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Reprinted from the Montreal Medical Journal, July, 1891.

OUR PROJECTION OF A SOUND SOURCE IN SPACE.*

By J. W. Stirling, M.B., &c.
Surgeon Oculist and Aurist to the Metropolitan Dispensary,

The title of my paper would have better been "our present *lack* of knowledge," than our knowledge of the projection of sound in space by the human ear. It is very remarkable how hazy the knowledge of the scientific world is as yet in regard to the functions of the various parts of the inner ear. We know that it is the end organ of the auditory nerve, but when one proceeds to specialize further, the subject is to a certain extent enveloped in doubt. This is the more striking when we compare it with our knowledge of the functions of the eye and its various elements, for in the latter we venture upon well trodden and thoroughly known ground.

Before proceeding to the subject of this paper allow me very briefly to run over the anatomy and physiology of the inner ear, as it will assist in making the subject matter clearer later on.

Hearing occurs in one of two ways,—either through the bones of the head, or per meatum- through the bones, as through all solid bodies, by waves of condensation. Let us glance at the latter and usual way.

The acoustic waves enter the meatus and are transmitted from the membrana tympani by means of the ossicles of the middle ear to the fenestra ovalis. Here the repeated shocks of the stapes set up a series of waves in the lymph of the labyrinth. In order

* Read before the Natural History Society of Montreal, April 27th, 1891.

to allow of the waves being transmitted through the lymph there must be yielding points, and these occur at the fenestra rotunda, the two openings of the aqueduct of the vestibule, the membranes of the aqueduct of the cochlea, and the pores of the blood-vessels in the bone.

Impulses started in the fluid of the labyrinth would thus result in its movements back and forth so as to produce a friction against the end apparatus of the auditory nerve. This friction would be increased by the action of the otoliths found in the fluid. Thus the waves started at the fenestra ovalis would be diffused over the vestibule and into the scala vestibuli of the cochlea, where they would flow to its head, being prevented by the separating membrane from entering the scala tympani.

It is not known certainly to what extent these waves flow through the helicotrema into the scala tympani, nor what are the exact relations between the waves in the scala tympani and those in the scala vestibuli. The basilar membrane is thrown into vibration through the unequal pressure of the moving fluid, and by its vibrations stimulates the nervous structures, ending in it, giving rise to the perception of sounds.

In the same manner the lymph of the semi-circular canals, their ampullæ and vestibuli, is thrown into movements.

The structure of the end apparatus of the vestibule and semi-circular canals is evidently not adapted to the analysis of musical tones like the basilar membrane.

The otoliths found in the ampullæ and also the hairs are not capable of regular sympathetic vibrations; moreover, they form no scale of structures corresponding to the scale of sensations of tone. This fact led Helmholz to consider that tones—*i.e.*, sounds of regular periodic vibrations—are heard only by the cochlea, while noises—*i.e.*, sounds of short, temporary, irregular vibrations—are procured by the saccule and ampulla. Helmholz has, however, abandoned this theory since Exner has shown that a tone pitch is also perceived in noises.

The function of the semi-circular canals has mainly to do with the space sense, acting in the preservation of our equilibrium, which, despite emphatic contradictions, Breuer of Vienna has lately proved very successfully to be the case. Breuer stimulated the ampullæ of the various canals by the galvano-cautery and electricity. He found that on stimulating the utricular end of the ampulla there was a movement of the head in the plane of the canal so stimulated and to the same side as that to which the canal appertained; while if the canal end of the ampulla were stimulated, the movement was in the plane of the canal, but to the opposite side.

However, there is little doubt but that the ampulla and canals have something to do with sound perception, and that likely in the way of perception of the source of a sound. I will dilate on this theory later on.

It is well at the outset to bear in mind that hearing is a mental act. Every auditory sensation is an affection of the mind, recognized as connected with an extra mental reality through the activity of the auditory nerve.

All mental sensations arising from stimulation of the auditory nerve are called sensations of sound. We know nothing directly through sensations either of the structure of the ear or of vibrating strings, or particles of air or of the physics of music.

That there is a certain sense of space or localization attendant on all sense perceptions there can be no doubt, but it is still a question what determines this power of localization. It is undoubtedly a matter of memory, experience and education.

Preyer of Jena, in 1884, made a series of very interesting investigations on infants and very young animals, in order to determine, if possible, the nature and development of this space sense. As a result, he found that at a very early stage of psychical development, animals and children regard the various parts of their body as entirely distinct from themselves. The chick plucks at its own nails, just as it would at the corn thrown out to feed it. The child tried to tear off its finger or divide its foot from its leg. Only later on do they begin to grasp the idea that limbs, etc., appertain to themselves and are distinct from the surrounding world, and then begin to locate each sensory impression correctly in a certain spot or direction.

It would be quite impossible, after this, to have any conscious sensory impression which will not have a certain sense of space or position in regard to the body, once that this latter is perceived to be distinct and separate from the rest of the universe.

Children are born deaf and only begin to hear about the fourth day after birth. About the eleventh week they begin to move the head in the direction from which a sound comes. A week later the turning of the head in the direction of the source of a sound is sudden and rapid, even when the glance of the eye does not take at once the correct direction, but once the direction was discovered the child hearkens with the closest attention. After the lapse of two or three weeks, the turning of the head toward the source of sound occurs with the certainty of a reflex movement.

Now for the first time distant sound impressions are perceived. The perception of sound through the bones of the head occurs somewhat earlier than fhe twentieth month. Darwin, Vierordt and Demme give varying periods as to the first perception of the direction of sound by an infant, the extremes being twelve weeks for the earliest and seventeen weeks for the latest.

Guinea-pigs noted sound and its direction the very day of birth, although deaf immediately after birth. The little auricles contracted and moved with great rapidity, comparable to the action of the pupil under light stimulus.

Cats and dogs I have found to give similar results, although they have a tendency to project a sound on their own level even though coming from above them.

We thus see animals are in advance of infants in regard to the early age at which they appreciate sound and its direction. As Preyer remarks, the child hears nothing at first, then hears some sounds indistinctly, later hears many sounds indistinctly. Now very gradually he distinguishes an individual sound disdistinctly from among many indistinctly, and finally hears much distinctly and distinguishes strong high tones earlier than deep ones. Only when this latter stage is being reached does the infant seem to obtain some certain idea as to the direction from which a sound comes.

This perception of sound and its direction, in common with all perceptions, is the result of an extremely complex activity of the mind. It is curious to note how, as it were irrationally, the child undertakes the synthesis of the number of sense data which it involves.

The exactness, however, of this space perception varies greatly in the different senses. The eye is very exact, thanks to its great motility and manifold innervation. The skin is not nearly so exact, and varies in different parts of the body. The hearing perceives not only distant sources of sound, but locates sound in the interior of the head, and perceives very slight differences in the pitch of sound by the vibration of the air in the external meatus. Only thus far has the entire tone perception by means of the ear any sense of space, for although these sound sources are perceived, they are rarely projected correctly. Hence this highly developed function is rarely used for the perception of space sense or orientation.

The oldest theory in regard to our perception of the direction of a sound is what is known in Germany as the *recht-links*, or right-left localization. The perception of direction according to this theory depends on the relation of either meatus auditorius externus to the source of the sound, and we obtain our information, especially, if we turn our head in the supposed direction of the sound.

If both ears are stimulated to the same extent, we project the sound source in the median plane anteriorly; but when one ear is stimulated more strongly than the other, the sound source is always projected to the side of the most powerful sensation. In testing this by moving a sounding object in a horizontal circle round the head on the level of the meatus auditorius externus, Rayleigh found that a variation of 1 per cent. in the strength of stimulus between the two ears is perceived. This seems slightly overdrawn, as 10 to 20 per cent. have been the figures asserted by all other authorities, and indeed the marked uncertainty of aural projection would favour the acceptance of the latter figures. Rayleigh further asserts that we perceive the direction of noises mixed with musical tones more easily than that of pure tones.

The position and shape of the auricle is an important factor in this right-left localization, for the projection of a sound is much more faulty in those cases where the ears are closely applied to the side of the head; at the same time, in those cases in which the auricles project from the side of the head, the posterior projection is generally false. Simple proof of this effect of the auricle may be obtained by placing the hollow of our hands in front of the ears, when any sound perceived will invariably be projected backwards, no matter from what direction it may come.

That the power of orientating ourselves in space with reference to external sounds varies in different individuals cannot be doubted. It is no doubt an acquired art, and depends on attention and experience, as well as the accurate interpretation of the smallest details. Just as in the matter of the vision of savages, which is proverbially so acute, it is a question of attention and practice in the interpretation of minute indications, and the perpetuation of this type through the requirements of their life.

Weber thought we could tell the direction of a sound by means of the perception of the varying swing of the membrana tympani. He instanced, in support of this theory, that eccentric projection is hindered if the meatus is filled with water. It hinders, but does not prevent the perception of the direction; about this I will speak later on.

These facts of the perception and projection of a sound to the side of the greatest intensity gave rise to the theory of acoustic shadows or of the amount of covering power which the sound produced by waves of a given intensity entering one ear would have upon the sound produced by waves of a different intensity entering the other ear.

According to Kessel, the best binaural audition is produced when the sound proceeds from the mesial plane anteriorly; the best monaural when the projection is exactly in a line with the meatus, at right angles with its opening. Kessel further advances the function of the pinna as being the main factor in determining the perception of the direction of a sound. He divides the pinna into five auditory districts which are sharply defined from one another, and are characterized by the fact that they convey sound to the ear with a different intensity, according to the direction of the head at rest or during movement. These districts for the perception of sound are: anterior, posterior, superior, inferior and central or direct. The different auditory districts are brought into use by means of suitable movements of the head; and in association with the sense of sight, the direction from which the sound proceeds is ascertained.

One more point in connection with this right-left localization. Steinbach has shown that both binaural and monaural audition may be direct, indirect, or mixed, depending on the direction of sound source. In the direct, the sound reaches the ear directly; in the indirect, only after one or more reflections; in the mixed, both with and without reflections. In binaural audition, both ears may be stimulated by the direct or indirect, or one ear by direct, the other by indirect sound waves.

The intensity of the perception of hearing depends upon the sum of the sound waves which are reflected from the pinna into the meatus; the size of the reflecting surface of the pinna, on account of its complicated form, being almost the same for the different directions of the sound waves. The direction of sound, Steinbach holds, is decided by the right-left theory.

If the source of the sound is in the district of direct audition, then its direction can be defined with tolerable certainty; nevertheless, each individual has for this judgment his own standard, which depends upon the angle which the two auricular surfaces make with each other. The smaller the angle the more certain the judgment.

Since the best binaural audition occurs when the sound source is directly in front in the visual direction, one involuntarily turns the face to the person speaking.

If the angle which the two auricles form is less than 60°, and this is usually the case, one hears better with one ear than two, and hence turns one ear in the direction of the source of sound. Changes of direction in direct audition are detected by alteration in the intensity of sound, whereas in indirect audition other factors assist.

Judgment, together with the assistance of auditory impressions which are from experience familiar, play a principal part.

In mixed binaural audition, in which direct waves of sound only reach one ear whilst both ears can be struck by indirect waves, one can only vaguely determine the direction of the sound, and its origin is placed in the district of that ear which is struck by the direct sound waves.

If we wish to define more accurately the direction of the sound in indirect or mixed binaural audition, we are assisted if we turn our head so that the sound is received from the district of direct binaural audition or from the boundary of two adjacent auditory districts.

Daily experience teaches us that secondary conditions enable us to assist the power of localization.

It is of interest to note here that a patient of Charcot's, in Paris, had absolute insensibility of both drums and auditory canals. When his eyes were closed he could not detect the direction in which a watch was held although he heard it distinctly.

These various theories having the right-left localization as their foundation were all unsatisfactory, not accounting for many projections. Münsterberg further elaborated the theory by bringing the semicircular canals into consideration as a factor. He considers these canals to be stimulated by sound waves, which stimulation gives rise to reflex impulse for movements of the head, and upon this latter the localization of the sound source depends. It is a theory which fails, as one can readily see, when it comes to a question of the localization of two simultaneous sounds from different directions. The right-left localization theory, without this addition of Münsterberg's, can account for the perception of two simultaneous sounds coming from different directions, as v. Kries has shown to be possible, at any rate, after a little practice, and if the sounds are of different pitch, the root of the matter being the comparison of the intensity of each sound in the two ears. In some individuals the prompt and accurate localization of the direction requires, as Hensen says, something more than the shadow theory to account for them. So much, then, for the right-left theory of localization.

There is one point where it fails badly, and that is, the projection of any special point in the median plane; a sound stimulating each ear with equal intensity is referred to the median plane, but no particular point in the said plane can with certainty be projected. One can hence perceive that without the addition of some new theory of the functions of the auditory organ, a discrimination of the various sound directions could not be explained by the right-left theory.

Preyer of Jena, in 1887, instituted a series of very exact investigations in regard to the extent and limitations of our power of appreciation of the direction of sound source. He examined a series of individuals in the same manner repeatedly. The sound tests were a toy called "cri-cri" and the tick arising from opening and closing the current on a telephone. Both sounds are short and sharp, so that the factor of reflexion can be excluded, as it is scarcely noticeable. The tests were applied in the thirteen different areas of the head, as follows:

(*a*) Three primary axes, the vertical, sagittal and transverse.

(*b*) Six secondary axes—antero-superior and postero-inferior, antero-inferior and postero-superior, right inferior and left superior, left inferior and right superior, right anterior and left posterior, left anterior and right posterior.

(*c*) Four tertiary axes—right antero-superior and left postero-inferior, right antero-inferior and left postero-superior, left antero-superior and right postero-inferior, left antero-inferior and right postero-superior.

Giving thus with both terminations of their areas twenty-six tests. Preyer measured the false projection when it occurred by the angle which the axis, in which the test was made, formed with the axis in which it was projected by the person being tested.

I will not reproduce his tables, as they are far too vast for a paper like this. The conclusions I will give. Out of 2,080 tests he obtained 29.4 per cent. correct, so that chance is excluded. The greatest number of failures were when the sound came from below. Never was a sound from the left projected to the right. Right and left were with far more certainty distinguished by the ear alone than anterior and posterior or superior and inferior. In the transverse plane 38.7 per cent were correct, in the horizontal plane 35.8 per cent., and in the sagittal 31.5 per cent. ; the percentage falling in the sagittal plane, as here the right-left localizing is wanting. Again, a greater number of superior projections were correct than of inferior ; 37.6 per cent. of various superior projections to 15.5 per cent. of inferior. Lastly, Preyer found 32.5 of the posterior projections were correct to 18 per cent. of the anterior.

The results of the examination also showed—

(1) That each of the twenty-six directions had been correctly projected ; true, some very seldom, *e.g.*, anterior inferior.

(2) That no sound coming from the left side was ever projected to the right and *vice versâ*—*e.g.*, left antero-superior for right antero-superior.

(3) That no sound coming from the right or left was ever projected in the median plane.

(4) That the converse of the last fact holds—*i.e.*, no sound from a point in the median plane was projected to the right or left.

(5) Every error which arises in the median plane occurs with nearly the same frequency on either side of the head.

Further, certain directions very rarely or not at all are mistaken for certain others—*e.g.*, inferior for anterior ; inferior and superior, inferior and antero-superior, anterior and postero-inferior never, and the corresponding directions on the right or left side only rarely.

On the contrary, many directions are more frequently mistaken for certain others than correctly projected—*e.g.*, anterior for antero-superior, posterior for postero-superior, etc.

The greatest errors were those of 180°, and occurred only in the median plane. The most frequent errors were 35.3° to 45°, and, as one would suppose, the number of mistakes were about the same on either side of the head. The large percentage and size of the errors in the median plane are, as one can readily see, caused by the elimination of the right-left meatus projection. The correct percentage (31.5) in the median plane seems to require something more than the right-left theory or any of its modifications detailed already to account for it. More especially when one compares this percentage with that of the transverse plane (38 per cent.), which it so nearly approaches. In this we are assisted by the study of comparative anatomy, as Preyer has pointed out.

Fishes have no labyrinth, only vestibule and semicircular canals, yet they hear, and, despite the absence of an external meatus, they undoubtedly perceive the direction from which a sound comes. Hence we must infer two things:

1st. It is by their semicircular canals that they perceive the direction of the sound.

2nd. That the course of the impulse must be through the bones of the head or by head conduction.

Further elaborating the first factor, it is quite comprehensible how that one semicircular canal will be stimulated more than the other two, or sometimes two more than the remaining one, according to the direction from which the sound stimulus comes.

Bone or head conduction is an established fact that requires no further proof here; but one can understand how, from the denser medium surrounding the fishes head, this would be more favoured than in animals living in the air.

Sound waves from different directions and of varying intensity would in every vertebrate skull set in motion the endolymph of the membranous semicircular canals, with corresponding rapidity and intensity of vibration, and isochronously on account of the curvature of every part of the canal wall.

Now these motions set the hairs of the ampulla into sympathetic vibration, and one has only to consider that by this stimulation of one ampulla through the vibration of the fluid of the corresponding canal a different sound sensation, although of the same pitch, intensity and quality, must arise than that caused by the same stimulus acting on another canal and ampulla, as it is another set of nerve fibres which is stimulated. Considering these factors, one cannot but hold this difference of sound sensation as being one of space.

The animals have, without exception, for innumerable generations, considered, if the nerves of the ampulla, say, of the left horizontal canal, were more powerfully stimulated than those of the other two, that the sound came directly from the left, and in like manner for the other two ampullæ, the superior and posterior, the sound must come from above or behind.

The specific energy of the ampullæ is a sense of space in connection with sound, and more precisely a sense of direction, the perception of a particular direction depending on the particular one or pair of canals which may be stimulated most powerfully as follows:

1. The horizontal canal is most powerfully stimulated by sound from a direction on the same side in the horizontal plane.

2. Superior vertical canal, which has a direction outwards and forwards, is most markedly stimulated by a sound from above, in front, and to the same side.

3. Posterior canal, which has a direction downwards, backwards and outwards, perceives most acutely sounds from below, behind and the same side.

If two sounds of different intensity come from opposite sides of the head, the sound is projected in the direction of that of the greatest intensity. If both sounds are of equal intensity and pitch, they are projected in the median plane. Preyer applies this theory to all the high vertebrata.

Preyer further says that in any case all three canals are stimulated, of course those of the side nearest the sound source more powerfully than those of the opposite side, and again of those canals of the more powerfully stimulated side, one or two more powerfully than the remaining, depending on the direction from which the sound came. This hypothesis being correct, then must all those sound directions be frequently confused with one another, in which a nearly equally strong stimulation of the different ampullæ occurs—*e.g.*,

Anterior—Ant.-sup.	
Post.—Post.-inf.	Post.-inf.—Inf.
Ant.-sup. left—Sup. left.	Ant. left—Sup. left.
Ant. left—Ant.-sup. left.	Post. left—Post.-inf. left.

This Preyer found to be really the case.

The decisions were very uncertain and varying *in re* antero-inferior, left antero-inferior, and right antero-inferior directions. Preyer considers this due to the stimulation of all the ampullæ being of equal intensity.

By normal hearing, a sound from the left is never projected to the right, and *vice versâ*, on account of the much greater strength of the stimulation of the ampulla of the side nearest the sound. For the same reason, no sound from the left or right is normally projected in the median plane, nor one in the median plane projected to the right or left.

Preyer next experimented with both ears closed, first by pressing in the tragus, or by filling the meatus with a solution of sodium chloride. The results arrived at were as follows:

1. The correct right and left projections which had been so good before were now uncertain. This being clearly to be expected since the horizontal canals are more easily affected by the movement of the stapes produced by ærial sound vibrations from the right or left than are the other two canals, the stapes lying in an almost parallel plane to the horizontal semicircular canal. Hence the cutting off of the ærial transmission by the meatus must annul the effects of this factor.

2. The absolute transposition of right to left or of either side to the median plane, and *vice versâ*, only occur as with open ears, for the first few trials. This holds even in a large series of experiments; hence one cannot discover a difference in audition by head conduction as compared to the ordinary audition.

3. The recognition of the direction is greatly increased in difficulty, likely from the absolute decrease in intensity of the sounds, and correspondingly relative decrease of the difference of intensity.

4. The number of correct decisions is greatly lessened.

In regard to the perception of sound direction with one ear closed, Chladni found, in 1802, that sound is always projected to the side of the open ear. (If bone conduction is equal normally to ærial, then sound would appear to come from the side of the closed ear.)

The idea is false that in usual audition the sound is entirely conducted by the labyrinthine fluid. Chladni showed, in 1802, that much is heard even after both ears are stopped. (Ewald has just demonstrated on pigeons that after removal of the labyrinth they perceive sounds acutely; hence that the trunk of the auditory nerve possesses power of sound perception. Only after destruction of the trunk were the pigeons completely deaf.)

Kessel says that with open ears the head conduction plays an important rôle, and without it the localizing of a sound source would be far more uncertain than it is.

Diminishing the intensity of the sound until it was no longer perceived with closed ears, then opening the ears, was the plan adopted by Preyer. The decisions were very uncertain and incorrect. He considered the bone conduction from the meatus to be better than from other parts of the head, and hence this method only partly shut off factor of bone conduction.

Preyer wants more experiments in this series. It is likely that repeated practice would render better results. This is Preyer's theory, and there is no doubt something in it.

The chief fault I find is, that it is hard to believe that with errors of 180° in the median plane there can exist a special physiological mechanism for the appreciation of the direction of sound. This fault, however, may be simply due to lack of education of this special division of the organ of audition, this lack of education extending through generations.

Gruber, in 1869, expressed the opinion that the semicircular canals were not exclusively an organ of the sense of space, and was induced to believe that they were concerned rather in a participation of the hearing function. There can be no doubt, after Breuer's experiments and the results therefrom attained, that they are at any rate partially organs for the perception of our position in space and maintenance of our equilibrium, might they not be also organs for the proper projection of sound in space—organs for space perception in a double sense? Add to this the two factors of bone conduction and their existence as the main part of the hearing organ in fishes.

That the eyes assist in the appreciation of the direction of the sound there can be no doubt, and that they have filled up or possibly have caused this deficiency in function of auditory projection is quite likely. Högyes holds there is a close connection between the eyes and the semicircular canals. He says he has demonstrated that a peculiar bilateral reflex connection exists between the muscles of the eye and the ampullary nerves, in conformity with which a reflex stimulus is transmitted by each labyrinth to certain muscles—from the left vestibular nerve to those turning the left eye upwards and outwards and rotating it inwards, and to those which turn the right eye downwards and inwards and rotate it outwards, the right vestibular nerve acting in exactly the opposite way.

H. vonKreiss has, during the past year, pursued a series of investigations much on the same plan as Preyer's. Judging that possibly some modification in the quality or intensity of a certain sound, according as it came from in front of or behind the head, would assist in localizing the source, Kriess varied the sound and also the distance from the head. He held that this modification in the quality or intensity could be learnt, and hence the projection would be really per meatum and fall under the category of the right-left theory. This power of localization from some modification he called "mediate localization." However, his experiments after this manner showed the uncertainty of median localization, as also the precaution with which the results must be judged.

Kriess conducted all his experiments in the median plane, holding that these points would be sufficient to prove the possibility of a special sound space mechanism, whereas the number of points examined by Preyer were only confusing. He used castanets and the telephone at a distance of twenty centimetres from the head. The antero-posterior differentiation varied greatly, but the superior-inferior was more accurate. Practice in some cases seemed to improve, in other cases to fail.

Kriess and his assistant projected almost always the posterior in front. In the posterior and inferior, both in front and behind, one-third were false. Kriess, to completely eliminate the factor of mediate localization, used seven different instruments, when, instead of producing a diminution of correct decisions, it caused an increase. A slightly prolonged sound was more accurately projected than a short one.

Kriess considers the capability of a median projection cannot be doubted, and it depends on (1) practice, (2) the nature of the sound, and (3) some disposition. Among a number of persons he examined there was one who was absolutely correct even at different examinations, and this one had no special talent for music, so that any variation in tone might have assisted.

It was easier to distinguish change of direction if one sound was produced very shortly after the other, say half a second.

Another peculiarity is the decided tendency which exists for certain errors—*e.g.*, some people invariably project a sound from behind as coming from in front, and in front always correct, also *vice versa*. Again, in others the sound source is projected much higher than it really is, although this appeared by preference when the weak telephone click was used, and more rarely when the castanets were employed.

Kriess gathered from his investigations that an almost certain median localization (at least in so far as a decision of posterior from anterior) *can* occur under certain conditions—*i.e.*, if the sound stimulus from examination to examination is changed both in regard to its quality, intensity and distance. On the other hand, one cannot help but notice the extraordinary uncertainty which appears if the same localization and other conditions are imposed.

The theory of a mediate localization (*i.e.*, by the slight modifications of a sound arising from its position) receives a check, for it is the very opposite to find that the certainty of localization is favoured by altering the sound from time to time.

There are here two facts worthy of mention. 1st, One could decidedly speak of the indirect nature of median localization if the distinction of the location were positively decided by the nature of the chosen sound stimulus—*i.e.*, a weak sound projected by preference behind and a loud one in front. This did not occur in any of Kriess' cases. Only in one case were nearly all projections accurate, even after repeated investigations. From this, one might conclude that if a physiological mechanism existed for the appreciation of sound direction, with it also the quality and intensity of the sound would come into consideration, and would be of influence in forming our decisions.

Just a few words now about the double direction perception. Using two sounds of different quality, a fife note and a hissing sound, Kriess found both in front or both behind were correctly localized, but so soon as one was in front and the other behind, a degree of uncertainty appeared. The fife note behind and the noise in front were correctly, as a rule, distinguished; but with the fife in front and the noise behind, both were projected behind. There was no doubt but that the noise from behind interfered with the localization of the tones in front.

By the opposite arrangement the sounds were much more certainly projected, thus clearly proving the power of a double localization. The results varied greatly, but clearly showed, nevertheless, the existence of this power.

Of course all the foregoing experiments were performed on individuals with their eyes shut. The great fault I find with both Kriess' and Preyer's investigations is, that in their endeavours to develop a new theory, they seem entirely to have lost sight of the shape and position of auricle, which there is no denying greatly influences the projection of a sound source.

In my own investigations it became very evident, insomuch that before beginning my work I could pretty clearly see where the greatest tendency to error would exist. As a test in my own work I used Politzer's acoumeter, which gives a short, sharp sound.

My experiments on cats and dogs I gave up as fruitless in one sense. One idea struck me that in animals with deficient accommodative power of the eye we find the auricle highly developed and very mobile, as in the horse, cat, dog, guinea-pig; in these animals the eye is markedly hyperopic, and for near objects the nose, as we continually see, is used as almost a third eye. On the other hand, in birds, where the accommodative power is more highly developed than in any of the vertebrata, being necessitated by their rapid flight, in these the auricles are absent, as also in aquatic animals.

In my own investigations the results were very variable, and only differed from those recounted above by the fact that I got a larger percentage of correct results. There were quite a number who, at any rate, at first projected the posterior sources most correctly, but these were generally endowed with auricles which were rather flatly applied to the head. Again, there was no doubt that the intellectual status had a good deal to do with the decisions. In those of rather dull mental condition, there was a hesitation generally terminating in a false statement.

Thinking and studying the matter well over, one can detect in all the theories some pretty big gaps. But just as the projection of an object to its correct position in space by the human eye brings into action many different factors, so I think the same holds good for the ear. For as in the eye an object makes itself perceived by stimulating the optic nerve, so in the ear the auditory nerve perceives the sound. The size and distance of an object is partly judged by the strain on accommodation by the projection of the two eyes and by experience.

In the ear the accommodation act is performed by the tensor tympani muscle, as Stricker, Hensen, Backendahl and Pollak have shown.

In the eye, we judge of the direction of an object by movement of the eye and the portion of the retina stimulated ; in the ear we have not this, but we should reasonably look for a sound projection apparatus, and judging by the comparative anatomy of the fish, for instance, as already noted, it would lie in the semicircular canals or ampullæ, assisted also by the meatal audition, as factors in the latter are the auricles, which I dilated on in treating of Kessel's theory, and also the walls of the meatus and membrana tympani, if one were to judge by the case of Charcot's already noticed, where, in anæsthesia of the walls of the meatus and tympanic membrane, the perception of the direction of sound was lost.

As a brief resumé, let me say—

1. The binaural audition plays the main part in our appreciation of the direction of a sound source, as evidenced in the elaboration of the right-left theory, with its modifications by

Kessel in regard to the function of the auricle, also possibly by the sensory state of the meatus wall. In this connection may be mentioned Münsterberg's oculo-aural theory. The failure of these theories is in connection with the projection of any source in the median plane.

2. To fill this gap, Preyer and Kriess brought out and elaborated the theory of projection by the ampullæ of the semicircular canals, which, judging by comparative anatomy, appears correct.

The fault here is that it is, as I have already said, hard to believe an error of 180° possible with the existence of a physiological mechanism for the appreciation of direction; but against this we have to put those cases where the projection was accurate, also some possible weakness of discrimination or lack of attention. It is likely that through lack of use or education the organ has never assumed its full function.