PAPERS

ON

DEAF-MUTISM.

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NOTE.

WRITTEN as these papers were for different audiences, and at different times, those who now peruse them as a whole will be good enough to pardon any repetition or overlapping which has occurred. Each of the papers presents a separate and distinct case, and was written with a definite object.

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1. THE HEARING POWER IN DEAF-MUTES.
—(*Archives of Otology*, April, 1893).

2. THE PATHOLOGY OF DEAF-MUTISM.
—(*Archives of Otology*, July, 1893.)

3. CONGENITAL DEAFNESS.
—(*Glasgow Medical Journal*, October, 1893.)

4. THE EDUCATION OF THE DEAF AND (SO-CALLED) DUMB; WITH A PAPER BY MR. W. H. ADDISON.
—(*Proceedings of Glasgow Philosophical Society*, 1893.)

THE HEARING POWER IN DEAF-MUTES; BEING THE RESULTS OF THE EXAMINATION OF 175 DEAF-MUTE CHILDREN.

By JAMES KERR LOVE, M.D.,

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DEAFNESS is almost always relative. A man may be deaf to the tick of his watch but hear conversation; or he may hear nothing of conversation and hear a church bell, or a clap of thunder. Most of us have a little hearing power in reserve, a little to spare. We may become "dull" to a slight extent, and if the dulness be not accompanied by any painful symptom we may be ignorant of its existence till some accident occur to test us. Then we find that the watch is not heard at the full distance; but as long as we can get along without difficulty in business, or in the parlor, or at church, we do not call ourselves deaf.

Moderate degrees of deafness are always measurable. The watch and the various acoumeters enable us to state, with regard to at least one sound of given quality and pitch, the hearing power in any case. A watch heard at 36 inches by a sound ear may be heard at 6 inches by a person hard of hearing, and we are able to state that for that watch the person has lost 50 per cent. of his hearing, or that his hearing is .5, or we may represent his hearing by the fraction $\frac{6}{36}$, always remembering that when thus represented by a vulgar fraction the case looks worse than it really is, for sound diminishes in intensity inversely as the square of the distance. The watch and the acoumeters are accurate as far as they go, but they do not go very far. A deaf person may not hear the watch at all, even in contact with his ear,

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and yet hear ordinary conversation quite well, or he may hear the watch at several inches and have much difficulty with conversation. Then watches and acoumeters tell us nothing in the case of very deaf people; they are all unheard. So that, for the very deaf, we have no hearing tests, and, what is worse, we have no accurate nomenclature. When deafness is extreme in early life, or if great deafness be congenital, muteness accompanies it, and we begin to talk of the deaf and dumb. It is true that dumbness is a result of a certain degree of hardness of hearing, that amount of hardness of hearing which makes conversation difficult or impossible, but it is not a necessary result of such hardness. If such deafness occur in the adult, he will never forget the art of speech, and will never be a deaf-mute. If it occur in the child he may be taught by the oral system, and although stone-deaf he may speak well. So that the term deaf-mute does not express any degree of deafness; it never had a very definite meaning, and the oral system has robbed it of some of the meaning it once had. And yet there is a degree of hardness of hearing which makes the acquisition of speech difficult or impossible by the ordinary methods, and which usually results in the loss of recently acquired speech; "Surdism" is the name I would apply to this degree of deafness. It is not measurable by any test we have; but it is sufficiently well defined by this: that it makes the acquisition of speech difficult or impossible, and that by no ordinary method can one communicate with its victim through his auditory nerve.

No acoumeter for this degree of deafness has been devised, and perhaps such an instrument, if invented, would not be of much value. The important query about the very deaf is: Can he distinguish the various sounds of the human voice? If he cannot, he will never speak unless he can make his eyes do duty for his dull ears. If he can, even with difficulty, you may confer on him, or preserve for him, the gift of articulate speech.

In testing the hearing of the very deaf, the victims of surdism, many instruments have been used, and the human voice has almost always been employed. Among instruments—watches, clocks, tuning-forks, and bells may be mentioned. A good synopsis of the results obtained by these tests will be found in Hartmann's book on deaf-mutism, and may be briefly repeated here.

Toynbee classed deaf-mutes under seven different heads. He examined 411 cases.

Totally deaf	245
Clapping of hands heard by	14
Loud shouting heard by	51
Loud voice close to ear heard by	50
Could distinguish and repeat vowels	44
Could repeat short words	6
Could repeat short sentences	1
	411

Amongst these 411 were 313 born deaf, of whom 141 heard certain tones, and 41 repeated vowels pronounced for them. Of the remaining 98 with acquired deafness, 73 were totally deaf, and 25 heard certain tones.

Kramer examined 45 deaf-mutes, and classed them thus:

	Congenital.	Acquired.
Completely deaf	10	13
Uncertain hearing for sound	5	3
Uncertain hearing for vowels	7	1
Distinct hearing for vowels	2	—
Distinct hearing for all words they have been taught	2	1
Distinct hearing for many words not known to them	1	—
	27	18

Hartmann examined 204 deaf-mutes at the Berlin Institution, and classed them thus:

	Congenital.	Acquired.	Uncertain.
Words heard	4	12	—
Vowels heard	6	12	—
Sounds heard	17	39	1
Totally deaf	24	86	3
	51	149	4

Hartmann classes Kramer's examinations and those at the two Baden institutions of Nursburg and Gerlachstein along with his own, and concludes as follows:

"More than one half (60.2 per cent.) of all deaf-mutes are totally deaf. A fourth have hearing for sounds, a seventh hear vowels and words. The difference in the hearing power of congenital deaf-mutes, and of those who have acquired deafness, shows itself principally in the fact that, amongst the latter class the cases of total deafness are far more numerous (68.4 per cent.) than amongst the former (44.2 per cent.)."

De Rossi of Rome examined the hearing of deaf-mutes with speech (through the speaking-tube), and with the tuning-fork (vibrating in the air and on the cranial bones), and with Helmholtz's resonator. He thus tested 70 cases, and states the result as follows:

Speech heard by	27
Watch heard by	4
Tuning-fork vibrating in air heard by	39
	70

In contact with the cranial bones, the tuning-fork was perceived by almost all the deaf-mutes, and there were only 11 who had no perception. He found only 3 cases of total deafness. More recently (in 1884) St. John Roosa of New York examined 147 deaf-mutes. In 1867 he and Dr. George Beard examined 296 cases. The latter set of cases gave but meagre results according to Roosa, the former were examined chiefly for the purpose of ascertaining the locality of the lesion causing the deafness. Roosa used the tuning-fork alone in his tests. I shall notice his work at greater length in a future paper on this subject.

In testing the children at the Glasgow Institution I used:

A large bell,
A large tuning-fork,
Politzer's acoumeter,
The human voice.

Of these, the last is the most valuable test, and where the classification of deaf-mutes for teaching purposes is the object in view, is almost the only test worth using. When testing with the voice, precautions must be taken against lip-reading. All very deaf people lip-read to some extent, and semi-mutes, even when untaught, lip-read to a very great extent. I pronounced the test words or vowels either behind the child's back, or I covered his eyes with my hand. Next in importance come the bell and fork. For determining the presence or absence of aërial hearing, the bell is the best test. Where any doubt on the point existed the child was made to count the strokes, which were delivered singly and at short intervals. Here too the eyes were covered during the test. The bell used was a large dinner-bell with a spring tongue attached at the junction of the handle and the bell, and so arranged that a violent shake produced a sound of great intensity. A little practice enables the operator to produce sounds of very uniform loudness. In the open air, at the Queen's Park, near Glasgow, the bell could be heard at a distance of nearly 1,000 yards.

The tuning-fork is a large one of about ten inches long, including the handle, and giving a note due to a vibration of 330. Although a powerful fork, it takes a good ear to hear it across an ordinary room by aërial conduction; and yet I met with instances of deaf-mutes who heard this fork at several inches from the ear, and who could not be made to hear the loudest strokes of the bell. But the fork is most useful for testing bone-conduction, and thus indicating the situation of the lesion causing the deafness. Although this is the special value of the tuning-fork, its usefulness is very limited. In very deaf people, when the handle is placed on the forehead, or over the mastoid, the mechanical vibration communicated to the skull is often mistaken for sound, and unless the deaf-mute be very intelligent and well-educated, one cannot be sure that he has heard the sound. He may only have felt the tremor. It requires a deaf-mute of more than the average intelligence to appreciate the tapering off and cessation of a sound produced during a bone-conduction experiment, or to compare the results of experiments on his two ears. These difficulties and the fact that the lesion is probably in many cases one which affects both internal and middle ears, render an exact diagnosis of its seat very difficult, and, in my opinion, only possible in a minority of cases; the presence or absence of bone-conducting hearing can generally be ascertained, but the amount of it is not usually measurable.

The acoumeter is the least important of the test instruments. I used it in my first hundred cases, mostly educated deaf-mutes, and then gave it up as being of little value, except in the case of semi-mutes with a large remnant of hearing, the amount of which it was desirable to measure accurately. I used it in testing both aërial and bone-conduction hearing. Twelve heard it aërially.

Throughout the whole of the work I was assisted by Mr. W. H. Addison, the principal of the institution, and have to notice not only his great kindness and helpfulness, but his thorough appreciation of the scientific value of the investigation. In all, 175 children were examined. In classifying them a distinction has to be made between the educated and the uneducated. An uneducated deaf-mute cannot describe his experience of a test like this; he has no finger language, his sign language is of the vaguest; he may hear a loud sound quite well, but he cannot imitate it. Unless he have a large residue of hearing and be only a semi-mute,[1] his testing cannot be relied on until he be about a year under tuition. Forty-nine of the whole number of 175 were thus disqualified because of inability to appreciate or reply to the tests. Three were found to hear perfectly, and to have their muteness due to some other cause than deafness. The remaining 123 were thus classified:

I. Stone deaf—hearing neither the bell nor the loudest shouting, nor the tuning-fork sounding in the air........	9
II. Could hear and more or less distinguish the loudest sounds, *e. g.* the voice from the bell..................	81
III. Could hear and distinguish the sounds of the human voice..................................	33
	123

[1] In the above, the term semi-mute is to be taken as meaning those whose remaining speech depends on their remaining hearing. They might have been called semi-deaf. The term semi-mute is sometimes applied to a different set of cases: those whose remaining speech is entirely a recollection of what they once heard, although they may now be stone deaf. The acoustic method is of course not applicable to them.

These latter 33 were found to consist of 20 who could hear and distinguish vowels only, 13 who could hear and distinguish vowels, consonants, and some words.

14 cases were quite deaf to the bell. Of these 5 heard the fork by aërial conduction, leaving 9 totally deaf.

Further, of the whole number (123) 80 heard the fork by aërial conduction, and 43 did not. The fork was appreciated by bone-conduction in almost every case, even where no aërial sound was heard. If this sensation were always hearing, and not mere tremor, the number of deaf-mutes who have no hearing would be very small indeed, but I have included as totally deaf all that have no aërial hearing.

From the above it will be inferred that the number of totally deaf is very small (about 7 1-2 per cent.) amongst deaf-mutes. In the second class are found the bulk of deaf-mute children (81 in 123, or about 65 per cent.). These hear and distinguish very loud noises, but cannot differentiate the various sounds of the voice.

The third class contains over a quarter of the children (33 in 123, or about 27 per cent.). Thirteen of these children would hear something of what their fellow-men say to them, if the latter would say it loudly and distinctly enough; that is perhaps too much to expect from the world. But they are seldom or never properly dealt with. Remember that these thirteen children can hear, distinguish, and repeat without lip-reading, consonants and some words. They are not dumb. They are sent to our deaf-mute institutions, and I have the strongest proof that most of these children become much deafer, and very soon quite dumb. Nothing is done to stimulate their auditory apparatus, and it gradually falls asleep, never again to wake. The proof I refer to is this. The thirteen children are drawn from all ages in the Institution, but not equally so. Ten were found among the 75 children admitted during the last two years. Only three existed amongst the 100 children admitted before that period. Nearly two years ago I had evidence of quite a different sort, pointing in the same direction. When first going over the children, I found several quite deaf to consonants and words, and even to vowels, who were described in the schedule report as having, at the date of admission, a good deal of hearing and a little speech. The schedule is usually filled up under the supervision of a medical man, and is usually correct. The conclusion is inevitable. Semi-mutes become deafer and totally mute, because no effort is made to preserve and develop their remaining hearing. This is not as it should be. Either these children should never enter an institution for the deaf and dumb, or special classes should be made for them, and teaching by the aural or acoustic method adopted. To teach them the finger method is to consign them to a world of silence. The oral method does not meet the case either. It may accustom the child to hear his own voice by bone-conduction, but it does very little to preserve his hearing for the sounds of the world around him. If the remaining hearing is to be preserved and developed, the stimulus must reach the auditory nerve by the ordinary channel, and the stimulus must consist of the distinctly articulated words of a teacher, and not merely of the imperfect imitations of the pupil himself.

Anticipating the subject of the causes of deaf-mutism, it may here be noticed, that of the 9 totally deaf, 7 were born deaf, and 2 were born hearing (as reported in the schedules). Of the 33 who distinguished voice sounds, 8 are said to have been born deaf, 20 born hearing, and regarding the remaining 5, doubt is expressed or information is not given.

Comparing these results and those of other observers, I find myself in accord with De Rossi in regard to the main points raised.

1. Total deafness is very rare among deaf-mutes. For aërial sounds it is not greater than 7 or 8 per cent., for bone-conduction sounds, even less.

2. Hearing for speech is pretty common. It exists to a utilizable extent in 25 or 27 per cent. of deaf-mutes, and from 10 to 15 per cent. are only semi-mute. Under the finger system of teaching these semi-mutes become rapidly deafer, and soon totally dumb. The oral system may do something to prevent this, but it can only be properly dealt with by the acoustic method.

3. Cranial conduction exists in almost all cases, and a large vibrating tuning-fork is almost always heard in this way. It is also heard in the majority of cases by aërial conduction. In a small number of cases can such sounds as those of a watch, or Politzer's acoumeter be heard. On the other hand, I am much at variance with Toynbee and Hartmann, who found most deaf-mutes totally deaf. Hartmann's further statement, that total deafness is commoner in acquired than congenital deafness, does not coincide with my experience. Most of those examined by me and found to have hearing for vowels, consonants, and words, were cases of acquired deafness. Only two of my nine cases of total deafness were said to have been born hearing.

I cannot altogether explain these differences. The absence of a standard test and a uniform method may account for them, but their existence makes the detailed description of instruments and methods given in this paper, very important.

THE PATHOLOGY OF DEAF-MUTISM.

By JAMES KERR LOVE, M.D., Glasgow.

IN a former paper[1] I have entered with some detail into the question of the hearing power of the 175 children examined by me at the Institution for the Deaf and Dumb at Glasgow, and I now propose to refer to the etiology of the condition ; a subject the study of which appears to have been much neglected in Great Britain.

From the admission-schedules of these children we find that the causes of the deafness are thus defined:

Adventitious or acquired	in 81	cases
Congenital	" 72	"
Doubtful	" 22	"

from which it appears that the acquired are more numerous than the congenital cases; this is not in accordance with most statements, but as these are not checked by personal examination they are of little value. I believe with Roosa[2] that whenever personal examination by an expert is responsible for the figures, the acquired cases will be found to be more numerous than the congenital.

Of these 175 children, nine were totally deaf, but we find that only two had been rendered so by disease, while seven had been born deaf. On the other hand, among those who distinguish the voice, twenty out of thirty have been made deaf by disease while ten have been born deaf. Taken as a class, then, "congenital" deaf-mutes are deafer than "acquired" deaf-mutes. I notice this point chiefly because Hartmann[3] states that the opposite is the case.

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[1] These ARCHIVES, vol. xxii., p. 170.
[2] These ARCHIVES, vol. xiii., p. 67.
[3] *Deaf-mutism.* Translation by Cassell's, p. 87.

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The hearing power in congenital and acquired deaf-mutes is shown in the following table:

TABLE I.

	Acquired Deafness.	Congenital Deafness.	Doubtful.	Total.
Totally deaf	2	7	—	9
Heard loud noises	36	32	13	81
Distinguished voices	20	10	3	33
Too young for testing	21	22	6	49
Dumb but not deaf	2	1	—	3
	81	72	22	175

With regard to the cases of acquired deaf-mutism, the following are the causes upon which the condition is said to depend:

Meningitis and brain fever	13
Convulsions, fits, and teething	7
Falls and injuries to the head	11
Measles	10
Scarlet fever	3
Whooping cough	1
Other fevers	3
Ear affections proper [suppurative affections]	8
Syphilis	2
Cold	2
Inflammation of the lungs	1
Fright	1
Unknown or unspecified causes	19
	81

In comparing this list with most of those previously published, I have to notice particularly the absence of typhus and cerebro-spinal meningitis. In Hartmann's tables these two diseases rank next to cerebral inflammation as causes of deaf-mutism. In the American table quoted in the *Royal Commission Report*, neither of them are specially mentioned, but in Roosa's table of 147 acquired and congenital cases, cerebro-spinal meningitis accounts for forty-seven! Typhus is now a rare disease in Great Britian, and with reference to cerebro-spinal meningitis in the epidemic form, Fagge[1] says: "Scotland, I believe, has been altogether spared by it." The absence of these diseases as causes of deaf-mutism in the west of Scotland is, therefore, not a matter of astonishment. In nearly all statistics, scarlet fever occupies a much more important place than in the above list, and I have no doubt that in this respect my figures are exceptional. In other respects the list represents fairly well the etiology of acquired deaf-mutism.

After deducting the cases due to unknown causes, we have sixty-two in which the cause is definitely stated, and of these twenty, or nearly a third, are cerebral inflammation, convulsions, and fits. If to these we add eleven cases due to injury to the head by falls, etc., we have exactly half of the cases of acquired deaf-mutism for which any cause is given, due to primary mischief in the brain or internal ear, without concomitant disease in the middle or external ear. Some of these may be cases of meningitis in which the mischief has spread to the auditory nerve and its expansion in the internal ear, but I think that meningitis is made to figure too prominently as a cause of deaf-mutism. Some of these cases are probably cases of primary labyrinthitis ending in total or partial destruction of the internal ear, without any brain affection whatever. In children, and even in adults, primary labyrinthitis undoubtedly occurs,[2] and some of our cases of recovery from apparent meningitis may be thus explained.

Measles accounts for ten of the sixty-two cases. If an additional reason were needed for the compulsory notification of this disease to local authorities, I think it may be found in these statistics of deaf-mutism. Scarlet fever would appear to be less destructive to the hearing of young children in Scotland than measles. This conclusion is contrary to the evidence of both American and German statistics, and for its qualification I append a statement of the concurrence

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[1] *Principles and Practice of Medicine*, vol. i., p. 691.

[2] Gruber, *Diseases of the Ear*, Law and Jewell's translation, pp. 515 to 525.

of infectious diseases amongst the children before their admission to the Institution:

Measles	in 91 of the cases
Whooping cough . . .	" 81 " " "
Scarlet fever	" 31 " " "
Small-pox	" 5 " " "
Diphtheria	" 1 " " "
Typhoid fever . . .	" 1 " " "

This statement of the occurrence of infectious diseases amongst young deaf-mutes is incomplete, as the schedules sometimes give no information at all, but measles appear to attack them about three times as often as scarlet fever, and it also accounts, as is shown in the previous list, for fully three times the number of deaf-mutes.

How these diseases act in producing the higher degrees of deafness it is not always easy to say, but there is very decided evidence to show that the labyrinthine affection in measles is in many cases secondary to the middle-ear affection. Mygind[1] of Copenhagen has described a case in which this was almost certainly the order of events. Moos[2] has described a similar case and has shown the part played by the micro-organisms in the invasion of the labyrinth. On the other hand, some of my cases point to the invasion of the labyrinth without the intervention of disease of the middle ear. Four of the ten cases in the above list show normal membrana tympani.

Hartmann appears to consider that the deaf-mutism which follows scarlet fever is always caused by a primary affection of the labyrinth, and he states that in nearly all cases of deaf-mutism where this disease has been the cause, he has found normal membranes. In six of my ten cases of measles the membrane was either perforated or otherwise distinctly abnormal, and in only one of the three cases of scarlet fever was it normal. Further, cases have just been published which show that the inflammation in scarlet fever may spread from the middle ear to the labyrinth and may totally obliterate and destroy that organ.[3] It may be true that when

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[1] These ARCHIVES, vol. xx., p. 310.
[2] These ARCHIVES, vol. xviii., p. 49.
[3] Mygind, These ARCHIVES, vol. xxii., p. 17; Moos, p. 64.

we look at all the otorrhœa due to scarlet fever, the percentage ending in deaf-mutism is small, but of the cases of deaf-mutism due to scarlet fever probably a large number depend upon labyrinthine disease due to infection from middle-ear inflammation.

That class of cases described as ear disease proper may be taken as being composed of cases of suppurative median otitis producing deafness in most instances by spreading of the mischief to the internal ear. In two at least of the cases the damage to the middle ear was very extensive. I removed a sequestrum from one ear of one of these children at the Institution, while I performed the same operation for the other child in one of the wards of the Royal Infirmary. In another of these cases suppurative inflammation was going on actively at the time of the examination. The class consists of eight cases, and in most, if not in all, we may assume that the cause of deafness is middle-ear suppuration, unaccompanied at its outset with scarlet fever, measles, or other general complaint. The ravages of suppurative middle-ear disease were seen in a much larger number of cases, but probably the disease in these cases set in after the occurrence of the deafness.

The work of inspection presented two difficulties:

1. The removal of obstacles from the external auditory canal.

2. The fixing of a standard of normal appearance for the tympanic membrane.

Thirty-seven children had their ears plugged with cerumen or a foreign body. The latter consisted of pebbles, a bead, bits of wood, and pieces of cotton wadding. All these were removed, and all the masses of cerumen except those in two cases were also removed; these two children left the Institution before the operation could be done for them.

It is almost impossible to fix a standard for the appearance of the healthy tympanic membrane. Normal hearing is consistent with great variety in the appearances. Politzer[1] found only twenty-five per cent. of normal membranes amongst normal hearing individuals. In Roosa's[2] examina-

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[1] Ocularinspection des Trommelfells. *Wien. Wochenblatt*, 18, 1862.
[2] These ARCHIVES, vol. xiii., pp. 65–68.

tions of the ears of deaf-mutes, very little at all is admitted as normal. Roosa and Beard, in their short account of the examination of the ears of deaf-mutes, say: "We consider a normal membrane to be a translucent pearly-gray membrane with the head and handle of the malleus distinct, not very prominent however, or projecting much above the plane of the membrane. On the lower segment is a reflection of the light of a general triangular shape, its apex resting on the lower extremity of the handle of the malleus. The angle formed by the membrane with the upper wall of the external auditory canal is 140 degrees."[1] Now in children the membrane exhibits, in cases of normal hearing, even greater variety than in adults, so that the setting up of any rigid standard like the above is not likely to lead to any valuable results. One gets accustomed to associate certain appearances with certain diseased conditions, and a large clinical experience gives a wider and truer idea of what is normal or abnormal than the application of any rigid standard. In examining these cases, therefore, I applied no absolute standard to the membrane. All perforations, all marked opacities, and all very distinct alterations in thickness, in color, or in curve were considered abnormal. But a membrane was not called abnormal merely because the cone of light varied a little from the triangular, or because the malleus was slightly more prominent than my idea of the strictly normal. Again, the distinction between the remains of suppurative and non-suppurative lesions cannot always be rigidly drawn, but all perforations, cicatrices, and pronounced calcareous changes were put down as due to suppurative diseases.

Both membranes were always examined, and both ears tested. But the testing of the ears separately by the tuning-fork on the forehead and mastoids has not given such definite results in my hands as in Roosa's. The statements of a deaf-mute about his sensations when the handle of a tuning-fork is vibrating on his forehead should be received with the greatest caution. None but the most intelligent deaf-mutes understand the nature of a relative test like this,

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[1] *American Journal of Medical Sciences*, April, 1867.

so that while in the journal of the cases I have notes of all of the conduction experiments, I hesitate to produce them here, or to found upon them any absolute conclusions as to the location of the lesion causing the deafness. For the same reason, and to simplify these statistics, I represent the membrane as either normal or abnormal; the occurrence, say, of a perforation in one, places that case among the abnormal, although the other membrane be intact. "Membrane normal," therefore, means that there is no marked pathological appearance on either side.

TABLE II.

	Acquired Deafness.	Congenital Deafness.	Doubtful.	Total.
Membranes normal...............	28	26	7	61
Suppurative otitis media, active or extinct........................	18	11	3	32
Changes indicating non-suppurative catarrh..........................	34	33	11	78
Unexamined	1	–	1	2
Meatus too narrow for examination.	–	2	–	2
	81	72	22	175

TABLE III.

	Meningitis and Brain Affections.	Falls and Head Injuries.	Measles.	Scarlet Fever.	Ear Affections Proper.
Membranes normal....	10	5	4	1	–
Suppurative lesions....	2	1	4	1	4
Non-suppurative lesions	7	5	2	1	4
Unexamined..........	1	–	–	–	–
	20	11	10	3	8

NOTE.—This table should be read in connection with the remarks made upon the various causes of acquired deafness in the earlier part of this paper.

When we compare the appearances (Table II.) in acquired and congenital deafness, the contrast is less striking than we expect. There are almost as many normal membranes in acquired as in congenital deafness. There is greater destruction of the membrane from suppurative disease amongst the acquired cases, but even here the contrast is not a strong one. In-drawing and other non-suppurative changes are commoner to a slight extent in the congenital cases, but there is an absence of characteristic lesions in parts which can be seen through the speculum.

There was no case of malformation of the auricle in the entire list of 175 cases. Two cases of extreme narrowness of the external auditory canal were found; both were cases of congenital deafness. In one, other deformities existed: these consisted of cleft palate[1] with posterior curvature of the spine and very deficient eyesight; the mouth and teeth were also markedly syphilitic. Another case of malformation, consisting of a very unusual arrangement of the fingers of one hand and the toes of one foot, with webbing between the digits, was found, but the boy had fairly wide auditory canals, through which were seen opaque, and somewhat lustreless but intact membranes. A well marked case of false membrane after suppurative disease was seen. Many of the lesions which disfigure the tympanic membranes of deaf-mutes occur subsequent to the onset of the deafness, and in this way much that is characteristic of the two classes of cases becomes obliterated. About seventy per cent. of the children showed distinct thickening of the tonsils, pharynx, or both. In about thirty-three per cent. the tonsils are described as being much thickened, or the pharynx as very distinctly altered in the direction of disease, but these latter cases are not associated with any special condition of the tympanic membrane.

Roosa and Beard's examinations tally almost exactly with my own estimates,—they found that fully two thirds of the deaf-mute children showed pharyngeal disease or enlargement of the tonsils. Has this anything to do with the production of the deafness? In most of the acquired cases I do not think it has. Most of these are fully accounted for by lesions which have set in with definite symptoms

[1] Compare Case 1 (Hyrtl), Hartmann's list. *Deaf-mutism*, p. 206.

leading up to the deafness. But over twenty per cent. of the acquired cases (19 in 81) have no cause assigned to them. The terms used in answer to the question are, "uncertain," "unknown," or "doubtful," or the information is simply withheld. Now it is noteworthy that in at least half a dozen of these cases, although the cause is stated to be "unknown," the date of the onset of the deafness is definitely stated, *e. g.*, "unknown at four years," "at three years," etc. There is here an absence of sudden onset or of striking concomitant symptoms, and deafness occurring under these conditions is suggestive of the insidious invasion of non-suppurative catarrh. It is amongst these "unknown" causes I think, that this disease plays its role in acquired deafness. But these cases do not represent all the mischief done by the disease. It is a common affection amongst the young between three and ten years of age, and young deaf-mutes cannot be freer from it than their hearing brothers and sisters. If then in a child some damage has been done to the labyrihth by accident or disease, and he be in consequence on the border of mutism, and if the condition of the naso-pharynx be favorable to the development of non-suppurative catarrh of the middle ear, his hearing may soon be damaged by this catarrh to an extent quite incompatible with the retention of speech. It is just possible too that this affection may account for some of the cases of so called congenital deaf-mutism. Any disease without striking symptoms causing deafness during the first year of life, will give rise to the impression that the case is one of congenital deafness, and we have no reason to suppose that the first year of life is free from non-suppurative catarrh of the middle ear.

A study of the anatomical conditions upon which congenital deafness depends is not within the scope of this paper. No light can be thrown on them by examinations such as the present. The absence of malformations in the external parts does not warrant a similar conclusion with regard to the labyrinth. It will be recollected that the vestibule, the semicircular canals, and the cochlea are all developed from a primary otic vesicle, after the latter has become a separate and closed sac, and that the tympanic cavity, the Eustachian tube, and external canal are the remains of the first post-oral cleft. Malformation or arrest of development may go on quite independently in these two regions, and if we are to judge from the reports of post-mortem examinations on congenital deaf-mutes, defective development is not uncommon within the auditory sac. The result of such arrest may be total absence of the labyrinth or deficiency in its component parts. The cochlea is sometimes reported to have a smaller number of turns than usual; one or more of the semicircular canals have been found wanting; or the fenestræ may be absent or ossified.

There is little more to add. Most of these cases of deafness are beyond the resources of our art before they are admitted to the Deaf and Dumb Institutions. I need not repeat the plea so often made for the early diagnosis and treatment of all diseases of the ear. Children frequently come to the Institution to be told for the first time that their deafness is incurable, and the parents quote opinions to the effect that their child's hearing would come right at seven or at fourteen years of age. Now this is such a common experience amongst teachers, that I have been asked by Mr. Addison, our Head Master, to mention the matter in this paper. Talk like this must be either founded on ignorance or be due to a delicacy about the statement of an unpalatable truth. But it is fraught with the greatest danger; it prevents the parents of deaf children from seeking advice at the right time, and it postpones in like manner the adoption of proper methods of education till the most valuable years of childhood have slipped away.

CONGENITAL DEAFNESS.*

By JAMES KERR LOVE, M.D.

To all who interest themselves in the deaf and dumb, the question as to whether the deafness is congenital or acquired is important. Those who teach the deaf think this question all important. They make their criticism of teaching, in some instances, hinge entirely on the distinction. "Show me," they say, "a child who was born deaf and who now speaks intelligently, and I will admit the superiority of your methods." Now, admitting for the moment that congenital and acquired deafness have distinct pathologies, if the result of the diseased process be neither more nor less than the production of "surdism"—that amount of deafness which prevents the development of speech—what matters it whether the disease happen just before birth, or say at the beginning of the second year of life? Indeed, hearing lost in the second year confers almost no ultimate benefit on those who at that age lose it, and hearing lost in the fourth, fifth, or sixth year is generally followed by muteness. So that it is useless for teachers to draw any line between those congenitally deaf, and those who lose their hearing in early childhood. The latter soon become as dumb as the deaf born. What a teacher should know about his pupil, in addition to the facts about his general intelligence, is the extent of his deafness. If he can get evidence that the child heard after the second year of life, he will look for the remains of acquired speech and for other effects on the child's intelligence of a prolonged contact with the hearing world.

We in the medical profession believe that congenital and acquired deafness have similar pathologies, that the seat of the deafness is almost always the labyrinth, often only the labyrinth, and hardly even the middle ear alone. If surdism were always congenital its pathology might interest us, but

* Reprinted from the *Glasgow Medical Journal*, October, 1893.

the study of that pathology would hardly lead to any practical results. Congenital deafness is a finished state before we detect it. We cannot mend it. But if any large number of our cases be acquired, the enquiry is all important. Like other recent diseased states, surdism will afford scope for treatment; the disease of which the deafness is the result may be either prevented or cured.

In the medical mind two erroneous impressions about the deaf and dumb have very distinctly fixed themselves. The first is that nearly all deaf-mutes are quite deaf, and the second that nearly all have been born so. Recently * I have shown that the first of these statements should be reversed, and should read—" almost no deaf-mute is quite deaf." In this paper I propose to take up the other question of congenital deafness.

Much difference of opinion has been given about the relative extent of congenital and acquired deafness. This is well illustrated by Scott,† who wrote as follows:—" In a circular issued from the Dublin Institution, it is stated that in 489 deaf children 423 were born so, the remaining 66 losing their hearing after birth from various accidents and diseases. In the thirteenth report of the Hartford (America) Asylum, it is said that out of 279 pupils 117 were born deaf, 135 lost their hearing in infancy, and 28 were doubtful." Statements differing so widely suggest a mistake somewhere.

Hartmann's illustrations on this point‡ are quite as striking:—

" According to the Irish statistics there are 4,010 cases of congenital deaf-dumbness among 4,930 deaf-mutes. In Schmalz's compilation there are 3,665 cases of congenital deafness, and 1,760 of acquired deafness in a total of 5,425. Hartmann states, however, that more recent statistics have resulted in a preponderance of acquired deaf-mutism. These, like the last figures given, are taken from German institutions, and show a total of 2,658 deaf-mutes, with 1,285 congenital and 1,359 acquired cases. Hartmann thinks that, on the whole, we may assume that a little more than one-half of the deaf-mutes have been born deaf, while the other half have acquired the defect by disease.

Writing in 1835, Kramer § says:—" Amongst the causes

* *Archives of Otology*, vol. xxii, No. 2, 1893.

† *The Deaf and Dumb*, by W. R. Scott (1870), p. 28.

‡ *Deaf-mutism*, translated by Cassels (1881), p. 51.

§ *The Nature and Treatment of Diseases of the Ear*, translated by James Ridson Bennett.

which act so perniciously on the organ of hearing during early life that the development of the faculty of speech does not take place in the usual way, original defects of conformation stand pre-eminent." In contrast with this statement of Kramer's, I quote from a letter sent me the other day by Dr. C. M. Hobby, the President of the Otological Section of the Pan-American Medical Congress:—"I have been working in the same field for eight or nine years, and have made personal examination of more than 500 mutes in institutions and outside. I go much further than Roosa in claiming that the actually congenital cases are not more than 15 per cent, and I believe that 10 per cent better represents the rate (of course this is for the United States). I know that of those I examined not more than 14 per cent could have been congenital, and the possibility exists that a large portion of these cases acquired deafness during the first six months of life. On the other hand, the more I come in contact with the parents, and where possible, the medical attendants during infancy, the more am I certain that cerebro-spinal fever and possibly allied pathology is the most important factor in producing deafness in the first two years of life."

Roosa,* above referred to, thinks that wherever personal examination by an expert is responsible for the figures, the acquired cases will be found more numerous than the congenital.

The most reliable source of information on this point is the admission schedules used by the institutions for the deaf and dumb. The parents are brought into contact with an intelligent teacher who can get at the truth about the state of the child's hearing during its first year of life with tolerable certainty; then the schedules are filled up by a medical practitioner. Errors sometimes occur, but there is no reason to suppose that they always tend in one direction, or that they are very great in any direction. The point one wants to be sure about is not whether the child ever spoke, but whether he ever heard or not. Now, a mother's word may usually be taken on this point. Long before speech can be expected, mothers have proof of the presence of hearing. During the first six months of life a moderate noise will break a child's sleep, or cause a waking child to start or look round, and if a mother is quite clear about these proofs of the presence of hearing, then mutism is due to disease happening after the age of 6 months, and the deafness is not congenital. I believe the difficulty of ascertaining the presence of hearing in early

* *Archives of Otology*, vol. xiii, p. 170.

infancy has been exaggerated. In nearly every case where the parent is closely questioned by an intelligent teacher, or by a doctor, the truth can be ascertained; still a small class of doubtfuls must be recognised, for it will always be found.

A disease may occur during the early months with striking symptoms, and may be supposed to account for an already existing deafness. On the other hand, acquired deafness may come on insidiously during early infancy, and give the impression of its having been born with the child. Hartmann thinks the errors on these two sides of the calculation probably about balance each other. I believe that careful enquiry will reduce the error to a small amount, and make the statistics of our institutions reliable. On this point more than usual care was taken with the cases admitted into the Glasgow Institution in 1892. They were 21 in all; 15 were born hearing, 4 born deaf, and 2 were doubtful. For 1891 the admissions were 36, of whom 17 are said to have been born hearing, 13 born deaf, and 6 are doubtful. These, taken together, make 57 admissions, 32 of which are certainly cases of acquired deafness, 17 of congenital deafness, while the state of 8 at birth is doubtful. I believe these figures represent something like the true proportions of congenital and acquired deafness in Scotland. It gives a percentage of—excluding the doubtful cases—

65·3 cases of acquired deafness;
34·7 cases of congenital deafness.

After deducting the doubtful cases, there is a total of only 49, and it may be urged that the number is too small to warrant general conclusions. I therefore take the whole of the children I have examined, 175 in all. These include those given above, and the remainder (admitted before 1891) were admitted after filling up the same schedule to the satisfaction of the predecessor of the present principal of the institution. From the total of 175, 20 have to be deducted as doubtful, and 3 are hearing perfectly, leaving 152 about whose state at birth there is tolerable certainty. Of these, 78 were born hearing and 74 born deaf, represented by percentages of 51·3 and 48·6. This is still in favour of the conclusion that the majority of deaf-mutes are born hearing, but not so much so as the figures drawn from the experience of the past two years. I believe the difference is chiefly accounted for by the fact that the later enquiries were more carefully conducted, and feel sure, with Dr. Hobby, that the more one comes in contact with the parents and medical attendants of the children, the clearer will it become that many of so-called congenital cases are due to disease in early childhood. The conclusions I give are based on the observation of cases drawn almost exclusively from Glasgow and the West of Scotland. When discussing the pathology of acquired deaf-mutism, I have noticed the comparative absence of two diseases which figure largely in deaf-mute statistics of Germany and America. I refer to typhus and cerebro-spinal fever.* The latter disease is common in the first two years of life. Dr. Hobby † points out how commonly it causes deafness, which afterwards is called congenital.

The most extensive observations in connection with any one institution with which I am acquainted have just been published,‡ and are as follows:—In 2,258 cases, assigned causes in the form of diseases after birth are given in 1,343 cases, leaving 912 congenital cases. This gives about 59·5 cases of acquired deafness to 40·5 cases of congenital deafness.

The acquired deafness in the Glasgow Institution may be thus compared with the congenital deafness.

The 78 acquired cases are drawn from 77 families. These families have a total membership of 469 children (an average of $6\frac{6}{10}$). They contain (including brothers and sisters not in the Institution) 82 deaf-mutes. Two cases occur in four families, and in no family do more than two cases occur.

The 74 congenital cases are drawn from 70 families. These have a total of 385 children (an average of $5\frac{1}{2}$). Amongst these 385 children are 109 deaf-mutes. Two cases occur in seventeen families, 3 in three families, 4 in one, and 5 in one family.

In the acquired cases there is 1 deaf-mute child to every 5·7 children born; amongst the congenital, 1 to every 3·5. These figures represent the families and their deaf-mutes at the date of admission of the defective child to the Institution. Where more than one child has been admitted, the information is taken from the schedule of the child last admitted. Subsequently children are born into many of these families, but there is no reason to suppose that the ratios would be altered. The figures, if not numerically correct to-day, are relatively so.

A detailed list of families which illustrate the various

* *Archives of Otology*, vol. xxii, No. 3, 1893.

† "Cerebro-Spinal Fever as a Cause of Deafness" (*Trans. Ninth Internat. Med. Congress*, vol. iii).

‡ *History of the Illinois Institution for the Deaf and Dumb*, 1838-1893. (Prepared for the World's Fair.)

important points bearing on congenital deafness may precede any general remarks on the subject.

1. In the Turton family—5 in all—there are 3 deaf-mutes, boys, and both father and mother are deaf-mutes.

2. The father and mother of Sinclair are deaf and dumb. There are 3 hearing brothers and sisters.

3. In the Duff family the parents are both deaf-mutes. One boy is totally deaf, and the only other member of the family (a brother) is so deaf that he has just escaped mutism.

There are 75 married deaf-mute couples in Glasgow, and these have about 90 children. Of these 75 couples, 6 have one or more children also deaf and dumb. I have referred to 3 of these already as being in the Institution. The other 3 are as follows:—

4. In the Elder family there are 2 deaf-mute children, and both parents are deaf.

5. The Menzies family is remarkable. As in the others, the parents are deaf-mutes; 2 children, both girls, are deaf-mutes. One of these girls married a deaf-mute husband, and a deaf child has been born to them. The husband has a deaf-mute brother.

6. In the M'Arthur family father and mother are deaf-mutes, and their only child is deaf and dumb.

So far as can be ascertained, the parents in all these 6 cases are congenital deaf-mutes.

On the other hand—

7. In the Reston family (4) both parents hear, but have 4 deaf-mute children—3 boys and 1 girl.

8. In the Fyfe family there are 10 children—5 deaf and dumb and 5 hearing. The deaf-mutes are not all of one sex. The parents both hear.

9. In the Kerr family (7) the parents hear, but there are 3 deaf-mute children. These belong to both sexes.

10. In the Lambie family both parents hear, but 3 children are deaf and dumb. The family consists of 7 children.

11. In the B. family parents hear, father is slightly deaf, and an ancestor was deaf. There are 3 deaf-mute children.

These are instances of families where several members are congenitally deaf-mutes, but where the parents both hear, and where all consanguinity between the parents is denied.

Outside the Institution I am able to add the following instance in the Glasgow district:—

12. In the D. family—8 in all—there are 6 deaf-mutes, 1 imbecile, and 1 healthy child. The parents hear and are not related.

13. Joseph Swan, Kilmarnock, was born deaf. He had healthy parents who heard and spoke. His mother died. His father married again, and the second wife had a deaf-mute child.

14. Another case, this time drawn from the Institution, shows how Case 13 may have come about. In the Dick family there are 2 deaf-mute brothers, both born so; there are 5 hearing brothers and sisters; both parents hear, but the mother's father and 3 brothers were deaf and dumb.

15. Martha Douglas is said to have lost hearing by tubercular disease of the ear at 6 months. I have classed her as an acquired case, but a slight doubt is thrown on this by the note that two grand uncles had each a child deaf and dumb.

16. Wm. Turnbull born deaf, but with hearing parents. Half brother and half sister of mother are deaf-mutes.

17. Annie Kerr has 7 brothers and sisters, all of whom hear Her parents hear, but she has a deaf-mute cousin.

18. Maggie Ralston has 3 brothers and sisters who hear; her parents hear, but she has a deaf-mute cousin in the Institution; her state at birth is described as doubtful.

19. Donald Currie has 7 brothers and sisters, all of whom hear; the parents hear; one child now dead was deaf-mute, and a cousin of the boy's mother was born deaf.

20. John M'Leod, born deaf, and with 1 deaf and dumb brother in a family of 6 in all. Father and mother full cousins.

21. Wm. M'Murdo, probably born deaf, with 3 others in the family who all hear. Father and mother cousins.

22. Geo. Harvey, born deaf, with 1 brother with very defective hearing. Father's great grandmother was great great grandmother to boy's mother.

23. Wm. Potter, born hearing, having lost hearing at 8 years from measles. Father and mother cousins.

24. In the G. family, 2 children, a brother and sister, in a family of 6 are deaf-mutes. Both are called acquired cases, 1 due to constitutional disease, the other to hydrocephalus. I refer to this as a case of multiple deafness, due probably to syphilis, and likely to give rise in the lay mind to an impression that the cases are congenital.

In 1835 Kramer * stated that no case has become known in which deaf-mute parents have produced deaf-mute children. Instances have been supplied of this direct heredity by various writers since Kramer's time. Cases 1 to 6 in my list are all instances of congenital deafness occurring in families where

* *The Nature and Treatment of Diseases of the Ear.*

both parents are deaf-mutes. These parents have, in all the cases, been born with the defect. In 4 of the 6 families the cases of deafness are multiple; in 1 the only child in the family is a deaf-mute, and in only 1 family there is 1 deaf-mute (amongst 4 children). No stronger proof of the direct heredity of deafness could be adduced.

Other cases suggesting heredity are those numbered 7 to 13. In these families there are 41 children, 26 of whom are deaf-mute and 1 imbecile, or over 63 per cent of defective children. In every case the parents hear and speak. A full history of the collateral branches of these families can seldom be got. If we had it, the trail of the tendency might be detected, and would point to the fact that there are not instances of an isolated outburst in the family history. Facts about a tendency like this are often deliberately suppressed. Case 13 shows how an apparently healthy father may transmit a defect from which he does not suffer even when his children come by different mothers. Cases 14 to 19 show indirect heredity; the parents hear, but instances of the defect are known in collateral branches of the family.

The intermarriage of blood relations has been supposed to cause deafness. The list of cases in the Glasgow Institution does not warrant the formation of any theory on this point. Only 4 cases of the marriage of cousins are noted at all, and in 1 the deafness in the child occurred at the age of 8 years from measles. In the other 3 the offspring was born deaf. In many instances, the consanguinity is not confessed. The statistics of the Illinois Institution (2,255 cases) shows that 112 of the pupils are the offspring of parents of consanguineous origin:—

79	children of	first cousins.
12	,,	second cousins.
11	,,	third cousins.
8	,,	fourth cousins.
1	grandchild of	first cousins.
1	child of	uncle and niece.

Illustrations are not wanting suggesting a connection between consanguinity and deafness. A good one is given by Moos.* "From the same family there are descended 3 deaf and dumb children in the second generation. The grandfather was married twice—in the first marriage to a niece—in the second he was not related to his wife. From the first marriage descended 2 sons and 1 daughter, from the

* "Ætiology—Results of examination of 40 cases of congenital deafness" (*Archives of Otology*, vol. xi, p. 299).

second 1 son and 2 daughters. Except that 1 of these daughters has a polypus in the ear, neither of the children of the second marriage nor their children (9 in all) have any disease of the ear. On the other hand, 3 deaf-mutes are found among the 13 grandchildren of the first marriage, and of these 3, 1 had a congenital malformation of the right ear."

Another case is given by Falke.* "Consanguineous marriages were contracted three times in the same family before deaf-mutism asserted itself in a frightful manner. A married couple, among whose relatives neither deaf-mutism nor any other hereditary disease could be traced, had 6 deaf-mute children. The parents were strong and healthy, and were 26 and 21 years of age respectively when married. It was ascertained that they were cousins; that the grand-parents and great-grandparents were also cousins."

On the other hand, the case of Da Souza quoted by Hartmann points in the opposite direction. "In 1849, at Widah, in the kingdom of Dahomey, a Portuguese landed proprietor, Da Souza by name, well known to all captains visiting the west coast of Africa, died. This man, being in his time an important personage in that country, had made a large fortune in the slave trade. At his death he left behind him a host of children, the fruits of his harem, containing 400 wives. The Government of the Kings of Dahomey suspicious of, and hostile to the introduction of a mongrel population, confined this numerous offspring in an enclosed space under the supervision of one of Da Souza's sons. Despised by the natives, and strictly guarded, these Mestizos could only propagate by intermixing among themselves. In 1863 there were already among them children of the third generation. The colour of the skin of the latter was already deep black, although some of them still bore plainly the features of their European ancestor. In spite of this intermixing of the family, defying every moral and conventional law, there were amongst this offspring neither deaf-mutes, blind, cretins, nor ill-developed individuals. However, this human herd is decreasing very much, and may soon become extinct." The case of Da Souza suggests that deaf-mutism is not necessarily a result of consanguinity. Given a family quite free from hereditary deafness, this tendency may not arise from intermarriage of its members.

Alongside the Da Souza case may be put Lord Polwarth's famous herd of sheep. Into this flock no new stock has been imported since its formation. In-breeding has been persistently carried out. The result is that not only has the flock come to

* Quoted by Hartmann, p. 61.

be marked by special characters, but that when crossed with other varieties these special characters are imprinted on the offspring in a far higher degree than where in-breeding has not been practised. Indeed, the special characters of the Polwarth flock are said in many cases to be exaggerated rather than diminished by the crossing. That parental consanguinity has special effects on offspring need not be doubted. That it emphasises already existing defects is also quite clear, and in this way many cases of multiple deafness in families may be accounted for. That it can create or initiate a defect such as deafness has not been clearly proved.

Mr. Graham Bell * gives his opinion thus:—"So far as my researches have gone, I have given considerable attention to the subject, and I can see no proof—at least, we have no statistics that undeniably prove that a consanguineous marriage is a cause of deafness; but I do see abundant proof that a consanguineous marriage occurring in a family in which there is already deafness increases the deafness in the offspring; it is simply a case of selection; the family peculiarities, whatever they are, are increased." He also discusses the question of the intermarriage of toto-congenital deaf-mutes, and suggests the production of a deaf variety of the human race from the cause. His reasoning is as follows: —"† That large numbers of the congenitally deaf shall marry one another, and that their congenitally deaf children, if they have any, shall again marry congenitally deaf, and that their congenitally deaf children, if they have any, shall again marry congenitally deaf, and so on; that that alone will result in an increasing proportion of deaf offspring in each succeeding generation, and ultimately, after a certain length of time, which we cannot calculate at the present time, a true breed of the deaf will be formed."

Mr. Bell thinks these conditions are being fulfilled. He cites the case of the deaf-mutes who left the Illinois Institution, "272 of whom married deaf-mutes, and 21 hearing persons. Only 16 of all of these have deaf-mute children, but the absolute number is, of course, not so important as the relative number." From an equal number of marriages of hearing persons, according to Mr. Bell's calculation, there should not have been one deaf child. It has been shown, in earlier part of this paper, that the deaf-mute offspring born to congenital deaf-mutes who have married is as high in

* *Royal Commissioners' Report on the Blind, Deaf, and Dumb*, p. 51.
† *Ibid.*, pp. 49, 50.

Scotland as in America, and doubtless the same process of accentuation of the defect is being carried out.

On the general question as to the probability or otherwise of deaf persons having deaf offspring, Mr. Bell says the general result is simply this :—" With one parent who is congenitally deaf, one-tenth of the children are deaf ; and with both parents congenitally deaf, one-third are born deaf. . . .

" It is quite true that, up to the present time, the majority of the children of deaf-mutes can hear ; but the proportion of deaf offspring of deaf-mutes is enormously greater than the proportion of deaf offspring in the community at large. Now, these children are going to have a larger proportion of deaf offspring than their parents had, if they marry deaf-mutes, and 95 per cent of those who marry are going to marry deaf-mutes. That is again the point—it is the continuous selection from generation to generation."

The consideration of this subject by the Royal Commission gave rise to the following recommendation :—* " We think that the intermarriage of the congenital deaf should be strongly discouraged, as well as the intermarriage of blood relations, especially where any hereditary tendency to deaf-mutism prevails in the family."

Other circumstances, such as unfavourable social surroundings, dipsomania, &c., have been supposed to cause deaf-mutism. There is no proof, however, that these have any specific connection with the defect.

* *Report*, page 91, sec. 26.

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[FROM THE *PROCEEDINGS* OF THE PHILOSOPHICAL SOCIETY OF GLASGOW.]

The Education of the Deaf and (so-called) Dumb. (Two Papers.)

By JAMES KERR LOVE, M.D., Aurist to the Institution for the Deaf and Dumb, Langside, Glasgow; and Mr. W. H. ADDISON, Head Master of the Institution, and Associate of the College of Preceptors.

[Read before the Society, 8th February, 1893.]

I.—DR. LOVE'S PAPER.

SOME three hundred and odd years ago, on a May day, two armies stood fronting each other on the slopes of contiguous hills south of the City of Glasgow. Before night the Battle of Langside had been fought, and the cause of religious and civil liberty in Scotland had scored a great victory. It is not now my business to describe the contest at Langside, nor its effects on Scottish History, but rather to make reference to that historic ground for the introduction of the subject of my paper—the Education of the Deaf in Glasgow. The institution for the instruction of those on whom the great calamity of deafness has fallen stands on the hill occupied by one of the opposing armies, the Victoria Infirmary has displaced the other; and one can hardly visit Langside, and think on that day and on this, without fervently hoping that the temper of the times has changed, that our civilisation is being leavened by charity and benevolence, and that the bigotry and oppression which make men fight have for ever fled away. But, if that be too much to hope for, it is not, I am sure, too much to expect that a company of Glasgow men and women will think kindly of, and listen interestedly to a few words spoken on behalf of, the poor children who live in the institution for the education of the deaf and dumb. Gathered in that building are 140 children who have, with few exceptions, never heard a mother's song or the kind word of a father, who are strange to all music, and who must live always under an oppression of loneliness such as never, even for a moment, visits any hearing mortal. This number does not represent anything like the total amount of deafness in this great community. The Rev. Mr. Henderson, the Secretary to the Glasgow Mission to the Deaf and Dumb, informs me that there are in and around Glasgow and the West of Scotland 600 deaf and dumb adults. To these must be added the children not of school age, and estimated by Mr. Wright, the School Board Officer, at 19. Mr. Wright also informs me that three under school age are known to the Govan School Board. When I add to these 30, being the number under tuition at Greenock and Burnside, we have a total of 813, which represents approximately the number of the deaf and dumb in our midst.

Adult Deaf and Dumb in Glasgow and West of Scotland,	600
Children at Langside Institution, - - - - -	144
Children under school age known to Glasgow School Board, - - - - - - - - - - -	19
Children under school age known to Govan School Board, - - - - - - - - - - -	3
Children being educated under Govan Board, - -	17
Children at other schools Burnside, Greenock, &c., -	30
	813

But let us return to the children at Langside. I have described them as the deaf, and I have done so advisedly. The dumbness is a mere adjunct to the deafness. You call them sometimes the deaf and dumb. They are quite as correctly described as the deaf and stupid, or the blind might similarly be called the blind and stumbling. Without education deaf children are nearly all dumb, and just as universally stupid. With education the stupidity goes, and very often the dumbness too; but deafness remains. It may vary in degree, but it is the one bond that links them all together. That is why they are at Langside, and not in the Board schools. When I speak of the deaf, therefore, I mean those who are too deaf to learn to speak, or, if young, are in great danger of losing any speech they have. I wish I had a more accurate phrase for this deafness. I have tried to invent one, and have used it elsewhere. This is, however, neither the time nor the place to coin new words; so I will continue to talk of the deaf.

The education of the deaf has always presented, and always will present, special difficulties. In earlier and less humane times not much thought was bestowed on the matter. Some peoples settled it in a very off-hand way, and drowned those born deaf. Amongst the Spartans, Greeks, and Romans, no attempt was made to educate them, or in any way to ameliorate their condition. They were considered a misfortune, and even a disgrace, both to the family and the nation. The problem of their education was never faced, and they perished with less consideration than the brutes. These latter days have been marked by great activity in settling the difficulty. The duty of educating our deaf is never now questioned. We know that most of the deaf can be made useful and intelligent citizens. Tremendous energy has been expended in bringing about this happy result. Rival systems have sprung up for its production, and the question before us is not—whether it is to be done or not, but how we may best do it. On this question debates have been held, congresses have sat, books have been written—and I need not add that over it many people have lost their temper,—and it is not settled yet. The bone of contention is this—Shall we try to make our deaf use articulate speech or not? Shall we give them a system of easy readable signs, natural and artificial, by which they can rapidly communicate with each other, but which hearing people, as a rule, know nothing about, and care less; or shall we try to make their eyes do the duty of ears, picking up from our lips what we say; and by a close imitation of what our mouths and lips do, shall we try to make the muscles of articulation in the deaf produce articulate speech? In other words—Shall we use the oral or the finger language? Now, if I were to rehearse the arguments used by oralists and manualists, I would not reach the special part of my work to-night, and Mr. Addison would not have a hearing at all. Opinions differ as widely as the poles. Many persons hold that the oral system is all a mistake, that the time spent on it is lost time, that all the orally trained find this system inadequate, and that they ultimately turn to the finger language. The other side—the pure oralists—are just as loud in their advocacy of the oral system as the manualists are in its denunciation. Two years ago, Mr. Van Praagh, of the London Oral Association, wrote me as follows:—"Every deaf child can be educated on the oral system except the idiot and the blind."

What I would like to show you is, that both of these statements are wrong; nay, that they must be wrong. I will give you *a priori* reasons for holding that all the deaf cannot be educated properly on any one system. The attempt to train all the deaf on a simple system shows an utter want of appreciation of the conditions present in deaf-mutism, and this remark applies to all systems, whether manual, oral, or combined.

Bear with me while I put the case of the deaf child before you in two lights—(1) Apart from the deafness; (2) with regard to the deafness.

I. Apart from the Deafness.

When I say apart from the deafness, I do not mean apart from its cause, but without regard to its amount. If the disease which has destroyed hearing has attacked the ear, and it alone; if it be, for instance, a suppuration which has destroyed the drum cavity and emptied it completely of its ossicles, and if no damage has been done to the brain or to the other organs of special sense, you will have a bright, intelligent child, with a keen eye, a perfect vocal apparatus, and endowed with every faculty but speech and hearing. But if the deafness has been caused by some cerebral disease, such as meningitis, you may have dulness and stupidity, approaching to idiocy, quite apart from the loss of hearing, and, in addition, impairment of eyesight, paralysis of the vocal apparatus, and other special complications. Take, again, the case of congenital deafness: in one child the defect may be limited to the ear, in another the brain may be stunted and the centre for hearing defective. The cases are not at all alike. An anatomist, a physiologist, or a pathologist would not compare them. He would contrast them. The absence of hearing, of course, they have in common. But *that* he would regard as accidental, and not at all belonging to the essence of the case. Is there, then, no difference to be noted when we come to teach them? Is it not reasonable to expect that what will present only moderate difficulty to the one will be quite impossible to the other child?

II. Look now at the Deaf Child in the Second Light: How deaf is he?

There are many superstitions about the deaf and dumb. Many think them wild, untameable creatures, others look on them as "uncanny," others as generally consumptive, but, perhaps, the grossest and most wide-spread mistake is as to the extent of the deafness. Most people, and, I am sorry to say, most medical men, think that nearly all deaf-mutes are totally deaf. Well, I have examined during the last two years 175 deaf mutes at the Glasgow

Institution, all but 49 of whom were capable of giving perfectly unequivocal answers to my tests; and I found only nine of them totally deaf. "How deaf is he?" is then an important question with regard to the deaf child.

Deafness is a relative term. "All men are insane" and "None is in perfect health." These are general statements, and are literally true. If we could fix an absolute standard of sanity or health, it is probable that no one could be found who entirely conformed to it. When I assert that all men are deaf, I but add another to this list of curious but true sayings. No absolute standard of hearing power can be fixed, and if it could, almost all who were tested would be found to deviate from it in some way or other. But the statement that most men are deaf is true in another and commoner sense. I hold in my hand a watch, the tick of which is heard by a good ear in a quiet room at a distance of 36 inches. Many healthy people under 40, and most over 40, could not hear it at more than 18 or 24 inches. Some slightly harder of hearing lose it at 8 or 12 inches, and, when the watch has to be brought to within 2 inches of the ear, you ask for a front pew in church, and your friends have to repeat half their conversation. One stage further and you cannot hear the watch at all; your friends have to shout to you. You are only hard of hearing, you say; but do you not know that you have crossed a most important line? You have crossed the Rubicon. It is only your past experience that keeps you out of the ranks of the dumb. With this degree of deafness at 5 years of age you must have grown mute, and at 18 months you never would have spoken at all. I wish I could get this picture graven on the hearts of all who have to deal with deafness in children. If all school teachers, all doctors, and, above all, if the parents of the semi-deaf only could see it as I see it, some at least of those who now swell the ranks of the mute would remain in the hearing world. The auditory nerve is like a person with opium poisoning, you must rouse it, shake it, stimulate it, make it work, or it will soon pass to its eternal sleep. If you do not, if you call your child by a move of the hand or speak to him in signs, either because of your carelessness or your ignorance, very soon he will exchange the gift of melodious, articulate speech for a series of finger gymnastics.

These remarks do not apply to all cases of deafness, even of acquired deafness, but they do apply to a class large enough and important enough to warrant the fervour of my pleading.

Deafness, then, is purely relative. It is present in almost every degree in speaking people, and in all the higher degrees among the dumb.

Now as to the children at Langside: none of them heard the watch at all. Only a few heard the instrument, which I now hold in my hand, a Politzer acoumeter, which gives a much louder tick than any watch. The tests applied were this large bell, this tuning fork, and the human voice. The tongue of the bell is attached at the junction of the handle and the metal by a spring, and when a decided shake is given to the bell a single loud note is emitted, which, with a little practice, can be reproduced with great uniformity. The fork was used sounding in the air, and applied to the bones of the skull. In this paper I refer only to its use as an aërial test. The accuracy of the observations was assured by the eyes of the observer being covered, by his counting the strokes, and by the delivery of false or noiseless strokes of the bell. The bell used in the testing could be heard in the vicinity of the Institution at a distance of about 1,000 yards by an ordinary ear. The fork used was a large one, of about 9 inches long, and gave a note caused by 330 vibrations per second. The voice sounds were uttered with the observer's eyes covered, or they were spoken behind his back. Total or stone deafness means absence of hearing for the sounds of the bell or voice, and for the fork sounding in the air:—

Total number tested, ...		175
Disqualified from youth, &c., ...	49	
Heard perfectly, but mute, ...	3	
Remaining, ...		123, classified thus :—

I. Stone deaf, ...	9
II. Heard bell or loud voice, ...	81
III. Heard and distinguished voice, ...	33
	123

Class III. was made up thus :—

20 heard and distinguished vowels.
13 „ „ „ consonants, and words.
—
33

14 were quite deaf to bell.
5 of these heard the fork.
—
9 totally deaf aërially.

80 heard the fork aërially.
43 did not hear it.
——
123

Turning again to Class III. :—

Of the 13 semi-deaf—

10 belong to the recently-admitted (1891-92) (10 in 75).
3 „ „ previously-admitted (3 in 100).
—
13

Now, out of the 123 children who were old enough to give intelligent and reliable answers, notice—

1. That only 9 were quite deaf, or $7\frac{1}{2}$ per cent. Nothing but experience, or rather experiment, can guide the teacher as to how these should be educated. They have no hearing left. Now and then a bright intelligent child, with a quick eye, may learn lip reading and articulate well, but the majority of these entirely deaf children will do better under the finger method.

2. With regard to the second class, which supplies about two-thirds of our pupils, experiment again must be our guide. Many of them will make good oral pupils.

3. The third class gives us a fourth of our pupils. Every child belonging to this class should be carefully and persistently tried by the oral method, and most of them will do well. Those belonging to this class who hear consonants and some words must have more than mere oral training. They are the true semi-deaf. They can be taught through their ears, and every aid to hearing, everything which will strengthen hearing power and assist the conduction of sound, must be enlisted. This is the acoustic method, or, as it will generally have to be helped by the oral method, it may be more correctly called the oro-acoustic method. The extent to which the help of the oral method may have to be enlisted in the training of the semi-deaf will vary in each case, and the teacher should have a free hand in using and combining the two methods, but there must be no compromise with signs. Finger-spelling must be accounted a deadly sin with the semi-deaf.

This boy [shown] illustrates oro-acoustic training. He repeats Andrew, John, Monday, and other well-defined words, when pronounced behind his back, but often fails at such words as Robert, &c. These latter he pronounces distinctly when they are spoken before his open eyes.

Now, why should this boy's remaining speech and hearing not be used in teaching him. He is a little too deaf to be taught along with hearing children in an ordinary school, but his ears are still the best road to his brain. If he were blind to a similar degree, we would give him lenses to assist him, but we would never think of leaving his remaining vision unused. If he were lame to this extent, he would be provided with crutches. Why, then, is there no corresponding utilisation of the hearing of the semi-deaf? The deafness which has shut him out of the Board schools is only a little greater than that which makes some of the pupils in the Board schools appear stupid and backward. The difference is not in kind, it is only in degree, and not in great degree. And yet the gulf which separates the methods by which the two are educated is enormous. To ignore this boy's hearing, and especially to instruct him even partially on the finger system, is little short of a social crime. And this crime is systematically committed in the Deaf and Dumb Institutions of this country.

I am not here as the advocate of any one system for the education of the deaf as a class. I believe the oral system to be applicable to a large minority of the deaf. I would give every child the chance of succeeding on oral training, but, after a fair trial, varying from six months to two years, I would hand him over frankly and finally to the finger-teachers if he did not promise well.

The finger method must, I think, be used in the education of at least a half of the deaf, perhaps even a larger proportion. Most of the totally deaf, all those with defective eyesight, all those markedly deficient in intelligence, the very few who have defective vocal arrangements, and all who have failed under the oral or oro-acoustic methods, must use the finger method. The heaviest indictment that I have against the finger method is, that under it the semi-deaf get deafer and soon totally dumb. This is a grave and serious assertion, made now, so far as I am aware, for the first time. I shall, therefore, proceed to prove it. Two years ago, when going over the children then in the Glasgow Institution, I found several quite deaf to all voice-sounds and totally dumb who were reported in the admission schedule to have heard and spoken to some extent on entering the Institution. These schedules are filled up under the supervision of a doctor, and are, I think, usually correct. I could not resist the conclusion that these poor children had degenerated both in hearing power and in speech during their education period. The finger system was practically the only one in use in the Institution before the beginning of 1891. But I have stronger proof that this conclusion is correct. Among the 175 children examined, 75 may be called those recently admitted—that is to say, admitted within the last two years. Of these 75, 10 are semi-deaf. Of the 100 admitted before 1891 only 3 are semi-deaf. The conclusion is inevitable: semi-deaf children trained under the finger system soon become deafer and totally dumb.

I am glad to have Mr. Addison's assurance that under the oral system the semi-deaf do not thus degenerate. My observations of those tested during these two years must be repeated before I can become responsible for any opinion on this point. I am prepared to find much better results amongst the semi-deaf trained by the oral method than when the finger method alone is used. But we want to do more than preserve the hearing in these semi-deaf children. We want to develop it. And it will develop only if the sound be made to reach the ear by the normal channel —the air—and if the source of sound be the loudly and distinctly articulated speech of a good teacher.

The principle which should guide us in selecting a method for the education of the deaf should be this:—Provided fair progress can be attained, that method should be adopted which least departs from the one by which hearing children learn.

Such is the principle which, I think, should guide those who would teach the deaf, and such are the *a priori* reasons for its adoption.

The classification which I have made is based on the amount of hearing present. Another might be made based on the amount of speech present, and this introduces a class not separately represented in the foregoing remarks—the deaf semi-mute—that is to say, children who are practically deaf, but whose remaining speech depends on the recollection of speech learned before the onset of the deafness. Thus the deaf would be subdivided into the true deaf-mute, the semi-deaf, and the deaf semi-mute.

I would fain leave the matter at this point, for Mr. Addison is here to tell you his experience of actual teaching. But I can hardly conclude without quoting from the latest and highest authoritative statement on the education of the deaf—the Royal Commission's Report. I quote only from the recommendations, and only with regard to the points raised in my paper :—

"We recommend that those children possessing some hearing capacity should be carefully and frequently examined by a medical practitioner, so as to test and improve their hearing, pronunciation, and intonation, by mechanical means, such as ear trumpets, &c." (See Par. 620, Sec. 6.)

In spite of this recommendation, I do not think this work is properly done in any country in the world. In Britain it is practically ignored. In America, although no very systematic medical examination has been adopted, the subject of acoustic training has been more extensively studied. And its most earnest advocate, Mr. Gillespie, the Head-Master of the State of Nebraska Institution, writes me in the most confident and encouraging terms about it.

Again, the Commissioners recommend—"That every child who is deaf shall have full opportunity of being educated on the pure oral system. In all schools which receive Government grants, whether conducted on the oral, sign-and-manual, or combined system, all children should be, for the first year at least, instructed on the oral system, and after the first year they should be taught to speak and lip-read on the pure oral system, unless they are physically or mentally disqualified, in which case, with the consent of the parents, they should be either removed from the oral department of the school, or taught elsewhere on the sign-and-manual system in schools recognised by the Education Department." (See Par. 620, Sec. 9.)

The Commissioners further recommend—"That children who have partial hearing or remains of speech should in all cases be educated on the pure oral system. The children should in all schools be classified according to their ability."

The plain English of all this is that we must have two distinct schools for the education of the deaf in Glasgow—one for the pure oral and the oro-acoustic methods, and another for the sign and manual method. The deaf of this great community will never be properly dealt with till this double school system is established, and the man or men by whose energy or money this result is attained will earn the lasting gratitude of all interested in the unfortunate deaf.

Appendix.

Table showing Occupations of Adult Deaf in Glasgow District.

Artist,	1	Glass decorators,	3
Bakers,	4	Jeweller,	1
Beltmaker,	1	Jewel-case makers,	2
Boilermakers,	6	House joiners,	3
Blacksmiths,	2	Iron workers,	3
Boxmakers,	5	Labourers,	15
Bookfolders,	4	Lamplighters,	2
Brassfinisher,	1	Lithographic artists,	15
Bookbinders,	19	Moulders,	3
Brass engravers,	7	Marblecutters,	2
Brushmakers,	4	Millworkers,	4
Bricklayers,	2	Needlewomen,	8
Butcher,	1	Painters,	2
Cabinetmakers,	2	Purse makers,	2
Chairmaker,	1	Patternmakers,	4
Capmaker,	1	Riveters,	2
Clerk,	1	Saddler,	1
Coopers,	2	Silver engraver,	1
Calenderer,	1	Shoemakers,	6
Caulkers,	3	Ship joiners,	5
Compositors,	5	Tailors,	12
Confectionery worker,	1	Ticket writer,	1
Carpet designers,	5	Tinsmiths,	6
Domestic servants,	3	Umbrella makers,	5
Dyers,	2	Upholsterers,	3
Diesinkers,	2	Weavers,	5
Draughtsmen,	6	Wood carvers,	4
Dressmakers,	10	Wood turner,	1
Fancy-box makers,	5	Washerwomen,	3
Fitters,	6		
Fishing-tackle makers,	2		244
Gardener,	1		
Glass stainers,	2		

(The above is kindly supplied by Mr. Henderson for this paper.)

II.—MR. ADDISON'S PAPER.

The subject which it is my privilege to bring before your notice this evening—namely, the Education of the Deaf and (so-called) Dumb—is one which has lately attracted a considerabl amount of public attention. This is owing, in some degree, to the greater interest taken in all educational matters, but chiefly, I think, to the revival of the oral method in this country, to the battle of systems resulting therefrom, and not a little to the wonderful stories of marvellous results achieved by the new method which, from time to time, have found their way into the sixpenny magazines and other media for the publication of sensational and highly-seasoned literature.

Thus, we were gravely informed by the then Secretary of the American Board of Education, Horace Mann, that in Germany one girl attained to such proficiency in lip-reading that she could converse with a maid-servant in the night after the light was extinguished by simply placing her hand on the chest of her companion; and of another, a boy who could read the lips of another person by placing his hand upon them in the dark.

I shall not attempt to startle you this evening by anything so wonderful as that; my business is not to arouse expectations which are only doomed to disappointment. I wish simply to place before you, in the words of truth and soberness, the main facts in connection with our difficult task of educating the deaf and dumb.

I must ask you, first of all, to dismiss from your minds two very general, but erroneous, notions which exist regarding us and our work. It is commonly supposed that Providence which, for some wise purpose, has denied to these unfortunates the faculty of hearing, has compensated them for this loss by bestowing upon them some special gift, and, in common parlance, made them very sharp—sharper than other folks, people say. This idea is a very great mistake. It will, perhaps, surprise you to be told that they are not only deprived of hearing and consequently of speech, but that many of them suffer in other ways—their vitality being below the average of that of hearing people. Some are deficient in mental power, and even if they could hear they would still be classed as imbecile; some are deficient in the sense of smell; others lack the sense of taste; and many suffer from weak eyes. In the Liverpool School a thorough testing by an eye doctor revealed the fact that the eyesight of about 70 per cent. of the pupils was below the normal standard, four of the pupils being so bad that they were taught to read the Braille type in anticipation of their becoming totally blind, and they were afterwards taught basket-making in the Blind Institution of that city. Graham Bell calculates that there are fourteen and a-half times as many blind persons among the deaf and dumb in proportion to the population as there are in the community at large, and forty-six times as many idiotic.

There are, of course, many brilliant exceptions to this dark picture, but I think the facts effectually dispose of the notion that the deaf, as a body, are more gifted than people with the normal senses.

I would also ask you to dismiss from your minds the idea which some persons entertain that the instructors of the deaf and dumb are a species of conjurors, who, by some magical art, engraft the tree of knowledge in the minds of these little ones. I can assure you, ladies and gentlemen, that what we are able to accomplish is not achieved by any feats of legerdemain, but is simply the result of downright hard work, patience, and persevering skill, directed towards a definite object. We must know, first of all, exactly what we have got to do, and then keep "pegging away" till our end is achieved; and we must never know what it is to be beaten, even under the most discouraging conditions.

In the short time at my disposal this evening, it will be impossible to enter fully into every part of the subject. I shall (1st) confine myself, therefore, to such an exposition as shall enable you to understand what is the problem with which we, as educators, are confronted; (2nd) I shall give a short historical sketch of what has been done in past times, with a review of the systems in operation at the present day, stating what, in my opinion, is the best course to pursue in a large school like the one at Langside; and (lastly) by means of an exhibition of the attainments of some of the children here present, I hope to show how far we can realise the hopes with which we set out on our task.

First, then, look at the problem before us. Have you ever pictured to yourselves what it really means to be born deaf? Have you ever seriously considered the true import of those short but terrible words, "*Deaf and Dumb?*" I doubt not. Says a deaf-mute himself, "There is nothing in the general outward appearance of deaf and dumb persons to attract the attention and pity of the bustling every-day world, busy as it is with its own affairs, and absorbed in the contemplation of more striking things. Unlike the blind, whose sightless orbs always painfully compel attention, the deaf and dumb appear like ordinary mortals, with all the senses normal; and, having no voice to utter complaint or make known their condition, they pass on their silent way, unheeded and forgotten. The mind, destitute of the means of communication except the very rudest signs, is shut up in a dreary prison-house; and so the poor mute grows up with all his mental faculties undeveloped; unable to read or converse with his friends, he is a solitary being in the family circle, a hermit in a crowd, a strong, able-bodied man with the mind of a child."

Many comparisons are drawn between the blind and the deaf and dumb, generally in favour of the latter; but it should never be forgotten that the affliction of the blind is chiefly physical, that of the deaf is mental, they being deprived of language, by means of which all the higher and sustained reasoning processes are carried on. The uneducated mute can and does reason in a limited sense, but of the higher processes he is wholly ignorant till education steps in. He has no knowledge of God, or of the Divine attributes, and practically he is a heathen in the midst of a Christian community.

Some may think I exaggerate when I say that the uneducated mute has no knowledge of God, but most teachers who have investigated the subject agree on this point. Alexander Atkinson, a deaf-mute who was educated in the Edinburgh Institution by Mr. Kinniburgh, one of our earliest and best teachers, speaks thus—"Unlike the Indian, who hears God in the wind, or the blind, who are so keenly sensitive to the sublime medium of sound as to infer from it some rude intimation of some superior spirit, I don't recollect anything like it. Whenever my mother took me to church with her, she bade me join my hands, look up, pray, and kneel down. Making me do the same at home on Sundays, she generally pointed her hand towards the sky; and occasionally showing me some large plates in her large family Bible figuring some child in a devout attitude, I may have imagined, faintly, that her prayers were addressed to the sky. I consequently addressed mine. This impression vanished and returned with the occasion, nor do I recollect any ultimate result from the repetition."

Others, again, have thought that people prayed to the sun, moon, and stars, when they saw them kneel down. The notions many of them are reported to have had in regard to natural phenomena are extremely curious. Snow was thought to be an old woman shaking down feathers; that rain was caused by the spouting of an elephant; and so on.

We see, then, that the problem we have to solve in undertaking the education of a deaf and dumb child is twofold;—we have to give him the means of communication with the world around him, to teach him language; and at the same time we have to develop his mind, to discipline it, and make it a fitting instrument for the fulfilment of its destiny.

And this is no easy task. Many people have an idea that the power to understand and speak the English language is innate, that we are born with the power, and that it comes to us without trouble and without learning; in fact, that, with a deaf child, all we have to do is to teach him to spell a, b, c, on his fingers, or say them with his tongue, and immediately he will have a command of the choicest classical English. No greater mistake can be made. The English language to a deaf and dumb child is a foreign language, and has to be learned by him in the same way as hearing people learn French or German. When he comes to school, no matter what may be his age, he does not know one single word—father, mother, cat, dog, stone, stick, words of the commonest description, are Greek and Latin to him; and to educate even the brightest born mute to a ready use of common colloquial English is a task of great difficulty and the work of many years. A hearing child, in a Board school, will spend years in learning French, and, at the end, find itself unable to understand or be understood by a Frenchman, and no one is surprised, because all can realise the difficulty in their own persons; but a deaf and dumb child, bereft of two senses, is often expected by parents and others to master the greater difficulties of our language in two or three years or even less. Why, the thing is impossible. "Your difficulty is to understand his difficulty," said Dr. Buxton, and no truer words have been spoken on this subject.

The mistakes made by deaf-mutes in their efforts at written composition are oftentimes very amusing, as well as very exasperating to the teacher, but not more so than the attempts of foreigners at mastering our tongue.

The act of dropping a piece of chalk on the floor was rendered by a class of big boys thus—"you floor the chalk"—"you chalk the floor;" "you wiped your forehead" became "you rubbed your brain;" "you knelt on your pocket-handkerchief" was written—"you quaker it with your legs." One boy said "I am a calf," another "I am a cow;" and when expostulated with by the teacher, altered it to "I am a useful cow." And a prominent member of an Institution Committee was considerably surprised one examination day by a boy writing for him on the black-board "you are an ass," the explanation being that the gentleman in question was the owner of one, and the boy had confounded the verbs "to have" and "to be," a very common mistake with the half-taught deaf and dumb. "Jesus was the father of Joseph and the mother of Mary;" "Adam was the wife of Eve;" "My dear brother, I am your affectionate daughter;" "I to you love best my send," are all examples of the confusion which exists in many a deaf-mute's mind with regard to the Queen's English.

From what I have now said you will be able to form a pretty accurate idea of the difficulties to be met with in training these children. Let us now see what our predecessors did in the matter. The Spartans, as might be expected from their well-known character, took the simplest way of dealing with the problem: they destroyed all deaf children, in common with all other defectives—a heroic remedy that we are not at present likely to imitate.

Lucretius seems to have held similar opinions, for he says—

> "To instruct the deaf, no art could ever reach,
> No care improve them, and no wisdom teach."

Herodotus records a case of a deaf man, son of Crœsus, suddenly recovering his speech through strong emotion, while the first notice we have of a deaf man being instructed in our own country occurs in Bede's "History of the Church of England," published in 733. There we are told that Bishop John of Hexham had cured a deaf and dumb man by blessing him. But the Bishop, as well as making him "put out his tongue and making the sign of the cross upon it, added certain letters by name, and bid him say A, and he said A; and B, and he said B; and when he had said these, he put them into syllables and whole words to be pronounced, and then commanded him to speak long sentences, and so he did; and ceased not all day and night following, so long as he could hold up his head for sleepe." "Here then," says Mr. Arnold, our latest authority, "appears to be a case of deaf-mute instruction in articulation, more or less successful, as early as the year 690."

We find little or no further mention of the subject till the middle of the 16th century, when Pedro Ponce, a Spanish monk, taught two sons of a Castilian nobleman with much success. It is reported that their progress was so rapid under his tuition that in a short time they were able not only to read and write correctly, but also to answer any questions put to them. One of them, who died at 21, understood Latin and Italian, and was learning Greek before his departure.

Ponce's successor, Jean Pablo Bonet, published a work entitled "The Reduction of Letters and the Art of Teaching the Deaf and Dumb to read," in which he records his methods as consisting of "artificial pronunciation, the manual alphabet, writing, and gestures, or the language of signs."

The accounts of the success of these teachers is supposed to have travelled to England through the visit of Charles I. to Spain; and John Bulwer, in the year 1648, "exhibited the philosophical verity of that subtil art, which may enable one with an observant eye to hear what any man speaks by moving of his lips, proving that a man born deaf may hear the sound of words with his eye."

John Wallis, a professor of mathematics at Oxford, also wrote on teaching articulation, while about the same time was published at Amsterdam a book entitled "De Loquela," by Amman, which probably was the book from which Heinicke, the founder of the German system, obtained many of his ideas. Wallis, besides writing on articulation, had more extended notions of teaching the deaf and dumb, for he also made use in his instructions of such actions and gestures as have a natural signification. He also showed that letters or writing might be at once associated with our conceptions without the intervention of sounds, a principle which forms the basis of the school of De l'Epee and modern teachers of the silent method, though the same truth had indeed been anticipated by the Italian philosopher, Jerome Cardan.

No general application of these methods to the education of the deaf generally seems to have been attempted till towards the close of the last century. Then it was that the Abbé de l'Epee in France, and Heinicke in Germany, instituted those methods of instruction known respectively as the French and German systems, and by the rivalry which they caused did contribute not a little to the rousing of the public interest in the subject, and thereby benefiting the cause of the mute.

Charles Michel de l'Epee was born at Versailles in 1712. He took orders and became a Catholic priest, and in the course of his vocation, having discovered two deaf and dumb girls growing up in ignorance, his heart was filled with pity at their desolate condition, and thenceforward his whole life was devoted to the development of a system of instruction for their benefit. By devoted labour and attention, the expenditure of his own private fortune and contributions from the benevolent and the Government, he was enabled to educate a large number of poor deaf and dumb children, and his success was so great as to attract universal attention. He was invited to London, where he exhibited his two cleverest pupils, and the interest thus aroused being turned to good account, institutions were established over the whole country—London Asylum dating from the close of last century, the Edinburgh Institution from 1810, and its offspring, the Glasgow Institution, from 1819.

The method employed by De l'Epee, wherein the pupils were first taught an elaborate system of artificial signs, by means of which writing was dictated to them, is now little, if ever, used, even by those who call themselves French system teachers. Great modifications were made in it by De l'Epee's successor, the Abbé Sicard.

De l'Epee's great rival, the German Heinicke, was a very different character from the benevolent Frenchman. His object in life seems to have been to make as much money as possible out of his system. Mr. Ackers thus contrasts the characters of the two men—"De l'Epee was frank, open, generous, self-sacrificing; Heinicke, reserved, mysterious, and apparently somewhat avaricious."

Heinicke, however, seems to have had a better grasp of the principles which underlie deaf-mute instruction, and the lines which he laid down for teaching language are now recognised as being more true to nature and more in accordance with the right method of teaching than those of De l'Epee.

And this brings me to the next part of my subject—a few words on systems. The common division is into three, namely:—the French, or, as many now prefer to call it, the silent system; the German, or oral; and the combined, claimed by some as of British origin, and by others as the American system. Though this division is, no doubt, a convenient one for red-hot partisans to swear by, it is to some extent a misleading one. There are innumerable gradations in vogue;—each system as practised in the different schools imperceptibly shades off into the other, according to the idiosyncrasy of the director; and there are schools called silent-system schools where fewer signs are used than in some of those called oral, and so on.

The French system is generally defined as that which trains the pupil to write on the black-board or slate, to spell on the fingers by the single or double alphabet, and gives instruction in the ordinary branches of education by means of spelling and signs.

The German or oral system professes to dispense with all artificial signs, and also natural ones, after the early stage of instruction is past; it tries to teach the pupil to speak and lip-read, and he is expected to gain all his knowledge of language directly through speech—written words not being presented to him till after he can speak and lip-read them. I say this system professes to dispense with all signs; but if any person can show me a deaf child who does not use some signs, I confess I shall feel astonished, as in the course of a somewhat long experience I have never met with any who did not use signs to some extent.

Thirdly, we have the much-abused combined system, which was the one used generally in this country. The advocates of this method, acknowledging the great importance of "speech for the deaf," but at the same time, unwilling to deprive them of the great help which signs afford, endeavoured to combine the advantages of both the extreme rival systems, while avoiding their weak points. Unfortunately they tried to teach speech as a mere accomplishment—that is to say, they devoted the greater part of the school hours to fingering and signing, and expected their pupils to master the gigantic difficulties of articulate English in the brief space of an hour or half-hour per day, or even less. It is almost needless to say that they failed in most cases in teaching their pupils to speak with any degree of fluency, though they turned out many good scholars in other respects.

Having thus reviewed the different methods according to current notions, it remains for us to ascertain what method or methods are most suitable for the circumstances of a school like our own. At the risk of being tedious, I must again ask you to consider what is our object when we commence the education of deaf children. As I said before, it is twofold—we have to give them the means of communication with hearing people, and we have also to give them the information necessary to guide their conduct in after life. Now, what is the means by which people communicate their thoughts to one another? It is language—language which is of two kinds, spoken and written. I am asked—Can the children who come to our school learn to speak intelligibly? In my opinion, the result of over twenty years of actual work in the school-room, combined with reading of all the literature I could lay hold of, and observations made in many schools in Britain and on the Continent, I say that some can and some cannot. You will immediately ask what percentage are able to speak intelligibly. Well, I think that is impossible to answer at present, for the simple reason that the ability of the children varies with each batch we admit. Some years we get in a good set, bright, active, and intelligent; at other times we receive a batch who turn out dull, heavy, and stupid; and the proportion varies from year to year.

These considerations have led me hitherto to favour a system which has been called the dual system. Each child who enters the school is first tried on the oral system, as recommended by the late Royal Commission, and, if found suitable, is kept at oral training throughout his whole school course; but if it is found impossible to teach him intelligible speech, he is placed in a silent-system class, and taught written language only. The children of the two classes mix out of school, and all use finger-spelling and signs in communicating to one another. As this has been urged as an objection to our method—and does, no doubt, to some extent injure the speech and lip-reading,—it has been lately proposed to establish a small supplementary oral school, where a full and fair trial could be given to the pure oral method under test conditions. This scheme has been carried out recently at Philadelphia, and is said to give satisfactory results.

The establishment of a similar school in Glasgow would be a contribution to the vexed question of systems worthy of the Second City of the Empire, which should aspire to lead rather than follow in matters educational, as well as in municipal and commercial affairs.

Before finishing, I should like to say a few words with regard to the prospects of the deaf after they leave school. Many people ask me what we do with them, and seem surprised to find that they are able to do anything for themselves, or to earn their own living. There seems to be a notion that there is something "uncanny" about the deaf and dumb—that we keep a menagerie of wild animals who have to be tamed; and we often hear people exclaim, in tones of wonder, "they look intelligent." It may surprise you to hear how *very* intelligent some of them are, and with what success they engage in the various pursuits of life.

The majority of those who leave our schools, belonging, as they do, to the artisan class, engage in the various mechanical trades, and are preferred by some masters to hearing-and-speaking workpeople. Some draw very well, and attain good positions as engravers, lithographers, &c. In Liverpool, one deaf-mute friend of mine makes a good living as an enlarger of photographs; he also acts as an assistant-master in the School of Art there, and is much liked and respected by his hearing and speaking pupils.

Several mutes have obtained medals in the national competition at South Kensington, and only last year one of our own pupils obtained a prize there for modelling in clay. In London there is a deaf sculptor who is patronised by the Prince of Wales, while several deaf painters exhibit at the Royal Academy.

In America there are two or three deaf clergymen, regularly ordained, who preach to their fellows; and there is one deaf-mute in Church of England Orders.

Some years ago I had the pleasure of an interview with a deaf gentleman from Norway, who is employed in the Government Audit Office at Christiania. Though stone-deaf, he knows Latin, French, and German, besides his own native language, and can write English as fluently as a native with all his senses.

Mr. B. St. John Ackers, who has made a thorough investigation of the subject, both in England and on the Continent, says—"In Vienna we saw a fancy-leather merchant who employed seventy men under him, whose premises the Emperor and Empress of Austria visited before the great Vienna Exhibition, who could not only speak the language of his country fluently, but also a little English; who had visited England and other countries, was a practical horticulturist, and altogether an agreeable, intelligent, wealthy man—wealthy through his own educated talents and industry."

Again Mr. Ackers says—"We saw a dressmaker who had the leading business in one of the smaller German capitals. She was rather shy of talking about herself at our first interview. This came to the knowledge of her lover, who begged we would pay his betrothed another visit, which we did, escorted by him. The meeting was most amusing. He took her roundly to task for having appeared to so little advantage in the morning; and after some lively sparring, rattled off between them just as though both, instead of one, had been hearing persons, we chimed in, and had a long and very pleasant conversation with the deaf dressmaker. She assured us, and this was confirmed by inquiries we made, that in following her occupation the only means of communication between herself and those who employed her were articulation and lip-reading; she never had recourse to writing; finger-talking and signs she did not understand. A brighter, happier, and more contented woman than this dressmaker no hearing person could have been."

I could give numberless instances like these of deaf-mutes prospering and making their way in the world, but I think enough has been said to demonstrate that the time and money spent on our institutions and schools are not thrown away, but bear a rich harvest in the social and intellectual improvement of our pupils. We have many trials to bear, and many disappointments to put up with, in our work. Some pupils turn out badly, and some have a weakness of intellect joined to their want of hearing, which prevents them making the progress we could wish; but, on the whole, there is much to sustain and encourage us in our efforts to ameliorate the condition of this unfortunate class of the community.

I trust that those of you who are here to-night will carry away with you an enlarged idea of the capabilities of the deaf and dumb as a class, and should you ever become acquainted with any of them, I hope you will show your sympathy for them, by talking to them, and doing what little acts of kindness you can to alleviate what, at best, is a very forlorn and desolate condition. By so doing you will have the reward of an approving conscience, and the hearty thanks of a class who are extremely sensitive to, and grateful for, any kindness shown to them.

AN INQUIRY INTO

THE LIMITS OF HEARING.

BY

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AN INQUIRY INTO THE LIMITS OF HEARING.

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THE following paper deals with the subject of the Limits of Hearing under these heads :—

I. The lowest audible notes.
II. The highest audible notes.
III. The perception of difference in pitch.
IV. The distance at which a note of given intensity can be heard.
V. Tone or note deafness. *

THE LOWEST AUDIBLE NOTES.

The determination of the lower limit of the hearing of musical tones is beset with peculiar difficulty, because not only is there much individual difference in the power of hearing such tones, but it is difficult to be sure in examining compound tones that the fundamental tone is not obscured by a stronger upper partial, or indeed that a true fundamental is present at all. Helmholtz † has proved, by experiments with the Siren, that motions of the air which do not take the form of pendular vibrations can excite distinct and powerful sensations of tone, of which the pitch numbers are 2 or 3 times the number of the pulses of the air, and yet that no fundamental tone is heard at all. He was the first to give definite data for

* I hoped to add a section on the appreciation of musical intervals, but the instrument I devised for testing appreciation of pitch was found to be too small for the former purpose. I have under consideration the construction of a larger instrument and hope to resume the investigation at an early date. The English literature of the subject is scanty. I have therefore to apologise for the liberal use made of Professor Preyer's papers, "Ueber die Grenzen der Tonwahrnehmung" and "Akustiche Untersuchungen," to which I am also indebted for some of the references not within my reach. For help in carrying on the investigation I have to thank Dr. M'Kendrick ; the President and Leader of the Glasgow Choral Union ; Mr. Ballantyne, Mr. Schofield, and Mr. Cunninghame, and other musical friends.

† *Sensations of Tone*, translated by Alex. J. Ellis, p. 175.

the examination of the lower ranges of hearing. Before his time, however, attempts were made to determine the lower limit.

Sauveur * found that an organ pipe of 40 feet long gave the lowest note he could hear, but the difficulty of hearing the fundamental tone of even much shorter pipes makes it probable that he heard only an upper partial. The fundamental tone of such a pipe would have a vibration number of $12\frac{1}{2}$.

Chladni † gradually shortened a string till it made 16 vibrations per second and here got the first impression of tone, but Dr. Preyer considers there is an entire want of evidence that he heard the fundamental tone.

Biot ‡ stretched a string by increasing weights, and found that a vibration number of 16 was necessary that even the best ears might hear a tone. The tone produced gave the same impression as that of an organ pipe 32 feet long. But proof is wanting that the tone heard from such is its fundamental tone and is not that produced by the combination of this with an upper partial.

Wollaston || after noting the fact that exhaustion of the air in the tympanum creates deafness to low notes, states that "in the natural healthy ear there does not seem to be any strict limit to the power of discerning low notes. All persons who are not palpably defective in their organs of hearing continue sensible of vibratory motion until it becomes a mere tremor which may be felt or even almost counted."

Savart § thought 8 vibrations per second were heard as a tone, but Helmholtz points out that the means used—a rotating rod striking through a narrow slit—was quite unsuitable for making the lowest tone audible and has no doubt that the tones heard were upper partials. By another method Savart himself fixed the number 32 per second as giving the lowest audible tone. Here he used a revolving toothed wheel.

Despretz ¶ thought no less than 16 vibrations per second gave a tone, because he could get nothing under this which gave a sound which he could compare with any musical tone.

Helmholtz,** in discussing the lowest tones produced in organ pipes of 16 and 32 feet long states that in the upper part of the 32 foot octave the continuous sensation of tone

* *Hist. de l'Acad. Roy. des Sciences* (Année 1700), p. 190.
† *Die Akustik* (Leipzig, 1802), pp. 2, 36, 294.
‡ *Lehrb. d. Experimentalphysik.* Leipzig, 1829.
|| *Philosophical Transactions for Year 1820*, p. 310.
§ *Poggendorff's Ann. der Physik und Chemie*, 1830, 1831.
¶ *Poggendorff's Ann.*, 1845.
** *Sensations of Tone*, pp. 175-176.

disappears and that in the lower half nothing but the separate impulses are audible. The sensation of tone disappears, therefore, according to this observation when the vibrations have been reduced in number to about 28 or 26 per second. He has produced deep simple tones by another method. He stretched a thin brass pianoforte wire on a sounding box having only one opening by which the air could escape into the ear. The copper Kreutzer piece was attached to the middle of the string, and when the latter was struck a compound tone resulted, having a deep prime tone easily separated from the lowest upper partials, which in this case are several octaves above the prime. The tone of $37\frac{1}{8}$ vibrations was very weak and rather jarring. At $29\frac{1}{3}$ hardly anything was audible. From two great tuning forks Helmholtz was able to hear a tone of 30 vibrations, but thought he heard nothing at 28 vibrations, although he was able to produce oscillations with an amplitude of about $\frac{1}{3}$ of an inch.

Professor Preyer,* of Jena, also experimented with great tuning forks, and found that at 28 vibrations he heard a grumbling tone. At 24 vibrations his forks failed, but as the individual vibrations might, he thought, be too weak to produce a tone, he fell upon another method. He used metallic tongues, which, vibrating over 40 times per second, always gave the fundamental tone, and under 8 times a second gave nothing. The apparatus was made by Herr Appunn, of Hanau. Dr. Preyer argued that between 8 and 40 the lowest vibration number must exist, and his experiments with the great tuning forks made him sure that this lowest audible vibration number was between 8 and 28. The metallic tongues stand upright, so that each can be seen through the containing glass case. The air is forced in by a very strong bellows. Without resonators the fundamental tones above 32 can be easily heard in spite of the strong upper tones. Below 26 the most attentive ear heard the fundamentals with great difficulty. But if at the moment, when all murmuring ceased, the ear was closely applied to the wooden box, a deep buzzing tone was heard gradually diminishing in strength till it suddenly disappeared. That this was a true fundamental Dr. Preyer considers as certain, for the tone agrees certainly with that of the great tuning forks, and this tone is much deeper than any upper tone heard. The depth of this isolated fundamental tone increases with the lessening vibration number for all normal hearing persons down to 24. Below that the intensity diminishes rapidly although the vibration amplitude

* *Ueber die Grenzen der Tonwahrnehmung* (Jena, 1876), pp. 7-17.

increases, therefore the fundamental tone becomes almost certainly inaudible.

Dr. Preyer found that for himself the vibration number of the deepest tones lay between 14 and 20. None tested by him heard anything below 14. The interruptions were felt and the vibrations were seen but nothing was heard. From 8 to 14 the sound of the oscillations of the individual vibrations was heard, but above 14 the individual oscillations were still heard, and in addition a dull sensation of tone. Between 15 and 28 individuals differ as to the point at which the sensation of tone begins. A violinist heard 24 distinctly but heard nothing at 18 and 22. Dr. Preyer heard a deep tone at 19, at 18 and 17 he heard it less distinctly; at 16 he sometimes heard and sometimes not; at 15 he heard a soft dull sound difficult to describe, which, however, like all the deepest tones, is not grating or rough but agreeable. An observer who was not theoretically instructed but was naturally quick at hearing agreed with him in all these conclusions. As the result of hundreds of trials, during which the observer knew nothing of the exact vibration numbers of the tones, Dr. Preyer has constructed the following table :—

8, 9	No tone; an intermittent rubbing sound is heard; the intermissions can be counted.
10, 11, 12, 13, 14	No tone. The tremor is felt and the movement seen; the rattle is weaker.
15—	No tone. Some perceive an obscure sound.
16, 17, 18	The sensation of tone begins. In addition to the tremor which can be felt, many hear an obscure tone.
19, 20	Many hear a clear impression of tone. The tone is lightly buzzing.
21, 22	Many hear a buzzing tone.
23, 24	Everyone with normal hearing now hears a deep mild musical tone.
25, 26, 27, 28, 29, 30	As the tone becomes higher it is less easily heard, its duration is less but it is still clear.
31, 32	Tone still clear, but of shorter duration.
34, 35, 36, 38	The tone is very short and difficult to hear.
40	No tone can be made out because the after-vibrations of the reed are too weak.

Dr. Preyer says that much practice is needed to hear the deepest tones. His observations on different tones support his conclusions regarding the lower limits of hearing.

Helmholtz * thinks Dr. Preyer's results cannot be trusted on the evidence above presented. He says—"With extensive vibrations the tongues may have very easily given their points of attachment longitudinal impulses of double the frequency, because when they reached each extremity of their amplitude they might drive back the point of attachment through their flexion, whereas in the middle of the vibration they would draw it forward by the centrifugal force of their weight. Since the power of distinguishing pitch for these deepest tones is extremely imperfect, I do not feel my doubts removed by the judgment of the ear when the estimates are not checked by the counting of beats."

Mr. Alex. J. Ellis was able to supply this check on a copy of the instrument used by Dr. Preyer. The copy is in the South Kensington Museum. After detailing his experiments, Mr. Ellis adds—"There can be no question as to the real pitch." Mr. Ellis' experiments are given in detail in his last edition of Helmholtz' *Sensations of Tone*, and are embodied in a recent statement on the subject by Dr. Preyer,† and appear to leave little room for doubt.

But while tones of 16 to 20 vibrations per second can be heard by some ears, they are of no value in music. I cannot appreciate accurately the separate intervals on the piano below the lowest E and F having vibration numbers of 40 and $42\frac{2}{3}$ respectively. This may be because the tuning of these low notes is seldom perfect, but this very difficulty in tuning shows that these tones are on the border of the musical scale.

Dr. Preyer ‡ has recently had two great tuning forks made which give 13·7 and 18·6 vibrations per second. The former gave no note at all; the latter gave a distinct dull tone free from droning or jarring.

The Highest Audible Notes.

The next point to look at is the other end of the range of hearing. What is the highest audible note? From the very low tones we have just been considering, those represented by higher vibration numbers become more definite and more used in music for about seven octaves, when their musical

* *Sensations of Tone*, p. 176.

† *Akustiche Untersuchungen* (Jena, 1879), pp. 1-11.

‡ *Akustiche Untersuchungen*, p. 2.

value begins rapidly to diminish and soon disappears. The notes having vibration numbers from 256 to 1024 per second are those we most commonly hear. Human voices range from about 64 to 1400. Anything above 1400 is unusual, even in treble voices. The 16 foot C of the organ gives a note having 32 vibrations per second, as we have seen, which is questionably musical, and which is seldom used alone in organ music. Above 4000 vibrations per second the notes begin to be too indefinite in pitch to have a musical value. The highest note of most pianos has about 3500 for its vibration number; the highest of the piccolo flute, 4700. Such notes are useful chiefly to give brightness to the combinations in which they occur. But the ear can appreciate and often hears notes having a very much higher vibration number. The sounds made by bats, crickets, and some insects are caused by vibrations occurring at the rate of from 5000 to 15000 per second. The squeak of a mouse too is among the very high ranges. While most ears can hear these and even higher notes, curious instances of inability occur. Professor Tyndall * gives a good one. When he was crossing the Wengern Alp, in company with a friend, " the grass on each side of the path swarmed with insects which to me rent the air with their shrill chirruping. My friend heard nothing of this insect music, which lay beyond his limits of audition."

Many attempts have been made to ascertain the upper limits of hearing. Sauveur † accepted 6400 vibrations as producing the highest audible note. This he got from a pipe $\frac{15}{16}$ of an inch long.

Chladni ‡ adopted a note having a vibration number of 8192 as the highest audible, and Biot agrees with him.

Wollaston || found, when experimenting with small organ pipes, that a friend, who in other respects heard well, and who had a good perception of musical pitch, could not hear a pipe which gave a note which was four octaves above the middle E of the piano, and had therefore a vibration number little over 5000. A small pipe of $\frac{1}{4}$ inch long was his own limit. This must have produced vibrations of about 20,000 per second.§ He thought deafness to the chirruping of the sparrow exceedingly rare, to the sound of the cricket, several notes higher, not common, and to the piercing squeak of the

* *On Sound* (Longmans, Green & Co.), p. 71.

† *Hist. de l'Acad. Roy. des Sciences* (1700), p. 190.

‡ *Die Akustik*, p. 34.

|| *Philosophical Transactions for 1820.*

§ This supposes a pipe of very small scale and open, also that measurement was from upper lip. See p. 22.

bat, considerably higher than these two, not very rare. Two relatives of his own were deaf to some of these higher natural sounds.

Despretz * had very small forks made which gave the following notes :—

C^{IV}	with	2,048	vibrations.
C^{V}	,,	4,096	,,
C^{VI}	,,	8,192	,,
C^{VII}	,,	16,384	,,
C^{VIII}	,,	32,768	,,

He found that with practice all could be heard. Some observers heard them well and recognised them for octaves, so that the interval C^{VI} to C^{VII} was heard, and after much labour accurately recognised, but the continual hearing of these high notes occasioned violent headaches, and the hearing of very high notes took place slowly. No tone above 36,864 (D^{VIII}) could be produced, F^{VIII} could not be produced by shortening the forks, and E^{VIII} was inaudible.

With Appunn's Siren 24,000 interruptions of the air were produced per second, and in addition to the current of air some observers heard a very distinct, although faint, high tone. Many, however, heard only the air current. König, of Paris, by means of steel rods reached a vibration number of 32,768, but Dr. Preyer found that only himself and another heard anything when the highest was sounded, and the two lower with 24,576 and 20,480 were no better heard by the majority of observers. Some heard a short faint tone at 20,480. Many older persons heard nothing at 12,288 and one student of 20 years of age could scarcely hear this tone although quick at hearing in other respects. In connection with this subject Herr Appunn has constructed a series of 31 tuning forks, representing a diatonic scale of 4¼ octaves with vibration numbers from C^{IV} 2,048 to C^{VIII} 40,960. These were constructed at immense trouble, and the difficulties connected with the higher forks can hardly be estimated. Herr Appunn informed † Mr. Ellis that 100 guineas would not pay him for the mere labour of making these forks. They were shown at the Loan Exhibition, and at the end of the Exhibition purchased by the authorities of the South Kensington Museum. The following are the notes and vibration numbers of the forks :—

* *Poggend. Ann.*, 1845.

† "On the Sensitiveness of the Ear to pitch and change of pitch in music," by Alex. J. Ellis. 1877, p. 10.

Fork.	Note.	Vibrations.	Fork.	Note.	Vibrations.
1	C^{IV}	2,048	17	E^{VI}	10,240
2	D^{IV}	2,304	18	F^{VI}	10,922$\frac{2}{3}$
3	E^{IV}	2,560	19	G^{VI}	12,288
4	F^{IV}	2,730$\frac{2}{3}$	20	A^{VI}	13,653$\frac{1}{3}$
5	G^{IV}	3,072	21	B^{VI}	15,360
6	A^{IV}	3,413$\frac{1}{3}$	22	C^{VII}	16,384
7	B^{IV}	3,840	23	D^{VII}	18,432
8	C^{V}	4,096	24	E^{VII}	20,480
9	D^{V}	4,608	25	F^{VII}	21,845$\frac{1}{3}$
10	E^{V}	5,120	26	G^{VII}	24,576
11	F^{V}	5,461$\frac{1}{3}$	27	A^{VII}	27,306$\frac{2}{3}$
12	G^{V}	6,144	28	B^{VII}	30,720
13	A^{V}	6,826$\frac{2}{3}$	29	C^{VIII}	32,768
14	B^{V}	7,680	30	D^{VIII}	36,864
15	C^{VI}	8,192	31	E^{VIII}	40,960
16	D^{VI}	9,216			

Dr. Preyer * has had opportunity of working with these forks. He and several others have heard all the 31 tones and have been able to distinguish the difference of tone in all. Up to C^{VII} the scale can be easily heard. Good observers can hear the octaves certainly up to E^{VIII}, but often fail at the fifths. To some the highest tones lose entirely their musical characters and they have the feeling "that very fine needles were being stuck into the ears." Other disagreeable sensations were described. One felt "as if a thread were being drawn through the cheek from the ear to the chin along the bone of the lower jaw." Another found the E^{VIII}, which many could not hear, very soft. To Dr. Preyer himself the notes from the E^{VII} upwards gave the sensation of "the tympanic membranes being drawn inwards." In every case when B^{VI} was strongly struck he had a keen pain in the ear and a feeling of creeping in the skin of the back. Prolonged listening produced headaches. But Dr. Preyer did not find that he heard these notes slowly as Despretz did, although the judgment of the pitch required more time. At 6 metres distance the painful effects disappeared, and all the tones up to E^{VIII} inclusive were heard pure and without pain.

From C^{IV} to C^{VI} the tones are pure and pleasant. At C^{VI} much depends on the intensity of the tone. Only where the forks were very strongly struck did the sound give rise to pain.

The technical difficulties in making such forks are so great and the price, of necessity, so high, that few can hope to have

* *Ueber die Grenzen der Tonwahrnehmung*, p. 21-25.

Dr. Preyer's experience of them.* Mr. Francis Galton has, however, given us a simple means of producing very high notes. He uses a whistle consisting of a tube of very fine bore, which can be shortened or lengthened by the movement of a small piston or plug. It is sounded by the compression of a small india-rubber bag fastened to the end of the apparatus. Mr. Galton tells me that the best whistles for testing human hearing are made by the Cambridge Scientific Instrument Co.

The whistle always makes two sounds at the same time, the high musical note best described as a shrill squeak and the noise made by the air leaving the mouth of the whistle. To apply the test the whistle is sounded and the length shortened till a point is reached when the squeak becomes inaudible. With a little practice this can be easily done. The length of the whistle is then measured, by inserting a wedge-shaped ivory scale between a flange fixed to the piston and a flange on the whistle, the numbers engraved on the whistle giving the length of the whistle in millimetres. I append the figures accompanying the Cambridge whistles :—

Length of Column of Air in millimetres.	No. of Complete Vibrations per second by calculation.	Length of Column of Air in millimetres.	No. of Complete Vibrations per second by calculation.
1·	85,000	3·5	24,290
1·2	70,830	4·	21,250
1·4	60,710	5·	17,000
1·5	56,670	6·	14,170
1·6	53,130	7·	12,140
1·8	47,220	8·	10,630
2·	42,500	9·	9,443
2·5	34,000	10·	8,500
3·	28,330		

(A correction has to be made for these figures which I shall shortly explain.)

Mr. Galton, in his *Enquiry into Human Faculty,* says—" On testing different persons, I found there was a remarkable falling off in the power of hearing high notes as age advanced. The persons themselves were quite unconscious of their deficiency so long as their sense of hearing low notes remained unimpaired. It is an only too amusing experiment to test a party of persons of various ages, including some rather elderly and self-satisfied personages. They are indignant at being thought deficient in the power of hearing, yet the experiment quickly shows that they are absolutely deaf to

* *Enquiry into Human Faculty.*

shrill notes which younger persons hear acutely, and they commonly betray much dislike to the discovery. Every one has his limit, and the limit at which sounds become too shrill to be audible to any particular person can be quickly determined by this little instrument. Lord Rayleigh and others have found that sensitive flames are powerfully affected by the vibrations of whistles that are too rapid to be audible to ordinary ears. I have tried the experiment with all kinds of animals on their power of hearing shrill notes. I have gone through the whole Zoological Gardens using an apparatus for the purpose. It consists of a walking stick that is in reality a long tube. It has a bit of india-rubber pipe under the handle, a sudden squeeze on which forces a little sound. I hold the stick as near as is safe to the ears of the animals, and when they are quite accustomed to its presence and heedless of it, I make it sound. Then if they prick their ears it shows they hear the whistle. If they do not, it is probably inaudible to them. Still, it is very possible that in some cases they hear but do not heed the sound. Of all creatures, I have found none superior to cats in their power of hearing shrill notes. It is perfectly remarkable what a faculty they have in this way. Cats, of course, have to deal in the dark with mice and to find them out by their squeals. Many people cannot hear the shrill squeak of a mouse. Some time ago singing mice were exhibited in London, and of the people who went to hear them, some could hear nothing while others could hear a little, and others, again, could hear much. Cats are differentiated by natural selection until they have the power of hearing all the high notes made by mice and other little creatures they have to catch. A cat that is at a very considerable distance can be made to turn its ear round by sounding a note that is too shrill to be audible by almost any human ear." Mr. Galton also found that small dogs heard much higher notes than large ones.

In consequence of the narrowness of the pipe, the usual rule for calculating the vibration number of any note from the velocity of sound and the length of pipe used in the production of that note, gives only a result which is roughly approximate to the truth. By acting on a sensitive flame in free air * Messrs W. N. Shaw and F. M. Turner found the true wave-lengths of the notes tested. The wave-length measured in this way was considerably greater than four times the length of the whistle pipe, and it varied appreciably

* "On some measurements of the notes of a whistle of adjustable pitch." (*Proceed. Cambridge Phil. Soc.*, 28th Feb., 1887.)

with the pressure of the air with which the whistle was blown. The flame flared, however short the length of the pipe, but the shortest length which gave notes was 15·84 mm. corresponding to a vibration frequency of 21·517 complete vibrations per second. The length of the pipe was 3 mm., and neither observer heard the pipe at a less length than 3·7 mm.; so that distinct notes were obtained when the sound was inaudible.

The general results of these investigations were :—

(1.) That the wave-length in free air is considerably greater than four times the length of the whistle.

(2.) That of 3 whistles tested, no marked difference was noticed in the individual results.

(3.) That the wave length perceptibly diminishes, that is, the pitch rises as the pressure of air increases.

In experimenting with very high notes I found Mr. Galton's whistle failed in the intensity of the sound produced. Its range, too, is limited. At 5 mm. where the vibration number is nominally 17,000, and actually about 13,000, the note to me loses its clearness and is much blinded by the rush of wind. At 4 mm. I can sometimes hear the note and sometimes not, but it is more of a metallic wheeze than a true note. I have met no observer who can hear the note at 3 mm. where Messrs Shaw and Turner found the vibration frequency to be 21·517. At 10 mm. the whistle becomes nearly inaudible to me, and I hear only a dull whish replacing the note, which however, now and then is heard by slight and careful blowing. Following Dr. Wollaston, I have used small open organ pipes for the production of high notes. The smallest pipes used in organs are called Fifteenths. These measure from 4½ to 5 mm. diameter. I have also had pipes made by Mr White, of Cambridge Street, of a diameter of 2 and 3 mm. By cutting these down I have succeeded in getting notes from a pipe of 6 mm. length, and in one case of 5 mm., measured from the upper lip of the mouth. (This is the plan of measurement adopted in the article "Organ" *Encyclopædia Britannica*, and is apparently adopted for the Cambridge Whistles.) The total length of the whistle or pipe is 1 mm. more than these figures. Calculating by length only, these pipes must give notes of from 28,000 to 34,000 (nominal vibration number), or, if Messrs. Shaw and Turner's correction can be taken for open pipes, of 21,000 to 25,000 vibrations per second. I have not yet had opportunity of testing them with the sensitive flame, but they appeal to the ear as higher than the notes of

Mr. Galton's whistle. With these small open pipes I have been able to make very high notes audible to elderly persons who were quite deaf to the notes of the whistle.

If Dr. Wollaston used an open pipe, and if the pipe was an ordinary organ pipe, his note must have been somewhere between 15,000 and 20,000 vibrations per second. I assume that the measurement was from the upper lip, but the absence of data as to these points deprives the experiment of much of its value. I have, therefore, thought it worth while to give the accurate measurements of the pipes I have used, and to add some remarks on the influence of width on the pitch of a pipe. In books on acoustics it is taught that pitch depends on length. No notice is taken of the " scale " or diameter of the pipe. Organ builders know that scale or diameter influences pitch, and build accordingly. Hopkins states the matter thus: "An alteration of scale produces a slight difference in the length of a pipe producing a given sound." The influence of the diameter on pitch can be shown by the following experiment: Let two ordinary metal diapason pipes, respectively of 11 and 15 mm. diameter, or " scale," be taken and cut down to a length of 68 mm. Under any ordinary wind pressure these pipes will give their fundamental notes, whether open or closed, and there is no risk of mistaking the fundamental for any over tone. Let the foot, languid, and lips be alike in the two pipes, and let them differ only in diameter. When used as closed pipes the broader will give the 1024 C, the narrower a full tone above this, the D with 1157 vibrations. Let now a third pipe of the same diameter as the broader of the first two be cut down to a length of 58 mm. It will give the same note as the narrow pipe of 68 mm. length. If the pipes be sounded as open pipes a similar difference in the higher octave is found. A and B will be a tone apart, whilst B and C will be in unison.

I have been unable to find in any English work a law which states the influence of diameter on pitch, but in *Annales de Chimie et de Physique*, vol. xxxi, p. 394, M. G. Werthein gives the following formula for cylindrical pipes:—

$$n = \frac{v}{2\,(L + 2\,c\,\sqrt{s})}$$ where

n = number of vibrations per second.

v = velocity of sound in air at given temperature.

l = length of pipe.

s = cross sectional area of pipe.

c = constant to be determined by experiment.

He also gives a set of tables which shows that this formula is not rigidly applicable, for in 42 experiments in cylindrical pipes the constant varies from ·17 to ·256. By the application of this formula to the above three pipes, a similar variation was found.

My observations on the hearing of very high notes corroborate, for the most part, those of Dr. Preyer and Mr. Galton. Between 40 and 50 years of age appreciation for these tones begins to be impaired, but not to the same extent in musical as in unmusical people. Deafness to the notes of Mr. Galton's whistle is common after 50. Hearing is sometimes retained at 60. I have met with one very remarkable case of deafness to high notes which is an exact parallel to that recorded by Dr. Wollaston. A musical friend, whose ear I have found to be acute for the appreciation of small intervals, is deaf to all notes above D^{V} (4752 vibrations.) He hears this note badly on the organ. He hears nothing when E^{V} is sounded (5280 vibrations), but he hears C^{V} (4220 vibrations) distinctly. Dr. Wollaston thinks that in very early life there is deafness to very high notes. He says, however, that this opinion is not founded on direct experiment but "rests on the statement of persons now grown up." My experiments with children do not support this opinion. Children old enough to understand the experiment hear high notes as well as adults.

Dr. Thomas Barr * found the perception of high notes destroyed or diminished in the case of boilermakers and others who work amidst noisy surroundings. I have met with one case in which shrill notes are very disagreeable to the left ear but are heard by the right ear without unpleasantness. A weakly-ticking watch was heard by both ears equally well, and hearing was in other respects normal. Examination by speculum showed both ears healthy and apparently alike. I do not know if this peculiarity has been noted before, but it is worth while recording, in connection with Fechner's statement, that in individuals of normal hearing the left is more acute than the right ear. In connection with this case Mr. W. H. Cole, with whom I discussed it, informs me that when listening attentively for anything out of tune in any of the instruments of his band, he "invariably uses the left ear and would never think of using the right." He thinks the use of the baton with the right hand may have something to do with this choice of the left ear.

* *Glasgow Philosophical Society*, 3rd March, 1886.

The Appreciation of Difference in Pitch.

THE determination of the smallest fraction of a semitone which can be perceived is a point of much interest and some difficulty. Delezenne * found that when a metal string of 11·47 mm. was so divided that one section was 1 mm. longer than the other, only practised ears could distinguish the difference in pitch. The relative vibration numbers were 1149 and 1145. Wilhelm Weber was able by the ear alone to distinguish tones so exactly that his mistakes at 200 vibrations per second were with intervals of less than 1 vibration. Sauveur perceived the difference between 2 unisonous monochord strings when the one was shortened by $\frac{1}{2000}$ part of the length. The pitch of the note is not given.

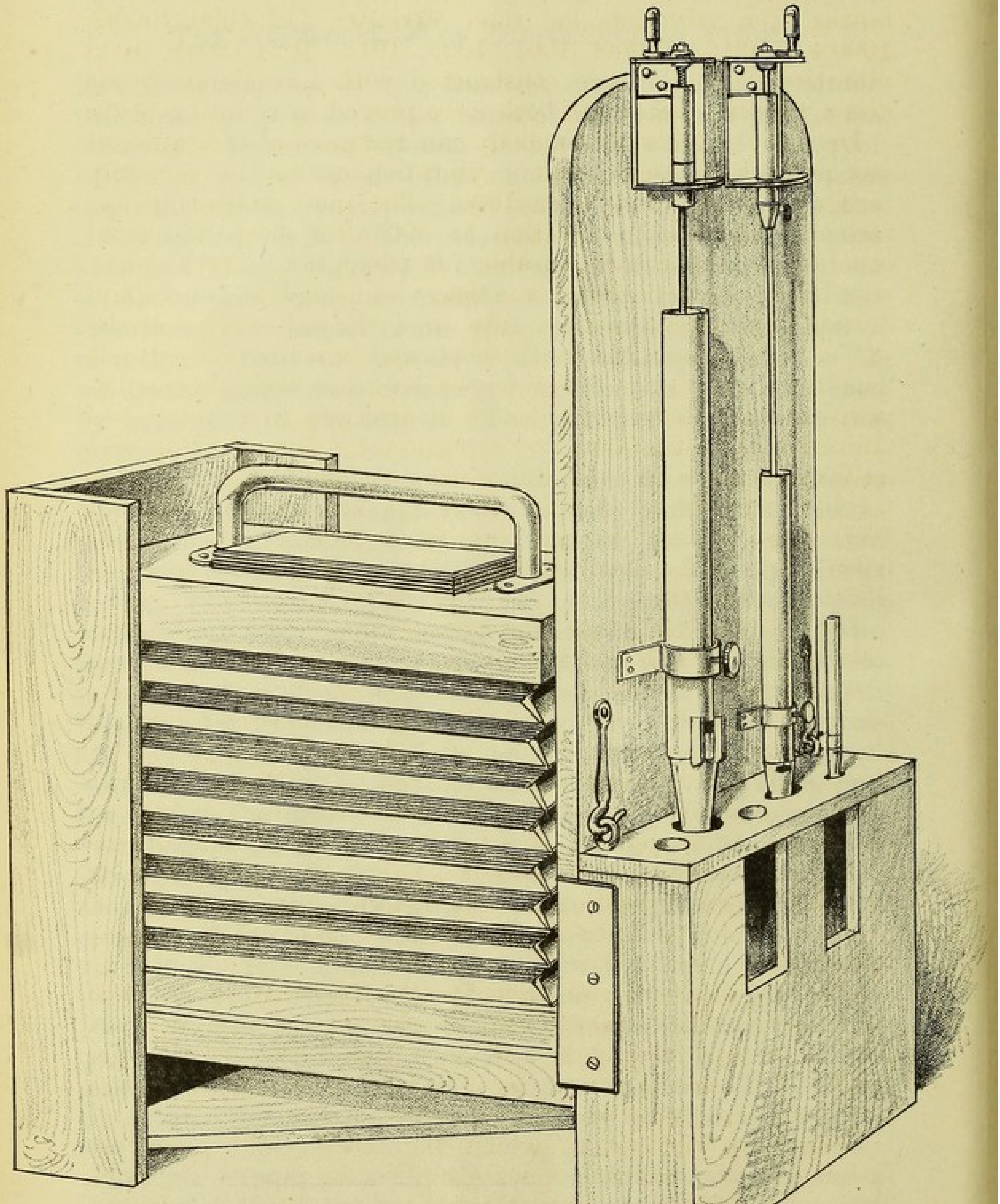
Seebeck † could distinguish a difference of one vibration at 1000 per second. He and two violinists could easily distinguish the difference between 2 notes having vibration numbers respectively of 439·636 and 440. By using forks having vibration numbers of 440 and 439·75, Preyer and another musician could easily make out whether the two forks were sounded successively, or if one was sounded twice in succession. Since, however, the experiment was not often repeated, Dr. Preyer does not insist on this ability to appreciate $\frac{1}{4}$ vibration-difference. By another method he examined sounds having vibration numbers from 128 to 1024, and found that the unskilled always detected a difference of 16 vibrations within these three octaves, that a difference of 8 vibrations near C 128, C 256, and C 512 was generally recognised by those unskilled or little skilled; near 1024 erroneous judgments were obtained with a difference of 8 vibrations. Here unmusical people often failed to distinguish the tones 1016 from 1024; 1016 from 1008, and 1000 from 1008. Such errors occurred even oftener when the difference was only 4 vibrations, even at C 256 and C 512. Those practised never made a mistake at 4 vibrations. They erred when the difference was only 1 vibration at 1000 and even at 500.

For his experiments Dr. Preyer ‡ used a Tonometer and a Differential Apparatus made by Herr Appunn. The tonometer contained 33 tones, from C 128 to C 256. The differential

* *Societé de Sciences de l'Agriculture et des Arts de Lille.* 1826.

† *Poggendorff's Ann.* 1846.

‡ *Ueber die Grenzen der Tonwahrnehmung* (Jena, 1876), pp. 28-35.



apparatus had 25 tones, from 500 to 501, proceeding by tenths of a vibration and then 504, 508, 512, 1000, 1000·2, 1000·4, 1000·6, 1000·8, 1001, 1008, 1016, 1024, 2048, 4096 vibrations. Both were constructed with harmonium reeds and a wind regulator and both were proved by counting beats.

Dr. Preyer finds that nobody can recognise $\frac{1}{10}$ vibration at any part of the scale, that $\frac{1}{5}$ vibration cannot be certainly recognised either at 500 or 1000. The most skilful always recognise $\frac{3}{10}$ and $\frac{4}{10}$ vibration at 500 after sleep and amid other circumstances favourable for perception. Such keenness Dr. Preyer found only amongst violin-players, tuners, and musical instrument makers, also in a clinical student accustomed to the use of the stethoscope, and in a linguist, but not usually in pianists. A few weeks' training with the instrument makes observers proficient in discriminating pitch, and training has reduced Dr. Preyer's minimum from a whole to a half vibration when the tones are near 500. He is not so sensitive at 1000 as at 500. Herr Appunn always recognises 1000 from 1000·5, but not 1000 from 1000·25, and not 500 from 500·2. The extreme limits appear to be 500 to 500·3, and 1000 to 1000·4.

The instrument I use for testing appreciation of small differences of pitch consists of closed organ pipes, which can be shortened or lengthened by movable stoppers. The stoppers are controlled by very carefully adjusted screws having a known number of turns to the inch. At the top of each screw is a horizontal index-plate round which a pointer turns. The plate is graduated to twentieths of its circumference, and as the screw is moved by the turning of the handle of the revolving pointer, the pipe can be lengthened or shortened by an amount corresponding to any distance greater than that represented by a twentieth of a turn. The figure shows the instrument.

The two screws I use have 21 and 42 turns to the inch respectively. The stoppers can be made to advance or recede within the pipe through any distance from 3 inches, the entire length of the screws, to $\frac{1}{420}$ or $\frac{1}{840}$ of an inch—the value of a twentieth of turn for the screws respectively.

Behind an upright to which the screws and pipes are fastened is the bellows which supplies the pipes with wind. This falls through a short distance—about 2 inches under a weight of three or four pounds, producing a note from the pipes of from $1\frac{1}{2}$ to 2 seconds in duration. The fall of the bellows is checked by its contact with two horizontal bars placed at its ends. Unless thus checked the tone begins to flatten appreciably when the supply of wind is almost exhausted. The note is brought to even a better and sharper termination if the bellows be caught up by the handle, the chief use of which is to raise the bellows preparatory to its fall. The bellows descends between anterior and posterior and lateral black-leaded slips which prevent rocking. The same loudness, duration, quality, and steadiness of successive tones is thus ensured, for the sounds are produced by the same volume of air expelled under a constant pressure. The pipes I have used chiefly are the 1 foot 6 inches and 3 inches closed pipes giving notes of 256, 512, 1024, and 2048 vibrations per second. The 3 inches pipe produces the two latter notes at its upper and lower ends respectively. Longer pipes than the largest of these make the instrument clumsy. The body of the pipes is made of brass to allow of the fitting of air-tight stoppers and of the application of a clamp to prevent the rising of the pipe under the application of the screw. A movement of the stopper through a given distance produces a different interval at different parts of the scale. For the coarser screw I found that 8 turns produced an interval of a semitone at the 512 C; 16 turns were required for the same interval at middle (256) C, and 4 and 2 turns for the two upper C's respectively. For the finer screw, of course a similar interval required twice the number of turns. Hence the necessity in stating the relative sensitiveness of two ears or the result of several observations on the same ear to give the pitch at which the experiment was tried, or at least to translate the reading of the screw into one of an absolute interval.

(Another reason for giving the absolute pitch, or at least for giving the pitch to the nearest tone or semitone, is that the ear is said to be sensitive in a very different degree at the various parts of the scale.)

TABLE SHOWING VALUE OF SCREWS IN FRACTIONS OF A SEMITONE.

	1 Turn.		$\frac{1}{2}$ Turn.		$\frac{1}{4}$ Turn.		$\frac{1}{10}$ Turn.	
	Fine Screw.	Coarse Screw.	Fine Screw.	Coarse Screw.	Fine Screw.	Coarse Screw.	Fine Screw.	Coarse Screw.
256	$\frac{1}{32}$ sem.	$\frac{1}{16}$ sem.	$\frac{1}{64}$ sem.	$\frac{1}{32}$ sem.	$\frac{1}{128}$ sem.	$\frac{1}{64}$ sem.	$\frac{1}{320}$ sem.	$\frac{1}{160}$ sem.
512	$\frac{1}{16}$,,	$\frac{1}{8}$,,	$\frac{1}{32}$,,	$\frac{1}{16}$,,	$\frac{1}{64}$,,	$\frac{1}{32}$,,	$\frac{1}{160}$,,	$\frac{1}{80}$,,
1024	$\frac{1}{8}$,,	$\frac{1}{4}$,,	$\frac{1}{16}$,,	$\frac{1}{8}$,,	$\frac{1}{32}$,,	$\frac{1}{16}$,,	$\frac{1}{80}$,,	$\frac{1}{40}$,,
2048	$\frac{1}{4}$,,	$\frac{1}{2}$,,	$\frac{1}{8}$,,	$\frac{1}{4}$,,	$\frac{1}{16}$,,	$\frac{1}{8}$,,	$\frac{1}{40}$,,	$\frac{1}{20}$,,

In using this instrument in the testing of the hearing of considerable companies, I wrote out a list of 15 to 35 tests, to which the observers were asked to listen. Each test was applied as follows:—A note in the neighbourhood of one of the C's was sounded and repeated, after which the screw was altered. As rapidly as possible the changed note was sounded, and the observer asked to put down his opinion of the third note in the words flat, sharp, or unchanged. Observers were seated as far apart as practicable, the working of the screws was hidden by a screen placed before them, and every precaution adopted to fix the attention of the observers on the experiment. They were asked never to guess, but, on the other hand, to give their ears the benefit of the slightest impression formed just after the sounding of the third or altered note. Under each octave several blank tests were given, to accustom the ear to the pitch; and in judging of the capacity of any ear, more emphasis was put on the later than on the earlier tests. The following is an example of a set of tests:—

1.	$\frac{1}{4}$	semitone	sharp,	256 C.
2.	$\frac{1}{8}$	,,	flat,	
3.	$\frac{1}{16}$	,,	sharp,	
4.	$\frac{1}{32}$	,,	sharp,	
5.	$\frac{1}{64}$	,,	flat,	
6.	$\frac{1}{8}$	,,	sharp,	512 C.
7.	$\frac{1}{16}$	,,	flat,	
8.	$\frac{1}{32}$	,,	sharp,	
9.	$\frac{1}{64}$	,,	sharp,	
10.	$\frac{1}{64}$	,,	flat,	
11.	$\frac{1}{80}$	,,	flat,	
12.	$\frac{1}{16}$	semitone	flat,	1024 C.
13.	$\frac{1}{32}$	,,	sharp,	
14.	$\frac{1}{32}$	,,	flat,	
15.	$\frac{1}{80}$	,,	sharp,	
16.	$\frac{1}{80}$	,,	flat,	
17.	$\frac{1}{8}$	,,	flat,	2048 C.
18.	$\frac{1}{32}$	,,	sharp,	
19.	$\frac{1}{32}$	,,	flat,	
20.	$\frac{1}{16}$	,,	sharp,	
21.	$\frac{1}{40}$	,,	sharp,	

Results got by this method can only be taken as representing roughly the capacity of any individual observer. In spite of my precautions guessing was probably adopted by some observers, and in such large companies little incidents occur which divert the attention from the business in hand. In testing pianists, violinists, and other trained observers, I have generally taken observers individually or in companies of two or three. But the observations with even the largest of the companies may be taken to represent the capacity of the class to which they belong, and are useful and quite reliable in making comparative statements of the capacity of such class.

The first tests were applied to 22 members of the 38th Company of the Glasgow Boys' Brigade. The ages of these ranged from 10 to 17 years, and the tests included intervals varying from $\frac{1}{2}$ to $\frac{1}{48}$ semitone. Five of these young observers were not reliable for the appreciation of a difference of $\frac{1}{3}$ semitone, 8 were doubtful of $\frac{1}{6}$, 3 were generally correct at $\frac{1}{12}$, 5 were usually correct at $\frac{1}{24}$, and 1 boy of 15 years made no error in the paper of 15 tests, which contained three intervals of $\frac{1}{48}$ semitone and several of $\frac{1}{24}$. This boy had no experience in the use of any instrument, but had two years' choral training in the Southern Boys' Choir. His is an example of a naturally fine ear, for choral singing does not do much for the faculty to which these tests were applied. Among the good observers—viz., those who detected $\frac{1}{24}$ and $\frac{1}{12}$ semitone with tolerable accuracy—nearly all the grosser errors were in the observation of notes which had been flattened. Ears which detected $\frac{1}{24}$ semitone sharp with much certainty sometimes mistook or failed to detect $\frac{1}{12}$ or even $\frac{1}{6}$ semitone flat.

The same set of tests were applied to 8 boys chosen by Mr. M'Nab as good ears from the membership of the Glasgow Southern Boys' Choir. Their ages were from 13 to 15 years, and their training had in each case extended to three years. Three of these boys detected all the sharps—viz., up to $\frac{1}{48}$ semitone. Their only errors were with flats, but these were sometimes with intervals of $\frac{1}{6}$ semitone. Another mistook one of the intervals of $\frac{1}{48}$ semitone, but had all other sharps correct. He had two errors of $\frac{1}{6}$ semitone flat. A fourth was pretty sure of intervals of $\frac{1}{12}$ semitone, and the remaining 4 made mistakes at coarser intervals, both sharps and flats.

A miscellaneous company was found in the class of Physiography at the Highlanders' Academy, Greenock. I mean miscellaneous so far as musical training and natural fineness of ear are concerned. Half of them were ladies, and the members varied in age from 13 or 14 to 22 years. The total number was 36. Sixteen were doubtful of intervals of $\frac{1}{3}$ or $\frac{2}{3}$ semitone; 5 failed at $\frac{1}{6}$, 5 at $\frac{1}{12}$, and the remaining 12 were generally correct at these intervals, but failed at $\frac{1}{24}$ and $\frac{1}{48}$ semitone. The same relative want of perception for differences in the pitch of flattened notes was noticed in all these observers. Professor M'Kendrick gave facilities for testing his class in the Physiology Class Room of the University of Glasgow. Forty-nine of these gentlemen, in two companies, subjected themselves to the tests. They may be taken as intelligent observers not generally musically trained. Of these 49, 25 so often mistook, or did not detect an interval of $\frac{1}{8}$ semitone that they could not be considered reliable for it. Eleven were generally correct at $\frac{1}{8}$ semitone but often incorrect at $\frac{1}{16}$; the remaining 13 sometimes detected intervals of $\frac{1}{32}$ and $\frac{1}{40}$ and sometimes not, but were usually correct with coarser intervals. Nearly all of these better observers were more correct with sharps than flats. I have had opportunities of testing the ears of 55 members of church choirs, choral unions, &c. Eighteen of these commonly made errors at $\frac{1}{8}$ semitone. Nineteen were generally correct at $\frac{1}{8}$, but often mistook or failed to detect $\frac{1}{16}$; 15 failed at $\frac{1}{32}$, but were usually correct at $\frac{1}{16}$; 2 were reliable at $\frac{1}{32}$ semitone sharp, but generally unreliable at $\frac{1}{64}$ and $\frac{1}{80}$ sharp, and these 2 sometimes mistook, or did not detect $\frac{1}{16}$ semitone flat. One was correct for all intervals of more than $\frac{1}{40}$ semitone. He had no pianoforte training, but played the instrument "from ear." The general remark regarding the relative want of appreciation for flattened notes holds good for all these observers. Trained musicians—pianists, violinists, and tuners—are shy of an experiment of this kind, but a large enough number have submitted themselves to my tests to enable some inferences to be drawn. Generally speaking, there was no difficulty with intervals greater than $\frac{1}{80}$ or $\frac{1}{64}$ semitones. Two friends, one a good vocalist and pianist (see reference after), the other a professional organ-tuner and a violinist, were tested with the following intervals :—

$\frac{1}{8}$	semitone	flat.	$\frac{1}{40}$	semitone	flat.
$\frac{1}{8}$	„	sharp.	$\frac{1}{40}$	„	sharp.
$\frac{1}{16}$	„	sharp.	$\frac{1}{80}$	„	flat.
$\frac{1}{32}$	„	flat.	$\frac{1}{80}$	„	sharp.

These were given under each of the 3 octaves 512, 1024, and 2048 as near the C's as possible, but in a different order for each octave. The pianist erred in only 1 of the 24 tests, $\frac{1}{32}$ semitone sharp in the 512 octave. The tuner erred in 2 intervals of $\frac{1}{80}$ at the 512 C, 2 of $\frac{1}{40}$ at the 1024 C, and was doubtful of 1 interval of $\frac{1}{80}$ at the 2048 C.

Another similar set of tests were applied to two pianists and two violinists. They were generally correct for $\frac{1}{32}$, $\frac{1}{40}$, and $\frac{1}{80}$ semitones, but none gave intelligent replies to the tests of $\frac{1}{160}$ semitones. This last interval I have tried only at the 512 and 1024 octaves.

Amongst these trained observers the errors were perhaps still chiefly with the flattened intervals, but the difference between the keenness for sharps and flats was much less marked than in the case of untrained ears.

The tests described above as having been set to the pianist and tuner lead to the consideration of what is known as Weber's Law. This law claims to be a scientific expression of the relations between the changes in the intensity of stimuli and the consequent changes in the quantity of the resulting sensations. It is applicable, according to Weber, its author, and Fechner, its chief defender, to all the senses. With reference to the subject here discussed, it is thus formulated:* "In the comparison of the heights of 2 tones it is a matter of no moment whether the tones are high or low, as long as they are not extremely high or extremely low. It does not depend on the number of vibrations which one tone has more than the other, but on the relation of the number of the vibrations causing the two tones which are compared."

In other words, if we assume that the least observable difference in sensation may be regarded as a constant quantity, then for the production of this the addition of a much greater amount of stimulus is required for the higher than the lower parts of the scale. For example, if in any given case the least observable difference at 500 vibrations be half a vibration, then at 1000 vibrations the least observable difference will be represented by something more than half a vibration, but these two least observable differences will have the same relation to the pitch numbers at which they were heard. By this law, therefore, we should be able to fix a fraction of an octave or of a semitone, which is the least observable at all parts of the scale except the lowest and highest, and which is represented by an increasing vibration number as the pitch rises.

Dr. Preyer cannot accept Weber's Law as applicable to hearing. He finds that between 256 and 1024 the smallest interval heard is between ·3 and ·5 vibrations, ·2 not being anywhere heard and ·5 always heard. He thinks that from A^{I} ($426\frac{2}{3}$) to C^{II} (512) a smaller vibration difference is recognised than at any other part of the scale, and that this part of the scale is therefore specially favourable for recognising small differences in pitch. He states that the recognisable difference in tone expressed in absolute vibration numbers is least in the neighbourhood of A^{I} and C^{II} and increases both upwards and downwards. The relative sense of difference increases with the pitch up to 1000, where $\frac{1}{2}$ vibration or $\frac{1}{2000}$ of a difference can be recognised. Dr. Preyer also found that below 128 vibrations keenness diminishes rapidly, and above 1024 very probably it decreases slowly, and appreciation becomes very dull above C^{V} (4224 vibrations). But he thinks a part of the scale may be found near Fis^{IV} ($2844\frac{4}{5}$ vibrations), corresponding to A^{I} and C^{II} where the ear is very keen. He

* Wagner's *Dictionary of Physiology*, 1846, vol. ii, p. 560.

thinks keenness is less at C^{IV} (2048 vibrations) than at C^{III} (1024 vibrations). Such are the arguments urged by Dr. Preyer against Weber's Law as applied to hearing.

The results of my experiments, while they may not support the minute application of the law, favour its adoption as a general principle. They are somewhat at variance with those of Dr. Preyer.

From the first the tests were arranged to bring out the ability of the ear at the various octaves. The notes were always very near the C's, and in every set of tests 3 or 4 at least were the same for each octave. Ultimately tests were given to trained ears to elicit the facts regarding the law. In respect of relative keenness untrained and slightly trained ears are as good at 256 and 2048 as at 512 and 1024 vibrations. It may be urged that observers who sometimes make errors at $\frac{1}{12}$ or $\frac{1}{24}$ semitones are not suitable for the experiment, for the results are not always the minimum observable differences. But again the conditions of the test are the same for each octave, and the results above stated are true of the great majority of the 200 observers I have examined. I can make out no special keenness for notes between A^{I} and C^{II}, and I believe that keenness does not appreciably diminish until the pitch is above C^{IV} (2048 vibrations).

A professional violinist and an organist were tested with the following intervals :—

$\frac{1}{40}$ semitone sharp.	$\frac{1}{40}$ semitone flat.
$\frac{1}{80}$ " "	$\frac{1}{80}$ " "
$\frac{1}{96}$ " "	$\frac{1}{96}$ " "

in a different order for 288 and 512 vibrations, and the results were slightly in favour of the lower octave.

The pianist referred to on page 21 was similarly tested with intervals up to $\frac{1}{80}$ semitone, and was quite correct in 8 tests at 288 vibrations, but made one error with the same interval at 512 vibrations. Several other violinists and pianists were tested similarly, and the results were generally to show that there was no greater relative keenness at 512 than at 256 vibrations. Below 256 vibrations I have been able to apply no tests, none of my pipes giving lower notes. In view of Dr. Preyer's suspicion that a zone of keenness might be found near Fis^{IV} ($2844\frac{4}{9}$ vibrations), I had a pipe made which enabled me to apply tests from F^{IV} 2560 to G 3072 vibrations. I found keenness to be less here than at C^{IV} 2048, above which pitch I believe it rapidly diminishes.

Taking the scale from 256 to 2048 vibrations, I believe the best ears recognise with certainty $\frac{1}{80}$ semitone at every part. Under 256 and above 2048 keenness probably diminishes rapidly. This interval of $\frac{1}{80}$ semitone is equal at 256 vibrations to ·2 vibrations, at 512 to ·4 vibrations, at 1024 to ·8 vibrations, and at 2048 to 1·4 vibrations. In individual instances special keenness for particular pitches may exist, but in many of these instances the nature of the musical training may explain this keenness.

My experiments tend to support Weber's Law in its application to the middle part of the musical scale.

Appreciation of a Sound or Note of Given Intensity.

In the consulting room the usual tests applied to hearing are the watch, the tuning fork, and whispered speech. Perhaps the watch, for clinical purposes, is the most convenient test for aerial hearing, but it is of little value where accuracy is necessary, or where, for purposes of comparison, a sound of constant intensity is needed; for hardly any two watches have the same strength of tick. Two watches I have can be heard respectively at distances of 7 and 14 feet. The tick of a watch, therefore, is not accurate enough as a test. The tuning fork, too, used in the ordinary way, is only a rough test for hearing. In pathological states it is of much value. As a test for aerial hearing it has the same defect as the watch, with the additional one that the same fork gives sounds of different intensity according to the vigour of the exciting blow. Speech is an important test for hearing, because it is for the appreciation of spoken language that the faculty is chiefly used. But it is difficult to reduce to an absolute test, and it approximates an absolute test only when whispered speech is used.

According to Hartmann,* whispered speech is heard at a distance of 20 to 25 meters in a room as noiseless as possible.

Various forms of acoumeters have been constructed with the view of producing a constant test for hearing.

Politzer's † acoumeter is accurate and convenient. It consists of a small steel cylinder, on which a hammer of the same metal is made to fall through a definite distance. Both the cylinder and the hammer are supported on a vulcanite upright, the ends of which are made concave for the reception of the thumb and forefinger which hold the instrument. The distance through which the hammer falls is limited by its end nearest

* *Diseases of the Ear.* Translated by Dr. James Erskine.

† *Lehrbuch der Ohrenheilkunde* (Stuttgart, 1878), p. 190.

the hand coming in contact with a check which projects from the upright. The sound produced is like the tick of a very loud watch, and is said to be accurately tuned to C, which, however, can hardly be appreciated by any but a well trained ear. The fall of the hammer gives a non-resonant metallic click. The instrument is made by Gottlieb, of Vienna. Hartmann found that many instruments made in Vienna were not uniform. With this instrument Politzer and Hartmann found that the average hearing distance was about 15 metres. Fechner found that in individuals of normal hearing the left ear was more acute than the right. My experiments with this instrument make me wish that it were improved in the direction of giving a sustained note, capable of being altered in pitch, and of a more definite pitch. Its click is too loud for testing normal hearing in a room of moderate size, and for the individual practitioner it has no great advantage over a watch he knows well. Hartmann, after the invention of the telephone, endeavoured to obtain an exact gradation of sound by means of electric currents. In the current he placed—1, a tuning fork, by which the current is interrupted at regular intervals; 2, a rheochord or a sliding induction apparatus, by means of which the intensity of the current could be varied and exactly regulated at will; and 3, a telephone at which is heard a tone corresponding to that of the vibrating tuning fork of more or less intensity according to the strength of the current. Although the hearing test can be made easily and rapidly by means of such an apparatus, it is, unfortunately, too complicated, and, as only a small number of tones can be produced, the apparatus has not yet been introduced into practice.

Schafhäutl * adopted as a test the minimum noise which could be heard in absolute stillness at midnight. He fixed the limit at the noise made by a cork ball weighing 1 milligramme falling from a height of 1 millimetre. Boltzmann and Töpler have reached results which Hensen considers to be as accurate as possible. By measuring the compression of the air at the end of an organ pipe of 181 vibrations per second they calculated that the ear responds with sensation to an amplitude in the vibrations of the molecules of the air not more than 0·00004 mm. at the ear. These calculations indicate that the motions in the cochlea must be astonishingly minute—far too minute to be observed even by the microscope.

* *Physiological Psychology.* Prof. Geo. T. Ladd (London, 1887), pp. 372, 373.

Note or Tone Deafness.

When discussing the appreciation of small differences of pitch the influence of vocal and instrumental training in producing keenness of perception was apparent. But very good results were in some cases obtained where this kind of experience had not been great, and these afforded examples of naturally fine ears. But the opposite condition of obtuseness to differences in pitch is also a familiar one. Almost every musical person, and especially when singing in such a musically mixed society as a church congregation, is painfully aware now and then of the presence of some one who sings out of tune. Such people sing literally in such a monotonous way that one is forced to believe there must be something like tone or note deafness analogous to colour-blindness.

My observations with the instrument described on page 19 show that a large number of these tested were unable to distinguish the difference of pitch between two notes, one of which was $\frac{1}{8}$ or $\frac{1}{6}$, or even a $\frac{1}{3}$, of a semitone higher than the other. One observer told me that he required an interval of a whole semitone before any difference was apparent to him, and his replies to the tests given supported his statement. Mr. W. H. Cole informs me that he had at one time a pupil who after three months' teaching was unable to distinguish the difference between C and D on the violin. Mr. Schofield, the organist of Camphill Church, has had a similar experience with a piano pupil. A very remarkable case of note deafness is recorded by Mr. Grant Allen.* The case is one of a gentleman of 30 years of age, well educated and capable of understanding and discussing psycho-physiological questions. This subject could not make out the difference between any two adjacent notes on the piano. He could make no distinction between C and F or A. From C to C^{I} or A^{I} he began to hear some difference in pitch; he therefore noticed the difference in pitch when the interval was extremely great, but not when it consisted of only a few notes. His power of appreciation was not the same for all octaves. In the middle octave he was able dimly to discriminate between notes having the interval of a third from each other, in the octave above the middle his best perception was a third, and a fifth, or a fourth, while at the highest and lowest octaves it needed a full seventh. His attempts at singing were failures: he sang "God Save the Queen" with hardly a single note correct. Discords had no

* *Mind* (1878), p. 157.

unpleasantness for him, natural intervals like the octave no special features for him. His hearing was in other respects acute; he heard shrill and low notes well when tested. He recognised some tunes, but apparently by volume of sound and time alone. His father was quite unmusical, but not note-deaf; his mother was fond of music; his sisters were more or less musical, but one had her meatus congenitally closed by a membrane. The musical bias of the family was on the whole unpronounced.

But this remarkable person was not altogether devoid of appreciation of the character of musical sounds. He distinctly appreciated the beauty of a single note, and liked the sound of a full rich tone such as that produced by the striking of a finger glass, and he was fond of church bells and chimes. He had a delicate ear for the metre of poetry. But he suffered great ennui when compelled to sit through a musical performance of two or three hours. On the other hand, when engaged in mental work he was not distracted by the performance of a brass band or a barrel-organ. Unless his attention was specially called to these, he was quite unconscious of their presence. He recognised what was lively, gay, tender, or majestic by the time and volume of sound, but could not recognise those minor changes of feeling which are exhibited within the limits of a uniform composition.

Mr. Allen thinks these cases are not uncommon, and Mr. Geo. T. Ladd * thinks persons insensible to differences of a tone and a tone and a half are not unfrequently met with. I have looked about a good deal for such cases, and have found none so extreme as that recorded by Mr. Allen, or even as those referred to by Mr. Ladd. Many of those who are said not to know one note from another rapidly improve under training. But such cases as that of the very unusual one recorded by Mr. Allen and that reported by Mr. Cole prove, I think, that a condition of tone or note deafness may exist.

In connection with this subject Dr. M'Kendrick † tested 10 such so-called non-musical persons—persons whom he describes as not knowing one melody from another, or who, on hearing the melody repeated, at last come to know it, yet lose it when the parts are added. He used the overtone apparatus of Appunn. He found that in all cases overtones were more or less perceived. He concludes as follows:—"The only difference I have noticed between musical persons and non-musical is

* *Physiological Psychology.*

† "Note on the Perception of Musical Sounds," by J. G. M'Kendrick, M.D. (*Proceed. Royal Soc., Edin.*, 1873-74).

that the musical hear tones of low intensity, such as the higher overtones, quickly and apparently without difficulty, whereas a person who is non-musical hears the lower overtones, but he cannot hear the upper at all, even with the aid of a resonator."

This subject raises the whole question of the function of the cochlea—a question much too large and too difficult for discussion in this paper. But it may here be noticed that the perception of overtones with or without resonators and the liking for notes rich in overtones may be quite consistent with very marked tone deafness, for the first three overtones are separated from the prime and from each other by very large intervals, and it is not till we reach the 7th, 8th, and 9th partials that the intervals between them are as little as a whole tone. A person tone-deaf, therefore, to the extent of considering two adjacent notes alike may still have his ear affected by those partials of a compound tone which are more than a full tone apart.

Summary.

I. Notes produced by 15 or 16 vibrations per second are the lowest which can be heard by the human ear. The difficulty of producing vibrations of sufficient amplitude to make such notes heard is great, but it is probable that sounds caused by a smaller number of vibrations are perceived as separate impulses and not as true musical sounds. Many ears cannot hear notes caused by less than 24 vibrations.

II. The most powerful very high notes are produced by very small tuning forks, and by them a vibration number of over 40,000 has been heard by Dr. Preyer and a few other observers. Other and more convenient means for producing very high notes are Mr. Galton's whistle and the small open pipes described in this paper. These tests show that most ears can hear nothing when the vibration frequency is over 30,000 per second. Many are deaf to notes produced by more than 20,000, and some to notes of 15,000 vibrations; in a few cases deafness to notes of 5,200 or 5,500 vibrations has been recorded.

III. The least observable difference in pitch is for untrained or slightly trained ears difficult to state, but (exclusive of cases of tone deafness) it may be put down as from $\frac{1}{6}$ to $\frac{1}{40}$ semitone. The ears of such trained musicians as violinists, tuners, and some pianists, can perceive with certainty a difference of $\frac{1}{64}$ to $\frac{1}{80}$ semitone. All observers, but especially the untrained, detect sharpened better than flattened intervals. Generally speaking, Weber's Law holds good for all but the highest and lowest parts of the musical scale.

IV. No quite satisfactory test has yet been found for the distance at which a sound of constant intensity can be heard. Politzer's Acoumeter is the best and most convenient test, and is heard by normal ears in almost perfect stillness at a distance of 15 or 16 meters.

V. Cases of tone or note deafness (deafness to intervals of a whole tone or more) are very rare, but some well authenticated instances have been recorded.

On the Acoustics of Musical Sounds. By JAMES KERR LOVE, M.D.

[Read before the Society, 1st May, 1889.]

I PROPOSE to night to show you a method of testing appreciation of musical intervals, to give you the results of some experiments made with the instrument I use, and to demonstrate some acoustical and musical facts for the demonstration of which I believe this instrument is peculiarly adapted. The understanding of my paper involves a knowledge of elementary principles which most of you possess. I shall in the first place refer to these elementary principles, but shall not dwell on them longer than is quite necessary for the sake of clearness. At the outset I should say that I have approached the subject of the hearing of musical intervals from its physiological side, and that although I have been dragged both into physical and into musical questions, my remarks on these must be considered, without forgetting that I am neither a physicist nor a musician. My instrument is primarily a physiological test. It is secondarily of use for the production of beats, for the exposition of the phenomena of consonance and dissonance, and for the illustration of temperament.

Musical sounds are produced by the periodic vibrations of the sounding body. Such periodic movements give rise to corresponding periodic wave movements in the atmosphere—the usual conducting medium between the sounding body and the ear. Musical sounds differ with regard to their strength, their pitch, and their quality. The strength depends on the extent or amplitude of the vibrations, the pitch on the number of vibrations occurring in any unit of time, and the quality on the wave-form resulting from the vibrations in the sonorous body. It is with the characters of pitch and quality that we have to deal in studying musical intervals and their appreciation. The pitch of the sounds used in music ranges from thirty or forty vibrations per second to something under 5,000. The form of vibration associated with the simplest quality of musical sounds is called a pendular vibration. Its curve is the one which an ordinary pendulum would describe, if its oscillation could be recorded as a curve on a moving surface. This curve is the ordinary curve of sines. The simple pendular vibration corresponds to the tones of tuning forks which have no harmonics. All compound tones—I mean tones with harmonics or upper partials—have more complicated wave-forms, but all these latter can be broken up into as many simple waves as there are partials in the compound. These various simple waves coexist in the air just as several different systems of waves may coexist on the same sheet of water. Before their meeting the components are alike in form; during their coalescence the value of each is represented by some modification in form of the resulting compound. After they have parted the individual simple forms again reappear.

Most musical sounds, then, are not simple. That element which has the lowest vibration number, which is the loudest, and which therefore gives most of its character to the compound, is called the fundamental or prime. The other and higher elements, the upper partials, have vibration-numbers which are 2, 3, 4, 5, 6, or more times greater than the prime.

This theory of the nature of what we regard as separate musical sounds is not a new one. The presence of harmonics has been long recognised, but it is to Helmholtz that we owe the means of isolating and studying individual harmonics. By taking advantage of the phenomena of sympathetic resonance he was able to emphasise the part of the compound corresponding to the proper tones of his resonators. These resonators pick out and strengthen their own tones from the other parts of a compound, just as the voice is seized by the string corresponding to it when a note is sung strongly into a piano.

Convinced, therefore, of the compound nature of the tones usually regarded as simple, let us see what relation the elements have to the prime. The first harmonic or second partial, as it is called, has twice the vibration number of the prime, and is the octave of the prime; the third partial has three times the vibration number and is the twelfth of the prime or fifth of the octave; the fourth partial has four times the vibration number of the prime and forms the double octave; the fifth corresponds to the third above this double octave, and so on. These partial tones are in very simple relationship to the prime, and coincide with some of the chief intervals used in music. We shall hear more of them when studying the intervals themselves.

Besides partials of higher pitch, another set of tones has to be taken into account in connection with musical intervals. These are the differential tones of low pitch having vibration numbers equal to the difference of the two primes or partials which continue to form them. They are of more practical importance than the other kind of combinational tones called summational. The loudest of these combinational tones are the differential tones of the primes, or of one prime and a powerful partial. They can be heard on any good harmonium. I can produce them distinctly on this instrument, as you hear; the deep buzzing sound you hear now when I sound this major third being caused by a differential tone with a vibration frequency of 132, and the fourth tone sounding being the differential one of this 132, and the lowest prime, or G, 396.

Many means have been proposed for determining the rates of vibration or pitch numbers of musical sounds. Some of these are very elaborate, but very accurate, such as the tuning fork tonometer of Schiebler. Others are difficult to manage. The Siren is one of the oldest and simplest, and is perhaps the most instructive. I wish I could have added the most accurate, for the Siren is of great importance in acoustics, chiefly in demonstrating the vibration ratios of musical intervals. This importance makes any improvement welcome which has for its object the obtaining of accurate results with the Siren. This beautiful little instrument, of which I now show you an example, is a frisky creature. It is difficult to tame it down to a steady pace. This difficulty is well illustrated by the complicated mechanisms devised by acousticians to surmount it. Helmholtz has had a small electro-magnetic machine with a constant velocity of rotation constructed, and has found it of great use in driving the Siren. In this case the Siren does not require to be blown, but the air is driven through the openings by means of a small paper turbine. Mr. A. J. Ellis says that the best work done with the Siren has been done by M. Lissajous, with the constant-pressure bellows of M. Cavaillè Coll, called the Soufflerie de Précision. I have not seen this bellows, nor have I been able to find any information regarding it in the library of this Society.

Whatever be the means employed, the end in view is the production of a condition of equilibrium between the pressure of the bellows, on the one hand, and the friction caused by rotation of the spindle, together with the action of gravity, on the other. When the counting apparatus is in action, the friction connected with its working has also to be taken into account. With a bellows of constant pressure there must be a maximum rapidity of the spindle, and therefore a steady note. This note would be attained only when friction made further increase of speed impossible. But then the added friction of the clock-work when counting begins flattens the note and spoils the observation. I have tried to improve the Siren by adding a brake to the spindle, and by using a bellows which is constant in pressure during the lower four-fifths of its rise, but diminishes gradually during the last fifth. This is managed by making the bellows take on small additional weights during its upward progress, except during the last fifth of the journey. Without these weights, or under a constant weight, the pressure increases as the bellows falls; with the auxiliary weights the pressure can be kept constant, for during the fall they leave the bellows in the same ratio as the pressure tends to increase. These auxiliary weights are slung from the roof of the box containing the bellows.

The brake is applied to the spindle, and has for its object the variation of the amount of friction. It consists of a thin silk cord twisted in a figure-of-8 fashion, so as to embrace the spindle by its middle part while the ends of the figure are carried round the uprights of the frame of the Siren. The silk cord is carried round a tiny pulley, and a small scale-pan is attached to its end in which various weights are put. The speed of rotation is therefore under the absolute control of the operator, for the weights on the one hand and the pressure on the other can be kept steady or varied by any given amount. Much practice is required in working the bellows. The weights may be likened to the coarse, and the graduated bellows to the fine, adjustment of a microscope. Dr. W. H. Stone represents the ordinary Siren as rather a defective instrument, and I have some reason to believe him. I am not sure whether he makes the statement on his own authority or on that of some other observer; but he says in his book on Sound that the ordinary Siren of commerce is not practically reliable within ten vibrations. When I began working with the Siren it must have been one of these ordinary commercial examples that fell into my hands. The instrument was made by one of the chief Continental makers, it is true, but had very evident defects in the way that the bearings were managed, and generally was an unreliable and easily-deranged apparatus. In contrast with this I would refer to the example of the Siren which has done service in Sir William Thomson's hands for over forty years. This Siren, which was kindly lent me for the purpose, was my chief guide in giving directions for the making of my own instrument, which, so far as I know, is the first Siren made in Glasgow. It was made by Mr. Macrae, of 10 Richmond Street. (See Plate V., Fig. 2.)

Yesterday afternoon, along with my friend Mr. Younger, I made an attempt to fix, or rather to check, the vibration number of some of these pipes by means of this Siren. The lowest C was found to give a steady note with a weight of 240 grains in the scalepan, and the counting to give a vibration number of 263·5 or half a vibration flat. The E pipe required 180 grains, and gave 330·6 for 330; the G pipe needed 120 grains, and gave 395·6 for 396. The higher C was weighted with 80 grains, and gave 527·5 for 528; the higher G was heavily enough weighted with the scale-pan itself, and gave 790·5 for 792; and the highest C, which was five vibrations sharp, gave exactly its pitch of 1,061 when the spindle was freed from the weight of the scale-pan. A second observation with this gave 1,059. This last observation was carried over a quarter of a minute only; all the others were for a whole minute. The numbers just given are in no way selected, but were in each case the counting got from a single observation with the pipe tested. These results lead me to hope that this little apparatus which I have added to the Siren will be found of practical value in determining pitch numbers with that instrument.

A convenient and instructive method of treating musical sounds is to range them on a vertical scale, such as is used when measuring heat by the thermometer, the vibration numbers rising as we ascend the scale. Any two notes struck at random would probably give the idea of their having no sort of connection with each other, or the combination might have an actually disagreeable effect. In the latter case we call the phenomenon *dissonance.* But many pairs of the notes when struck together would give an idea of smoothness and harmoniousness which is peculiarly pleasant and this we recognise as *consonance.* This harmoniousness is greatest when the vibration ratio of the two notes struck is simplest. It is complete when the vibration numbers are the same. It is also perfect when they bear the simple ratio of 2 : 1, or when one is the octave of the other. When the ratio is 3 : 2 we have the perfect consonance of the fifth, when 4 : 3 that of the fourth, 5 : 3 the major sixth, 5 : 4 the major third, and so on; and we may say that the simpler the ratio the more perfect the consonance. And if we study this phenomenon of consonance more closely we shall see that the simple ratios just referred to tell us more. They explain the actual cause of the consonance. They tell us that the corresponding partial tones have the same vibration number. Thus, in the fifth, the third partial of the lower number and the second of the upper have the same vibration number, and are perfectly unisonous. Consonance, then, is a smooth, uninterrupted, continuous flow of two tones. Let us look at the nature of dissonance.

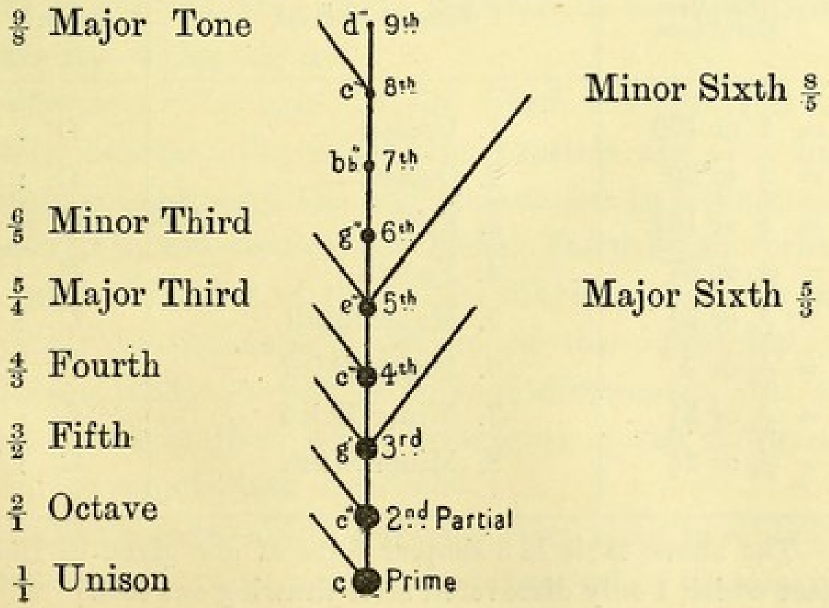
The sound you now hear is from a pipe with a vibration number of 264. By tuning another pipe I make its vibration number exactly the same, and the two pipes may now be sounded together without either disturbing the other. In front of one of these pipes is a graduated scale by which I am guided in lengthening or shortening this pipe till it makes exactly one vibration less or more than the first pipe—263 or 265 per second. When the pipes are now sounded together what is called a beat is heard, which, under the pressure of this large bellows, can be kept up as regularly at 60 in the minute as the pulse at your wrist. On further lengthening the pipe, or on shortening it, I can produce any given number of beats per second, and the number of beats in every case represents the difference of the rates of vibration of the beating sounds. Here is something which has disturbed the smoothness of the consonance. Beats are the essence of dissonance. Up to a certain point you can count them ; now they are so rapid that you would hardly undertake to count them correctly, although they are quite distinguishable as rapid beats. Now—the interval is a semitone—the roughness is extreme, the dissonance is very marked, and the beats are so rapid that unless we had arrived at the dissonance by the preceding gradations we could hardly recognise it as due to beats.

As the distance between the beating tones is further increased the disturbance does not increase. At the major tone it is still great, but not so great as at the semitone, and as we approach the minor third it rapidly diminishes. The minor third, indeed, in the ascending scale is the first of those intervals where the vibration ratio is low, where the coincident upper partials are strong enough to have a marked effect, and consequently where the phenomenon of consonance again reappears. Ascending the scale further we come upon another dissonant area, the dissonance now being caused by the beating, not of the primes, but of the upper partials; then comes a point of agreement at the major third; then a dissonant area followed by the fourth; then another dissonant area followed by the fifth. With the exception of the octave, these last two intervals—the fourth and fifth—are the best consonances we have. They are near the middle of the octave. The disturbance from the primes on the one hand, and the prime and first upper partial on the other, are least. Ascending the scale further, we have the consonances of the major and minor sixth comparable in respect of harmoniousness to the thirds because separated by a distance from the first upper partial similar to that between the thirds and the prime. On approaching the octave the disturbance between this prime and the second partial of the lower note—I mean its first upper partial—causes acute dissonance. On arriving at the octave we have the most perfect consonance.

Perfect consonance, therefore, means all absence of beats. It is the steady, uninterrupted flow of two tones which have no tendency to disturb or cut into each other. Theoretically it is impossible, unless we can be sure that the number of partials is limited, for the eighth and ninth partials in any compound are only a tone apart, the fifteenth and sixteenth only a semitone; and hence the braying, dissonant notes of some brass instruments which have the higher partials strongly developed. Practically it exists when neither the prime, nor any partial, nor any combinational tone is near enough any other element of the compound to form a beating pair with it.

Dissonance is the rough, disturbed, broken sensation of tone caused by rapid beats, rapid enough to produce the disagreeable effect common to interruptions of sensation, but not so rapid as to leave the impression of a continuous flow of sound.

Tree of Consonance.



For the study of consonance I have constructed a tree of consonance or harmoniousness. (See p. 7.) The discs on the stem are meant to represent the relative strength of the various partials in such qualities of tone as these pipes. After the sixth or seventh their strength is hardly appreciable, and they may be almost disregarded. The intervals derived from the next lowest member in the scale are shown on the left side of the stem, and their position decides their degree of harmoniousness. The degrees of consonance of the unison, octave, fifth, fourth, and major and minor thirds are thus graphically shown. On the other side of the stem are ranged the other consonant intervals, the major and minor sixths, which must find their fellow-partials higher up in the tree than the position of the next higher partial. In a quality of tone such as is here supposed this necessarily weakens the consonance, for the partials lose force as we ascend the scale. The tree is read as follows:—In comparing, for example, the consonance of the fourth and major sixth which spring from the same point on the stem, we call the fourth the better consonance because it finds its fellow-partial at the first higher step on the stem, whereas the sixth must travel to the second for its fellow. Again, when comparing the major third and major sixth, the latter must be called the more harmonious, for although it travels two steps to find its fellow it starts with a stronger partial a step lower in the scale or stem.

The diagram, therefore, shows the intervals to be consonant or harmonious in the following order—the table referring only to intervals within the octave:—

Coincident Partials.	Relative Harm'ness.	Name of Interval.	Distance from C.
1×1	$= 1$ or 100	1. Unison	C : C
1×2	$= \frac{1}{2}$ or 50	2. Octave	C : C
2×3	$= \frac{1}{6}$ or $16\frac{2}{3}$	3. Fifth	C : G
3×4	$= \frac{1}{12}$ or $8\frac{1}{3}$	4. Fourth	C : F
3×5	$= \frac{1}{15}$ or $6\frac{2}{3}$	5. Major Sixth	C : A
4×5	$= \frac{1}{20}$ or 5	6. Major Third	C : E
5×6	$= \frac{1}{30}$ or $3\frac{1}{3}$	7. Minor Third	C : E♭
5×8	$= \frac{1}{40}$ or $2\frac{1}{2}$	8. Minor Sixth	C : A♭

[NOTE.—The above table is a simpler form of one given in Helmholtz's book—a fact which I only discovered after drawing out this.]

An examination of the coincident and disturbing partials will prove this to be correct.

The Unison.—This is included simply for comparison with the intervals proper. It cannot be actually dissonant unless the very high partials are strongly developed.

The Octave.—The beating of the primes prevents anything like perfect consonance in the lower parts of the scale, but at its upper end the Octave is a perfect consonance, for it simply emphasises certain elements of an already existing combination. It adds nothing new to it. It is easily disturbed from the strength of the partials which then beat.

The Fifth.—In the middle of the octave we have the Fifth depending for its consonance on the coincident second and third partials, both well marked in all good qualities of tone. But it is not to be classed with the octave, for the fifth introduces a new element in its third partial, D, which is only a tone from the C and E, the fourth and fifth partials of C. The beats are too rapid, it is true, to cause disturbance, but the effect is sufficient to separate the fifth from the unison and octave.

The Fourth.—This interval is worse than the fifth, not only because the coincident partials are weaker, but because the beats between the third and second partials of the respective primes are not so rapid as the beating we found in the fifth. Still they are very rapid and produce no great disturbance.

Major Sixth and Major Third.—In the former of these the third and fifth partials are coincident, in the latter the fourth and fifth. Both are therefore good consonances, the Major Sixth having the advantage because of the stronger third partial. This advantage is greater in low positions where the third is sensibly disturbed by the proximity of the primes.

The Minor Third and Minor Sixth.—These intervals are but poorly defined; the coincident partials are of a high order and therefore weak, and the consonance due to the coincidence is much marred in the case of the Minor Third by the proximity of the primes, and in that of the Minor Sixth by a similar proximity of its prime to the second partial of the lower note. These intervals are really on the borders of dissonance, and owe their positions chiefly to their being inversions of the more consonant intervals, the major sixth and third.

From what I have said it will be noticed that, in addition to the positive harmoniousness given to any interval by the coincidence of the partials, there has to be taken into account the disturbance due to the rapid beating of the partials which form the consonances adjacent to that interval. These beats are always rapid, and generally cause no appreciable roughness, but they give special character to the consonance. In the case of the fifth, as we have seen, where the third and second partials are coincident, the partials which coincide for the adjacent interval of the fourth—namely, the fourth of the lower note, or C, and the third of the higher, or D, are only a major tone apart; and although their beats in this high position are very rapid (about 130 per second for the 2-foot C) and cause no appreciable roughness, they give a character to the fifth which is entirely absent from the octave.

Another point to be noticed is that the more acute dissonances are to be found near the best consonances. The semitone gives the maximum of roughness because the strong primes then beat at the rate which in medium positions gives the whole body of sound an intermittent and disagreeable character. And where two partials are strong enough to cause positive harmoniousness by their coincidence, they are strong enough to cause acute dissonance when mistuned. Hence the most acute dissonances are to be found near the octave and fifth.

We have to do with temperament only in so far as its defects are appreciable by the ear. Just intonation or temperament fixes the steps in the scale after the plan we have followed, and has for its object the obtaining of the minimum roughness. But this arrangement is just or natural only with respect to the intervals fixed from a single tonic. If we begin with D instead of C, the interval to F is not a true minor third, nor that to A a true fifth. Both are flat by a fifth of a semitone. The voice can, of course, raise its F and A to suit the D, but keyed instruments, like the piano, cannot. Hence to play correctly we must have two Fs and As. Every change of key would require fresh notes, and indeed for accurate work on the piano we would need from 70 to 100 notes to the octave. Temperament, as applied to keyed instruments, is an attempt to make twelve keys do duty for a much larger number—an attempt to escape the detail which nature asks of us. The unequal temperaments put certain less-used intervals out of tune in order to keep others true. Equal temperament divides the octave into twelve equal semitones. Pythagorean intonation fixed the intervals by a succession of fifths.

Just, equal, and Pythagorean temperaments are compared in the following table :—

NOTE.	PYTHAGOREAN INTONATION.		JUST INTONATION.	EQUAL INTONATION.	
	Vibration No.	Error.	Vibration No.	Error.	Vibration No.
C	264		264		264
D	297		297	− ·7	296·3
E	334·1	+ 4·1	330	+ 2·6	332·6
F	352		352	+ ·4	352·4
G	396		396	− ·5	395·5
A	445·5	+ 5·5	440	+ 4	444
B	581·2	+ 6·2	495	+ 3·4	498·4
C	528		528		528

In the Pythagorean intonation the errors occur in the thirds, sixths, and sevenths. In equal temperament these intervals are affected to a less degree, but the second, fourth, and fifth are slightly out of tune. We shall see whether the ear is cognisant of the errors.

(Illustrations of just and tempered Thirds, Sixths, Fifths, Fourths, and Major Chords were given by the author.)

After this rapid but, I hope, clear statement of the acoustics of musical sounds, let me go on to the subject of the appreciation of musical intervals. The subject has been studied carefully in Germany by Dr. Preyer of Jena, but not much in this country. Dr. Preyer used reeds which have some advantages, I admit, over pipes: reeds retain their pitch and are not nearly so susceptible to changes in temperature. The pitch of a *small* pipe varies on the slightest provocation; these two pipes are so nearly alike in pitch that no beat is heard on sounding them together. I hold one of them in my hand for half a minute, and now they give a harsh dissonance. The pipe will remain sharp for many minutes. These difficulties can be got over only by the most rigid care. In my experiments I never handle a pipe; the movable tops which I shall presently allude to are raised or lowered by this knife or a steel tuner, and if a pipe has to be removed from its place a pair of tongs, the points of which are guarded by rubber tubes, are used instead of the hand. By this means, and by carefully comparing the pipes with a set of standard tuning forks before the beginning of the experiments, a steady pitch is maintained, and the results obtained are reliable. All measurements are, as I shall show, checked by beats.

The experiments with unisons were made with a much smaller instrument than the one I now show you, and the results, along with a figure of the instrument, will be found in the *Glasgow Medical Journal* for August and September, 1888. The instrument consisted of a small bellows in front of which were erected the pipes to be sounded. The bellows was lifted to its highest, and fell through a space of two inches under a weight of three or four pounds, giving a note of nearly a second and a-half in duration. The pitch of the pipes was altered by means of movable stoppers governed by accurate lathe-turned screws. Successive notes were therefore produced under the same conditions, for the bellows fell under a constant pressure through the same distance during the same time. About 200 observers of all ages and at all stages of musical training were tested, and the results, to which I shall presently refer, may be taken as substantially correct; but the instrument was tentative, and was found too small for experiments with intervals; nor could it produce a sustained note. Some observers, too, complained of the dull, woolly character of the tones—a character attaching to the tones of all stopped organ pipes, and due to the absence of some of the partials. I therefore had this larger instrument made, which I have called the "Organ Audiometer." (Plate V., Fig. 1.) It consists of a large bellows, 24 × 30 inches, over which are ranged two octaves of metal organ pipes, the lowest pipe being the 2-foot C with a vibration number of 264. The diatonic scale for these two octaves occupies the front rank, and the semitones occupy the back rank. All the pipes are open. The chromatic pipes are provided with movable brass tops, by which they can be lengthened or shortened at pleasure. In the case of the larger pipes, this is effected by means of the ordinary tuner. The tops of the smaller pipes are raised by means of the screws which I used in the former instrument. These tops have pointers attached to their lower ends which mark off the amount of movement given to the top against a half millimetre scale attached to the front of the pipe. Any tone, therefore, between the notes of the diatonic scale can be produced by the chromatic pipes. The pitch of the diatonic pipes has been fixed by making them beat with a set of standard tuning forks, got from Messrs. Valentine & Carr of Sheffield, and has been carefully checked by the Siren attached to the instrument. Each pipe is placed so far from its neighbour that flattening from shading is impossible. The pipes during any experiment, and for some hours before its commencement, are not handled. Experiments are always made at the same temperature, 60° Fah., that at which the vibration numbers of the pipes were fixed. The pipes have in the first place been tuned by a professional tuner, and are now easily kept in order by a very little use of the tuning cone. All intervals are checked by beats. In a recent letter to me on this subject, Mr. Ellis says, "Beats have been my salvation." In this instrument no pitch is settled till it has been accurately checked by beats.

In testing for intervals the method is as follows:—Let the interval to be used be a sixth. One of the Cs in the front rank is first sounded, and immediately afterwards the A♯ pipe in the rear rank, which has been previously tuned exactly to a known amount of error, and the listener is asked to give his verdict on the purity of the interval—true, sharp, or flat. The accuracy of tuning may be demonstrated by the absence of beats when C and A in the front rank are sounded together, by counting the beats between A and the impure A of the rear rank, and by the beating of the impure A and the standard C. If this method be carefully followed the risk from errors due to changes of temperature is much decreased, and the objections that have been urged against pipes for the testing of the appreciation for intervals fall to the ground.

I shall present Dr. Preyer's results in the form of a table copied from his paper,* which shows the relative sensitiveness of the ear for defective intervals. I should mention here that for some of the intervals, and particularly for the octave, Dr. Preyer states that the number of tests has been too small to allow him to fix any exact limit of sensitiveness. The same remark applies in a less degree to the major sixth. It should be further remembered that these results are confined to the 4-foot octave with the lower C at 132 vibrations and the upper at 264, except in the case of the interval of the octave, which is taken at several places from very low pitches to C 2112. I refrain from entering on any detailed criticism of the tables which Dr. Preyer attaches to his discussion of the separate intervals, because my own instrument

* "Uber die Greuzen der Tonwahrnehmung," Jena, 1876.

has been so recently completed that I have not been able to construct any parallel tables. My experiments only warrant me in indicating the work of which the instrument is capable, and in discussing in detail one or two points in Dr. Preyer's paper which I have had time to study specially. Dr. Preyer's table, just referred to, is here given. I have added the figures for the unison and octave from other parts of his paper :—

	Recognised.	Not Recognised.	Appreciation.
Fifth,	1 : 353	1 : 536	444
Fourth,	1 : 170	1 : 173	172
Major Third,	1 : 143	1 : 173	158
Major Sixth,	1 : 143	1 : 157	150
Minor Third,	1 : 92	1 : 100	96
Minor Sixth,	1 : 86	1 : 96	91

Unison, { at 500 : 0·3 vibration was recognised = 1,666
at 1,000 : 0·4 do. do. = 2,500

Octave, 500·5 and 1,000·1 was called pure.
500·4 and 1,000·1 was called impure, = 5,000

With reference to the unison, my observations corroborate very closely those of Dr. Preyer, as shown in my paper of last year. In no part of the scale was anything less than 0·2 vibration certainly heard. With reference to the octave, Dr. Preyer says, "from the available data it can be proved that the sensitiveness for purity in the octave is greater than for all other intervals," greater even than for the unison where naturally we expect the greatest sensitiveness. This is well shown by the foregoing table. This superiority of the octave over the unison is to me one of the most remarkable points in Dr. Preyer's paper, and has led me to make more experiments with the octave than with any other interval. I do not think I can depend on my instrument to produce differences of a tenth of a vibration. But I can produce a difference of a half vibration as checked by beats, and this difference, which at 528 C equals a sensitiveness of 1 : 1,056, is often not recognised by good ears. On the other hand, a difference of one vibration is generally distinguished clearly. I believe, therefore, the sensitiveness for the octave to be between 500 and 1,000. As far as I can gather from the paper of Dr. Preyer, he in many instances is satisfied with the opinion of the listener as to the purity or impurity of the interval without any opinion as to the nature of the impurity. Where the impurity is marked its direction is indicated, but where it is slight it is simply called impure. My plan has been to insist on a definite opinion as to the nature of the impurity. This difference in method is a very important one, and may account for the apparently contradictory results.

Another point which I have given some attention to is the relative sensitiveness for the major third and sixth. My own case is instructive in this connection. In six tests with the major third of the 2-foot octave (264 : 330) all were correct except one where one and a-half vibrations were not detected, giving an appreciation of 1 : 220. With the major sixth, out of six similar tests, the only error was in not detecting an impurity of two vibrations giving an appreciation of just the same degree. Perhaps the precedence of the third over the sixth in Dr. Preyer's tables is accounted for by the fact that thirds are more used in music than sixths. An amateur violinist, however, gave the preference to the sixth; a vocalist gave it to the third. These two were subjected to a set of parallel tests for all the intervals except the minor sixth. It is curious to note that the only actual mistake made by the violinist was with the fifth, where a flat was put down for one vibration sharp. The fifth, however, had the smallest number of undetected impurities. I do not tabulate these results, for the data are insufficient to warrant the formation of any rigid conclusions; but their general tendency is to arrange the intervals in something like the order shown in Dr. Preyer's table, and in something like the order indicated by the tree of consonances which I have described. The smallest impurity is detected in the unison where the sensitiveness is somewhere about 1 : 1,000 or 1 : 1,500. The octave follows the unison with 1 : 500 to 1 : 1,000. The fifth follows the octave. The fourth should probably be grouped with the major third and major sixth, and these three may be reckoned as causing a sensation of impurity when the vibration number of the upper tone of the consonance is 1 : 200 out of tune. The minor third and sixths come last of all. Much of the interest of this inquiry centres about the thirds and sixths, for these are the intervals most palpably deranged by equal temperament. In equal temperament these intervals are deranged by an amount easily appreciated by any good ear even in simple melody. In the case of the major third the derangement is over two and a-half vibrations in the 2-foot octave; in the sixth four vibrations. We have seen that one and a-half or two vibrations of error produce an appreciable impurity for these intervals. Any temperament, therefore, which would be satisfactory physiologically, even for melody, must reduce the errors in the thirds and sixths to at least half the amount which occurs in equal temperament.

The degree of harmoniousness of any consonance, therefore, is some guide to the amount of derangement which that consonance will suffer without its purity being appreciably affected. The principle by which the consonant intervals are perceived seems therefore to be that conjectured by Helmholtz and put by Mr. Ellis in the following way—" the remembered identity of a partial tone in the second note with a partial tone in the first." Dr. Preyer has had some trouble in finding a solution for this order of appreciation, for he says—"after many futile speculations I came to the view that the sensitiveness to the purity of a consonance increased with the frequency of its occurrence" (in the natural scale of harmonics); for instance, how many octaves occur to the fifths, how many fifths to the fourths, &c. Dr. Preyer does not explain why he rejects the more probable theory that appreciation depends on the strength or defining power of the lowest pair of coincident or common partials. On this principle the relative sensitiveness for the consonances is, I think, quite explained. The higher the common partials, they are of course the weaker, and the more hidden by the stronger lower partials, and therefore the less likely are small derangements of consonance to be noticed.

I am too little acquainted with the technicalities of keyed instruments to suggest any measures by which the difficulties connected with temperament may be removed. This subject has received much attention at the hands of such men as Helmholtz, General Thomson, Mr. Ellis, and Mr. Colin Brown of our own city. The difficulties in using such enlarged and complicated keyboards are not so great as at first appear, and the succession of chords on such instruments is described as extraordinarily harmonious.

But if tempered are so distinguishable from just intervals, as these experiments go to prove, then the continued use of tempered intervals must damage the appreciation for natural intervals: "Evil communications corrupt good manners." I believe I have seen this effect when testing pianists for intervals. In any case, in teaching to sing, tempered instruments should be avoided. Perhaps the commonest way of teaching to sing is by causing the learner to imitate the air played on a piano. If this method be adopted the instrument should be tuned to just intonation on one key, or two or three instruments should be at the disposal of the teacher, each tuned on a separate key to just intonation. I cannot but think that the tonic sol-fa-ists, by avoiding the errors of temperament, have done something to preserve the sensitiveness of the ears of the present generation.

The Audiometer was made by Mr. Brook, Organ Builder, London and Glasgow. For valuable assistance in the experiments with the Siren, I have to thank Mr. A. Scott Younger; and for similar help in the tuning of the Audiometer, Mr. Wm. Schofield.

DESCRIPTION OF PLATE V.

Fig. 1.—*A*. Andiometer complete.

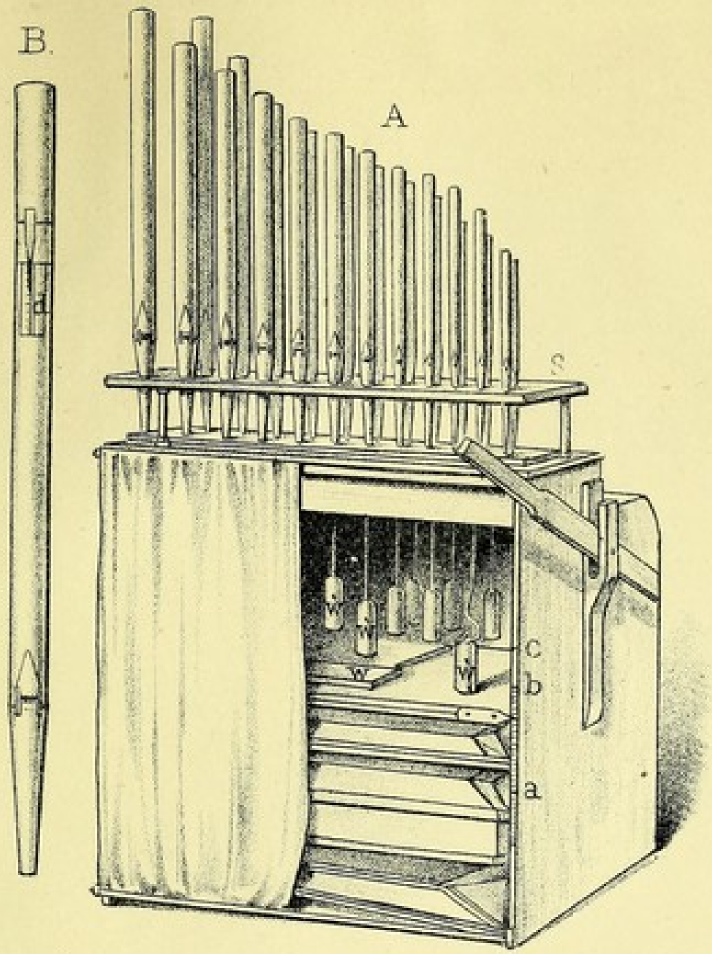
B. One of the larger pipes, in which a movable top is seen, with its pointer against the millimetre scale *d*.

In *A* the bellows is partially exposed, and the constant weight (*W*), together with the auxiliary weights (*W*), are seen.

Between *a* and *b* the pressure is constant; from *b* to *c* it decreases. The position of the Siren is shown at *S*.

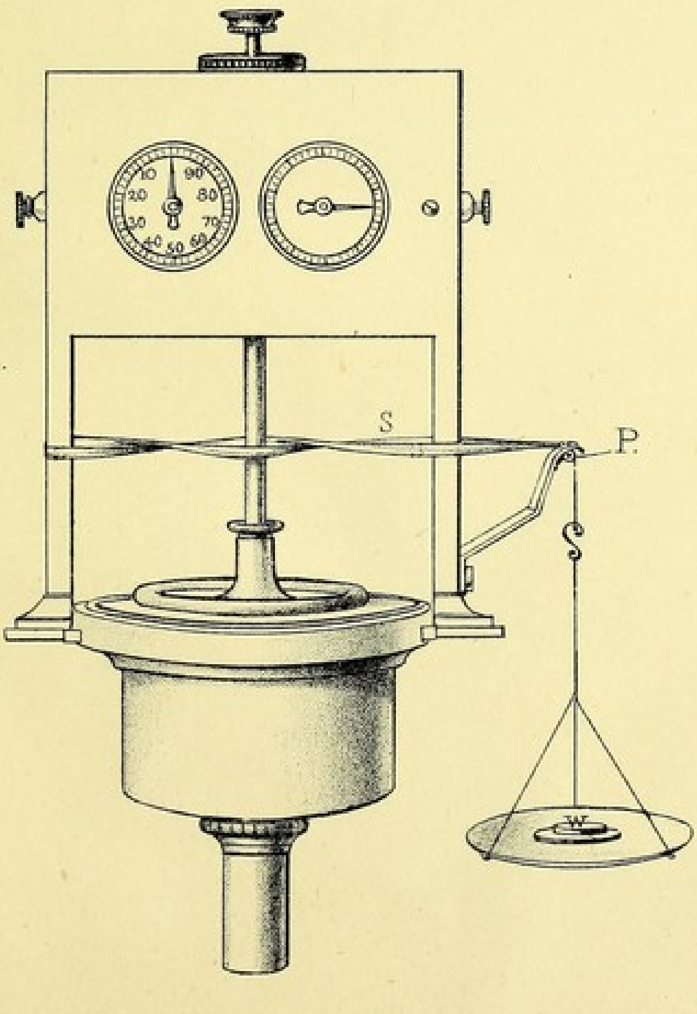
Fig. 2 shows the Siren. The silk-cord brake is shown at *S*, passing over the pulley *P*, and carrying the weight *W*.

Fig. 1.



Scale-about ½ Inch to 1 foot

Fig. 2.



About ⅓ Actual Size