PSYCHOLOGY

How Do We Hear?

Recent Research Suggests Basilar Membrane Acts as Series of Receivers Tuned to Different Wavelengths

By MARJORIE VAN de WATER

WHY does the beautiful high note of Lucretia Bori sound different from the deep tone of Lawrence Tibbett?

You can tell the difference between them, of course. Each note throughout the whole range of the human voice and beyond—through the whole gamut of the entire orchestra from the highest shrill note of the violin to the deep rumble of the bass drum—is distinguished by you from all the others. The physicist can tell you that each tone is a vibration of a different speed or frequency. Young people with good hearing can hear frequencies of from 20 per second to 20,000 per second. But how can your hearing apparatus distinguish these different frequencies?

The delicate, sensitive mechanism in your ear that makes this possible is still a mystery to scientists. No one knows for certain just how it works.

Is your ear like a telephone? Does it send along all the sound impulses, just as they come into the ear, over the same nerve pathway to the central exchange in the brain, where they are sorted out and recognized as different from one another?

Or is the important inner part of your ear more like a battery of radio receiving sets, each one tuned to pick up a different wavelength? Does one area pick up the shrill note of the peanut whistle, and an entirely different part pick up the thunder of a passing elevated train? Does each sound then travel to the brain by a different nerve pathway and perhaps reach a different final destination?

Research Difficult

One reason for the mystery is that it is not possible to watch an ear in operation. Hearing is an intangible sort of thing—it is not visible.

But in spite of this obstacle to research, scientists have discovered much about how hearing takes place. Now they have even mapped the inner ear to show just at what spot any particular note is picked up and sent on its way to the hearing center in the brain.

Physiologists have long tried to trace the pathway of sound from its source to the brain where you become aware of it. The first steps are fairly simple and have been known a long time.

Everyone knows that sound enters by the outer ear into the small opening to the hearing machine itself. It comes to the ear as an air wave or vibration.

First the sound wave in the air strikes a membrane stretched across the opening and sets this eardrum in motion. Next the vibrations are transmitted through three little bones called, because of their shape, the hammer, the anvil, and the stirrup, to the inner ear. Here the certainty of scientific knowledge becomes mixed with theory and speculation or scientific guess. Here is another membrane, but this one is not stretched over an opening like a drum, but is coiled up like a garden snail in its shell. It is very tiny. Uncoiled, it is only 1¼ inches long. At its widest end it measures about 1/75 inch across; it gradually tapers until at the other end it is only 1/600 of an inch wide. It is as though you took a very fine hair and trimmed a wedge-shaped slice off it.

Picks Up Vibrations

Somehow this basilar membrane, as it is called, picks up the vibrations and transmits them to the sense cells which in turn are connected with the nerve fibers of the auditory nerve. In this way the vibrations give rise to nerve impulses which are conveyed to the brain. But scientists differ about how this part of the hearing machine works.

"Listening in" on the hearing nerve of a cat gave the first clue. Two ingenious psychologists at Princeton University, Drs. E. G. Wever and Charles W. Bray, were the scientific detectives who thus "tapped the wires" of the cat's hearing apparatus.

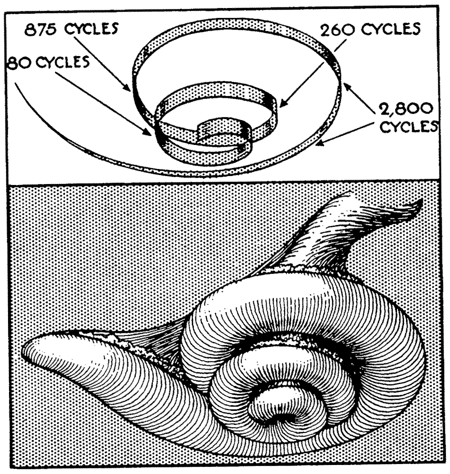
The impulse traveling up the hearing nerve to the brain gives rise to an electrical impulse, they found. This electric impulse can actually be picked up on a telephone wire, and when it has been amplified, just as the tubes in your radio amplifies the radio waves, it can be heard by the listening scientist. Thus, if someone whistled near the cat's ear, the scientist in another room could hear that same whistle over the telephone connected only to the cat's hearing nerve. If a high C were sounded, the sound in the telephone would be high C. If middle C were sounded, middle C would be picked up.

Here seemed to be confirmation of the "telephone theory" of hearing. According to the telephone theory, the basilar membrane has no other office than to translate the sound vibrations carried through the bone into nervous currents of the same frequency. These currents then travel unchanged to the brain.

There, in some unexplained manner, the brain sorts out the frequencies and you hear them as sounds of different pitch.

Too Fast for Nerve

The first difficulty encountered by those who favored the telephone theory is that the human nerve fiber does not seem capable of carrying such rapid impulses. Sounds are audible when the frequencies are as great as 20,000 a second. Yet it does not seem likely that any



COCHLEA

The important part in your inner ear which picks up sounds and sends them on to your brain is shaped very much like a garden snail curled up in his shell. This coiled membrane which is contained in the snail-shaped part of the inner ear is partly made up of about 24,000 tiny fibers running crosswise of its narrow width. Each area is thought to be "tuned" to pick up tones of different frequencies. In a guinea-pig, the outer turn picks up the extremely high sounds above 2,800 cycles. The final inner turn seems to pick up the deep low notes below 80 cycles.

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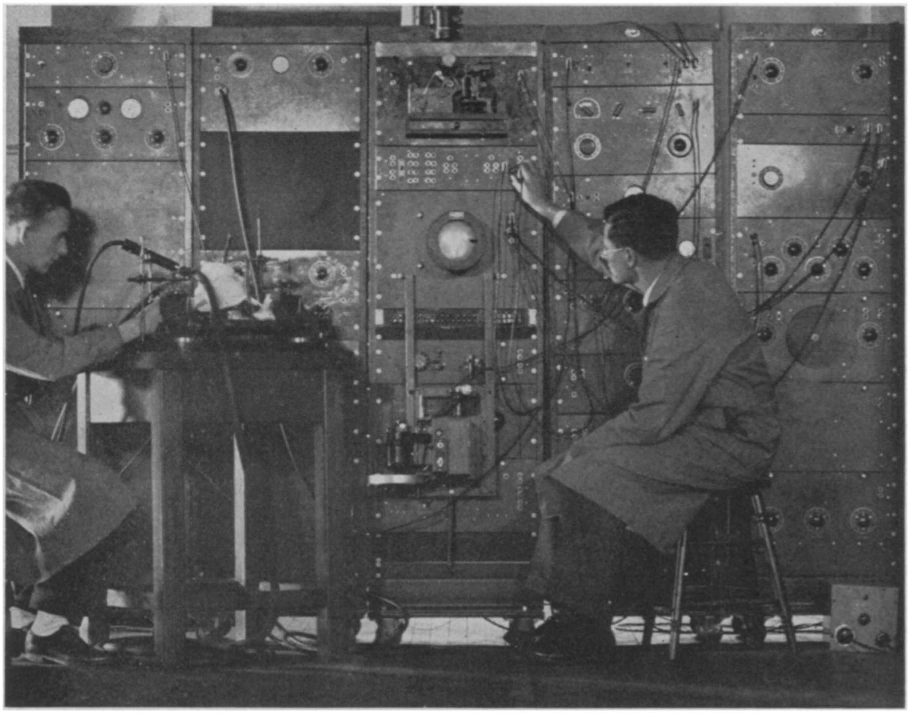

LISTENING IN

Dr. H. Davis (right) is plugging in so that the sound in a guinea-pig's ear will be picked from his hearing nerve and reproduced, amplified, in the loud speaker to the extreme right of the picture. Thus the ear of the guinea-pig does the job of a broadcasting studio microphone. The man working at the table on the left is Dr. A. J. Derbyshire. The scene is the laboratory at Harvard.

nerve fiber can respond to frequencies much greater than 1,000 a second. Nerve fibers must have a resting period after each impulse is carried; this rest, or refractory, period precludes the possibility of such rapid response.

A modification of the theory was therefore proposed in 1929 by scientists, including the late Dr. Leonard T. Troland of Harvard. It might be that there is a division of labor among the nerve fibers, he suggested. Although no single nerve fiber could respond to the higher frequencies, it might be that a single fiber would respond to every other sound wave or every third wave. Other fibers alternating with them would make it possible for the whole bundle of fibers to transmit the sounds to higher frequencies.

Confirmation

Confirmation of this suggestion came with further research at Harvard by Drs. H. Davis, A. Forbes and A. J. Derbyshire. They picked up action currents from the hearing nerve of a cat, following the same method of Drs. Wever and Bray, except that instead of listening in, they measured the frequencies picked up with a cathode ray oscillograph.

They found with this apparatus that when the sound reaching the ear of the cat was of a frequency of 700 or lower—that is, below the upper limit of the cello or alto singing voice—the frequency of the action current that goes up to the brain is exactly the same.

Sharp Drop

Between 700 and 900 cycles, however, a sharp change occurs in the size of the waves picked up. It drops to approximately half the size of those produced by equally loud sounds of lower frequencies. The sharp drop in the amplitude of the wave to half size was interpreted as meaning that at 700 to 900 cycles the nerve fibers had reached their speed limit and each was now responding to only one of each two successive waves. Since only half the fibers responded to any one wave, the size of the response was only half as great as when all were working.

At a frequency of 1,700—somewhere among the high notes of the flute and violin and above the limit of the clarinet—another drop occurs, indicating a breaking up of the nerve fibers into three groups, each responding to every third wave.

So far, the facts seem to be in confirmation of the "volley," or division-of-labor, modification of the telephone theory. But, unfortunately for that theory, the research was carried still further.

When the pitch of the sounds was still higher, that is, at frequencies of 2,800 or above, the responses became completely irregular. The auditory nerve, even by means of rotated activity among the fibers, cannot transmit frequencies above 2,800, it would seem. Yet these high notes are heard very well. Here the "volley" theory too falls down. Psychologists must seek further for an explanation of how we become aware of the shrill sound of the peanut whistle, or even the highest notes of the violin.

Clue in Structure

Another clue, which may provide the answer to this scientific riddle, is found in the structure and appearance of that puzzling part of the ear, the snail-like cochlea and its enclosed basilar membrane.

When physiologists examined the membrane as a physicist would look at a machine, the appearance of it seemed to suggest the solution of the problem.

When this membrane was unrolled from its spiral and examined, part of it was found to consist of some 24,000 fibers of different lengths—for all the world like a piano as it looks when you lift the cover and expose the grouped strings inside.

Now if you stand in front of the piano and hum a tone, you will notice that the piano repeats this same tone after you. Each string in the piano is tuned to vibrate at a certain frequency. When a note of that frequency is sounded in the vicinity, that string will pick it up.

Why couldn't this same thing happen in the ear, psychologists wondered.

When you hum a certain note, it may very well be that one particular "string" or group of fibers in the membrane picks up the vibration and is set to quivering at a similar rate, they reasoned.

Acts Selectively

Each part of the membrane has attached to it its own nerve fibers. When you hear middle C, the middle C area of the membrane vibrates, and the middle C nerve fibers pick up the impulse and carry it to the brain. When you hear high C, the high C area vibrates and an entirely different set of fibers pick up the impulse, carrying it by an entirely different pathway to the brain and perhaps to a different area of the brain's hearing center.

This is the famous theory suggested

long ago by Prof. Hermann Ludwig Ferdinand von Helmholtz. It was developed as a result of knowledge of physics and examination of the anatomical structure of the ear, but it is now receiving new support from physiological studies of the ear in operation by the aid of new techniques unknown to science in the days of Helmholtz.

Invention of the audiometer was important in this connection. With this modern electrical instrument, it is possible to make precise scientific tests of the hearing of persons for all the many pitches throughout the whole auditory range in much less time.

Lose High Tones

Persons of middle age or older become hard-of-hearing for high notes. Beginning at about forty years of age, tones above high C must be sounded with increasing intensity in order to be heard, and the highest notes that can be heard even when sounded loudest drop from an average frequency of something like 20,000 at 20 years to 10,000 at 60. This old age drop is not so great as it may seem from the figures, for after all it means a loss of only about one octave and that at a pitch way above the highest notes of the piano and those ordinarily used in conversation. Low tones are heard equally well by all normal groups.

This aging of the ears, corresponding to the dimming of eyesight in the aged, has been known for a long time. It was verified by exact tests made at Johns Hopkins University by Dr. C. C. Bunch, who is now at Washington University, St. Louis.

Not Equally Distributed

Microscopic studies of the snail-shaped inner ear were made by a group of Dr. Bunch's colleagues at Johns Hopkins, including Drs. S. R. Guild, S. J. Crowe, and L. M. Polvogt. These studies showed that the nerve fibers are not distributed equally throughout the whole length of the basilar membrane. The number rapidly decreases toward the base of the membrane where, it is now thought, the higher tones are received.

It may be that with age the nerve cells and fibers deteriorate, leaving parts of the membrane useless. The count of nerve fibers on the membrane varies markedly between young persons with normal hearing and hard-of-hearing aged persons. One man of 30 with normal hearing was found to have 25,245 of these nerve fibers. Another man of 63 with impaired hearing had only 4,437. Since the fibers are more widely scattered at the "high" end of the membrane, total deafness would occur there first.

As the records have accumulated, it has been possible to map out the basilar membrane to show just where an injury to nerve cells or fibers will cause deafness to certain tones. This map serves also to indicate just where on the basilar membrane hearing for the different frequencies takes place. The highest tones are picked up by the outer coils of the "snail" where the nerve cells are commonly not so numerous and where the ear's discrimination between neighboring frequencies is not so keen. The lower tones are picked up in a crowded area in the center of the coil.

Similar work on animals done at Johns Hopkins and also at Harvard by Dr. Davis working with Dr. S. S. Stevens have made use of the Wever-Bray listening-in technique to determine what tones were not picked up by animals with injuries to different areas on the basilar membrane. One at a time, the areas for each corresponding tone-deafness were located and plotted on a map. This map agreed very well with that worked out on the basis of autopsies on human ears.

Another map made by Dr. Elmer Cullers, of the University of Illinois, was made electrically by applying each of 23 frequencies throughout the auditory range to one place after another on the membrane, until the area of greatest response was located. This map, too, agrees with the others, and together they seem to provide a weight of evidence in favor of the theory that sounds of different pitch are each picked up by a different area on the basilar membrane "tuned" to that particular frequency and thence conveyed to the brain by its own "private wire."

The final chapter has not yet been written in this particulr scientific mystery story. Although these experiments on animals do not conflict with what is known of human hearing, scientists know that the results cannot be considered as applying directly to man. Physiologists are still searching with microscope, audiometer, radio hook-ups and every other known device to find out the working principle for this minute, delicate, yet marvelously efficient mechanism, the human ear.

Science News Letter, January 18, 1936

PHYSICS

Experimental Cornerstone of Einstein's Theory Checked

A FOUNDATION stone in the great mathematical structure that is the relativity theory of Prof. Albert Einstein has again been checked and found correct.

This, in essence, is the significance of the highly complex report presented to the National Academy of Sciences on behalf of Drs. F. L. Whipple, T. E. Sterne and D. Norman of Harvard College Observatory.

The Harvard experiment was an unsuccessful new attempt to detect in the speed of light some effect of what is known as ether-drift.

It was the failure of Michelson and Morley to discover an ether-drift that became a foundation for Einstein's relativity theory. It is a question of whether light in different directions with relation to the universe speeds along at the same pace.

The Harvard experimenters used prisms to bend light six times a day, with their spectrograph pointed in various directions. Precise measurements on lines of light showed no changes larger than the very small probable error of the instrument. Incidentally, the Harvard paper did not mention ether-drift but just gave the experimental results. Scientists will interpret the results as reassuring to the most widely held ideas about the lack of an ether-drift.

Science News Letter, January 18, 1936

A powerful station for television broadcasting is to be installed on the Eiffel Tower in Paris.

●RADIO

January 21, 4:30 p. m., E.S.T.
REMEMBERING WHILE YOU SLEEP
—Dr. Harry M. Johnson, American University.

January 28, 4:30 p. m., E.S.T.
MIDWINTER HEALTH — Dr. R. R. Spencer, Senior Surgeon, U. S. Public Health Service.

In the Science Service series of radio discussions led by Watson Davis Director, over the Columbia Broadcasting System.