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I. *Introductory.*

In analysing the factors determining our localisation of sounds, it will be found convenient to distinguish "laterality" from "incidence." By the laterality of a sound I mean its apparent position in relation to the median vertical front-to-back, or "sagittal," plane; thus, a sound may give the impression of rightward or leftward laterality, or it may appear to have zero laterality—that is to say, its position may seem to be in the median plane. By the incidence of a sound I means its apparent position in relation to the horizontal "interaural" or "coronal" line, thus, a sound may give the impression of more or less upward, downward, forward, or backward incidence, or it may appear to be directly sideward, neither above nor below, neither in front of nor behind, the interaural line—when the incidence is of zero value.

I consider it important to distinguish at the outset these two elements in localisation, since they are dependent on very different factors. In normal subjects, that is to say, in persons who have normal binaural hearing, the one certain and obvious determinant of laterality consists in binaural differences of intensity. A sound is localised on the side of that ear which receives the stronger stimulus; it is localised in the middle line, midway between the two ears, when they are equally stimulated by the sound.*

But such binaural differences of intensity must clearly fail as a basis of our determination of incidence. Whether a median sound lies immediately in front of or behind us, or whether it is placed immediately above or below our

* Another determinant of laterality, binaural differences of wave phase, was suggested in 1907 by Lord Rayleigh ('Phil. Mag.,' vol. 13, pp. 214–231, 316–319); but, taking into consideration the physiological fact that, owing to the bone conduction of sound across the skull, it is impossible to stimulate one ear without stimulating the other, I have indicated, in collaboration with H. A. Wilson ['Roy. Soc. Proc.,' A, vol. 80, pp. 260–266; 'Brit. Journ. Psychol.,' vol. 2, pp. 363–385 (1908)], how the effects of binaural phase differences are ultimately explicable in terms of the differences in binaural intensity to which they may be supposed to give rise. Lord Rayleigh has since ['Roy. Soc. Proc.,' A, vol. 83, pp. 61–64 (1909)], allowed that "for the moment the choice between the competing views [as to the manner in which phase differences at the two ears produce their effect] is likely to depend upon preconceptions as to the manner in which the nerves act."

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head, it must stimulate the two ears with the same intensity. It is just under these conditions that our localisation becomes erratic. As is well known, a sound coming from in front is apt to be localised behind, and *vice versâ*. So, too, in regard to sounds placed before and behind the ear: a sound produced midway between the front and the side of one ear is often localised midway between the back and the side of that ear, and so on.

It has been found that, although extremely erratic, our determination of the incidence of a sound is capable of enormous improvement by practice, and, seeing that our accuracy is greater with sounds richest in overtones,* it has been supposed that our awareness of incidence is dependent on the variations of timbre which occur with variations in the angle at which the sound waves impinge on the auricle.

Now, if it be true that variations in timbre are responsible for our determination of the incidence of a sound, it should be possible to put this assumption directly to the test by experimentally varying the timbre of a given sound while its position is kept constant, and by observing what changes, if any, in its apparent position are produced thereby. Such has been the main purpose of the experiments described in this paper, and, as will be seen, they afford a striking proof of the correctness of the assumption.

Two other possible factors affecting sound localisation have yet to be mentioned. It has long been recognised that sounds coming from in front of the subject's auricle are better heard than those coming from behind. The auricle is so inclined and is so formed as to "catch" forward sounds better than rear ones.† Such variations in loudness, according to the relative positions of the sound and of the ear, may conceivably help in determining the incidence of the sound. The other possible factor, assisting the determination of laterality and incidence, consists in the tactual sensations which vibrations of sound may conceivably evoke by their contact with the auricle, the external meatus, or the tympanic membrane. The experiments described in this paper also afford some estimate of the value to be attached to these two factors.

II. *Experimental Methods.*

The experiments were conducted in a sound-proof room (R, fig. 1), the walls and ceiling of which, composed of stone, peat-moss, and cork

* Angell and Fite, 'University of Chicago Decennial Publications,' vol. 3, part 2 (1902).

† How the ear "catches" sounds is quite unknown. The old explanation of reflection of the sounds from the concha to the tragus, and thence into the meatus, is untenable in view of the disproportion between the size of the ear and the length of the sound waves.

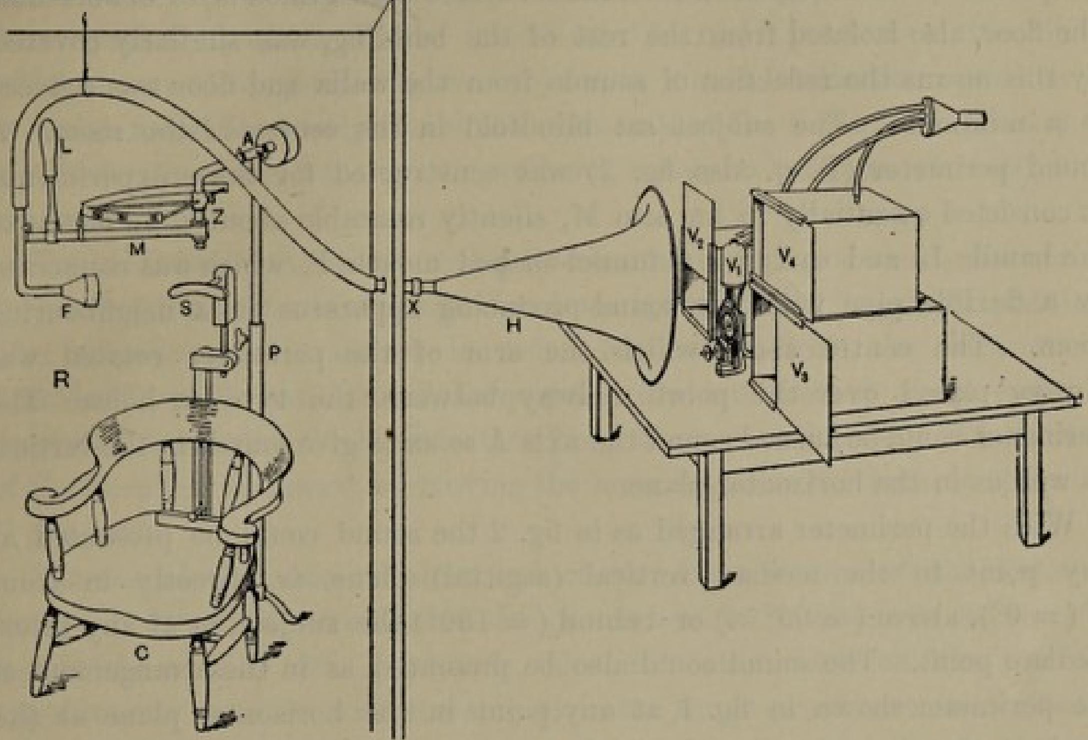

FIG. 1.

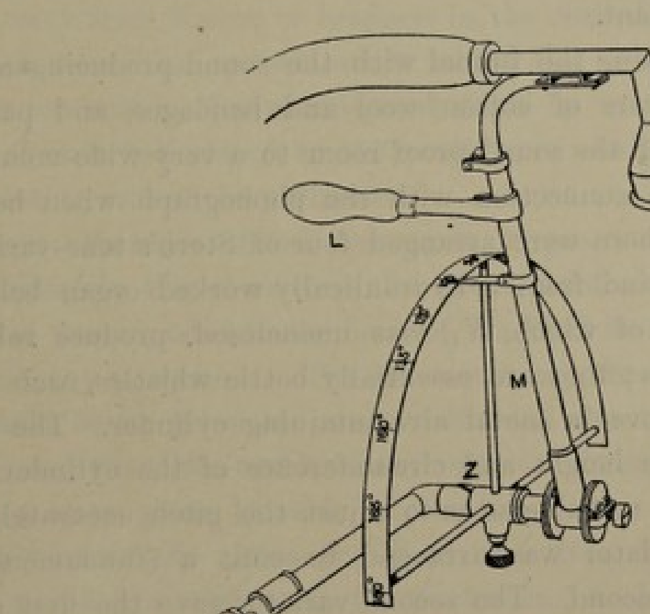

FIG. 2.

composition, were covered on their inner surface with a thick layer of horsehair. The floor, also isolated from the rest of the building, was similarly covered. By this means the reflection of sounds from the walls and floor was reduced to a minimum. The subject sat blindfold in the centre of the room. A sound perimeter (P, *cf.* also fig. 2) was constructed for these experiments. It consisted essentially in an arm M, silently rotatable about Z by means of the handle L, and carrying a funnel-shaped mouth F, which was connected by a flexible pipe with the sound-producing apparatus in a neighbouring room. The centre about which the arm of the perimeter rotated was always placed over the point midway between the two ear-holes. The perimeter could be turned round the axis A so as to give sounds in the vertical as well as in the horizontal plane.

With the perimeter arranged as in fig. 2 the sound could be presented at any point in the median vertical (sagittal) plane, *i.e.* directly in front of (= 0°), above (= 90° v.) or behind (= 180°) the subject, or at any intermediate point. The sound could also be presented, as in the arrangement of the perimeter shown in fig. 1, at any point in the horizontal plane at the level of the ears, *i.e.* directly in front of (= 0°) or behind (= 180°) the subject, or exactly opposite the right or left ear (= 90° h. or 270° h.) or at any intermediate point.

The pipe connecting the funnel with the sound-producing apparatus was enveloped with layers of cotton wool and bandages, and passed through a tube in the wall of the sound-proof room to a very wide-mouthed horn H, such as is used in connection with the phonograph when heard in large halls. Before this horn were arranged four of Stern's tone-variators, V_1, V_2, V_3, V_4, blown by wind from a hydraulically worked organ bellows. These tone-variators, one of which, V_1, was unenclosed, produce relatively pure (overtone-free) tones; they are essentially bottle whistles, each consisting of a mouthpiece fixed over a metal air-containing cylinder. The pitch of the note depends on the height and circumference of the cylinder, the base of each cylinder being movable so as to adjust the pitch accurately. The first or largest tone-variator was arranged to emit a (fundamental) tone of 215 vibrations per second. The second variator gave the first overtone, the third gave the second, and the fourth gave the third overtone, of this fundamental, *i.e.* they emitted tones of 430, 645, and 860 vibrations per second respectively. In order to reduce and to vary at will the loudness of these overtones, the three corresponding variators, V_2, V_3, V_4, were each enclosed in a wooden box, open at one end. The open end of each box could be more or less completely closed by means of an adjustable slide, thus allowing the intensity of the overtones (and hence the timbre of the total sound) to be experimentally varied.* Three positions of the slides were adopted: position B, the middle or "normal" position of the slides, which was used for practising the subjects in sound localisation; position A, in which the slides nearly closed the open ends of the boxes; and position C, in which the slides were drawn well out so as to produce relatively loud overtones.

The loudness of the whole sound (fundamental and overtones) was varied by moving the horn nearer or farther from its middle or "normal" position. The subjects were practised in sound localisation with the horn at its "normal" or B position. Subsequently, the loudness of the sound was decreased by moving the horn farther from the tone-variators (the A position of the horn) or increased by moving the horn nearer to the tone-variators (its C position).

The use of the tone-variators and of varying positions of the slides or horn, just described, necessitated the presence of an assistant in the room in which the sounds were produced. Communication between him and the experimenter, who sat with the subject in the sound-proof room, was effected by means of loud-speaking telephones and an electric bell, so that by pre-arranged signs the assistant might give the sounds at the desired moment, and vary their timbre or loudness in the desired order.

Experiments were also carried out in which the sound was produced by the experimenter within the sound-proof room by means of a telephone buzzer or an electric bell placed at the position of the funnel F, at the free end of the rotating arm of the perimeter.

Except when otherwise stated, the mode of procedure was as follows: The subject, seated in the chair C in the sound-proof room, was blindfolded, and a head rest was adjusted to the back of his head in order to prevent, so far as possible, any movement. The perimeter was then arranged so as to allow of sounds being given in one or other of the two planes (vertical or horizontal), and the slides and horn were set at their respective B positions. Several sittings were given by each subject for practice in localisation, and later the positions of the slides and horn were irregularly varied for the study of the effects of variations in the timbre and loudness of the sound in one of the two planes, before similar experiments were made in the other plane. The production of the sound which the subject was required to

* In a number of preliminary experiments, I employed resonators at variable distances from the variators, but the tones conducted from the resonators by narrow rubber tubes to the sound-proof room were too weak for my purpose. I also tried a loud-speaking telephone for conducting the tones, but, owing to the unsatisfactory timbre and inconstancy of the resulting sound, I had to abandon this method likewise.

localise was preceded by a warning "Now"; and the sound was allowed to last for about two seconds. Immediately after each sound was given the subject was required to indicate its supposed position. In the early stages of practice the sounds were given at any position within the half circle (from 0° to 180°) of the plane concerned, and the subject's forefinger was armed with a large graduated quadrant carrying a freely movable index, so that when he pointed to the apparent direction of the sound the index registered the angle at which the sound appeared to be placed. In the later experiments, when only three positions of the sound in any one plane were employed, and the subject was either being instructed in correct localisation or (still later) being tested for the effects of variations in timbre and loudness, he learned to return his answers orally in terms of the angle from which the sound appeared to come.

Eleven subjects were investigated, seven male and four female, all under 40 years of age. Each sitting lasted about 40 minutes, and each subject gave from three to six sittings, making from 200 to 400 judgments of localisation.

III. *Experimental Results.*

1. *Localisation before Practice—*

(a) *For Sounds in the Median Vertical Sagittal Plane.*—Without practice the complex sound from the variators proved extraordinarily difficult to localise. Whatever the actual position of the sound, some subjects localised it in front, others localised it behind, others were unable to give any consistent localisation. As one subject remarked, "I could put it anywhere; I seem to think out where it might be and then it seems to be there." Another subject reported, "When you tell me where it comes from, I see it can do so, and can place it there."

When the variators were replaced by a telephone buzzer before the horn, no appreciable difference in the certainty or accuracy of localisation was observable.

It was always difficult to arrange the apparatus so that the sound appeared exactly in the middle line. At first the difficulty was traced to a slight leakage of the sound through the flexible tube which conducted the sound from the inlet pipe in the wall to the funnel-shaped opening borne on the perimeter. But even when this difficulty was surmounted, the slightest error in the position of the perimeter in regard to the sagittal line of the head immediately occasioned lateral (right or left), instead of purely median, localisations.

Wondering whether any possibly still remaining leakage of sound during transmission could be responsible for the extreme difficulty and inaccuracy of localisation of the variator sounds, I replaced the funnel-shaped mouth first by an electric bell, later by a telephone buzzer, in the expectation of obtaining more accurate and certain localisation when the sound was generated on the perimeter instead of being conducted to it from the room outside. The same diverse and erratic localisations were maintained. Some subjects never localised the sound behind 90° v. if it was placed at 180°; others never localised in front of 90° v. a sound given at 0°. Here, for example, are the records of two subjects, J. and Ss., for sounds of the buzzer (affixed to the perimeter) at 0°, 90° v. and 180°:—

	J.						Ss.		
0°	0°	0°	0°	0°	0°	0°	180°	180°	180°
90 v.	90	120	90	90	90	90	135	135	135
180	90	90	90	90	90	90	130	200	200

Before I had obtained evidence of these striking individual differences in localisation, I wondered whether inequalities in the reflexion of the sound from the four walls of the room could be responsible for the gross errors met with. Accordingly, on several occasions, I reversed the position of the subject, testing him now with his face, now with his back to a given wall. With these changes one subject was tested with the variator sounds, two subjects with the buzzer sound conducted from the room outside, and one subject with the bell ringing on the perimeter. But in no case was any change in localisation relatively to the subject observable. If he had localised all sounds to his rear in one position, he continued to localise all sounds to his rear in the reversed position, and so on.

This result is striking evidence of the influence of natural tendencies and prejudices on the part of the subject in his localisation of sounds placed in the median sagittal plane. The influence of expectation was also clearly demonstrable by directing the subject's attention forwards or backwards at the moment of the production of the sound, whereupon the apparent position of the sound was generally changed in the sense of such direction of the attention.*

(b) *For Sounds in the Horizontal Plane.*—But if the ability to localise fore and aft sounds in the median vertical sagittal plane is so defective, we should not expect to be better able to localise fore and aft sounds placed along the horizontal plane; for both kinds of localisation are instances of what I

* The following conversation between subject (S.) and experimenter (E.) will serve to illustrate this feature :—S. "I expected a sound behind and I got it [sound given at 0°] there." E. "Now try to imagine it in front" [sound at 0° repeated]. S. "Yes, I certainly get it there, too." E. "Now try to imagine this sound [at 180°] behind." S. "Yes, certainly it is there, but when I change my idea to its being in front, I get it there too."

have termed incidence. Laterality can only concern whether the sound is placed to the right or left of the subject or somewhere in the median line; and, as I have already said, errors in laterality were never found in these experiments, provided that the auditory acuity of the subject's two ears was normal and that the position of the sounds relatively to the two ears was such as to produce the required binaural difference (or equality) of loudness. On the other hand, whatever factors are responsible for the determination incidence should hold for the horizontal, as well as for the median sagittal, plane.

Experiments carried out on five subjects with variator sounds given in the horizontal plane reveal just the same inaccuracies as have been described for the median sagittal plane. The first of these subjects localised all sounds—whether fore (45° h.), side (90° h.), or aft (135° h.)—behind his ear, the second localised them all in front of his ear, the third localised fore and aft sounds in front of his ear, while the fourth and fifth subjects gave too variable a localisation to allow of any more general statement than that they showed total inability to distinguish fore, side, and aft sounds from one another.

Two questions naturally arise:—How is it that previous observers, while recognising a liability to err in the localisation of such sounds, have not laid stress on the initial grossness of the errors of localisation revealed under the conditions of these experiments? How is it that these errors do not play an equally prominent part in our everyday life? We are all aware of occasional errors in fore and aft localisation, but it is relatively seldom that they are brought to our notice.

Now, one important factor consists in familiarity with the sound. As we shall see, with practice every subject learned to localise correctly. Another important factor employable in everyday life, but eliminated to a very large extent in these experiments through the use of a head rest, consists in head movement. On several occasions in the course of these experiments I expressly instructed my subjects to move the head while they were listening to the sound, whereupon their errors in localisation were immediately and often quite accurately corrected.

In some experiments, moreover, performed in the open air, in which I acted as subject, where the vowel E was spoken by an assistant and his position had to be ascertained, I localised both fore and aft positions forward, but when the experiments were repeated with a small head movement carried out during the production of the sound, I at once changed the localisation of the rearward sounds from fore to aft.

Obviously, by turning the head, the sound is alterable in intensity; for, as I have already mentioned, the position of the auricle is adapted for "catching" sounds coming from in front (and in consequence of which our auditory acuity is keener for forward than for rearward sounds). But turning the head alters, too, the timbre of the sounds; a forward sound appears to the ear not only louder than, but also of a different timbre from, the sound placed to the rear.*

It is noteworthy, however, that, whereas change in the position of the head while the sound was being heard was remarkably effective in correcting errors of localisation, change in the position of the sound while the head was at rest proved of little or no advantage for such correction. It generally resulted in an interpretation of increased or diminished loudness, or of increased or diminished distance of the sound; less frequently, a movement of the sound was detected, but the direction of the movement was not always correctly given, and the initial error in localisation failed to be corrected by the detected movement of the sound. This difference in effect between what may be conveniently termed "active" and "passive" change in the position of the sound is of considerable interest in relation to the associated function of the semicircular canals and (in animals) of the movements of the auricle.

Two other factors which are conceivably of importance in determining the incidence of sounds, but which were almost wholly eliminated in these experiments, may be briefly mentioned. Of these the influence of expectation has been already alluded to on p. 273, and was almost always successfully ruled out by the noiseless movement of the perimeter. On several occasions I expressly asked the subjects if they had any notion of where the sound was coming from, and they generally replied that they had no idea. In everyday life, however, and, perhaps, in many of the experiments otherwise conducted, various cues may determine a favourable attitude of expectation in the subject. The remaining factor, the effect of sound reflections from the ceiling, walls, and floor, was prevented by the peculiar construction of the sound-proof room (pp. 268–270). But in everyday life and after brief practice in experiments, conducted under ordinary conditions, there are indications that such reflections are taken into account and thus assist in determining the incidence of the sound.†

* It is practically impossible to increase the loudness of a sound (*i.e.* the intensity of the fundamental and its overtones) without altering its timbre (the relative intensity of the fundamental and its overtones). Even if this could be physically realised, the varying position of the peculiarly formed auricle relatively to the sound may be expected to influence the ease with which it takes up the different overtones contained in the sound.

† Since writing this, I have examined two subjects, first in an ordinary room, and later (after a rest) in the sound-proof room, using the perimeter with an attached

2. *Localisation during Practice*—

(a) *For Sounds in the Median Vertical Sagittal Plane.*—The practice experiments were carried out during several sittings, the number (*cf.* p. 272) depending on the rapidity of improvement in the subject's accuracy of localisation. The subjects were now told when they were right or wrong, and only three positions of the sound were given—at 0° directly in front, at 90° v. directly above, and at 180° directly behind an imaginary line between the two ears.

The final result was always to establish absolute accuracy in the localisation of the sounds. But the three positions were not learned with equal ease; consequently the total number of right answers varied with the position of the sounds, the figures during relatively late stages of practice with the variator sounds being—

For	0°	80 per cent. of answers correct.	
„	90 v.	72 „	„
„	180	67 „	„

The criteria apparently employed during the subject's practice, in order to distinguish these three positions, were (i) so-called "tactual" experiences; (ii) right or left laterality; (iii) difference in timbre, loudness, or nearness. Of (i) further mention will be made later (pp. 280–283). Reliance on (ii) was only possible when the sound was not accurately produced in the middle line; if, for example, the rotating arm swung a little obliquely from before backwards, the subject came to realise that when the sound was heard (say) to his left it was placed (say) behind him, whereas when it appeared to his right it lay to his front. In regard to (iii) various subjects stated that at 0° the second was "fuller," "more voluminous," or "more open," while at 90° v. it was "duller," "drearier," "more drony," or "more booming," and at 180° it sounded "rather like an echo," "faint," "lacking in assurance," "fuller than at 90° v., though very like it," yet "duller and more distant than 0°."

Similar results were obtained during practice when the telephone buzzer took the place of the variators before the horn.

(b) *For Sounds in the Horizontal Plane.*—In these experiments only three subjects received practice for sounds placed at 45° h., 90° h., and 135° h., but the results were precisely similar to those obtained for the sounds in the vertical plane. Two subjects thought that at 90° h. they could distinguish

electric bell and buzzer. Despite the practice gained in the ordinary room, their errors increased by about 50 per cent. in the sound-proof room, showing clearly the influence of the strange environment. Over 300 judgments were obtained.

(i) "tactual" sensations. Of course in the positions used in the horizontal plane (ii) laterality could afford no clue as to the fore or aft localisation of the sound. The remaining factor (iii), differences in timbre, loudness, and nearness, proved the most important criterion in learning to localise the sounds correctly. One of the subjects complained of special difficulty in distinguishing sounds at 90° h. and at 45° h.; another of special difficulty in distinguishing sounds at 90° h. and at 135° h. At 135° h. the sound seemed to two subjects "more remote and weaker," "less clear and less distinct," than at 45° h. or 90° h.; the third subject, however, observed that at 135° h. it was "nearer and more rounded," "not so veiled," as at 45° h.

3. *Experimental Variations in the Timbre and Loudness of the Sounds—*

(a) *For Sounds in the Median Vertical Sagittal Plane.*—In the case of two subjects, after being thoroughly practised in the correct localisation of sounds given at 0°, 90° v., and 180°, instructive results were obtained by experimentally varying (i) the timbre and (ii) the loudness of the variator sounds. In both subjects variations in timbre (produced by varying the position of the slides) yielded less striking errors of localisation than variations in loudness (produced by varying the position of the horn). Thus in one subject, who had just given 17 of 18 answers correctly for the normal or B position of the slides and horn, variations in the position of the slides produced one doubtful and one ambiguous* answer in 11, while variations in the position of the horn gave one wrong and four doubtful or ambiguous answers in nine. On another occasion the same subject, after giving two doubtful or ambiguous answers in 18 for the normal position of the slides and horn, gave 10 wrong answers and one doubtful answer in 18 when the position of the horn was varied. The disturbing uncertainty thus produced was in some degree carried over to the subsequent experiments immediately carried out with variations in the position of the slides, when three wrong and two doubtful or ambiguous answers in 13 were returned.

The second subject, who was examined only for the positions 0° and 90° v., gave five wrong and two doubtful or ambiguous answers in 27 for the normal or B position of the slides and horn, followed by three wrong and two doubtful or ambiguous answers in 18 when the position of the slides was varied. On another occasion, when the same subject had just given 12 consecutive right answers for the normal or B position of the slides and horn, six wrong answers in 21 were obtained by varying the position of the horn. In both subjects it was found that, whereas the sounds at 0° suffered least,

* An answer is "doubtful" when the subject is obviously uncertain; it is "ambiguous" when the subject ascribes to the sound alternative positions, of which one is correct.

those at 90° v. suffered most in the accuracy with which they were localised under the above conditions.

These results may be tabulated thus, the figures showing the percentages of error, doubtful or ambiguous answers being counted as half errors, wrong answers as whole errors, and the two vertical columns for each subject representing the results respectively obtained from the two sittings at which each was examined:—

	Subject I.		Subject II.	
Horn and slides in B position......................	6	6	22	0
Horn in B position, slides in varied position...	14	31	22	—
Slides in B position, horn in varied position...	33	58	—	29

Six times, the near or C position of the horn caused a sound at 90° v. to be located at 0°, and on two occasions, one at 180° to be located at 90° v. Three times, immediately following a sound given with the open or C position of the slides, a sound given at 0° with the B position of the slides was located at 90° v.; and on two occasions, immediately following a sound given with the B position of the slides, a sound given at 90° v. with the C position of the slides was located at 0°.

The following answers illustrate the difficulties in which the subjects found themselves, and indicate the bases of their judgments of localisation:—

Sound given.		Subject's reply.
Slides C	90 v.	0°. "Because it was so full; yet it seemed perfectly vertical and hit me on top of the head."
,, C	90 v.	0° or 90° v. "It seemed loud, hence front; yet far away, hence top."
,, A	0	? 90° v., hesitation. "Because, though not so weak as a top sound, yet it does not seem so direct as a front one."
,, A	0	90° v. "Because it is so faint."
,, A	0	? 0°. "It is rather weak, though, for a front sound."
orn C	90 v.	? 0°. "It has the character of a front sound in coming from a distance, but it's so drony and dreary."
,, C	90 v.	0°. "Its character resembled the previous sound [B, 90° v.], yet it came from so short a distance as to seem front."
,, A	0	90° v. "It's drony, yet it's rather too loud for top."

(b) *For Sounds in the Horizontal Plane.*—The influence of changing the timbre and loudness of the sounds on their localisation is not less marked for sounds in the horizontal plane, although certain differences are to be noted. In the following record of one of my subjects the first two columns give the actual, and the third column gives the apparent positions of the sound, the observations of the subject being given in footnotes:—

Sound given.		Subject's reply.	Sound given.		Subject's reply.
	°	°		°	°
Slides A	135 h.	45 h.	Horn B	90 h.	? 90 h.
,, B	135 h.	135 h.	Slides A	135 h.	45 h.†
,, B	45 h.	45 h.	,, B	90 h.	90 h.
,, B	90 h.	90 h.	,, C	135 h.	135 h.
,, B	135 h.	135 h.	,, B	45 h.	45 h.
,, B	45 h.	45 h.	Horn A	90 h.	90 h.
,, C	45 h.	135 h.	,, C	90 h.	90 h.
,, B	135 h.	135 h.	,, B	45 h.	45 h.
,, B	90 h.	? 90 h.	Slides A	45 h.	45 h.
,, B	135 h.	135 h.	,, B	45 h.	45 h. or 90 h.
Horn A	90 h.	? *	Horn A	90 h.	45 h. or 20 h.
,, B	45 h.	45 h.	,, C	45 h.	45 h.
,, B	135 h.	135 h.	,, B	135 h.	135 h.
,, B	135 h.	135 h.	Slides A	90 h.	45 h.
,, B	90 h.	90 h.	,, B	90 h.	45 h. or 90 h.
Slides C	45 h.	45 h.	,, C	45 h.	45 h.

* "It has the quality of 45° h., but it is not so far back, I think, nor so distant as 90°."
† "That's the 45° h. all right!"

That is to say, for 19 estimations in the normal or B position of the horn and slides, only four doubtful or ambiguous answers occurred (11 per cent. of errors), whereas for six estimations in the A or C positions of the horn there were two such answers (17 per cent. of errors), and for seven estimations in the A or C position of the slides there were four wrong answers (57 per cent. of errors). Thus the effect of varying the loudness of the sound was to reduce the certainty of this subject's answers, while the effect of varying the timbre of the sound was to change the apparent position of the sound.

It will be noticed that whereas changing the positions of the horn produced greater confusion in the vertical plane, changing the position of the slides produced greater confusion in the horizontal plane. We might be inclined to conclude from this that localisation is based on differences in loudness for sounds in the vertical plane, and on differences in timbre for sounds in the horizontal plane. But we have to remember that changes in the position of the horn must have affected not only the loudness but also, though much less markedly, the timbre of the sound; and that changes in the position of the slides must have affected not only the timbre but also, though much less markedly, the loudness of the sound.

We have also to bear in mind that in the vertical plane we were dealing with sounds placed at forward (0°), topward (90° v.), and backward (180°) positions, while in the horizontal plane, the sounds were given half-forward (45° h.), to the side (90° h.), and half-backward (135° h.).

We may, I think, legitimately conclude that for sounds given at 0°, 90° v., and 180°, our localisation is based principally upon differences in loudness, whereas for sounds given at 45°, 90°, and 135° in the horizontal plane our localisation is based principally upon differences in timbre; "principally" because changes in the position of the horn must have affected not only the loudness but also, though much less markedly, the timbre of the sound, and because changes in the positions of the slides must have affected not only the timbre but also, though much less markedly, the loudness of the sound.

This conclusion is in harmony with other considerations. There are enormous differences between sounds at 0°, 90° v., and 180°, as regards the favourableness of their position for being "caught up" by the pinna. The pinna catches sounds coming from the front better than it catches those coming from the rear; as is well known, auditory acuity is keener forwards than behind. It is hence not surprising that we learn to distinguish fore, aft, and top sounds principally by differences in loudness. On the other hand, sounds given at 45°, 90°, and 135° in the horizontal plane must differ little in loudness; the difference between the extreme positions, 45° and 135°, is much less than that between positions 0° and 180°; 45° and 135° are almost, although not quite, equally favourable positions for the sound to be caught up by the pinna, and indeed 135° is the angle most suitable for the direct entry of the sound into the meatus.

4. *The Rôle of Tactual Sensibility in Auditory Localisation*—

These experiments appear to prove conclusively not only that variations in timbre and loudness are responsible for our determination of the incidence of sounds but also that cutaneous sensibility can play no part whatever in sound localisation. That cutaneous sensations can play no part so far as concerns laterality is shown by the well-known fact that whereas we are able correctly to localise two simultaneous tones of clearly different pitch, placed one on each side of our head, whatever be their relative loudness, our localisation of two tones thus placed, when they are of identical pitch, depends upon their relative loudness; if the two tones are equally loud, the sound is localised in the median plane; as soon as they become of unequal loudness, the sound is immediately localised in that ear which receives the stronger stimulus.*

Now, if the sounds falling on each ear gave rise to tactual sensations, there can be no reason why, whatever their pitch and relative loudness, two such tones should not be correctly localised, one on one side of the head, the other on the other. On the other hand, it is quite clear that sound localisation rests on an auditory not on a tactual, sensory basis, since when the tones are of identical pitch only a single sound is heard and its localisation is

* I omit for simplicity's sake the consideration of phase difference here (see, however, footnote to p. 267).

accordingly ascribed to a single position, median or lateral, instead of to two lateral positions.

Further, when the tones are of different pitch, it is impossible to see how tactual sensibility can be the basis of their separate localisation. For suppose that one pinna, meatus or drum receives a series of tactual stimuli from the one tone, and that the opposite pinna, meatus or drum receives another series from the other, it is inconceivable how the subject can refer these two series of tactual stimuli to their respective tones; how can he decide which tone to allot to which ear merely on the basis of his tactual sensations? Again, suppose that a subject has become absolutely deaf in both ears; why on the hypothesis of tactual localisation should he not still be able on request to localise successfully a sound stimulus though unable to hear it as sound? Yet this is inconceivable save in the case of the very lowest tones, the stimuli of which evoke tactual as well as (indeed ultimately in place of) auditory sensations. Moreover, the unimportance of the tympanic membrane in sound localisation is shown by the preservation of localisation in cases where the membrane has been removed through disease, and in cases of tinnitus aurium where the sensations although localised arise subjectively, within the inner ear.

That tactual stimuli received by the pinna play a part in the localisation of sounds in the median sagittal plane is rendered highly improbable by *a priori* considerations. The following experiment, moreover, appears decisive. After preliminary practice, I acquired correct localisation of sounds in this plane; whereupon I placed a short piece of narrow rubber tubing in each ear, the result of which was to make an obvious change in the loudness and timbre of the sounds heard. Now if the pinna had been responsible for the previously correct localisation, no change should have resulted from the insertion of the rubber tubes into the two meatus. But in point of fact, I was quite unable to localise the sounds correctly, and had to start afresh re-learning them. There was no doubt in my mind that I had based my previously correct localisations on changes in the relative loudness and timbre of the sounds dependent on their position in regard to the ears. The results of this experiment confirm those already described in this paper showing the definite changes in localisation produced by definite changes in the loudness and timbre of the sounds.

Nevertheless, the belief that auditory localisation is, at bottom, of tactual origin dies hard. Started by Weber* and perpetuated by Wundt† and others, the tactual hypothesis has been recently invoked by Hocart and McDougall‡

* 'Ber. d. Kgl. Sächs. Ges. d. Wiss.,' 1848, p. 237; 1851, p. 29.

† 'Grundzüge der Physiologischen Psychologie,' 5th ed., vol. 4, p. 487.

‡ 'Brit. Journ. Psychol.,' vol. 2, pp. 386–405 (1908).

to account for their experimental results. In my own experiments, were I to trust the introspective data of several of my subjects, additional evidence could be supplied in favour of this view.

Thus for sounds given in the median sagittal plane, one subject in her early stages of practice described those at 0° as follows: "It hit my head just above the forehead," "it hit me just above the forehead," "it hit me just in front of the top of my head," while the 90° v. sounds seemed to have "a more vertical feeling," "a straight-downward feeling." Now to this subject all sounds (in the median sagittal plane) at first appeared to come from the ceiling cornice in front of and above her. Most descended and hit her forehead and vertex, while a few others remained there. Sounds at 180° were accordingly described thus: "It remained on the ceiling, but pointed to the forehead"; "it was located in front of and above me at the ceiling cornice, but it struck me at once on the vertex"; "it seemed a little lower than the rest, but it hit me in the middle of the forehead." Another subject, who at first ascribed a backward position for all sounds in the median sagittal plane, described the 0° and 90° v. sounds as hitting him at the occiput, and the 180° sounds as hitting him at the nape of the neck. Yet another subject reported on 90° v.—"that reached my eye instead of my ear."

In the case of sounds in the horizontal plane similar examples may be quoted. One subject, who at the start ascribed a position of 45° h. to sounds given at 45° h. and at 135° h. and a position of 22° h. or 45° h. to sounds given at 90° h., at a later stage of practice mentioned that sounds at 90° h. "seemed several times to end up opposite my ear, possibly giving a touch sensation." Yet when the perimeter arm was moved from 135° h. to 90° h., while the variators were sounding, this subject replied that the sound "seemed to move from 30° h. to 45° h.," and that "I felt something blowing on my skin at 45° h. in front of my ear."

In the face of such evidence it seems incredible that tactual sensibility plays any important part in sound localisation. Only a few of my subjects reported its presence, and these agreed that ultimately they discovered the only reliable basis of localisation to consist in differences of timbre and loudness. We seem forced to conclude that the localisation of such tactual sensations is to be regarded as resulting from, instead of giving rise to, determinations of sound localisation.*

* It would be rash to assume that auditory stimuli do not give rise to tactual sensations: the longest sound waves unquestionably do. Nevertheless, it is unlikely that the shortest waves excite tactual sensations, and it seems certain that whatever tactual sensations an auditory stimulus may evoke, they play no part in determining sound localisation.

This view of the illusory function of tactual sensations in sound localisation receives support from other data afforded by my subjects. Many of them, at their early stages of practice, seemed compelled to objectify the sound in tactual visual terms. Thus to one subject a sound at 90° v. "appears to come from a central point," while one at 180° "appears to come from different sides as if entering the ear by various rays instead of by a central one." Another subject said "I can't attend to the sensation as such; I have to fancy a motor cycle behind me," or "I fancy myself in a wood with the sound (given at 180°) low down at the end of the path before me." A third subject observed "I give each sound a body, and each is generally circular—a ball." A fourth subject, who had described the variator sounds as generally coming down and hitting her, observed that the buzzer sounds "seemed in many cases to remain in their place and to throw out a sort of pseudopod, like a wriggling worm pulling its tail through." In view of these descriptions, need we hesitate to ascribe localisations of tactual sensation, when they occur, to an inevitable tendency to treat localised sounds as if they were external objects describable in visual and tactual language, and as if they hit the ear, face, vertex, or occiput according to their localisation determined on the basis of timbre and loudness?

IV. *Conclusions.*

1. The "laterality" of a sound (*i.e.* its estimated position in relation to the median "sagittal" plane) is determined by binaural differences or equality of intensity of the sensation.* Experimental changes in the timbre or loudness of a sound make no difference in its laterality.

As soon as an infant begins to take notice of sounds, their laterality is at once appreciated. There are no trial movements of the head, this way or that, for sounds placed to one side of the median sagittal plane. The reception by one ear of a stimulus stronger than that reaching the other ear at once determines in the infant a movement of the head and eyes to bring the latter towards the source of the sound.

2. On the other hand, even in adult life, the grossest errors are made in determining the incidence of a sound (*i.e.* its estimated position in relation to the horizontal "interaural" line), unless the subject has been practised in the changes in timbre and loudness produced by such changes of incidence, or unless he is allowed to make movements of the head, the effect of which is to vary the timbre and loudness of the sound while it is being heard.

* And, according to Lord Rayleigh, by binaural differences or identity of phase of the sound waves (see, however, footnote to p. 267).

3. The "incidence" of a sound is hence determined by its timbre and loudness. Experimentally produced changes in the timbre or loudness of a sound lead to marked changes in its apparent incidence.

4. Tactual sensibility appears to play no part in auditory localisation. Localised tactual sensations evoked by auditory stimuli are generally the outcome of interpretations by the subject, resulting from his natural tendency to treat sounds as material objects, and to refer to them a localisation based on solely auditory data.

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