"SOME OBSERVATIONS ON BONE CONDUCTION."*

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(*From the Ferens Institute.*)

PART I.—(*A*) Peripheral sensory mechanisms. "Homogeneous sensory fields." Screening effects in homogeneous sensory fields. Some experimental work upon the eye.

(*B*) The Phenomena of bone conduction. Normal and Pathological anomalies. Review of literature. Increased bone conduction. A suggestion — its inferences. The Bing and Weber phenomena.

PART II.—Results of examination of a series of cases of conduction deafness. The absolute bone-conduction test. Its rationale. Clinical significance.

PART I.—(*A*) **Peripheral Sensory Mechanisms.**

The conception of a sensory field as a number of semi-isolated excitable units is one which has had a long vogue, and in the phenomena of cutaneous and retinal sensibility it has had a stronghold which may properly be described as formidable. The punctate nature of the sensory responses of the skin was strongly questioned by Waterston[1] in 1923, and a re-reading of his paper has been a potent factor in fostering our doubts in the matter. The facts that he adduced were briefly these: Taking a given area of skin, definite spots could be marked out for touch, pain, and temperature. On repeating the investigation, however, the position of these spots can never be re-established, and this applies to succeeding re-investigations. Taking the sum of a number of such experiments we are driven to conclude that every part of the area at one time or another reacted to touch, every part to pain, and every part to temperature changes.

Waterston considers the sensory field for touch to be the epithelium itself with the associated terminal ramifications

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of the nerve-endings, each unit microscopical, and each so intimately connected with its neighbour by intercellular fibrillæ as to form a closely amalgamated whole. Such a conception of a sensory field I have thought it worth while, for the purposes of general convenience and also with a view to pointing a contrast, to describe as a homogeneous one. The contrast being with the prevalent view of such a field based upon an essentially punctate distribution of the tactile sense organs. The protopathic nerve-endings appear to be located in the deeper layers of the epidermis and may be investigated apart by blistering of the superficial layers which carry the epicritic sensorium. The inconstant behaviour of the epicritic in relation to the protopathic mechanism, which results in the varying findings obtained in touch and pain spot experiments, is probably to be attributed to the constantly fluctuating conditions of the local capillaries. In the light of increasing knowledge regarding the behaviour of capillaries, this does not seem to be unreasonable.

Protopathic (Dyscritic) and Epicritic Systems. — In dealing with this question it would perhaps be as well, in view of the criticism to which Head's[2] work has been subjected by Boring,[3] in America, and by Trotter and Davies,[4] and more recently by Schäfer[5] in this country, to take a definite line in the matter. Although Head's own interpretation of his results with regenerating nerve lays itself open to the very logical and cogent objections which Trotter and Davies apply to it, nevertheless such objections, based upon a set of circumstances outside the limits of normality, cannot be said to invalidate Head's postulate of a dual sensory mechanism. The existence of such a mechanism has evidence in support of it, more than can be adduced from the periphery of the nervous system only.

The two sets of sensation take different paths in the spinal cord and may be picked off by central disease of the spinal cord. Their behaviour in relation to the cortex and thalamus are also essentially different. The protopathic impulses enter consciousness at the lower level of the primitive cortex, represented by the "essential organ" or the thalamus. Such sensibility is poorly localised and heavily charged, as Parsons[6] says, with "affective tone." The nature of the epicritic sensibility differs widely from this. It is an affair of the

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cortex. Localisation is marked, and there is a conspicuous dampening of "affective tone." It is, in all probability, a comparatively recent achievement of the living nervous system, both phylogenetically and ontogenetically.

In the case of the retina, the basic fact has for a long time been that the power of spatial discrimination in the area of the macula lutea, or, as Parsons[7] puts it, the "minimum separabile," corresponds, it has been thought, to about one minute of angle. A measurement which can be connected with the surface area of each cone. So that once again enters the idea of the punctate sensory field with each cone as a light spot with a definite local sign.

According to Hartridge,[8] Weymouth and Anderson,[9] and others who have been over the question again more accurately, the "minimum separabile" is very much smaller than heretofore accepted, much smaller in fact than to justify association with the area of the cones, and although I believe that Parsons still holds the other view, it would seem that the idea of the homogeneous sensory field justifies serious consideration in the retina as well as the cutaneous sensorium.

Localisation and Spatial Discrimination.—In the retina this is a function of the cone apparatus or what Parsons, who accepts Head's work, describes as the epicritic system of the retina as opposed to the older rod apparatus or dyscritic system which is more concerned with pure light and movement perception.

If we accept the view of a sensory field as a number of punctate excitable areas each with a local sign, it is a logical inference that the spatial discrimination sense would bear some relation to the richness in spots of the field in question, or, in other words, the abundance of its nerve supply. Now this last is to a great extent a matter of pure anatomy and may be largely reinforced by that afforded by the use of Von Frey's Hair Tests.

The evidence of Von Frey's Hair Tests and Anatomy coincide fairly closely. So that I think we may take the threshold of stimulus for a cutaneous part as assessed by the Hair Test as a fairly reliable indication of the richness in sensory nerve-endings of that particular field, excluding such areas as the heel where of course extra thickness of the horny layer would invalidate comparisons. In comparing results of

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spatial discrimination tests with touch threshold tests by the Hair method, some very striking anomalies are found. Thus on the inner aspect of the sole of the foot and great toe the touch threshold is very low, as low as for the finger-tips. In the matter of spatial discrimination, however, the finger-tips have a very pronounced advantage. Thus there appears to be a marked independence of these faculties in the skin, instead of the interdependence demanded by the punctate theory.

In the development of these faculties too the same independence is displayed. The educated finger-tips of some blind subjects whom I have had the opportunity of investigating show a marked increase in the spatial discrimination sense with little if any concomitant lowering of the touch threshold. Educative processes then, at any rate in the skin, appear to be directed very specifically in the direction of enhancing the spatial discrimination sense. In the eye this is re-enacted in the development of the macula where the spatial discrimination sense reaches its maximum. In the uneducated eye, found after removal of a congenital cataract, this spatial discrimination sense, which is associated with exact vision, is absent and of course tends to remain so, although the general sensibility of the retina, as assessed by light threshold methods, is not reduced. Inasmuch as the faculties of localisation and spatial discrimination are essentially cortical, it seems logical to conclude that education of these faculties is also a cortical process. Exact localisation depends upon the development in the cortex of association centres. If the sensory field in question is a well educated one, the centres per unit of area are numerous (or, as it may be expressed, its cortical value is high) and the limits of error of localisation are narrow. If it is poorly educated, its cortical value is low and the limits of error of localisation are wide, and for an adjacent stimulus to be appreciated as separate it must be outside these limits. In other words, the spatial discrimination sense is poor. We have thought it desirable to go fairly far afield in the consideration of the nature and properties of sensory fields in general in order to provide something like an adequate basis for the study of the more specifically interesting auditory field. With regard to the theories of the cochlear mechanism, I think that Helmholtz's theory, with its weak points supported as Wilkinson and Gray [10] support them, is now accepted by the

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majority of authorities, and it is the theory which I propose to adhere to.

The Auditory Field.—With the eye, the ear comes into the category of what Parsons describes as the distance receptors. The first striking feature of the neuro-sensory part of the auditory field is its contours which are conspicuously linear. The other feature, which is even more striking, is the curious combination with this neuro-sensory apparatus of the purely physical differential apparatus of the basilar membrane. The question as to which unit in the line of nerve cells is to be stimulated by a given note is decided by this extraneural differential apparatus. There is nothing specific in the nature of individual hair cells. They are equivalent units in a homogeneous field. The only specific quality which can be attributed to any such unit is its position in the field.

Localisation of stimulus in this and in other such sensory fields is brought about by the cortical process of local sign development. In the other distance receptor, the retina, we have a not dissimilar arrangement of equivalent units in a homogeneous field activated by the physicochemical mechanism of the visual purple. Here again localisation is brought about by the purely cortical process of local sign development. The logical conclusion that we would like to indicate from these comparisons is that from the view-point of pure neuro-physiology, the mechanism by which a high note is perceived to differ from a low note is identical with that which differentiates a light stimulus in the nasal field of vision from one in the temporal field, or a touch upon the dorsum of the foot from one upon the sole. A statement which is, I think, logically acceptable even if it carries an air of strangeness.

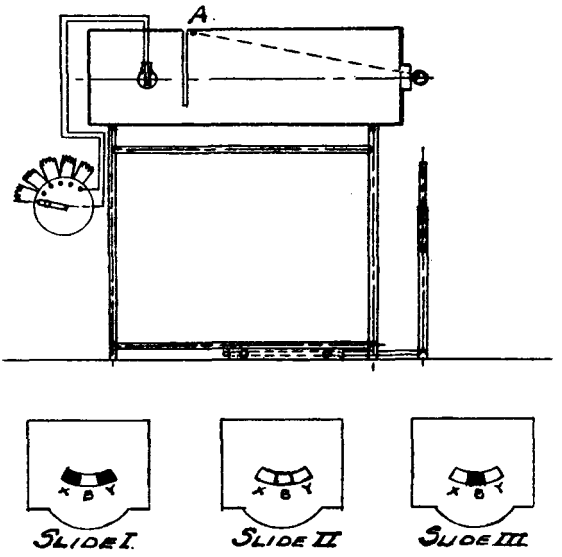
Screening Effects in the Auditory Field.—These have been very precisely studied by Knudsen,[11] Fowler,[12] and Harvey Fletcher,[13] in America, by the auditory threshold method for notes of various pitch with concomitant disturbing tones of variable pitch and intensity. Their work is very convincing, and their conclusions definite. They find a sharp rise of the threshold of perception with any concomitant stimulation of neighbouring parts of the field, varying to a large extent with the degree of propinquity in the field of the disturbing stimulus. Disturbing sounds affecting the apical coils of the cochlea are particularly potent.

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Screening Effects in the Retina.—In the eye an experiment may be carried out with an apparatus which I have had made for me and which had best be described by the aid of a diagram.

The picture represents a tube mounted in a stand so that it can be rotated upon its long axis. The observer's eye is as illustrated with the chin upon a rest. A fixation point is provided by the luminous spot A upon the wall of the tube. Next we have a slit in the tube into which can be inserted a number of slides which separate the eye from the light chamber. Here we have a small bulb suspended by leads



passing through the wall of the tube. The current is supplied by a battery with a variable resistance.

Slide I. is now inserted. This has in it a translucent area B whose form is a sector of a circle with centre at the fixation point A. By the use of the variable resistance a light threshold is now arrived at for a definite area of the retinal field. This area, of course, corresponding to the translucent area B in the slide.

Slide II. is now inserted. Area B is as before. Adjoining it, however, are sectors X and Y rather more translucent than B. The shape and centring of the circles is designed to provide that B, X, and Y should all be of equal valency from

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the point of view of rod and cone distribution in the retina. All three areas are therefore adjacent sectors of a circle with its centre at A.

With Slide II. the same strength of illumination is employed as with Slide I.

Slide III. follows. This has areas X and Y as in Slide II., but area B is now completely opaque. Stimulation in this case of the area of the retina corresponding to B is absent, and the impression produced is of complete absence of light in this area.

The important comparison to be made is the impressions produced by Slides III. and II., and the interesting finding is that they are indistinguishable. A mydriatic is advisable and a dark adaptation period of twenty minutes is allowed.

The facts evolved are :—

1. Stimulus from area B in Slide I. is first of all proved to be adequate by the threshold method when unaccompanied by stimulation from adjacent areas of the field X and Y.
2. In Slide II. this identical stimulus is provided with concomitant stimuli from adjacent areas X and Y.
3. The impression produced by Slide II. is indistinguishable from that produced by Slide III. where we know there is an absence of stimulation in area B.

From these we conclude that a stimulus in a given area of the field which is adequate in the absence of adjoining stimuli becomes inadequate in the presence of such stimuli. The postulate that we feel justified in making is that the threshold of sensation in any part of a sensory field is raised by concomitant stimuli in other parts of that field.

Whether the mechanism underlying these screening effects is a peripheral or central one must still be a matter for conjecture. Pavloff's work [14] in the field of conditioned reflexes, wherein the idea of cortical zones of inhibition under certain conditions receives convincing support, affords a line of thought in the matter which points very definitely in the direction of the cortex.

Summary.—The touch and pain spot question in the cutaneous field is considered. Waterston's criticisms are supported. Objections to Head's theory of a dual sensory mechanism in the skin are not found valid, although Head's own interpretation of his experiment upon regenerating nerve

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was probably incorrect. Explanation of the term "homogeneous sensory field": The faculties of localisation and spatial discrimination are considered. Analogies are made in all particulars with the visual and auditory fields with a view to establishing some evidence of constancy of character and behaviour in all. Screening effects: These also are found to be constant in all the fields considered. An experiment is described bearing upon screening effects in the retina.

(*B*) The Phenomena of Bone Conduction.

One of the most intriguing aspects of otology is the curious position which the qualitative tuning-fork tests occupy in the fields of normal and pathological experimental findings. We are faced with a mixture of outstanding fact and obscure principle. The fact in point is the fact of increased bone conduction in uncomplicated cases of disease of the conducting apparatus. The saliency of this fact has been sufficient to tinge the whole of otology, and is only matched by the darkness of its rationale.

It was fully described by Schwabach[15] and afterwards became a member of the Bezold Triad. Bing[16] found it applicable to conducting deafness produced by occluding the meatus, and later it was found to apply also to cases of total extirpation of the conducting mechanism as after a radical mastoid operation. The most authoritative writing upon this last point in recent years in this country is by Keen,[17] who reports in detail the after-results of some sixty radical mastoid operations.

My own experiences with some forty cases that I have had the opportunity of examining in the last few years would agree with Keen's findings. The rationalisation of the increased Schwabach rests largely upon the views of Bezold who considered first of all that the mechanism of bone conduction was cranio-tympanic, *i.e.* vibrations of the fork upon the skull are transmitted to the tympanic ring, thence to the membrane, and so to the inner ear via the ossicular chain. An experiment to which G. Mackenzie[19] draws attention has a pertinent bearing upon the question. In this the ears of two individuals are connected by an auscultation tube.

The vibrations of a tuning-fork upon the vertex of one is heard via the auscultation tube by the second. This has led

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to the view that the drum and ossicles are as much a part of hearing by bone conduction as by air conduction. That they play a part in the former is proven by the experiment. That they play more than a part is doubtful.

Investigation of this question with persons of exactly equal hearing by air and bone using plaster mould ear-pieces as suggested by Pohlman,[20] justifies the conclusion that perception of the fork by the observer is less than that of the observed who has the fork upon his head. The terminal stages of hearing by bone conduction are probably by true molar vibration of the bone itself. According to the cranio-tympanic theory, inflammatory conditions of the tympanum lead to increased rigidity of the membrane and ossicles which enhances the efficiency of hearing by bone conduction. Hence the Schwabach phenomenon. Simple logic would, however, seem to raise an objection to such an explanation. The ordinary air-borne sounds also employ the vehicle of the membrane and ossicles, and should also benefit by the increased efficiency of the mechanism. In other words, with increased bone conduction we should certainly not expect to find the decreased air conduction which is so essential a feature of tympanic disease. Most conclusive evidence on the point is, I think, afforded by the case of the radical mastoid. In a case of double radical mastoid which I have had the opportunity of examining, both meatuses were packed firmly with wet wool, with a view to inactivating the stapes. Under these circumstances all tympanic elements might be safely considered as out of gear. According to the cranio-tympanic theory bone conduction could hardly fail to show gross reduction.

Investigation of the case in conditions of absolute silence showed that this was far from being the case. Comparison with the normal showing no great alteration whether the meatuses were packed or not. The only mechanism here available is that suggested, *i.e.*, direct transmission to the cochlear walls via the skull bones. This mechanism is still intact and perception of the tuning-fork is accordingly not reduced.

The question which still remains is that of the Schwabach phenomenon. How can we explain the increase of bone conduction found in tympanic damage?

Bezold's explanation cannot be considered satisfactory.

The Screening Theory which I should like to put forward and endeavour to support is a fairly straightforward one and

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a logical conclusion to the foregoing parts of this paper. I should like to begin by considering the case of a normal cochlea submitted to bone-conduction tests under two distinct sets of conditions. In both the test is carried out in an ordinary room. Under the first set of conditions we are provided with a normal middle-ear mechanism. The auditory field is occupied now by first of all the tuning-fork conveyed via the bone and secondly the very considerable degree of sound present in an ordinary room, this last being enhanced in intensity by the amplifying mechanism of an intact middle ear.

The presence of such additional stimuli in the field would be expected to raise the threshold of perception for the tuning-fork. Compare this with the case of an ear with a damaged middle-ear mechanism. Here the extraneous stimuli are excluded; and the theory in question would lead us to expect perception of the fork vibrations conveyed via the intact mechanism of direct transmission to be enhanced. In so much the theory is brought to fit the facts and may, I think, make claim to a very real simplicity.

Its further advantages, and very real ones in such a field where fact and fancy are so inextricably mingled, are that it invites the application of two strong and distinct lines of investigation, upon the evidence of which as foundation its truth should rest with a certain degree of security. The argument upon which the first line of investigation is based is as follows: increased bone conduction resulting from a screening effect of a damaged middle ear would disappear if the observer's cochlea was also screened, *e.g.* by occluding the meatus of the observer. The proof of such a statement is therefore the first requisite of the theory; and here I feel on comparatively strong ground; ground moreover which has been largely strengthened for me. Bone-conduction tests corresponding with the conditions just described have been carried out by Mr Hastings as a routine in all his cases for some ten years and also by Mr Cleminson.

Their work covers a field of very many hundreds of cases and its results confirm my own experiences of some 120 cases in the last three and a half years.

I think that I am right in saying that the empirical truth of the statement enunciated above is one of which both Mr Hastings and Mr Cleminson feel assured. Just to repeat the test and its findings: In cases of increased bone conduction

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due to impairment of the tympanic mechanism, the bone conduction is reduced to normal limits by occluding the meatus in both the observer and the patient; or in the language of the theory which I favour, when the two cochleæ in question are equally screened.

This is the so-called Absolute Bone-Conduction Test. Its truth which is, I think, now assured, is as outstanding as the truth of the Schwabach and its rationale in the light of prevailing theories is obscure. The facts of the Schwabach are admittedly strange. In evolving an additional fact of equal strangeness in the absolute bone-conduction test we can scarcely be said to be improving the position unless some theoretical consideration can be adduced which will rationalise both facts upon a common basis and so convert them into real weapons in our hands instead of the rather clumsy bludgeons they so often are. Working upon the basis of the screening theory, both Schwabach and absolute bone-conduction test rest upon a foundation of common logic. The second main line of investigation, which is logically invited by the theory is as regards the effects of absolute silence. It is clear, I think, that in the absence of any disturbing adventitious sounds whatever that the screening effect of a damaged middle ear would be inoperative. In other words, that in absolute silence the disadvantage of the normal unscreened cochlea in the ordinary Schwabach test would disappear.

This leads us to the second main line of investigation. It concerns the effect upon Bone-Conduction Tests of Absolute Silence. For this purpose I have availed myself of the Silence Room at the Royal Ear Hospital, and I should like to take the opportunity of thanking Mr Tilley and the authorities there for their kindness in putting the room at my disposal. The first step in this part of the investigation has been to endeavour to establish the limits of normality for bone conduction in normal hearing individuals. For normality in such a matter to take a dead straight line is not to be expected if alone from the variability in structure and density of mastoid processes, and Siebermann stresses this point very suitably.

The forks used were the C_1 and C_2 (256 and 512 D.V.'s per second respectively) of the Gardiner Brown type. Forks above and below these frequencies were not found suitable for bone-conduction work.

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Bone-conduction tests were made on some 34 normal hearing individuals, comparisons being made in all cases against myself and in about 25 per cent. of the cases with other normals. In all some 48 comparisons were made.

The results may be expressed as percentages in the following Table:—

	Increase (4-5 secs.).	No Difference.	Decrease (4-5 secs.).
C_1 . .	20 per cent.	65 per cent.	15 per cent.
C_2 . .	2-3 secs. 20 per cent.	65 per cent.	2-3 secs. 15 per cent.

In 35 per cent. of cases therefore there is a departure from the dead level, and the limits of normality would appear to be 5 seconds each way with the C_1 fork and 3 seconds each way with the C_2 fork.

The Bing Phenomenon.—Occlusion of the meatus in the normal subject in an ordinary room leads to increased perception of a tuning-fork upon the cranium (usually the mastoid). The most reasonable of the explanations in vogue is probably that which appears in Kerrison's text-book. This attributes the increase to the added resonance of the meatus obtained by converting it into a closed cavity.

According to the screening theory put forward, this is due to the effect of the meatal occlusion in screening the cochlea from extraneous stimuli and enhancing its perception of the fork.

A similar explanation is applicable to the Bing negative phenomenon in impairment of the conducting apparatus, in cases of which occlusion of the meatus leads to little or no after-perception.

Under these circumstances the cochlea may be said to be already adequately screened by the middle-ear condition already present. To this the occlusion of the meatus adds nothing and after-perception is absent.

The next line of inquiry has been to do with the effect of absolute silence upon the Bing phenomenon in a number of normal individuals.

Occlusion of the meatus in an ordinary room was found to give rise to an after-perception of 14 seconds using the C_1 fork in a series of some 46 normal ears. This figure represents the

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average finding. In 30 of the ears this was the precise figure. In the other 16, limits were from 10 seconds to 18 seconds, a variation of 4 seconds on each side of the line. With the C_2 fork the average duration of after-perception was 5 seconds, practically all cases approximating very closely to this figure. Results obtained in the Silence Room appear in the following Tables :—

C_1 after-perception .	nil	16 ears = 36 per cent.
	just heard	10 ,, = 23 ,,
	2-3 secs.	6 ,, = 14 ,,
	4-5 ,,	12 ,, = 27 ,,

C_2 after-perception .	nil	18 ears = 43 per cent.
	just heard	14 ,, = 33 ,,
	1-2 secs.	4 ,, = 9 ,,
	2-3 ,,	6 ,, = 14 ,,

The results may be summarised as follows :—

In all cases the effect of silence is to produce a marked diminution in the after-perception resulting from occlusion of the meatus. In about one-third of the cases after-perception actually disappears. In these cases it would appear that after-perception is entirely a matter of a screening mechanism produced by occlusion of the meatus.

In absolute silence this screening mechanism becomes inoperative.

In the rest of the cases some degree of after-perception persists, although inasmuch as it undergoes a constant reduction here also the screening factor appears to be an important one. What is the other factor at work which prevents the entire disappearance of after-perception in absolute silence in these cases? I think it is reasonable to expect that the resonating qualities of different meatuses would vary with their varying qualities of size, shape, and structure. Hence different results in resonance effects would follow occlusion of such meatuses.

Under some conditions of meatal structure occlusion with a tuning-fork upon the skull may give rise to harmonics in the scale other than the fundamental. These would affect fresh and unfatigued areas of the auditory field. The net result

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would be fresh perception of a note whose quality is slightly changed. And I think that, speaking for myself at any rate, the quality of the bone-conducted tuning-fork note does undergo some change upon occluding the meatus. Subjects from whom I have endeavoured to elicit an opinion in the matter describe the sound sometimes as becoming more hollow. All this amounts to a re-statement of the view supported by Kerrison concerning the mechanism of the Bing phenomenon with an attempt at more accurate analysis of the idea of altered resonance of the meatus resulting from occlusion.

I think we may say that although in some two-thirds of the ears examined, this altered resonance factor was present, in the remaining third it was wholly absent, the screening factor here being entirely responsible for the Bing phenomenon, and is eliminated by absolute silence.* In the remaining two-thirds of the cases the screening factor was also present but accompanied by the altered resonance factor which is still operative in the presence of absolute silence.

The Weber Phenomenon.—Investigation of the Weber phenomenon in the Silence Room was found to give inconclusive results, as I think it often tends to do under all circumstances. Normal hearing individuals who succeed in localising the tuning-fork upon the vertex to the occluded ear in an ordinary room do so with almost equal certainty in absolute silence. If, however, they are kept unaware of the side of the occluded ear by using two similar ear-pieces, one of which has its lumen closed, their power of localisation becomes extremely uncertain. The whole mechanism and working of the Weber test is, I think, rather obscure and unsatisfactory, and I am not inclined to stress any of the results obtained.

Summary—*Increased Bone Conduction.*—Prevailing theories of the Schwabach and Bing phenomena and their difficulties are considered. The theory is put forward that increased

* The standard of this has been taken as that afforded by the Silence Room at the Royal Ear Hospital. That the degree of silence obtained here can really be accepted as a true standard is questionable; and my information is that it does not stand comparison with the *camera silentissima* at Utrecht. Though I have not had the opportunity of confirming this personally the possibility must be accepted; and the variation of results obtained pertaining to the Bing phenomenon may in fact be attributable to faulty experimental conditions. Correction of these may make it possible to dispense with the meatal resonance theory altogether.

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bone conduction is a screening effect. Two lines of work bearing upon the possible truth of such a theory are indicated.

The first concerns the so-called Absolute Bone-Conduction Test. The second concerns the effect upon Bone-Conduction Tests of absolute silence. Preliminary studies are made of :—

(1) Limits of variation of bone conduction for the forks to be used employing a number of normal hearing individuals. These limits are established and are shown to be fairly wide.

(2) Effects of silence upon the Bing phenomenon in normal individuals. The period of after-perception upon occluding the meatus is shown to be constantly lowered in absolute silence.

(3) Effects upon the Weber test of absolute silence. Results were found to be inconclusive.

PART II.—**The Investigation of Bone Conduction in Cases of Conducting Deafness.**

The cases used in this part of the work have been taken from the Out-Patient Clinics of Mr Hastings and Mr Cleminson at the Middlesex Hospital. They numbered 44 in all and are subdivided as follows :—

Class I.	Radical Mastoids	7 cases
Class II.	C.S.O.M. and sequelæ . . .	6 ,,
Class III.	Otosclerosis	16 ,,
Class IV.	Chronic Catarrhal Deafness . . .	15 ,,

Full tests with voice acumeter and a range of forks from C. 128 to C. 2048 were done in every case. The tests of importance, however, from the point of view of this paper and which appear in the Tables are the following three :—

1. The Absolute Bone-Conduction Test.
2. The Schwabach (in an ordinary room).
3. The Schwabach (in the Silence Room).

In all cases comparisons were made with myself, and in 8 of the cases 2 normal controls were used as well.

The results for **Class I.** appear in Table I. (Figures represent seconds, N = normal.)

Cases 1, 3, and 5 have an increased Schwabach and a normal absolute bone conduction which gives figures approximating to those of the Schwabach in the Silence Room. I should describe the condition in these cases as of a normal cochlea

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fairly well screened by the middle-ear condition, thus giving the increased Schwabach under ordinary conditions.

Cases 2 and 4.—Here there is a diminished absolute bone-conduction test, with a Schwabach which roughly corresponds, and a moderately increased Schwabach under ordinary conditions. Here we are dealing with a cochlea whose intrinsic sensibility is deficient. Nevertheless the degree of screening provided by the extirpation of the middle-ear mechanism is such that the cochlea under ordinary conditions is actually at an advantage as regards bone-conduction tests. Hence

TABLE I.

	Schwabach (Ordinary Room).	Absolute B.C.	Schwabach (Silence).
Case 1 C_1	+8	N	+3
Case 1 C_2	+7	N	N
„ 2 C_1	+6	−15	−13
„ 2 C_2	+5	−7	−4
„ 3 C_1	+7	−3	N
„ 3 C_2	+6	N	N
„ 4 C_1	+4	−10	−10
„ 4 C_2	+3	−5	−6
„ 5 C_1	+8	N	−2
„ 5 C_2	+7	N	+4
„ 6 C_1	+18	+6	+8
„ 6 C_2	+12	+3	+8
„ 7 C_1	−5	−15	−17
„ 7 C_2	−5	−12	−10

the increased Schwabach. The fact to note here is that the important truth of the cochlear deficiency is latent, masked by the screening effect of the damaged middle-ear mechanism, and is only brought to light by the logical application of either absolute silence or equal screening for the observer's ear as in the absolute bone-conduction test.

Case 7.—This is a patient who had some symptoms of labyrinthine irritation during the course of her otitis which probably accounts for the marked cochlear loss shown by her absolute bone-conduction tests. Silence Schwabach again roughly corresponds. The ordinary Schwabach here was reduced. This is a case of marked cochlear loss, of such a degree that the beneficial screening effects of the middle-ear

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condition are not sufficient entirely to restore the balance. Hence a moderately decreased Schwabach. Some degree of cochlear loss is apparent here even with the ordinary Schwabach. Its full amount is, however, masked by the concomitant screening effect of the damaged middle ear, and is only revealed by equable conditions for the two cochleæ involved in the comparison, that is to say, by the use of absolute bone-conduction test. I should like to add that the removal of bone in the radical mastoid operation introduces a factor of inequality in bone-conduction tests upon the mastoid in

TABLE II.

	Schwabach (Ordinary Room).		Absolute B. C.		Schwabach (Silence).	
	Right.	Left.	Right.	Left.	Right.	Left.
Case 1 C_1	+12	+12	N	+2	N	N
Case 1 C_2	+6	+10	N	N	+2	N
" 2 C_1	+8	+10	−10	N	−8	+4
" 2 C_2	+5	+6	N	N	N	N
" 3 C_1	+7	+4	N	N	N	−2
" 3 C_2	+7	+5	N	N	+2	+3
" 4 C_1	+8	+8	−4	−4	N	−2
" 4 C_2	+10	+6	N	N	+2	N
" 5 C_1	+7	+7	−10	N	−12	+2
" 5 C_2	+7	+10	−8	+4	+2	+2
" 6 C_1	+8	+8	+3	+2	+1	N
" 6 C_2	+6	+8	N	N	N	+1

question, and bone-conduction comparisons in such cases are best carried out upon the vertex of patient and observer.

In Case 6 a good deal of bone had been removed, and it will be seen that the Schwabach in the Silence Room was still +8 seconds. Vertex comparisons, however, gave :—

	Ordinary Room.	Silence.
C_1 . . .	+12	N
C_2 . . .	+ 6	N

Class II. *Chronic Suppurative Otitis Media and its Sequelæ.* —Results obtained in bone-conduction tests in this class appear in Table II.

Most of the cases are people from 30 to 40 years of age. The average length of history being about ten years. In all

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except Case 5 there is little change in the absolute bone conduction. In this class as a whole, therefore, we are dealing with a normal cochlea well screened by the middle-ear damage Hence the marked increase in the ordinary Schwabach.

If one were entitled to draw a general conclusion from such a short series, it would be that chronic suppuration in the absence of any labyrinthine involvement does not lead to any marked diminution of the cochlear sensibility.

The next two classes of case are described as otosclerosis and chronic catarrhal deafness respectively. Whether some of the cases deserve the distinction made, I am not at all sure. What can be said is that in the chronic catarrhal class have been put cases whose Eustachian tubes and membrane do not appear to be within the limits of normality, as far as I should care to define such limits. In the otosclerotic class have been included cases whose tubes and membranes cannot be definitely placed outside such limits.

In all cases in both classes the deafness came on from 15 to 30 years of age.

Family history, paracusis and tinnitus do not appear to be distinctive features of either class, and I have not felt justified in making any of them decisive issues in classification.

Class III. *Otosclerosis.* — The results in otosclerosis appear in Table III.

In the first 8 cases on Table III. it will be seen that there is a well-marked lengthening of the Schwabach and no marked alteration in the absolute bone conduction which corresponds largely with the figures for the silence room Schwabach. Here we are dealing with cochleæ whose sensibility is apparently not much disturbed. They are well screened by the otosclerotic involvement of the conducting mechanism. One would almost be willing to assert that in these cases the otosclerotic process was limited to the stapedio-vestibular junction. The ordinary Schwabach is as would be expected well lengthened. The later cases in the series show an important difference. They display mostly some diminution of absolute bone conduction with again silence Schwabachs which roughly correspond. Ordinary Schwabach is either normal diminished or only slightly increased. Here we appear to be dealing with subnormal cochleæ. Hence the reduction in absolute bone and silence Schwabach tests. They are well screened, however, by the otosclerotic involvement of the stapedio-vestibular junction and the ordinary

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Schwabach is consequently normal or slightly reduced only. The full extent of the cochlear mischief due to the otosclerotic process is only revealed by the absolute bone-conduction test.

TABLE III.

	Schwabach (Ordinary Room).		Absolute B.C.		Schwabach (Silence).	
	Right.	Left.	Right.	Left.	Right.	Left.
Case 1 C_1	+10	+5	N	N	−5	+3
Case 1 C_2	+6	+5	N	N	N	N
„ 2 C_1	+12	+7	−3	−6	−8	−7
„ 2 C_2	+6	+3	N	−2	N	N
„ 3 C_1	+9	+8	−2	N	−4	+4
„ 3 C_2	+4	N	−3	N	N	N
„ 4 C_1	+6	+12	N	N	N	N
„ 4 C_2	+6	+6	N	N	N	N
„ 5 C_1	+5	+6	−6	−5	−8	−7
„ 5 C_2	+3	+6	N	−5	N	+2
„ 6 C_1	N	+5	−12	−8	−10	+4
„ 6 C_2	N	+5	−3	N	+2	−2
„ 7 C_1	+8	+6	−8	N	−3	−2
„ 7 C_2	+5	+8	−8	N	N	N
„ 8 C_1	+6	+14	−10	−3	−4	−8
„ 8 C_2	+8	+18	N	N	N	N
„ 9 C_1	N	−4	−15	−25	−15	−25
„ 9 C_2	+3	N	−6	−12	−8	−9
„ 10 C_1	−12	−20	−20	−30	−20	−20
„ 10 C_2	−8	−8	−8	−8	−10	−12
„ 11 C_1	−2	−3	−15	−18	−12	−10
„ 11 C_2	+6	+5	N	N	N	N
„ 12 C_1	+10	+6	−10	−15	−3	−12
„ 12 C_2	+8	+5	−5	N	N	N
„ 13 C_1	+9	+8	−12	−15	−7	−7
„ 13 C_2	+6	+7	N	N	N	+2
„ 14 C_1	N	+5	−25	−18	−15	−8
„ 14 C_2	+7	+8	−7	−3	−3	N
„ 15 C_1	−7	−15	−20	−20	−18	−18
„ 15 C_2	+8	+4	N	−8	N	−4
„ 16 C_1	+10	+8	−8	−10	−10	−8
„ 16 C_2	+8	+6	N	−8	N	−3

Most of the last 8 cases are well advanced in years, the average age being 40 years. Case 6, however, is a notable exception. Here at the age of 23 with a seven months' history there is

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quite a definite loss of cochlear function. Cochlear involvement in otosclerosis would on the evidence of this series appear to be a delayed process. Its behaviour is, however, quite irregular and it is possible that it may be present from the first as in Case 6. Involvement of the conducting mechanism in the oval window region is constant in all cases and results in a screening effect upon the cochlea in its responses to the ordinary Schwabach test, which is consequently lengthened. When cochlear involvement occurs in this disease it is rendered latent (at any rate in the important early stages) by the screening effect of the concomitant stapedio-vestibular involvement, resulting in a Schwabach round about the normal. The full extent of the cochlear involvement is again revealed by the absolute bone-conduction test with which the silence Schwabach test tends to correspond.

Class IV. *Chronic Catarrhal Deafness.* — The results obtained in this class appear in Table IV.

In the accompanying tables it will be seen that the Schwabach tends to be uniformly reduced in absolute silence; and although at times it is still absolutely increased, the level of this increase is low and does not overstep the limits of normality for bone conduction which we have previously endeavoured to establish.

In the first 6 cases in Table IV. we are again presented with the picture of approximately normal absolute bone conduction and silence Schwabachs which roughly correspond with a marked increase in the ordinary Schwabach, once more exemplifying a normal cochlea screened this time by the catarrhal middle-ear condition.

The rest of the cases show marked loss of absolute bone conduction. Silence Schwabachs again roughly correspond. Ordinary Schwabachs are normal or they may show some actual reduction. The feature of this last type of case which forms the bulk of the class of deafness labelled chronic catarrh is the loss of cochlear sensibility as witnessed by the absolute bone-conduction test.

I think it is true to say that in most cases of chronic dry deafness which cannot be included in the otosclerotic group, loss of cochlear sensibility tends to develop by the time the disease has existed some five to ten years, if not before. This loss is latent, as tested by the ordinary Schwabach on account of the screening effect of the middle-ear component of the disease which results in a Schwabach which is normal or only slightly

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reduced. Once again the full extent of the cochlear loss is only revealed by such equitable means of comparison with the normal ear as is afforded by the absolute bone-conduction test.

TABLE IV.

	Schwabach (Ordinary Room).		Absolute B. C.		Schwabach (Silence).	
	Right.	Left.	Right.	Left.	Right.	Left.
Case 1 C_1	+8	+8	N	N	N	−6
Case 1 C_2	+8	+8	N	N	N	N
„ 2 C_1	+8	+6	N	N	−8	+5
„ 2 C_2	+8	+6	N	−5	N	−2
„ 3 C_1	+5	+5	N	N	−3	+3
„ 3 C_2	+10	+7	N	N	N	N
„ 4 C_1	+12	+8	−5	N	−12	−10
„ 4 C_2	N	N	−8	N	−8	−10
„ 5 C_1	+20	+20	N	N	+5	+3
„ 5 C_2	+6	+6	N	N	N	N
„ 6 C_1	N	+12	−5	−2	−3	N
„ 6 C_2	+4	N	N	−2	−2	N
„ 7 C_1	+6	+14	−10	−3	−4	−8
„ 7 C_2	+8	+8	N	N	N	N
„ 8 C_1	+9	+10	−5	−7	−3	−8
„ 8 C_2	+8	+8	−4	N	N	N
„ 9 C_1	+8	+6	−20	−30	−12	−20
„ 9 C_2	+5	+5	N	N	N	N
„ 10 C_1	+5	+6	−5	−9	−7	+3
„ 10 C_2	+9	+9	N	N	+2	N
„ 11 C_1	+10	+6	−10	−15	−3	−12
„ 11 C_2	+8	+5	−5	N	N	N
„ 12 C_1	−12	−20	−20	−30	−20	−20
„ 12 C_2	−8	−8	−8	−8	−10	−12
„ 13 C_1	N	+5	−25	−18	−15	−8
„ 13 C_2	+7	+8	−7	−3	−3	N
„ 14 C_1	N	−8	−8	−25	−5	−20
„ 14 C_2	N	−4	N	−10	N	−10
„ 15 C_1	+6	+6	−15	−20	−15	−15
„ 15 C_2	+6	N	−6	−8	−3	−6
„ 16 C_1	...	...	...	...	...	...
„ 16 C_2	...	...	...	...	...	...

In comparing these cases with the later cases of what one feels justified in describing as otosclerosis (see Table III.), the fact which most strikes the eye is their similarity in bone-conduction reactions. In both, we have evidence of cochlear

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disease as witnessed by lowering of the absolute bone conduction. In both, this loss is rendered latent, partially or completely by the concomitant middle-ear condition, thus giving a Schwabach which is normal or only slightly reduced. In both, the full extent of this cochlear loss is only revealed by the use of the absolute bone-conduction test.

The Causation of Loss of Cochlear Sensibility.—This, in the case of otosclerosis, we will, I think, be willing to attribute to the otosclerotic process itself, a well-defined pathological entity. To what are we to ascribe it in the other class of case? a class which probably forms the bulk of all cases of severe chronic dry deafness. Fraser and his school would consider the pathology of the two classes to be identical. In other words, that the sharply defined pathological process found in cases of unquestionable otosclerosis is also at work in a large number of the so-called catarrhal deafnesses. The pathological examination of material which can alone prove this question has yet to be done, and it would be idle to express an opinion in the matter.

Confining ourselves strictly to the limits of established truth it would appear reasonable to put the matter in some such way as this: Cases of chronic dry deafness, whose drums and Eustachian tubes are not sufficiently within the rather ill-defined limits of normality to warrant their inclusion within the category of downright otosclerosis, usually develop within some five to ten years an affection of the cochlear sensibility itself. Whether this is due to true otosclerosis or not it is neither pertinent nor profitable to say. The fact of such cochlear affection rather than its ætiology is the salient point which we wish to stress.

Given a case of chronic deafness, of all single pieces of information the most important would almost certainly be the absence or presence in any marked degree of loss of the cochlear sensibility.

Now in middle-ear disease of all kinds we have to face the invariable fact of involvement of the conducting mechanism. In assessing cochlear function by the ordinary Schwabach test any loss of sensibility is largely rendered latent by the concomitant screening effect of the impaired middle-ear mechanism. When the cochlear loss is of such a degree that even the ordinary Schwabach is reduced, nerve deafness is then apparent to all. Less extreme degrees of cochlear affection are latent and can only be revealed by the more equitable method of comparison with the normal cochlea provided by the absolute

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bone-conduction test. A test which had best be described as one logically demanded by the theory of increased bone conduction put forward in this paper.

The Treatment of Chronic Catarrhal Deafness.—The treatment of this class of case is probably one of the most vexed and unsatisfactory in otology. That a minority of such cases are improved by local treatment of the middle-ear, Eustachian tubes, and nose and throat is, I think, admitted. That the majority of such cases really repay treatment along these lines is not, I think, admitted by the majority of experienced observers.

The crucial question is: What is the guiding line which will indicate the patients in whom energetic treatment is likely to be attended with benefit? That cochlear loss as witnessed by a decrease of bone conduction in the ordinary Schwabach precludes much hope of successful treatment is, I think, an admissible statement. This, however, is an extreme condition and it is in the earlier stages of disease in which we need guidance. Cochlear loss in these cases is, as we have endeavoured to show, largely latent and its true extent can only logically be expected to be revealed by the use of the absolute bone-conduction test.

The statement which we should like to venture and which is really the rational outcome of all which has gone before is this: That in any case of chronic middle-ear deafness in the early stages the most important single fact in determining prognosis and the advisability of energetic local treatment of the ear, nose, and throat is the absence or presence of any definite cochlear loss. This loss is usually latent and is revealed by the use of the absolute bone-conduction test.

Summary.—Bone-conduction tests were carried out in a series of cases of conducting deafness. These being divided into the following four classes:—

Class I.—Radical mastoids.
Class II.—Chronic suppurative otitis media and sequelæ.
Class III.—Otosclerosis.
Class IV.—Chronic catarrhal otitis media.

Comparisons were made of the results obtained in an ordinary room with those obtained in the Silence Room. The general trend of results appears to show very definitely that the increased bone conduction found by the ordinary Schwabach in these cases undergoes a constant reduction to within normal limits in the Silence Room.

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Much the same results being obtained by the use of the absolute bone-conduction test.

Cases in which the ordinary Schwabach is round about the normal show a marked loss in the Silence Room or with the absolute bone-conduction test.

In these cases there is thought to be a true loss of cochlear sensibility. This is latent under ordinary circumstances of the Schwabach. The importance of the absolute bone-conduction test in revealing this loss is stressed.

It is suggested that latent cochlear loss in the early stages of chronic middle-ear deafness is the most important factor in guiding prognosis and treatment.

The importance of the absolute bone-conduction test in revealing this loss is again accentuated.

Conclusion.

From the comparative fewness of the cases examined and the methods of controlling the results we feel that anything but a very tentative tone in this paper would be unjustified. Any downrightness of statement which may be employed for purposes of definition does not therefore accord with our feelings in the matter.

I should like to express my thanks in the various quarters in which they are due. Once again to Mr Tilley and the authorities of the Royal Ear Hospital where part of the work was done; and to Mr Hastings and Mr Cleminson whose long experience in the use of the absolute bone-conduction test has been of the utmost value. I should add that the significance of the test as regards the prognosis and treatment of early cases of dry deafness is one to which they have both attached considerable importance for some years.

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