; on the other hand, the waves of sound pass down to the coarser motion which can be only felt. It is a familiar fact that all the lower waves of sound can be felt by the sense of touch if only they occur in a medium sufficiently inelastic. With this is associated yet another difference; the waves of light, like the common waves of water, are transverse to the line of propagation ("transversal" waves, according to the double adjectival form which physicists have revived). But the waves of sound are "direct"; they occur in the line of propagation, as the

motion between billiard balls when one at the end of a row is struck and that at the other end flies off. These "direct" or "end-on" variations (as they might be called) manifestly possess a greater impetus, and such wave motion is nearer to the simple motion of a mass, by which the nerves of touch are commonly affected. These facts, which point to an essential identity between the stimulus of touch and that of sound, are not disturbed in their significance by the special character of many auditory sensations, such as musical notes. Their significance is, moreover, carried further by the facts of development, which show a common (epiblastic) origin for the structures that subserve each form of sensation by the facts of anatomy, which show that sound is received by minute hairs that act upon the nerves; and by the facts of comparative anatomy, which show the early form of the ear to consist simply of hairs upon the skin connected with a special nerve, homologous with that of hearing in higher animals. We shall presently see in other ways the importance, for our subject, of this relation of hearing to the sense of touch, but I may point out that it removes one apparent anomaly—the fact that one part of the auditory nerve seems to have nothing to do with hearing. Although we cannot say that sound does not act upon the structures of the semicircular canals, we cannot doubt that their chief function is to cause nerve impulses to be produced by the simple motion of the fluid within them and its varying pressure on the hairs in their dilated ends. We have in this a response to the very simplest form of motion, quite as simple as that which excites the nerves of touch. And I would ask you especially to note the fact that, in the same organ, structures which closely resemble each other give rise to sensory impulses which seem to us quite different on superficial observation, but may ultimately prove to be alike. The impulses produced in the semicircular canals do not act upon consciousness, although their effects may do so. This should teach us not to regard conscious sensation as a test of the nerve impulses that may be produced in other structures of the ear.

LOCALITY AND LOCALISATION.

I may safely assume that the chief features and varieties of tinnitus are known to you, and the limitations of time compel this assumption. You know that tinnitus may be a continuous sound or pulsating, and that in the latter case the pulsations correspond to the arterial waves. You know also how many and extensive are the variations in character, from the simplest to the most elaborate sound. The very frequent coincidence of these sounds with evidence of ear disease, varying in seat and character, but usually involving the labyrinth and commonly limited to it, compel the conclusion that the most common source of these sounds is the internal ear, in which the auditory nerve is normally excited. But we have cases, especially those in which the sensations are the warning of epileptic fits, in which we must regard the auditory centre in the cortex of the brain as their source, and in rare cases the correctness of this conclusion has been proved by the discovery of organic disease in this region. It is strange that we have practically no evidence to show that any part of the intermediate path between the organ of hearing and the auditory cortex may be a cause of such sensations. We should, indeed, hardly expect them to be due to a morbid process in the nerve fibres which conduct the auditory impulses, but the grey matter at the junction of the pons and the medulla, which seems to be an intermediate centre, might reasonably be thought occasionally to give rise to impulses which produce in the centre the effect necessary for a sensation of sound. Yet such evidence is not forthcoming. We are led at once to some important considerations by the common name of the symptom—"tinnitus aurium" or "tinnitus capitis"—in popular language, "noises in the ears" or "noises in the head." Leaving for the present the reference of the sound to the head itself the question arises, Why is the subjective sound referred to the ear and not to the external world? Subjective visual sensations always seem of outside origin, why do not those of hearing? The answer is complex and brings before us many points connected with the subject. The apparent source of the sound seems to be, in part, a matter of mental inference. Continuous sensations—hissing or buzzing, for instance—seem as a rule to be of external origin

when they are first observed, but their persistence soon convinces the sufferer that they cannot be; knowing that they must have their origin in the ear, he ceases to refer them to an external cause, and they then seem to him to be felt in the ear, although often, if he can separate the sensation and the inference, he can still for a moment realise that they are due to something outside. It is so also with brief unfamiliar sounds. At first—now and then, indeed, always—they seem to have an external cause, but their repetition involves the knowledge that they have not, and the knowledge so acts on consciousness that their aural source seems to be felt. An instance of this was afforded by a patient who was subject occasionally to the sound of a bell several times repeated. When he first became liable to the sound he actually sent a message to his next-door neighbour asking that the clock might be stopped, the sound of which so much annoyed him, and he only discovered the subjective nature of the sound when he was informed that the neighbouring house did not contain a single striking clock. An instance of persistent reference to an external cause was a girl subject to a sound so perfectly resembling two or three taps at the door, that, in spite of her past experience of this subjective nature, she frequently called out "Come in." Another was a woman who had long been liable to attacks of a rumbling sound, each lasting from a quarter to half a minute, but was never able to distinguish them from distant thunder. Even after she had long known of their subjective nature she would ask persons near her whether they did not hear distant thunder.

PULSATING TINNITUS.

More elaborate sounds generally seem external, but, on the other hand, pulsating tinnitus is almost always referred to the ear even from its commencement. It may be compared by the patient to machinery and the like, but only as regards its character. The mechanism of pulsation in tinnitus is a question of very great interest, because this feature is common when there is no increase in arterial pulsation, and when there is no auditory hyperæsthesia. Of course, it is met with in both these conditions, but I am referring now only to the common form. I must leave the consideration of the possible explanation of this feature, but I think that this sensation is seldom or never purely auditory, although it is only from the observation of very intelligent patients that the fact can be ascertained. There is a local sensation beside that of sound; it is, perhaps, generally perceptible only as a local character of the sound; sometimes, however, it is distinctly a suggestion of a pulsating sensation within the ear distinct from that of hearing. This fact gives importance to other local sensations not auditory. One patient with labyrinthine deafness and attacks of vertigo had occasionally, as an isolated symptom, a brief sensation which could only be described as a "rushing out" through the ear, evidently much more a simple sensation than a sound. Another patient, a man aged 50 years, with changes, probably gouty, in the left labyrinth, causing some deafness, had a buzzing noise which would occasionally change to a throbbing sensation certainly not auditory; and sometimes there would occur behind the ear a momentary sensation as if the bone were being crushed in, neither pain nor sound. These cases show how much we need more facts on this point from patients with the ability to observe. I think (or shall I say I fear?) that there must be many members of our own profession capable of adding much to our knowledge from their personal experience.

REFERENCE TO THE EAR.

It is not altogether difficult to understand such a feature as the local sensation I have referred to. We cannot doubt that nerve impulses are continually passing from the ear to the brain of which we have no consciousness. Disease of the internal ear may cause pain. Wherever pain may be caused—for instance, by inflammation—there must be afferent nerves, however free from sensibility the structure normally may seem to be. Wherever there are afferent nerves those nerves must be in constant activity, in some degree, as a condition of their functional capacity. In such an organ as the ear morbid states which act on the auditory nerves

may readily produce impulses also in nerves that are of different function—impulses that act on consciousness. We can feel sure that unfelt afferent impulses are constantly produced in the middle ear. They must be continuously generated by its muscles. The action of at least one of these may cause a strong sensation, and the fact can be verified without difficulty. In many individuals, probably in all, a voluntary contraction can be produced in, apparently, the stapedius muscle. By closing the eyes tightly, and then trying to turn the eyeballs up, a loud fluttering sensation is produced in the ear, which continues as long as the contraction in the face lasts. It is in part a sound, but in greater part a simple sensation, evidently the result of muscular contraction. A little practice will enable those who are sufficiently curious to produce it very readily by a mere contraction of the orbicularis.¹

The nerves through which this sensation is produced must be constantly excited without sensation by the changes in the state of the muscles, which, we cannot doubt, are constant. A similar fluttering sensation may be a morbid symptom. A woman aged 53 was liable to occasional attacks of severe neuralgic pain in the left side of the head, and when the pain was at its height a fluttering in the left ear could be perceived lasting five or ten minutes at a time. Moreover, she presented an illustration of another association of these sensations because, during the severe pain she would sometimes hear an occasional loud noise referred to the front of the ear and compared to guns going off. There is also some evidence to show that a spontaneous contraction in this muscle during sleep is the cause of the sensation of falling with which a dream is usually associated.

VIBRATION AND TONE.

I shall have presently to refer to the sounds that are referred to the head, but I may anticipate this to mention a very curious instance of another sensation not quite auditory. If we conceive the function of the cochlea as blending into tone, by repetition, the quickly recurring waves that are rhythmical, it is a curious question how we should hear such musical notes if the cochlea were absent. If the waves had sufficient amplitude, sufficient impetus, and were not too frequent, they would be perceived as isolated sounds, as are the vibrations by the sense of touch. Indeed, a tuning-fork vibrating twenty times a second is thus perceived if held near the ear.² A very intelligent woman, after the cessation, under treatment, of paroxysmal headaches, became liable to a musical sound which seemed to fill the head and was accompanied with a strange feeling of extreme fullness of the head. Her hearing was perfect to all tests. She could hear Galton's whistle up to 8,000, 12,000, and even 16,000 vibrations a second. External noises prevented the subjective sound from being noticed. On sounding various tuning-forks she identified the sound as C²—that is, the C below the treble. But the sound was always immediately preceded by a distinct sense of vibration in the head, which would sometimes remain as such, and at other times change to the sound. When she touched the sounding tuning fork with her finger she said the feeling was exactly the same as that of the vibration she experienced in the head. I give this curious fact without comment. I believe the sensation is accurately described, and that the observation may be trusted. It is possible, perhaps probable, that the sensation was of central origin, but there must be a correspondence between the central action and peripheral excitation, and the effects of the latter may be primarily central. A similar sense of vibration is met with in other cases, although not frequently, and its associations deserve careful study. A woman, aged 50 years, had labyrinthine deafness, slight in the right ear, and

moderate in the left, with slight continuous sound, for many years. She had also had three attacks of more considerable tinnitus in the preceding four years, apparently in both ears, the second of which was said to have been accompanied with deafness, and yet with peculiar sensitiveness to sound, and to have ended soon after a great increase in the sound. The last attack had existed for six months, and was characterised by a frequent sound in the head; it might be general, or more on one side or on the other. It was usually a very rapid vibration, but at times had been like music, although not any definite tune. Yet if she heard a tune played on the piano she would often continue to hear it after the instrument had ceased. This case also illustrates the association of cephalic vibration with musical tone. It also illustrates the apparent co-operation of the centre in the effects of labyrinthine change.

REFERENCE TO THE HEAD.

These two cases are examples of the point next to be considered, the reference of subjective sounds to the head and not to the ear. The second case conforms to an explanation often given—that subjective sounds produced simultaneously in both ears seem to the sufferer to be in the head. This is occasionally true; but exceptions are, I think, more frequent. Bilateral tinnitus may be referred solely to the ears, and sounds may be referred to the head which are produced only on one side. We see in this, moreover, the difference between abnormal local excitation of the nerves and their normal stimulation; when the latter occurs on both sides the sound is always referred to an external cause. Sensations produced in one labyrinth are sometimes referred only to some one part of the head on that side. In one case of left-sided labyrinthine deafness, the sound was always referred to the left side of the head, but it seemed to spread when loud through the whole head; it was never referred to the ear. In other cases I have met with it has been referred to the parietal region, to the parietal and occipital, to the occipital only, and in one with considerable nerve deafness a persistent rumbling sound was always referred to the region between the temple and the vertex, never to the ear or any other part. In these cases of one-sided head sound the extension to the whole head, when the sound becomes louder, is very common.

It is not easy to suggest an explanation of these varieties of localisation. We may, however, remember that the sound of a tuning-fork applied to any part of the head is referred, approximately, to the region on which it is placed, quite apart from the sense of vibration communicated to the bone; although many or even most waves must reach the labyrinth by the membrana tympani and ossicles, they pass also from the bone to the membranous labyrinth, either directly, where two are connected, or through the perilymph. The correct localisation of the sound must be due to the precise group of nerve endings that are chiefly stimulated. Since the causes of labyrinthine tinnitus are for the most part random processes, the nerve endings may be affected in various combinations, and it must happen that sometimes these combinations are such as to correspond to those that would be excited from some part of the skull. The same subjective localisation will then occur. Yet cases are met with which seem to baffle all attempts to explain the apparent localisation. A woman with slight bilateral nerve deafness, who was unable to hear high notes, and on the right side could not hear any tone above C⁵ (about 2,000 vibrations per second), described a continuous squeaking sound, which was not referred to the ears, but seemed to her to be inside each parietal bone and to be loudest on the side on which hearing was least affected. The subjective sound in this case corresponds roughly to that which the patient was unable to hear—a noteworthy instance of the double effect of local disease in hindering and causing sensation.

LOCALISATION OF CENTRAL SOUNDS.

It is a curious fact that the subjective sounds which originate in the auditory centre in the cortex are referred to the same seats as those of labyrinthine origin. This is frequently the case with the central sounds included in this survey—those that occur as the warning of epileptic fits.

¹ In passing I may note that if it is due to the stapedius, which is supplied by the same nerve as the orbicularis palpebrarum, the facial nerve, there is this interest in it that the function of the stapedius is believed to be to guard the labyrinthine structures from undue shock, by instantly contracting when sudden pressure tends to force the membrane in to which the stapes is attached, while the office of the orbicularis is, of course, to guard the eye. Thus each of these muscles which act together is the guardian of the organ of sense.

² By many persons, but to some ears the continuous tone can be perceived, though even to them the effect of the separate waves is more obtrusive. I should, perhaps, state that the commonplace physiology of this lecture is purposely given in a simple, applied form.

When these are elaborate they are, it is true, referred to the external world, but when they are simple or "crude," they generally seem to the patient to be produced either in the head or in one or both ears. As examples I may mention a whistling sound referred to both ears, a similar sound referred to both sides of the head above the ears, a buzzing sound which seemed to pass through the head from one ear to the other, a whistle referred to the ear on the side on which the subsequent unilateral convulsion occurred, and a whistle seemingly at the top of the head in one case and in another at the occiput. To the character of these epileptic sensations I shall have to return.

FEATURES OF LABYRINTHINE SOUNDS.

Some of the characters of the sounds that are due to labyrinthine disease have been already referred to and others will have to be mentioned in connection with points yet to be considered. These variations are so great as to baffle any attempt at minute classification, as they also baffle the capacity of language. Our vocabulary, however extensive, is quite inadequate to describe our sensations, and the similes to which the sufferer has recourse are often misleading. A rough division may be made into (1) crude sounds, such as hissing, humming, machinery, rumbling, and the like; (2) tones as a whistle, simple musical note, or the sound of a bell; and (3) elaborate sounds such as music or voices distinct or indistinct. We cannot usefully separate the continuous and pulsating sounds because a continuous sound so frequently becomes pulsating when it is louder. Yet it is probable that the difference is of significance when invariable—when a sound, for instance, remains continuous, however loud it at times becomes, or remains pulsating, however slight it may often be. The precise character of sounds needs to be carefully noted, since it will probably prove to be important, when we obtain more careful and discriminating observations, pathological and therapeutical.

ABNORMAL HEARING.

One feature, which promises occasionally to be of definite practical importance, is the relation of the tinnitus to external sounds. It the majority of cases the subjective sound is heard most when there is silence, sometimes is noticed only then. Doubtless external sounds often merely prevent its notice, although we cannot be so sure that this is all. There are cases in which external sounds increase the tinnitus, and some of these are both curious and noteworthy. There may be a peculiar hyperacusis, by which certain sounds seem especially loud and unpleasant, and seem to increase the subjective sound. Although this feature suggests central co-operation, the cases present evidence of labyrinthine change. Yet such co-operation seems the only way to explain another symptom met with especially in this connection, the occurrence of an echo or repetition of the sound not always in the same pitch. A man, aged 70 years, with slight reduction of hearing, not equal on the two sides, experienced such an echo with musical notes and high-pitched voices; every syllable seemed repeated in a lower note, although of the same duration. I found that the sound of C³ tuning fork and higher sounds were thus repeated, but the C² was not. It seems to be impossible to explain the change of note, as of labyrinthine origin. But in one case of the kind the labyrinthine affection was secondary to disease of the middle ear two years before, with lasting perforation of the tympanic membrane. A rushing sound was varied by buzzing and by an occasional sound like the ringing of several bells. Loud sounds seemed to pass straight to the middle of the head; some notes of the piano were particularly distressing, and the sound of these was repeated as an echo. Allied to this symptom is another—the addition of an abnormal quality to sounds that are heard. For instance, a peculiar clanging character was added to all sounds in a gouty patient 34 years of age with labyrinthine deafness and also other forms of more simple tinnitus. This may be conceived as labyrinthine, but it is often associated with a sense of discord and with increased sensitiveness, hyperacusis, which may be either peripheral or central. It is often very difficult to say to which seat the sense of discord is to be attributed. All music sounded discordant to a woman aged 37 years who had double

slight labyrinthine deafness, not equal, with simple tinnitus on the side of better hearing. On this she could hear the higher tuning forks (C⁵ and C⁴) better than the lower (C³ and C²), but no note of Galton's whistle. Once she had a sudden sound as if a coach horn were blown. These symptoms suggest that the discord was peripheral. But she also sometimes heard a sudden sound as if someone had spoken to her, and the impression that this was a fact was strong for a moment, although she could never distinguish the words—a symptom which can hardly have been other than central.

HYPERACUSIS.

I regret that time prevents me saying more on the co-operation of the centre in labyrinthine disease. The production of a morbid functional state of the centre in consequence of the impulses that reach it, which involves the addition of central sensations to those of labyrinthine origin, is a question of some importance in regard to treatment. Simple hyperacusis is not common. I have mentioned a case in which it was partial, but coexisted, strange to say, with slight deafness, the sounds which succeeded in stimulating the nerves being heard too loudly. Again, a highly-cultured man, aged 57, had slight nerve deafness on both sides, with tinnitus chiefly on the left, seldom on the right. It was like "gas escaping," and he had an occasional noise in the head, described as a "churning." But a moderate sound was heard too loudly: water poured into a bath sounded to him like the noise of a waterfall, and the voice of a person speaking was heard with unpleasant loudness, and also in a confused manner, which seemed to make it difficult to distinguish the words, in spite of their loudness. It caused a distressing sense of mental strain, and sometimes a similar effect is met with of a character distinctly suggestive of temporary word deafness. I leave unnoticed the cases without sign of local disease, in which a combination of pulsating tinnitus and hyperacusis is met with in cases of general increased sensitiveness of the nervous system, when all sensory impressions are too acutely felt, and the arterial pulsations affect the nerves of the ear so as to influence consciousness.

The threads of this subject interlace in such a manner as inevitably to lead us, if not astray, at least away from the point under special consideration. I have thus been led to wander from a question of some practical importance—the induction of tinnitus by sound. It is not often well marked, especially in such tinnitus as can be reasonably regarded as labyrinthine, but such cases occur, and an important point is the beneficial influence of silence upon them. A clergyman, aged 54 years, certainly gouty, began to suffer, at the age of 50, from gradual deafness of the right ear, tinnitus, and attacks of vertigo. An aural surgeon found the meatus and middle ear to be normal. The deafness was almost complete to high notes, C² being heard but not C³; the voice being, however, heard fairly well. The subjective sound was continuous in character, but it was slight or absent when there was external silence, and was excited by any loud sound of more than brief duration. A short ride in a cab would make it loud, although at starting he had been free. The effect of the music in his church was so great that for a time he had to abstain from duty, and the influence of his own voice, if he read aloud for an hour, was distressing. Either influence would cause the sound to become such that he compared it to "the blowing off of a full head of steam in a locomotive." Even then, if he retired to his room, in perfect silence, the sound would gradually lessen, and in the course of two hours would cease entirely. In this case great benefit was obtained by following the indication thus afforded, and securing prolonged freedom from external sound.

RELATION OF TINNITUS AND VERTIGO.

As might be anticipated, a large proportion of the cases of aural tinnitus, which have furnished the ground for these remarks, were brought under my observation by the vertigo with which it is so frequently associated. But this common result of the irritation of the labyrinthine nerves is only within our survey so far as the subjective sounds are related to its occurrence. We refer the vertigo to the coincident affection of the semicircular canals by the same morbid process which, in the cochlea and vestibule, gives rise to

the subjective sounds. That we are justified in doing so by the few definite facts we possess is, I think, undoubted. The relation of the subjective sounds to the giddiness is, however, extremely variable. In current descriptions of aural vertigo it is often said that the noise becomes suddenly and rapidly louder, to a culmination with which sudden intense giddiness coincides. But this relation is quite exceptional. Such increase of sound may occur and culminate, for instance, in a sudden crash, without any attendant giddiness. But a gradual increase often precedes the vertigo. In the case of the clergyman just mentioned the increased loudness of the sound was often followed by an attack of giddiness, until he learned the effect of external silence. He found that when this had diminished the subjective sound he was safe from an attack of vertigo. This is a significant fact, although one not to be too hastily interpreted. It seems, however, to show that there is a certain solidarity, so to speak, in the labyrinthine functions for which we should scarcely be prepared by the difference in their apparent character, although it agrees with the continuity of the labyrinthine structures. Moreover, we can trace a like solidarity in the corresponding central functions, as we shall presently see. In other cases the tinnitus exists only just before the vertigo, although without any increase or culmination. In a man, aged 36 years, with labyrinthine deafness on one side only and attacks of severe vertigo the sound occurred only two or three minutes before each attack of giddiness. It seemed to him to be in both ears, and was compared to a very loud roaring without pulsation. But the sound may simply coincide with the giddiness and not precede it. This was the relation in several cases, with evidence of one-sided labyrinthine change, causing deafness, in which the sound was pulsating, and was compared to machinery, a steam engine, and the like. In another case, a clergyman, aged 38 years, a continuous hissing sound occurred only during attacks of giddiness, which was accompanied by nausea and sometimes by retching. The sound and the vertigo always began together, and the sound ceased as the vertigo gradually passed away in the course of a few hours. The sound was referred to the left ear, but no permanent deafness could be discovered, although, as long as the noise lasted, in spite of the fact that it was not very loud, he had great difficulty in hearing; a strong voluntary effort was needed to enable him to discern the nature of external sounds. This peculiar difficulty, needing a mental strain to overcome it, is probably a central symptom, and is not very rare. In some other cases with definite one-sided labyrinthine deafness, a pulsating sound, compared to machinery or a steam engine, was also limited to the vertigo. This relation is, as I have said, difficult to explain. But so also are instances elsewhere of the sudden paroxysmal effect of a process that is gradual and perhaps stationary. We have a similar phenomenon in the paroxysmal lightning pains of stationary tabes. These may occur during years, although the morbid process is unchanged. These tabetic pains are perhaps a more pertinent analogy than the sudden attacks of pain in neuralgia, because we have good reason to refer the pains of tabes to changes at the extremity of the sensory nerves, to which also our knowledge leads us to refer the attacks of tinnitus. Doubtless causes which we sometimes can, but more often cannot, discern determine the attacks, just as changes in the weather have so potent an influence in determining the pains of tabes.

SOUNDS OF CENTRAL ORIGIN.

Let us leave the ear itself and turn to the centre to which its impulses pass. As I have said, in the symptoms of epilepsy we can feel reasonably sure that we have to deal solely with the features of central sounds, although we cannot limit them to that disease. These higher auditory sensations vary much in character; they may be crude or elaborate. But I am reluctantly compelled to pass by the subjective sensations which have a mental character, the hallucinations and illusions, and the warnings of epilepsy which consist of a sense of spoken words. To touch upon their relations would carry us too far, and away from the region with which we have been specially concerned. They have to do with instability in the higher functional regions of the brain, as is illustrated by the fact that epileptics with such an aura are

in far greater danger than others of becoming insane. The cruder auditory sensations which usher in a fit, severe or slight, deserve careful consideration. One fact, to which I have already referred, is the occasional association of a subjective sound with the sense of definite vertigo which is alone so very common a warning. In some cases the commencing central discharge mimics pure aural vertigo in a way that is alike curious and suggestive as well as often puzzling. The difficulty that is caused in diagnosis is the greater because there are cases of aural vertigo in which the suddenness and character of the disturbance produce actual loss of consciousness. These cases are quite distinct from epilepsy, and yet the superficial resemblance is close. This combined epileptic aura is another illustration of the fact of which I have just spoken—the very close connection which exists in the central processes between the two functions of the labyrinth and also between the two symptoms which their disturbance generates. The sound which accompanies the epileptic vertigo is as simple as that which occurs in the labyrinthine form, and the fact which makes the association so difficult to understand is that all our knowledge points to the motor centres as the source of the sensation of giddiness, while that of sound is purely sensory. After all, however, the connection does but illustrate and emphasise the fact I have already mentioned—that since all the sensory impulses produced at the periphery are perceived through a related activity of the higher centre, functional processes in this must be possible, corresponding to every peripheral process, and it also illustrates the fact that the readiness with which associations are produced from the periphery must entail a corresponding central facility. The processes of the epileptic discharge seem to be sometimes quite random in their character, although they are the same, by developed habit in successive discharges.

We have already considered the varied localisation of these central sounds, but some other features deserve at least a brief mention. Even the pulsatile character of aural tinnitus may be reproduced in the centre. It is unquestionably a rare symptom, but is of great interest. In a highly complex aura which I have recorded elsewhere, a sensation of beating in the chest passed up to the head and there became a pulsating sound, accompanied by two lights before the eyes, which approached with a rhythmical motion. We must, I think, ascribe this character to the mechanical influence of the arterial pulsations on the discharging centre. We know the influence of such pulsation upon pain, we know the susceptibility of nerve structures to mechanical influences, and we must assume that, in the process of actual discharge, all their susceptibility is raised to the highest degree. The influence is, therefore, not difficult to understand, whether the pulsatile pressure augments or hinders the progressive liberation of the nerve energy. It is not rare for the central sound to be described as "machinery," and this generally implies pulsation. A vibrating sound compared to the noise of a faradaic apparatus (which reminds us of the vibrations already considered in relation to musical tones) was referred to the left ear by one patient as the warning of left-sided fits. Here, again, we have in a very curious degree the central reproduction of peripheral impressions.

Although the elaborate sensations of psychical character, definite words and the like, are not within my subject, I may mention that in patients with such a warning of severe attacks the minor attacks—*petit mal*—may be characterised by a quite crude auditory sensation. In one case of the kind simple "buzzing" referred to both ears, with obscuration of consciousness, constituted the slight attacks, while the onset of the severe seizures was characterised by a vision of figures who spoke intelligible words.

CENTRAL CO-OPERATION IN LABYRINTHINE SOUNDS.

In leaving the higher centre we must, however, let it carry us again to the labyrinth. A point that is not only of interest, but will prove, I think, of practical importance, is the co-operation of the centre in determining the character of the sounds produced by labyrinthine irritation. This is not difficult to understand when we consider how disturbing to the central structure must be constant abnormal impulses from the ear. The fact which raises this question is the fre-

quency with which labyrinthine deafness is associated with sounds of such elaboration that it is very difficult to think that they are solely peripheral in nature. Another important question also is thus brought before us, What degree of elaboration of sound is consistent with a purely labyrinthine origin? Of course, the crude sounds, which have occupied us so much, we must regard as peripheral. On the other hand, elaborate sounds, such as a voice uttering distinct or even indistinct words, must be regarded as central. But there are other forms of tinnitus that cannot be referred with certainty to the labyrinth alone. To it, indeed, we may reasonably ascribe all sudden, simple tones, when we consider the analogy of the brief, momentary sensations of pain which are experienced in tabes, and the grounds we have for ascribing them to the morbid action of the degenerated nerve endings. This applies especially to the sudden sound of a bell, which is not rare, or even to repeated bell-like sounds. But we must, I think, recognise a secondary central action in such a case as that of a woman, aged 43 years, in whom, after an attack of giddiness, bilateral tinnitus referred to the ears commenced and increased gradually. It was a buzzing sound, loudest at night. After a time there was an occasional change, for a few hours or days, to that which seemed to her just like a band of musical instruments. She described it as so distinct that, although she could not recognise the tune, she believed that if she had been acquainted with harmony she could have written down the full musical score. At times also she seemed to hear voices, and, although she never could distinguish words, the sound was that of a human voice, and occasionally she had seemed to hear herself called. But this was no real hallucination. She referred all these sounds to the ears, and they never seemed to her for a moment to be of external origin.

There is much more that I should like to say that I must leave unsaid. I should have liked to refer to some conceptions of the process of stimulation of the special senses which might establish more unity in our conceptions, and with this to have considered the probable relation of the energy which excites to the nerve impulse that is excited, and the nature of this. But this subject is too fascinating for me to touch upon it now. I especially desired also to call attention to some series of facts related to my special subject. One is the frequency with which labyrinthine tinnitus becomes associated with unpleasant cephalic sensations, feelings of pressure, fulness, throbbing, and the like, constant or varying, and sometimes related to the sound in a way which connects them with the sounds and other paroxysmal sensations referred to the head itself. And I also desired to mention some facts which have come under my notice regarding the relation of tinnitus to paroxysmal neuralgic pain either in the ear or head—facts of much suggestiveness that would, however, need some time for their consideration, because even in outline this would need to be careful and deliberate. All these, however, I must leave, but leave, I hope, only for a time.

LABYRINTHINE PATHOLOGY.

It is strange how few facts we have regarding the pathological changes which underlie the symptoms in the common class of cases, with some deafness, tinnitus, and often vertigo, gradual in onset, and often slowly progressive. It is strange, because our Poor-law infirmaries and workhouses contain always many cases of the kind, because modern methods have increased so much the revealing power of the microscope, and because the present generation of workers are not prone to leave neglected any unexplored field. But we can surmise much with reasonable sureness. In cases with striking and unusual symptoms conspicuous changes have been found, concretions and the like. Further, we know that the parts chiefly concerned are a fibrous or fibro-epithelial structure, in which epithelial hairs receive the sound vibrations, and in some way these excite nerve impulses in the delicate structures by which the two are united, and we know with what extreme readiness this process must be deranged and how minute a structural alteration may suffice. We know, also, that this membranous labyrinth may be the seat of acute inflammations, of which the most significant is that which occurs in early life, and sometimes in adults, as the effect of a catarrhal blood

state, one of those peculiar toxic states which have a special local incidence, for the inflammation is limited and symmetrical. It is now generally recognised that when there is complete deafness as the sole result of what was regarded as an attack of meningitis in early life, the malady was not meningitis but bilateral inflammation of the labyrinth, the general cerebral symptoms of which closely resemble those of meningitis. We have in this fact not only the indication of a special blood state, but also of special susceptibility of the part of the labyrinth. We know from many other facts that such susceptibility to acute inflammations of this kind and the part of fibrous structures involves also a proneness to suffer from chronic changes in later life, especially in cases where there is an inherited rheumatic or gouty tendency, the tendency which may be called, and I think has been called, "tissue gout." We can thus understand the fact, so often illustrated, that these chronic labyrinthine changes are especially common in such subjects. We also know that in late life, apart from such predisposition, the tendency to analogous affections of other fibrous structures is common, as in the great tendency to chronic rheumatism in the old, which we may ascribe to the influence on the tissues of waning vitality, coupled with the effect on the blood of the age imperfection of the organs on which the blood state chiefly depends. It happens that only a week ago a pertinent illustration of this came under my notice. A man aged 58 years, with some family history of rheumatism, although not of known gout, had suffered from vertigo, and for some years from tinnitus and from deafness. His tissue tendencies were clearly shown by a contraction of the palmar fascia of one hand, of the ulnar side, passing down the little finger and keeping it flexed. The deafness was partly labyrinthine, but was in greater degree due evidently to the middle ear, and Mr. Field's report on the cause of this was very instructive. He found on each side considerable thickening of the membrana tympani, with complete fixation of the ossicles. The latter must be due to fibroid adhesions, while the state of the membrane was doubtless an indication of that throughout the cavity, including no doubt the membranes which close the foramina leading to the labyrinth. Moreover, the clear evidence of labyrinthine deafness, in addition to the impaired conduction, leaves little doubt that there was a like condition in the labyrinth, although, perhaps, in less degree. We need to know the precise influence of such fibroid thickening on the junction of the epithelial hairs with the nerve endings. Of course, other processes, including direct injury and traumatic inflammation, are often met with in these cases.

PRIMARY ATROPHY OF THE AUDITORY NERVE.

The same symptoms are, moreover, produced by a primary atrophy of the nerve, but I should like to utter a very emphatic protest against the readiness to invoke atrophy of the auditory nerve as the morbid state whenever labyrinthine deafness is recognised in conditions in which nerve degeneration is sometimes met with, and especially in tabes. It is, indeed, partly for this reason that I have preferred, for the most part, in this lecture, to use the term "labyrinthine deafness" rather than "nerve deafness." Statistics have been published in which in every case of tabes in which there was any degree of labyrinthine deafness this has been put down as atrophy of the auditory nerve; such atrophy has therefore been said to exist in a considerable proportion of the cases, and the facts have been received and quoted as conclusive. Symptoms of more or less random labyrinthine changes, generally non-progressive, are not rarely met with in tabes. The previous life of a large number of the patients has been such as disposed them to tissue degenerations, while the effect on the blood state is often much increased by the diminished amount of exercise which the developed malady entails. Among all the cases—and I have notes of many hundred cases of tabes carefully examined—I can count on my fingers those in which there was reasonable evidence of auditory nerve atrophy. Until, therefore, we have far more definite knowledge of the symptoms of primary atrophy much more caution should be exercised in the diagnosis, or even suspicion, of this change. But, as evidence of the process which cannot admit of doubt I may mention one case. A man

with tabes, who had progressive bilateral deafness, presented a progressive concentric limitation of the range of hearing, quite similar to that which occurs so often in tabetic atrophy of the optic nerve. When first examined he was deaf on one side, and on the other could hear only the notes between the G below the treble and the E above it, the range of audition being thus reduced to two octaves. In the course of the next month the contraction of the range had reduced it to one octave, from the E on the lowest line to the E in the highest space, and so sharp was the limitation that while he could hear the lower E he could not hear E flat, a semitone below; soon afterwards the deafness was total. You may search in vain through the reported cases of tabetic atrophy for such evidence as this. I know that atrophy of the optic nerves does not always take this form, and it is not likely to be the only, and perhaps not the most common, manifestation of that of the auditory nerve. But the atrophy of the optic nerves is steadily progressive when once established, and we are justified in regarding with more than suspicion all cases of alleged auditory nerve atrophy in which a progressive course is not conspicuous.

FUNCTIONAL STATE OF THE NERVE ENDINGS.

It may seem at first difficult to understand that defective hearing should so constantly coincide with the production of these sensations. But the due reception of external stimuli and their adequate effect upon the nerve endings must depend on structural integrity, molecular integrity, we may say, in the superficial elements. Organic changes in these may prevent the sound waves producing their due effect, and yet may also induce the molecular alterations in the terminations of the nerves on which the spontaneous sensations depend. Once more we must remember how disproportionate are the effects upon consciousness and the processes upon which they depend. We must remember, also, another fact of at least equal importance. In the normal condition all nerve structures must be in constant functional activity—at least, in some degree. This is necessary for the maintenance of nutrition; it is a necessary effect of vitality; it is essential for the capacity of full action on an inadequate stimulation. In the case of a large number of nerves we are quite unconscious of the persistent functional action. It need be only of the slightest to subserve the constant renewal of molecules which must occur for life to be maintained and function possible; but the phenomena of disease show us that a similar persistent action is also a part of the processes of life under abnormal conditions. It seems to be as constant when nerve endings have undergone molecular changes as when they are normal. The morbid changes in the fibrous tissue of the labyrinth of which I have spoken, do not necessarily destroy the nerve endings, and they only interfere with their function in so far as the terminations are altered and the access of sound waves is hindered. We can thus understand that the subjective sounds are the result, under altered conditions, of the same vital state which normally maintains the nerves in perfect readiness for instant action by a continuous unperceived activity.³ We can understand that the damaged structure and altered molecular arrangement, while it does not impair spontaneous activity, changes its form and increases the energy of the impulses, possibly, indeed, in greater degree, because the nerves are deprived of some of their normal excitation. It is not, I think, difficult to perceive that the persistence of the sounds, which seem so strange, especially when combined with deafness, is due to one of the conditions on which the functional capacity of the nerve structures essentially depends.

SOME PRINCIPLES OF TREATMENT.

That which I can say regarding the treatment of these sounds must of necessity be limited to some of its principles. Details I am obliged to omit, and if that which I say seems to be meagre, believe me this subject has been before my mind throughout the preparation of this lecture more definitely than any other. Most of that which I have said tends

towards this; the great object of our work, though it may be its tendency, is not always obvious. The treatment of these affections constitutes one of the most difficult and most obscure branches of therapeutics. This is not, indeed, surprising. We have seen to what a large extent they depend upon chronic processes. Of all slow processes of disease, it may be said that the morbid process, at every period and at every stage, is an accomplished fact. Damage and cicatrization go hand in hand, but the process of cicatrization is not recovery. In acute disease the alterations caused in the tissue may pass away to a large extent, and the normal state to that extent may be reproduced. But a change indistinguishable from cicatrization perpetuates all slow disease, and thus its effects necessarily endure. But we have some power even now, and we hear on every side lessons which should teach us to be very, very slow to give up hope or even anticipation, or to relax our efforts to obtain that which we now lack. How impressive is the lesson we have just had from science that the word "impossible" should find no place in our vocabulary. Even two years ago, had the wisest among us been asked the question, Is it possible that before the end of the century we should be able to see through a deal door—what would have been the answer? The humility which this should teach should equally prevent us from limiting the possibilities of power to any department of our science or any branch of the art that is founded thereupon. The reason why, through this effort to discern some of the relations of those subjective sounds, their treatment has been ever before me is because I believe that the first necessary step for the attainment of greater power is more minute and accurate recognition of their features and relations. It is through these that we must hope to be able to apply, with more prospect of good, the measures which we already know to have some influence, and by the discrimination they permit to employ any means which the future may give us. Empirical measures, on which we are obliged so largely to depend in many other maladies, have at present almost no place in the treatment of tinnitus. The treatment which is based upon a vague perception of the conditions which underlie the symptoms needs far more accurate discrimination of their character for its effective use. We know, for instance, that tinnitus is sometimes lessened by bromide, although the influence of this is far less than on the vertigo which is so often associated with it. But we know also that the influence of bromide is especially exerted on the centres in the brain. I doubt, indeed, whether we have at present any evidence of its action on the peripheral nerve structures. But the evidence I have mentioned that the auditory centres become secondarily involved in some cases and give rise to some special features of the subjective sensations is reason for a careful systematic attempt to discern the relation between such central co-operation and the power of bromide to relieve the symptoms. The possible power of relief by silence in suitable cases I have already sufficiently dwelt on. There are many cases of labyrinthine tinnitus in which counterirritation has a considerable influence for good, but there are also many cases in which it is powerless and we are not yet able to distinguish the two. The distinction can only come, and probably will come, from careful discrimination both of the conditions under which the process develops and of the precise symptoms by which it is manifested. At present we cannot form any opinion, and certainly are not justified in forming any negative opinion, regarding the significance of differences in the minute characters of the subjective sounds. We are already supplied with so many means of lessening the morbid action of other peripheral nerves that it is strange if the early future does not yield us means of lessening, at least in some degree, that of the nerves of the labyrinth. We have almost no guidance in treatment from influences which are found by the sufferers to diminish the sound with the exception of the effect of silence already mentioned. In one labyrinthine case, it is true, the sound was always lessened by firm pressure on the posterior part of the temporal fossa, and the fact is suggestive, but it is no more. Another patient found that a diminution was always caused by inclination of the head towards the side on which the tinnitus was heard, but this, I think, is only a special example of a more frequent influence. The sound may be often lessened

³ Regarding this continuous activity, see Professor Michael Foster's lecture in the *Lancet* of November 7th, 1896; also note by myself on the Dual Activity of Nerve Cells, *Lancet*, p. 1006, vol. 1, 1890. The words "nerve structure" should apparently be now used instead of "nerve cells," as I endeavoured to explain in the address published in the *Lancet*, October 22nd.

by pressure on the arteries of the neck. Strange to say, this result has seemed to me more common when the tinnitus is a continuous sound than when it is pulsating.⁴

I cannot now pursue the possible suggestiveness of this fact, but it leads up to another. I feel compelled to mention to you one case, which has been described in Germany,⁵ on account of the importance of the lesson it conveys. An elderly man had gradually become completely deaf in the right ear, with most troublesome tinnitus. The left ear was becoming deaf in the same way. The tinnitus was so loud, so persistent, and so distressing that the man had several times declared that he could endure it no longer and must end his life. This proceeding on his part was made unnecessary by the treatment which was adopted. It was found that pressure on the carotid artery diminished the sound. The right internal carotid was therefore tied. It is very difficult to understand the grounds for the operation. The blood supply to the labyrinth comes partly from the external carotid and partly from the basilar. The path by the auditory nerve to the opposite hemisphere is entirely within the blood supply of the basilar. The opposite auditory centre is supplied by the opposite middle cerebral artery. It is thus easy to understand that the operation was found to have no effect whatever on the tinnitus. It produced left hemiplegia and left hemianopia, and death resulted on the fifth day. I draw attention to this case because I think it should for ever prevent any repetition of this operation for the relief of labyrinthine tinnitus.

I wish that I could have made this lecture less unworthy, alike of this College and of the memory of him to whose request it is due. But when we find our work, our efforts to secure practical results, beset by conditions alike rugged and unyielding, one consolation is at least available—that that which is unsatisfactory now may be less so in the future. It does not do to pass such subjects by for those of greater promise. We have to till the fields to which our path may lead us, however barren they may seem, and hope that some of the seed sown, even upon stony ground, may germinate and bring forth fruit, at least in time to come.

TWO LECTURES

ON THE

STUDY OF ANATOMY AND ITS APPLICATION TO THE PRACTICE OF MEDICINE AND SURGERY.

Delivered at Guy's Hospital

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LECTURE II.

Look, now, at a vertical antero-posterior section of a vertebra and observe the cancellated structure of the body through which is transmitted in varying directions the weight of the trunk, together with what additional weight it may be bearing at the time. The cancellous tissues of the bodies are arranged to transmit weight to best advantage along the directions in which pressure is usually greatest. These vary considerably in the bodies of the different portions of the column. All, however, are exposed to a tendency to the forward displacement of the vertebra above from that below when the spine is flexed. The cancellous tissue is therefore universally arranged to oppose this tendency, and this is most marked in the parts of the spine most exposed to force of this kind. Perhaps the vertebrae about the lumbo-dorsal curve show it best. The normal bodies are only capable of simple displacement from one another without fracture under rare conditions and in certain positions, since their surfaces are united together most firmly by the powerful intervertebral discs. If the vertebrae are exposed abruptly to a degree of flexion greater than they can bear the upper and anterior angle of the lower vertebra yields, partly in consequence of the pressure it sustains and partly

because of the traction exerted upon it through the fibres of the superjacent disc. As the result of this displacement and fracture, the cord is more or less completely crushed between the posterior superior angle of the fractured body and the lamina of the displaced vertebra immediately above it. Comparing the structure of the body with that of the arch, the latter is seen to be composed chiefly of compact tissue. This results from the exercise of strain upon or the transmission of pressure through this part of the bone exerted almost always in the same direction.

I have described these fractures and their mode of production in detail to impress on your mind that you should examine carefully and consider the functions of the compact and cancellous tissue in the long bones of the parts you dissect, and that you may understand that bones vary largely in the detail of their structure during the several periods of life. This variation depends solely on changes in the characters of the mechanical influences which determine their structure, and without the constant influence of which they cease to retain their type.

Again, you observe the use of cancellous tissue in the bodies of the vertebrae in order to obtain a mass of considerable bulk, of as little weight as possible, and composed of a material which serves to transmit force in varying directions at the greatest mechanical advantage. It breaks or deadens shocks transmitted through it, so securing the very sensitive structure of the brain and spinal cord as much as possible against sudden injury. I would point out to you that when the spine ceases to perform its normal function, as in old standing lateral and angular curvatures and in the various curves due to occupation or disease, the superjacent weight is no longer transmitted through the bodies of the several vertebrae in very variable directions, but along a single fixed plane, then the construction of the bone is changed to meet the altered mechanical conditions, cancellous tissue being replaced very largely by compact tissue, new material being superadded also upon the surface so that the bones are altered in shape. This I will illustrate more fully later, but these specimens show very well many of the coarser changes. A very good instance of the application of the use of cancellous tissue to deaden the abruptness of the shock resulting from the sudden application of force is seen in such bones of the vault of the skull as are uncovered by muscle. The more readily vulnerable parts of the skull—namely, the vault—consists of two layers of compact bone separated by a thick layer of cancellous tissue, while the base of the skull, which is relatively free from direct injury, is composed almost entirely of compact tissue; this is most marked along such directions as force is transmitted to the condyles of the occipital bone, and through them to the spinal column. The directions of the lines of force along which the weight of the skull and its contents are transmitted are the same as those along which the added weight of a load born on the head is also transmitted, and as you must remember also the direction is the same as that along which a sudden and abrupt massive impact is also transmitted. This last point is, as you will readily understand, one of vital importance in the protection of the brain, and in this manner. If the top of the skull be struck a heavy blow insufficient to produce a fracture, a large surface of the brain is driven forcibly against the base of the skull, and the portion that sustains the impact is damaged in proportion to the force of its impact on the base of the skull. Owing to the convex outline of the surface of bone struck, the force is distributed largely over the surrounding area and is transmitted directly and indirectly to the occipito-atloid articulation. Much is transmitted through the layer of cancellous tissue which serves to deaden the force transmitted through it and to limit the vibrations of the outer layer of compact tissue. The area of distribution of the impact to the smaller are formed by the inner layer of compact tissue is greater still. By this means the impact upon the surface of the brain by the vibration of the vault is diffused as widely as possible and its force reduced very considerably. The area of the brain immediately beneath the surface struck sustains but trifling injury as compared with that borne by the surface which impinges on the base of the skull. If the force applied is sufficient to produce a fracture, a fissure extends from the point of impact to one side along the whole breadth of the base of the skull, unless stopped by extending into the fora-

⁴ The fact that reduction of pulsating tinnitus by pressure on the vertebrae has been described by Dr. Dundas Grant, and this leads me to express a hope that those whose observation are not mentioned will note the statement in an early part of the lecture. Its scope is limited to some of the facts which have come under my personal observations, and the suggestions they seem to me to present.

⁵ Linsmayer, *Wien. Med. Blätter*, 1893, Nos. 8 and 9.