11 1888

On the Limits of Hearing.

(Thesis for Degree of M. D.)

by

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Preface

The scope of this paper is narrower than I could have wished, but the instrument for testing appreciation of pitch was found to be too small for the examination of musical intervals. I have therefore left the whole subject of the appreciation of intervals untouched. I have the construction of a larger instrument, with a set of standard pipes, under consideration, and hope at an early date to resume the Inquiry. The English literature of the subject is scanty. I have therefore to apologise for the liberal use made of Dr Preyer's papers "Uber die Grenzen der Tonwahrnehmung" and "Akustische Untersuchungen" to which I am indebted for some of the references not within my reach.

I. K. L.

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The lowest audible notes

The determination of the lower limit of hearing 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. [1] 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 the examination of the lower ranges of hearing. Before his time however attempts had been made to determine the lower limit.

[2] Sauveur found that an organ pipe of 40 feet long gave the lowest tone 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 $12\frac{1}{2}$.

[3] Chladni gradually shortened a string till it made 16 vibrations per second & here got the first impression of tone, but Dr Preyer

1) Helmholtz Sensations of Tone, translated by Alex. J. Ellis p. 175.
2) Hist. de l'acad. roy. des sciences Annee 1700 Seconde Edit. Amsterdam 1734 P 190
3) Die Akustik. Leipzig 1802 P 2. 36. 294.

considers there is an entire want of evidence that he heard the fundamental tone.

1) 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

2) 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 sounds. 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."

3) 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 vibrations per second as giving the lowest audible tone. Here he used a revolving toothed wheel.

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1) Lehrb. d. Experimentalphysik. Leipzig 1829

2) Philosophical transactions for the year 1820 pt II p. 310.

3 Poggendorff Ann de Physik u Chemie 1830, 1831

1) 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

2) 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 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 36 per second. He has produced deep simple tones by another method. He stretched a thin brass piano forte 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 nearest 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

2) From two great tuning forks Helmholtz was able to hear a tone of 30 vibrations but thought he heard nothing and 28 vibrations although he was able to produce oscillations with an amplitude of about $\frac{1}{3}$ of an inch.

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1) Poggendorff. Ann. 1845

2) Helmholtz. Sensations of Tone pp. 175-176

[1] Professor Preyer of Iena 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 a 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 audible vibration-number must exist and his experiments with the great tuning forks made him sure it existed 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 uppertones. 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 is a true fundamental tone 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

1) Über die Grenzen der Tonwahrnehmung. Iena 1876. pp 7-1
See also p. 10 where Dr Preyer's experiments with even larger forks are noticed

for all normal hearing persons down to 24. Below that the intensity diminishes rapidly although the vibration-amplitude increases, therefore the fundamental tone becomes almost certainly inaudible.

Dr Preyer found that for himself the vibration number of the deepest tone 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 is heard but above 14 although the individual oscillations are still heard a dull sensation of tone begins. 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 hears a deep tone at 19, at 18 + 17 he hears it less distinctly, at 16 he sometimes hears and sometimes not, at 15 he hears a soft dull sound difficult to describe, which however like all the deepest tones is not grating or rough but agreeable. An observer who is not theoretically instructed but is 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.

Vib

8
9 } No tone; an intermittent rubbing sound is heard whose 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 sensation of 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 have 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 beautiful tone

25
26
27
28
29
30 } As the tone becomes higher it is less easily heard ~~[illegible]~~ its duration is less but it is still clear.

31
32 } The tone is still clear but it is 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 have become too weak.

Dr Preyer says that much practice is needed to hear the deepest tones. His observations on difference tones support his conclusions on the lower limit of hearing. He has been unable to hear any difference tone distinctly with a less vibration number than 18.

1) Helmholtz thinks Dr Preyers results cannot be trusted on the evidence which he - Dr Preyer presents. Helmholtz says. "With extensive vibration the tongues may have very easily given their point 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 judgement of the ear when the estimates are not checked by the counting of beats." Mr Alex. J Ellis was able to apply this check on a copy of the instrument used by Dr Preyer. The copy referred to 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 detailed in the last edition of Helmholtz Sensations of Tone and are embodied in a recent statement on the subject by Dr Preyer[2] and appear to leave little room for doubt. But, while tones of 16 to 20 vibrations per second can be heard they are of no value in music. I cannot appreciate exactly the separate intervals on the piano below the lowest

1) Sensations of Tone p 176.
2) Akustische Untersuchungen Jena 1879 pp 1 - 11.

E and F having vibration numbers of 40 & 42⅔ respectively. This may be because the tuning of these low notes is seldom perfect but this very difficulty shows that these tones are on the borders of the musical scale.
1) Dr Preyer has recently had two great tuning-forks made giving 13·7 and 18·6 vib per second. The former gave no note at all, the latter gave a distinct dull tone free from droning or jarring.

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1) Akustische Untersuchungen Jena 1879 P. 2.

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 7 octaves when their musical 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 3,500 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[1] 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.

2) Sauveur accepted 6400 vibrations as producing the highest audible note. This he got from a pipe 15/16 of an inch long.

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

4) 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 4 octaves above the middle E of the piano & had therefore a vibration-number little over 5000. A small pipe of 1/4 inch long was his own limit. This must have produced vibrations of about 20,000 per second.[5] 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 bat — considerably higher than these two — not very rare. Two relations of his own were deaf to some of these higher natural sounds.

6) Despretz had very small forks made which

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1) On Sound, Longmans Green & Co. Lond 1883 p 71.
2) Hist. de l'acad. roy. des Sciences 1700 p 190.
3) Die Akustik. p 34
4) Physiological Transactions for 1820.
5) This supposes a pipe of very small scale & open, also that measurement was from upper lip. See p 22.
6) Poggend. Ann 1845.

gave the following notes

c^{IV}	with	2048 vibrations
c^{V}		4096.
c^{VI}		8192
c^{VII}		16384
c^{VIII}		32768

He found that with practice all could be heard. Some observers heard them well and recognised them for octaves so that the interval $c^{VI}-c^{VII}$ was heard and after much labour accurately recognised, but the continued hearing of these high notes occasioned violent headaches, and the hearing of very high notes took place slowly. No tone above 36864 (d^{VIII}) could be produced f^{VIII} could not be produced by shortening the forks and e^{VIII} was inaudible

With Appun's Siren 24000 interruptions of the air were produced per second & 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 32768 but Dr Preyer found that only himself and another heard anything when the highest was sounded & the two lower with 24576 and 20480 were no better heard by the majority of observers. Some heard a short faint tone at 20480 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 Appun has constructed a series of 31 tuning forks representing a diatonic scale of 4 1/4 octaves with vibration-numbers from c^{IV} 2048 to e^{VIII} 40960. These were constructed at immense trouble & the difficulties connected with the higher forks can hardly be estimated. Herr Appun informed 1) 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 & vibration number of the forks

Fork	Note	Vibrations	Fork	Note	Vibrations	Fork	Note	Vibrations
1	c^{IV}	2048	12	g^{V}	6144	22	c^{VII}	16384
2	d^{IV}	2304	13	a^{V}	6826 2/3	23	d^{VII}	18432
3	e^{IV}	2560	14	b^{V}	7680	24	e^{VII}	20480
4	f^{IV}	2730 2/3	15	c^{VI}	8192	25	f^{VII}	21845 1/3
5	g^{IV}	3072	16	d^{VI}	9216	26	g^{VII}	24576
6	a^{IV}	3413 1/3	17	e^{VI}	10240	27	a^{VII}	27306 2/3
7	b^{IV}	3840	18	f^{VI}	10922 2/3	28	b^{VII}	30720
8	c^{V}	4096	19	g^{VI}	12288	29	c^{VIII}	32768
9	d^{V}	4608	20	a^{VI}	13653 1/3	30	d^{VIII}	36864
10	e^{V}	5120.	21	b^{VI}	15360	31	e^{VIII}	40960.
11	f^{V}	5461 1/3						

2) Dr Preyer has had opportunity of working with these forks. He & several others have heard all the 31 tones & 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 & they

1) On the Sensitiveness of the Ear to Pitch & Change of Pitch in Music by Alex J Ellis 1877 p 10

2) Über die Grenzen der Tonwahrnehmung p 21-25

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^{vii}, 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^{vii} 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 judgement 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 + pleasant. At c^{vii} much depends on the intensity of the tone. Only when the forks were very strongly struck did the sound give rise to pain.

The technical difficulties in making such forks is so great + the price of necessity so high that few can hope to have Dr Preyers experience of them. Mr
1) 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 indiarubber bag fastened to the end of the apparatus. Mr Galton tells me that the best whistles for testing Human hearing are made by the

1) Enquiry into Human Faculty

Cambridge Scientific Instrument Co.
The whistle always makes two sounds at the same time, the high musical note best described as a very 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 scale giving the length of the whistle in millimeters.

I append the figures accompanying the Cambridge Whistles

Length of Column of air in milli-metres	Number of complete vibrations per second by calculation	Length of Column of air in m.m.	Number 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	9 440,
2·5	34,000	10	8 500.
3·	28,330		

A correction has to be made for these figures which I shall shortly explain (See p. 18)

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 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 powers of hearing shrill notes. I have gone through the whole of the 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 air into the whistle and causes it to sound. I hold it 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~~ 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 only roughly approximate to the truth. By acting on a sensitive flame in free

air[1]) 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 always considerably greater than four times the length of the whistle pipe and it varied appreciably 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 nodes was was 15.84 mm corresponding to a vibration-frequency of 21.577 (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 m.m; so that distinct nodes were obtained when the sound was inaudible
The general results of their 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 Galtons Whistle failed in the intensity of the sounds produced. Its range too is limited. At 5 m.m. where the vibration number is nominally 17000 and actually about 13000 the note to me loses it clearness and is much blinded by the rush of wind. At 4 m.m. I can sometimes hear the note and sometimes not, but it is

1) On some measurements of the note of a whistle of adjustable pitch. Proceed - Cambridge Phil. Soc Feb 28th 1887.

more of a metallic wheeze than a true note. I have met no observer who can hear the note at 3 m-m. where Messrs Shaw & Turner found the vibration frequency to be 21.517. At 10 m-m 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~~ Fifteenths. These measure from $4\frac{1}{2}$ to 5 m-m. diameter. I have also had pipes made by Mr White of Cambridge Street of a diameter of 2 and 3 m-m. By cutting these down I have succeeded in getting notes from a pipe length of 6 m-m. and in one case of 5 m-m. measured from the upper lip of the mouth. (This is the plan of measurement adopted in the Article "Organ" Encyclopoedia Brittanica and is apparently adopted for the Cambridge Whistles) The total length of the whistle or pipe is 1 m-m. 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 & Turner correction can be taken for open pipes, of 21000 to 25000 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 note of Mr Galtons 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 + 20,000 vibrations per second. I assume that the measurement was from the upper lip. But the absence of data as to these points deprive the experiment of much of its value. I have therefore thought it worth while to give the accurate measurement 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 generally taken of the "scale" or diameter of the pipe. Organ builders know that "Scale" or diameter influence pitch and build accordingly. Hopkins state 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 m.m. diameter or "scale", be taken and cut down to a length of 68 m.m. 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 overtone. 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 1152 vibrations. Let now a third pipe of the same diameter of the broader of the first two be cut down to a length of 58 m.m. It will give the same note as

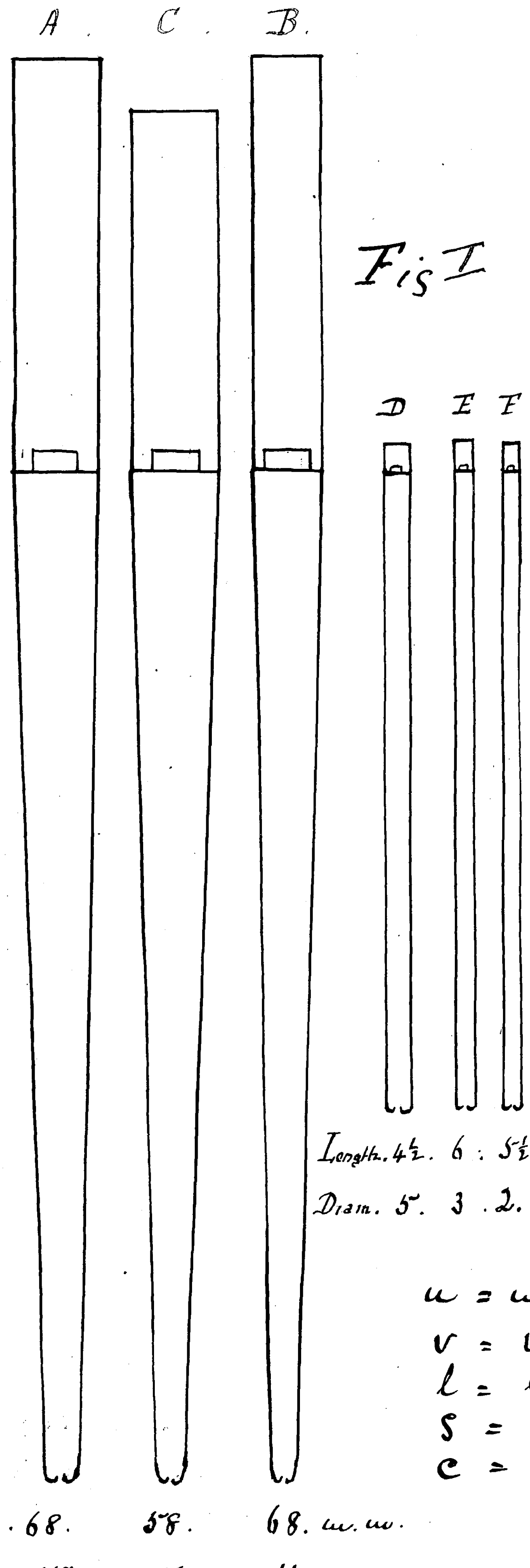

Fig I

the narrow of 68 m.m. long
If the pipes be sounded as open pipes a similar difference will be noticed in the higher Octave A + B will be a tone apart whilst B + C will be in unison. + (See Fig I
In the figure D. E and F are three open pipes such as I have described above as giving very high notes.

+ (I have been unable to find in any English work a law which states the influence of breadth on pitch but in Annales de Chimie et de Physique Vol 31 p 394 M. G. Wertheim gives the following formula for cylindrical pipes.

$$n = \frac{v}{2(l + 2c\sqrt{s})}$$

where

n = number of vibrations per second
v = Velocity of sound in air at given temp^{e}
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 show that this formula is not rigidly applicable, for in 42 experiments with cylindrical pipes, the constant varies from ·17 to ·256. By the application of this formula to the above 3 pipes a similar variation was found)

My observations on the hearing of very high notes corroborate for the most part those of Dr Preyer & 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 Galtons whistle is common after 50, it is sometimes retained at 60.
I have met with one very remarkable case of deaf-ness 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 vib) He hears this note badly on the organ He hears nothing when the E^v is sounded (5280 vib); but he hears C^v (4220 vib) distinctly.
Dr Wollaston thinks that in very early life there is deaf-ness to very high notes. Dr W. 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 exper-iment hear high notes as well as adults.
Dr Thomas Barr found the perception of high notes destroyed or diminished in the case of boilermakers & 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 Fechners 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 slightly 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

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.

1) Delezenne found that when a metal string of 11.47 m.m. was so divided that one section was 1 m.m. longer that 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.

3) Sauveur perceived the difference between two unisonous monochord strings when the one was shortened by 1/2000 part of the length.

2) Seebeck could distinguish a difference of 1 vibration and 1000 vibrations per second. He and two violinists could easily distinguish the difference between two notes having vibration numbers respectively of 439.636 and 440.

By using two forks (a') having vibration numbers of 440 and 439.75 respectively Dr 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 perceive 1/4 vibration.

By another method Preyer examined sounds having vibration numbers from 128 to 1024 and found that the unskilled always detected a difference of 16 vibrations within these 3 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 c (1024) errone...

1) Société des Sciences, de l'agriculture et des arts de Lille 1826

2) Poggendorff Ann. 1846

3) The pitch is not given.

judgements were sometimes 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

1) 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 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 respectively. Both were constructed with harmonium reeds and a wind-regulator and both were proved by counting beats.

Dr Preyer found that nobody could recognise $\frac{1}{10}$ vib at any part of the scale, that $\frac{1}{5}$ vib cannot be certainly recognised either at 500 or at 1000. The most skilful always recognise $\frac{3}{10}$ and $\frac{4}{10}$ vib. at 500 after sleep and amidst other circumstances favourable to perception. Such keenness of perception 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 pitches, and training has reduced Dr Preyer's minimum from a whole to a half vibration when the tones are near 500 vibrations per second. He is not so sensitive at 1000 as at 500.

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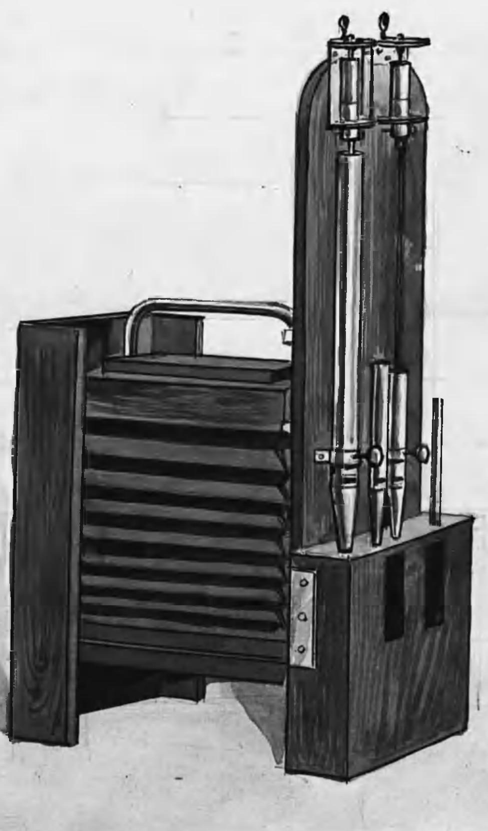
1) Über die Grenzen der Tonwahrnehmung Jena 1876. pp 28–35.

Herr Appun 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 100·4. Dr Preyer thinks that ·2 vibration is not anywhere certainly recognised.

The instrument I use for testing appreciation of small differences of pitch consists of closed organ pipes which can be shortened or lengthened by moveable 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. Fig. II shows the instrument

Fig II



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 a 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 3 or 4 pounds producing a note from the pipes of from $1\frac{1}{2}$ to 2 seconds in duration. The falls of the bellows is checked by its contact with two horizontals bars placed at its ends. Unless thus checked the tone begins to flatten very 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 descend between anterior and posterior and lateral black-leaded slips which prevent rocking. The 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

† I have in some cases added a pipe giving nearly 3000 vib

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 results 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 sensitive in a very different degree at the various part of the scale; keenness being greater in the middle octaves than at very high or very low notes.

Table showing the value of Screws at different pitches

Note and	1 turn		$\frac{1}{2}$ turn		$\frac{1}{4}$ turn		$\frac{1}{10}$ turn		$\frac{1}{20}$ turn.	
Vib. No.	Fine S	Coarse S	Fine S	Coarse S	Fine S	Coarse S	Fine S	Coarse S	Fine S	Coarse S
256 C	$\frac{1}{32}$ 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	$\frac{1}{640}$ Sem	$\frac{1}{320}$ Sem
512 C	$\frac{1}{16}$ -	$\frac{1}{8}$ -	$\frac{1}{32}$ -	$\frac{1}{16}$ -	$\frac{1}{64}$ -	$\frac{1}{32}$ -	$\frac{1}{160}$ -	$\frac{1}{80}$ -	$\frac{1}{320}$ -	$\frac{1}{160}$ -
1024 C	$\frac{1}{8}$ -	$\frac{1}{4}$ -	$\frac{1}{16}$ -	$\frac{1}{8}$ -	$\frac{1}{32}$ -	$\frac{1}{16}$ -	$\frac{1}{80}$ -	$\frac{1}{40}$ -	$\frac{1}{160}$ -	$\frac{1}{80}$ -
2048 C	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{4}$ -	$\frac{1}{16}$	$\frac{1}{8}$ -	$\frac{1}{40}$	$\frac{1}{20}$ -	$\frac{1}{80}$ -	$\frac{1}{40}$ -

In using this instrument in 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 neighborhood 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 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, and every precaution adopted to fix the attention of 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 of the series. The following is an example of a set of tests given.

Octave	Test	Interval	Direction
C 256	1	1/4 Sem	sharp
	2	1/8 "	flat
	3	1/16 "	sharp
	4	1/32 "	sharp
	5	1/64 "	flat
C 512	6	1/8 "	sharp
	7	1/16 "	flat
	8	1/32 "	sharp
	9	1/64 "	sharp
	10	1/64 "	flat
	11	1/80 "	flat
C 1024	12	1/16 Sem	flat
	13	1/32 "	sharp
	14	1/32 "	flat
	15	1/80 "	sharp
	16	1/80 "	flat
C 2048	17	1/8 "	flat
	18	1/32 "	sharp
	19	1/32 "	flat
	20	1/16 "	sharp
	21	1/40 "	sharp

The intervals in smaller brackets are more or less parallel although not specially set to test Weber's Law.

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. Sometimes twenty observers were tested at once. In testing pianists, violinists, & other trained observers I have generally applied the tests individually or to two or three observers at once and have repeated the tests when desired. 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 & quite reliable I think 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 the observers ranged from 10 to 14 years, and the tests included intervals varying from $\frac{1}{2}$ to $\frac{1}{48}$ of a Semitone. Five of these young observers were not reliable for the appreciation of a difference of $\frac{1}{3}$ sem; 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 a boy of 15 years made no errors in the paper of 15 tests which contained 3 intervals of $\frac{1}{48}$ sem and several of $\frac{1}{24}$. This boy had no experience in the use of any instrument but had two years experience of choral singing 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, — those who detected $\frac{1}{12}$ and $\frac{1}{24}$ sem with tolerable certainty, — nearly all the grosser errors were in the observation of notes which had been flattened. Ears which detected $\frac{1}{24}$ sharp with much certainty, sometimes mistook or failed to detect $\frac{1}{12}$ or even $\frac{1}{6}$ sem flat.

The same set of tests were applied to 8 boys chosen as good ears by Mr McNab the conductor of the Southern Boys Choir from a membership of nearly 100. Their ages were from 13 to 15 and their training had in each case extended to 3 years. Three of these boys detected all the sharps viz up to $\frac{1}{48}$ sem. Their only errors were with flats but these were sometimes with intervals of $\frac{1}{6}$ sem. Another mistook one of the intervals of $\frac{1}{48}$ but had all other sharps correct. He had two errors of $\frac{1}{6}$ sem flat. A fourth was pretty sure of intervals of $\frac{1}{12}$ sem & the remaining 4 made mistakes at coarser intervals both sharp and flat.

A miscellaneous company was found in the evening class of Physiography at the Highlanders Academy Greenock. (I mean miscellaneous so far as musical training is concerned) Half of them were ladies and the members varied in age from 13 or 14 to 22. The total number was 36. Sixteen were doubtful of intervals of from $\frac{1}{3}$ to $\frac{2}{3}$ of a sem; 5 failed at $\frac{1}{6}$ sem, 5 at $\frac{1}{12}$ sem and the remaining 12 were generally correct at these intervals but failed at $\frac{1}{24}$ and $\frac{1}{48}$ sem. The same relative want of perception for differences of pitch in flattened notes was noticed in all these observers.

Professor McKendrick gave facilities for testing his Class in the Physiology Class Room of the University of Glasgow. Forty-nine of these gentlemen in 2 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 $\frac{1}{8}$ of a Semitone, that they could not be considered reliable for it. Eleven were generally correct with $\frac{1}{8}$ sem but often incorrect with $\frac{1}{16}$ sem, The remaining 13 sometimes detected intervals of $\frac{1}{32}$ and $\frac{1}{40}$ sem and sometimes not, but were usually correct with coarser intervals. Nearly all of these better observers were more correct with sharps than flats. One only was more correct for flats than sharps.

I have had opportunity of testing the ears of 55 members of church choirs, musical associations etc. Eighteen of these commonly made errors at $\frac{1}{8}$ sem. Nineteen were generally correct for $\frac{1}{8}$ sem but failed to detect or often mistook $\frac{1}{16}$ sem; 15 failed at $\frac{1}{32}$ sem but were usually correct at $\frac{1}{16}$ sem. Two were reliable at $\frac{1}{32}$ sharp but generally unreliable at $\frac{1}{64}$ and $\frac{1}{80}$ sharp and these two sometimes mistook or did not detect $\frac{1}{16}$ sem flat. One was correct for all intervals greater than $\frac{1}{40}$ sem. †

The general remark regarding the relative want of appreciation for flattened intervals 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 these have no diffi

† He had a naturally fine ear playing the piano "from ear". He had no piano training

culty with intervals of more than $\frac{1}{80}$ or $\frac{1}{64}$ sem.
Two friends, one a good pianist and vocalist, the other a professional tuner who was also a violinist, were tested with the following intervals

$\frac{1}{8}$ flat	Sem.	$\frac{1}{40}$ flat	Sem.
$\frac{1}{8}$ 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 - 512, 1024, 2048, but in a different order for each octave. The pianist erred in 1 only of the 24 tests - $\frac{1}{32}$ sem. sharp in the 512 octave. The tuner erred in 2 intervals of $\frac{1}{80}$ at the 512 C 2 of $\frac{1}{40}$ sem at the 1024 C and was doubtful of 1 interval of $\frac{1}{80}$ sem near the 2048 C.
Another similar set of tests were applied to 2 pianists and 2 violinists. They were generally correct for $\frac{1}{32}$, $\frac{1}{40}$ and $\frac{1}{80}$ sem. but none gave intelligent replies to tests of $\frac{1}{160}$ sem. This last interval I have tried only at the 512 + 1024 C.s.
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[1] "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 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 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 ½ vibration then at 1000 vib. the least observable difference will be more than ½ vib., but these 2 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.

2) 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 vib. ·2 not being anywhere heard and ·5 always heard. He thinks that from a' (426⅔ vib) to c'' (512 vib) a smaller vibration difference is recognised than at any other part of the scale and that this part of the scale is therefore specially favorable for recognising small differences in pitch. He states that the recognisable difference in tone expressed in absolute vibration numbers is least in the neighborhood of a' and c'' and increases both upwards and downwards. The relative sense of difference increases with the pitch up to 1000 where ½ vibration or $\frac{1}{2000}$ of a difference can be recognised. Dr Preyer also found that below 128 vib keenness diminishes rapidly

1) E. H Weber. Wagner's Handwörterbuch der Physiologie Vol II p 560 1846.
2) Über die Grenzen der Tonwahrnehmung. p. 32. Jena 1876.

and above 1024 very probably it decreases slowly. and appreciation becomes very dull above c^{v} (4224 vib) But he thinks a part of the scale may be found near fis^{iv} (2844 4/9 vib) corresponding to a' and c'' where the ear is very keen. He thinks keenness is less at c^{iv} (2048 vib) than at c''' (1024 vib) Such are the arguments urged by Dr Preyer against Weber's Law as applied to hearing.

The results of my experiments are somewhat at variance with 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 1/2 or 1/4 sem. are not suitable for the experiment, for the results are not always the least observable differences. But on the other hand the conditions of the test are the same for each octave and the results above stated are true of the great majority of the nearly 200 observers I have examined. I have found no special keenness for notes near c'' and I believe that keenness does not appreciably diminish until the pitch reaches c^{iv} (2048 vib) Mr W.H. Cole and Mr William Schofield were tested with the following intervals —

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

in a different order for (288) D and 512 (C) vibrations and in both cases the results were slightly in favour of the lower octave. The pianist referred to on p. 35 was similarly tested with intervals up to $\frac{1}{80}$ sem. and was quite correct in 8 tests at 288 vib but made one error with the same intervals 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 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 4/9 vib) I had a pipe made which enabled me to apply tests from E^{iv} (2560) to G^{iv} (3072 vib). 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 vib. I believe the best ears recognise with certainty $\frac{1}{80}$ sem at every part. Under 256 and above 2048 keenness is less. This interval of $\frac{1}{80}$ sem is equal at 256 vib. to about ·2 vib, at 512, 1024 and 2048 the fraction is equal to a larger vibration number.

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 go 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

The distance at which a sound of given intensity can be heard.

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 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 intensities 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 difficult to reduce to an absolute test and it approximates an absolute test only when whispered speech is used. 1) According to Hartmann whispered speech is heard at a distance of 20 to 25 meters

1) Diseases of the Ear translated by Dr James Erskine

in a room as noiseless as possible.

1) 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 fore finger which hold the instrument. The distance through which the hammer falls is limited by its end nearest 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 meters. 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 & of a 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

1) Lehrbuch der Ohrenheilkunde Stuttgart 1878 P 190

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.
1) 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.
1) 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 organpipe 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 m. m. 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"

1) Physiological Psychology Prof. Geo T Ladd (Lond. 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 mono-tonous 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 p. 28 show that a large number of those 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 $\frac{1}{3}$ of a semitone higher than the other. One observer told me that he re-quired an interval of a whole semitone before any difference was apparent to him, & 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 3 months teaching was unable to distinguish the difference between C & D on the violin. Mr Schofield the organist of Camphill Church has had a similar experience with a piano pupil.

1) 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 & F or A. From C to C' or A' 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 half 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 unpleasantness for him, natural intervals like the octave no special features for him. His hearing was in other respects acute; he heard shrill & low notes well when tested. He recognised some tunes but apparently by volume of sound, and time alone. His father was quite unmusical

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1) Mind 1878 P. 157.

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 2 or 3 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 + 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[1] thinks persons insensitive 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 + have found none so extreme as that recorded by Mr

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1) Physiological Psychology.

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.

1) In connection with this subject Dr McKendrick tested 10 such so-called non musical persons — persons whom he describes as not knowing one melody from another, or who on having the melody repeated at last come to know it, yet lose it when the parts are added. He used the overtone apparatus of Appun. He found that in all cases over-tones were more or less perceived. He concludes as follows. "The only difference I have noticed between musical persons & non-musical is, 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 ~~hear~~ be noticed that the perception of overtones with or without resonators, and the liking for notes rich in overtones may be

1) Note on the Perception of Musical Sounds by J. G. McKendrick M.D. Proceed. Royal. Soc Edin 1873–74.

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 interval between them is 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 15 or 16 vibrations per second are the lowest which have been heard by the human Ear. The difficulty of pro-ducing vibrations of sufficient amplitude to make such notes heard is great, but it is probable that notes produced by a smaller number of vibrations are perceived as separate impulses and not as musical sounds. Some ears cannot hear notes caused by less than 24 vibrations per second

II The most powerful very high notes are produced by very small 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 15000 vibrations. In a few cases deafness to notes of over 5220 or 5500 vibrations have been recorded. After 40 years of age deafness to very high notes becomes much more common.

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 & some pianists can perceive with certainty a difference of $\frac{1}{64}$ and $\frac{1}{80}$ Sem. Generally speaking Weber's Law holds good for all but the highest and lowest parts of the musical scale (256 to 2048 vibrations)

IV No quite satisfactory standard has yet been given for the distance at which a sound of constant intensity can be heard. Politzer's acoumeter is the best and most convenient test and can be heard 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.