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The Truth About Hearing

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Abstract:
The paper discusses the direct path of sound waves to the receptor, especially high frequencies. Attention was drawn to inertia in the middle and inner ear. The significance of the resonance of the longitudinal wave in the fluid with the transverse wave of the basilar membrane's natural vibrations was critically assessed. Problems related to the rocking movements of the stapes and the difference in the speed of the sound wave in the fluid and the traveling wave on the basilar membrane were pointed out. Comments are presented on the traveling wave and the amplification of soft sounds. A new molecular mechanism has been proposed for the simultaneous reception and transmission of very large amounts of information encoded in sound waves. The mechanism of energy and information transmission via sound waves to the receptor is briefly presented. The mechanism for intracellular amplification of received information that is too weak to reach the CNS has been described.

Keywords: ear

Introduction

The auditory signal path to the receptor

Some of the energy of sound waves is received by the auricles. The main energy flow reaches the tympanic membrane through the external auditory canal. Sound waves incident on the human earlobe are partly absorbed and partly reflected in accordance with the law – the angle of reflection is equal to the angle of incidence. The surface of the auricle is uneven, which causes the reflected waves to disperse. Only a small part of the reflected waves is directed into the external auditory canal [1]. The situation is different in mammals, where large, hanging ears completely obscure the external auditory canal. The wave energy received by the auricles is used to recognize the direction from which the wave is coming. Dogs such as dachshunds, basset hounds, setters, and pointers have long, hanging ears that obscure the auditory canal - they hear perfectly, recognize directions well, and are hunting dogs. Cats have 32 ear muscles that are used to adjust the ear position for optimal reception of wave energy. They can adjust their ear position by 180°, which prevents waves from being transmitted into the auditory canal. The auricles of these mammals are heavily furred, which increases the absorption of wave energy.

sound wave incident on the tympanic membrane is conducted, absorbed and reflected. A wave with a frequency of 1000 Hz and an intensity of 90 dB, with an amplitude of 500 nm, is conducted to the middle ear as a wave of 80 dB = 100 nm. Fraction of the wave absorbed according to Huygens' principle: "Every point in the environment that the sound wave reaches becomes the source of a new spherical wave" and is conducted further. The wave from the tense part of the tympanic membrane is conducted through the fibrocartilaginous ring and the tympanic sulcus to the temporal bone

The vibrations of the elastic tympanic membrane are transferred to the malleus, which is connected to the tympanic membrane, and then to the incus and stapes.

Information received by the auricles, especially in animals, is transmitted to the skull bone. They are subject to constructive interference with waves transmitted from the ossicles of the middle ear and especially from the stapes plate during rocking movements. During each constructive interference of subsequent sound waves, the wave amplitudes are added together – a final wave is created, which goes directly to the hearing receptor.

By observing the vibrations of the tympanic membrane and malleus through a microscope, Bekesy noticed that up to a frequency of 2400 Hz the malleus vibrates in unison with the tympanic membrane. Above this frequency, the malleus cannot keep up with the vibrations of the tympanic membrane [2].

Vibrations from the malleus are transmitted to the incus and stapes, as well as to the oval window and the fluids of the inner ear.

Inertia in the middle ear

The vibrating mass of the middle ear ossicles with the tympanic membrane was assumed to be 70 mg for the calculations, and AI performed calculations for various frequencies and intensities.

For 60 dB, an amplitude of 10 nm and a frequency of 2400 Hz, inertia = 1.59 x 10-5 Newton.

For 60 dB – 10 nm – 100 Hz – inertia = 2.76 x 10-7 N.

For 60 dB – 10 nm – 1000 Hz – inertia = 2.76 x 10-5 N.

For 60 dB – 10 nm – 10000 Hz – inertia = 2.76 x 10-3 N

For 100 dB – 1000 nm – 10000 Hz – inertia = 0.276 N.

N – Newton = 1 kg x m/s.

If, in wave motion, a section of the signal path to the receptor that has mass vibrates, then inertia occurs in this motion. Inertia is directly proportional to the amplitude and the vibrating mass and proportional to the square of the frequency – formula: (2 π x frequency)2 x amplitude x mass g/mm x s2. Calculations show that, for the same sound intensity and the same vibrating mass, an increase in frequency from 100 Hz to 10000 Hz causes an increase in inertia of 10000 times. This means that the energy required to generate such a wave in the presence of a vibrating mass is impossible in the ear. Since we can hear frequencies up to 20 kHz and other mammals can hear up to 100 kHz, the conclusion is obvious: High-frequency auditory information is transmitted to the receptor by sound waves, without mass vibration of the vibrating elements. This principle also applies to the inner ear, where the vibrating mass of the basilar membrane, together with the organ of Corti and the cochlear fluids, is much greater.

According to the law of inertia, high frequencies conducted by sound waves in the environment, having no mass, cannot generate cochlear fluid flows. The evidence is stapedotomy, without high-frequency transmission [3,4].

We hear high frequencies, which indicates a different mechanism for transmitting these frequencies to the receptor. Low frequencies are conducted by vibrating elements with mass, through fluids, soft tissues, and bones to the receptor. Evidence of the easy conduction of low frequencies through various tissues is the hearing of a child in the mother's womb from the second half of pregnancy, when the outer and middle ears are not yet functioning properly. An elephant receives low frequencies with its legs as the waves are conducted to the inner ear through various tissues.

High frequencies are received and transmitted without the vibration of mass-bearing elements in the middle and inner ear.

Rocking movements of the stapes

The transmission of high frequencies to the cochlear fluids is hindered by the rocking movements of the stapes plate. Low frequencies are conducted by the piston-like movements of the stapes plate. High frequencies cause rocking movements of the stapes. Depending on the pitch of the sound, the plate vibrates along either transverse or longitudinal axis. During such vibrations, one part of the plate generates a forward wave motion while the other part of the plate simultaneously generates a backward wave motion. Two simultaneous fluid streams moving in opposite directions experience friction, creating destructive interference with significant disruptions in the transfer of information via sound waves to the cochlear fluids. This creates a problem with the formation of a proper traveling wave on the basilar membrane. The resonance of the abnormal wave in the fluid with the natural vibrations of the basilar membrane does not ensure the proper transmission of auditory information.

Resonance of waves in the inner ear, traveling wave of the basilar membrane.

The natural vibrations of the basilar membrane were incorrectly calculated [5]. To calculate the natural vibrations of the basilar membrane, Bekesy calculated the elasticity, mass and dimensions of small sections of thin, prepared basilar membrane. He did not take into account that the basilar membrane does not vibrate on its own. It vibrates with the entire organ of Corti, which lies on the basilar membrane.

Traveling wave peaks cannot arise on the basilar membrane itself. They can arise on the reticular membrane or on the peaks of hair cells that vibrate with the basilar membrane. The connective tissue on the lower surface of the basilar membrane vibrates, along with the basilar membrane and the massive organ of Corti, and the cochlear fluid also vibrates. The whole thing has a large mass, it is a wave motion, inertia is mandatory - is it not taken into account in the calculations (?).

Amplification of soft tones by 40-50 dB

When soft tones are amplified by 40-50 dB, the shrinking outer hair cell, which has no direct connection with the basilar membrane – it is part of the organ of Corti lying on the basilar membrane – pulls up the basilar membrane together with the organ of Corti and the hair cells [6]. It causes the basilar membrane to vibrate without knowing the wave that is passing through the basilar membrane at that time. It is intended to induce fluid flow that also encodes harmonic components, length of sound, phase shifts, accent, phase and transmits information via tip-links to the receptor [7].

We hear peri-threshold tones when the input wave amplitude is 0.05 nm. As it travels through the cochlear fluids and basilar membrane, the amplitude of this wave decreases approximately 500 times. The energy of this wave decreases 250,000 times!! This wave, about a million times smaller than the diameter of the hairs of the hair cells, is supposed to bend them, because the hairs are connected at their tips to the tectorial membrane. Bekesy did not know the magnitude of the wave energy decay on the way to the receptor, which he himself determined. Laser vibrometric tests confirm such a decay of wave energy.

Nature could not accept such a hearing mechanism.

Mechanical amplification of soft sounds poses a significant energy problem. Generating an additional vibration of a mass of approximately 250 mg requires increasing energy proportional to the square of the increase in the frequency of the amplified wave. There is no sufficient energy available in the ear for high-frequency amplification using this method.

250 mg ---40 dB = 1 nm ---100 Hz ----98.7 nano N
250 mg -40 dB = 1 nm ---1000 Hz ---9.88 micro N
250 mg—40 dB = 1 nm—10000 Hz - 98.7 milli N
250 mg -100 dB = 1000 nm - 10000 Hz -- 0.988 N

Prestin is not an energy storage device. Such energy cannot be derived from the electrochemical potential of the hair cell, because disturbances and loss of membrane potential by an excitable cell, such as the hair cell, lead to disturbances in intracellular processes and subsequent cell death.

An abnormal longitudinal wave in a fluid is a forcing wave for the vibrations of the entire mass vibrating in a highly damped fluid.

When listening to peri-threshold tones, the energy of the forcing wave is smaller than the attenuation of the forced wave – in such a case, resonance does not occur, there is no traveling wave. Humans hear peri-threshold tones with an input amplitude of 0.01 – 0.05 nm, which reach the receptor via a different path. The reason for the lack of resonance is not only the lack of amplification of the wave in the middle ear, but its disappearance. The input wave of 1000 Hz, 90 dB = 500 nm, at the stapes plate is: 11.57 nm. A 10000 Hz, 90 dB = 500 nm input wave has an amplitude of 0.1157 nm at the stapes plate. Laser Doppler vibrometry studies rule out amplification of the wave in the middle ear. They show a significant decrease in wave amplitude on the way to the stapes and a decrease in wave energy in the middle ear proportional to the square of the increase in wave frequency.

In stapedotomy, the difference in the area of the tympanic membrane and the piston is 50 to 100 times in favor of the tympanic membrane, and does not cause amplification of the wave.

Fluid flows and the described vortex motions of fluids at high frequencies are impossible. The flow of cochlear fluid is supposed to bend the hairs of the hair cells. The tip-links mechanism does not work at high frequencies. The signal reaches the receptor via a different route. We hear. .

The resonance of the longitudinal wave with the transverse wave of the basilar membrane has vectors directed at right angles to each other. The wave speed in the fluid of 1450 m/s is converted into a variable traveling wave speed on the basilar membrane from 50 m/s in the area of the oval window to 2.9 m/s in the area of the cap (according to Bekesy). The lower wave speed, from 29 times near the base of the cochlea to 500 times at the peak, causes a very big problem in information transfer due to variable wave compression. For the lowest frequencies, recording information on a 1450 mm wave in fluid over 1 ms must be recorded on a 2.9 mm traveling wave. Each frequency of a sound wave resonates with a transverse wave at a different location on the basilar membrane and at a different time, due to the different wave speed.

For polytones with numerous harmonic components this is impossible. Wave resonance occurs at the same or similar frequencies and requires time for the resulting forced wave to reach its maximum deflection.

Intracellular amplification:

Intracellular amplification is a whole complex of factors such as: phosphorylation and dephosphorylation of ion channels responsible for the conductivity of cell membranes, ATP concentration, cAMP and cGMP levels, cell pH, osmotic pressure, presence of ligands, and the operation of Ca++ATPase pumps. These pumps associated with the cell membrane play a significant role in maintaining a variable calcium level within the cell. Intracellular amplification is also related to the activity of calcium-binding proteins, where calmodulin plays an important role, influencing the production and breakdown of cAMP and cGMP. It activates protein kinases and phosphatases and regulates the calcium pump. It influences the contraction of muscle and non-muscle cells by activating cAMP-independent myosin light chain kinase. Calmodulin also influences transmitter exocytosis.

Calmodulin's binding of four calcium atoms increases its effect 1000-fold.

The process of enzyme production or the rate of their breakdown is regulated.

Calcium is a second messenger of information in the cell, acting faster than other second messengers: cAMP, cGMP, DAG, and IP3, which are produced in connection with increased calcium levels or activated by G proteins. The second messenger production step is one of several mechanisms of intracellular amplification. One enzyme molecule can produce several hundred second messengers. Received tones whose energy is too low to reach the brain are amplified.

Intracellular signal amplification is one of the main pillars of the "Submolecular Theory of Hearing."

Mechanoreceptor

The receptor receives wave signals lasting tenths of a millisecond [8,9] when only one or two wave periods are active. Wave resonance in such a short time is not possible. It is difficult to explain how the resonance of such different waves in terms of the direction of resonating waves and the wave speed, transmits, in addition to amplitude and frequency, phase shifts, length of sound and accent. How does wave resonance ensure the transfer of quantized wave energy in the form of packets of multiple energy units, i.e. energy quantum?

It is difficult to explain how wave resonance and the traveling wave on the basilar membrane can transmit an unlimited amount of auditory information simultaneously reaching the ear. This situation occurs when listening to large symphony orchestras in concerts. How many wave peaks can occur simultaneously on the basilar membrane? A single wave cannot transmit all the information simultaneously. A trained musician recognizes the individual musical instruments that create different sounds.

In the case of sound waves reaching the receptor via a different route, directly, without resonance and traveling waves on the basilar membrane, this is possible, because this is how we hear music.

The amount of energy transferred per unit of time to the receptor is directly proportional to the transmission speed and frequency and inversely proportional to the path length and losses along the way. Sound waves reaching the receptor, regardless of the route, transmit information in the form of mechanical energy to the receptor, to the hair cell.

An acoustic wave involves the transmission of wave motion from sound source, where information is encoded to receptor. Wave motion is the transport of wave energy through environmental particles oscillating around their equilibrium position. The amplitude of particle deflections depends on the sound intensity. The frequency of deflections/s is the frequency of the sound wave. The size of the molecules depends on the number of atoms in the molecules that make up the sound wave.

The change of a molecule in the course of energy transfer to the next molecule takes place at the electronic level in attoseconds – 10-18 s. Chemical reactions in the hair cell take place in 10-14 s. (Femtosecond – 10-15 s). “Difficult” reactions take place 1000 times slower, but it is still 10-11 seconds.

Symphony:

The information transferred concerns amplitude, frequency, harmonic components, length of sound, melody, accent, and phase. The analysis involves polytones and listening to music concerts where 50 or 100 musicians simultaneously generate sounds of different intensity, different frequencies and various other components. (Ludwig Von Beethoven – Symphony No. 9 – 53 musicians, Gustav Mahler – Symphony No. 8 – 160 musicians!).

The problem lies in how so much, such diverse information, encoded as wave energy, simultaneously reaches the receptor, is received, transmitted to the auditory cell, and to the brain, where a faithful image of the music being heard is created. Theoretically, it must be possible to transmit and receive waves generated by a given instrument simultaneously, because that is how we hear [10,11].

Transmission of information:

Air plays an important role in hearing as a medium for sound waves. Air particles are in constant motion, and there is superimposition of this motion with the energy generated by the sound source. Particles have: an electric charge, or are neutral, they have: rest mass, mechanical momentum, magnetic momentum. The stationary state is the minimum energy of particle before receiving external energy. The atoms in a molecule are linked by chemical bonds.

The distance between collisions is called the free path. A molecule collides at a rate of 2.3 x 109/s per second. The diameter of an air molecule is 2 x 10-7 mm. Mean free path 2.1 x 10-4 mm = 1000 molecule diameters. In 1 cm3 of air there are 2.7 x 1019 to 2.7 x 1021 molecules. The change in momentum is equal to the added impulse and involves accelerating or decelerating the momentum of the molecule. The added impulse (energy) is transferred by the molecule to the next molecule, returning itself to its basic energy level. There are about 1 billion such collisions in 1 second. A sound wave in the air travels at 340 m/s. This means about 3000 particle collisions over a distance of 1 mm. Regardless of the number of collisions, the energy encoding information transferred to subsequent particles does not change, even after a change of environment to the auricle, tympanic membrane, ossicles, soft tissues or the cochlear bone casing.

Vibrations occur around an equilibrium position – kinetic energy and potential energy are exchanged – this is the total energy. Vibrations are oscillations of individual atoms which, when added together, create the oscillations of molecule. Secondary vibrations are the rotational motion of atoms, which alters the angles of chemical bonds. Each change in oscillation, rotation and change in bond angles is associated with a corresponding portion of energy. This is how the energy encoding information is transferred from one molecule to the next, all the way to the receptor. Each molecule can accept and transmit an amount of information proportional to the square of the number of atoms in the molecule [12].

A 10-atomic molecule can accept and transmit 1010 changes of energy – that is, so much information at once. The transfer of information between molecules takes place at the electronic level - through electron clouds. The transmission takes place in attoseconds = 10-18 s. This ability to transmit a huge amount of information at the same time makes it possible to listen to large symphonies. The second problem is the transfer of information from sound wave to the auditory cell receptor - it takes place on the same principle. The sound wave particles, endowed with additional energy – i.e., information – transmit the information to the competent sound-sensitive molecules of the receptor. There is a genetically determined ability of receptor to receive energy at a specific frequency. High-pitched sounds are received near the oval window. Lower and lower frequencies are received towards the cap. The basilar membrane – a connective tissue lacking innervation or the ability to change tension – provides mechanical support for the most important part of the inner ear – the organ of Corti.

The receptor receives the mechanical energy of the sound wave and converts it into the energy of the chemical bonds of sound-sensitive molecules and then into the receptor potential by regulating the openness of the potassium mechanosensitive channel in the hair cell membrane, thanks to conformational changes in the molecules responsible for gating the potassium channel [13].

The energy encoded in sound wave is quantized, meaning that an integer multiple of a quantum of energy represents one piece of information. The number of such separate energy packets in the sound wave that reaches us is unlimited. The number of information-receiving molecules in the receptor is genetically determined and distributed in the organ of Corti along the basilar membrane. The capacity of each information-carrying molecule depends on the number of atoms that make up the molecule. These are unimaginable possibilities. A 4-atomic molecule can accept and transmit 10,000 pieces of information. A 5-atomic molecule can already carry 100,000 pieces of information, a 6-atomic one - a million, etc. Information is generated both in voice emission and in music at the same time, with different intensity, quantity and magnitude of information. But in total, the amount of information produced is smaller than the capacity of environmental molecules to absorb information. A molecule with basic energy has the ability to accept external energy in the form of energy quanta, and after colliding with another molecule, it gives off energy to the molecule, which, when colliding with the next one, gives off the excess energy it previously absorbed. Such molecule collisions, with the transmission of information, occur 10 billion times per second.

This is how the sound wave travels through the air to the auricle and the tympanic membrane.

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