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A new philosophy of hearing

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Introduction

A detailed analysis has been conducted for the current Bekesy's travelling wave theory of hearing proclaimed in 1928. Repeatedly complemented, the theory still contains ambiguities, as well as informal and formal fallacies. Common acceptance of the present state of knowledge about hearing and blocking the discussion on this topic hinder learning the truth about hearing. Achievements in numerous scientific disciplines and experimental research by scientific centres worldwide provide grounds for presenting a new vision of hearing. The first part of this paper is dedicated to a critical analysis of Bekesy's travelling wave theory. In the second part, an abridged version of a new theory of hearing is put forward under the name of the "submolecular theory of hearing". The full version of this theory is provided in the study Submolecular Theory of Hearing published in 2022.

Analysis of Bekesy' s travelling wave theory

If the path of the signal to the receptor is interrupted and the receptor receives the signals, then this proves that there is another path of the signal. This is evidenced by a cochlear implant in partial deafness where the basilar membrane is blocked, the existing hearing capacity is preserved.[1]

The signal becomes several hundred times less intense on its way to the receptor via the basilar membrane and the cochlear fluid. The threshold wave, which is 8 pm at the entry, becomes about 100 times less intense on the pathway. It is unable to make the auditory hair cells lean down, about a million times thicker than the sound wave amplitude. The signal reaches the receptor – via another route.[2,3]

According to the theory, a wave that is 90 dB (500 nm) on the tympanic membrane is 80 dB (100 nm) on the side of the tympanic cavity, amplification in the tympanic cavity is 33 dB. Vibrometric tests show that the amplitude of this wave on the stapedial base is 11.7 nm = ca. 70 dB.[4]

A wave below the threshold is not detected by the receptor. Too soft to reach the centre, the received signal is amplified in the auditory cell on a molecular level. This is intercellular amplification.

The energy is transferred by sound waves with no mass displacement. Fluid displacement cannot code the information about the quantitative, the harmonics and the phase shifts of multitones. Quantization of energy is impossible.

A travelling wave is incapable of coding all the information. Auditory hair cells cannot code all the information. Cadherin tip links that pull the cellular membrane of an adjacent hair cell do not code all the information; it is not possible for them to regulate the molecular mechanically-activated potassium ion channel gating mechanism.

Transferring the complete information of the longitudinal wave in the cochlear fluid on the transverse wave of the basilar membrane is impossible. The resonance of waves of different frequencies on different planes is either difficult or impossible.

Natural vibrations of the basilar membrane in mammals are inconsistent with the frequencies of the sound wave in the cochlear fluid that reach up to 200 kHz. The membrane is immersed in a liquid that shows high dampening properties. It does not have the ability to vibrate at the range from 5 Hz up to 200 kHz in animals that have the same hearing mechanism that a human has.

The speed of a wave in liquid is 1450 m/s. The speed of a travelling wave is 2.9 m/s – 50 m/s (according to Bekesy). With the speed of wave being this disproportionate, information transfer becomes problematic. The speed of the longitudinal wave is constant. The speed of the travelling wave is variable, with the transfer compressed from 29 to 480 times.

Up to a certain limit, soft tones are amplified in the middle ear by 33 dB, then, amplification of the inner ear by means of contracting outer auditory cells amplifies the sound 40-50 dB.[5,6] In total, a 20 dB wave is 90 dB after the amplification and we still hear it as a 20 dB wave.

From the base up to the top, the canals of the cochlea become 3 times narrower. In turn, the basilar membrane that separates them becomes 3 times wider in this direction.

The canals of the cochlea, measuring from 4 mm at the base to 1.4 mm at the top in diameter, which hold fluids of various electrolyte concentration levels, are separated by the basilar membrane that is from 0.25 mm to 0.75 mm wide (according to the theory). Is not the remaining part of the partition a basilar membrane?

The basilar membrane vibrates with the entire organ of Corti and the rest of the membrane separating both canals. Natural vibrations of the basilar membrane are calculated using the width of the basilar membrane 0.25-0.75 mm, with no load, without dampening the cochlear fluid.

On both sides of the basilar membrane there is a fluid that dampens vibrations of the basilar membrane. When the dampening of the fluid is greater than the energy of the incident wave, the resonance of the longitudinal wave in the fluid with the basilar membrane is impossible. The hearing threshold is preserved.

According to Kemp,[7] in the spontaneous emission in the ear, an OHC contraction generates a sound wave that is reverse to the outer auditory duct. An OHC contraction is formed after depolarisation – the response and action potential need to be detected during an ECoG test. The energy of the vibration of the basilar membrane acts on the cochlear walls in all directions. The waves acting on the walls of the canals of the cochlea must be recorded on the bone surface.

The time of transfer for soft and loud tones from the outer auditory duct to the point at which ECoG measurement is taken is 1.5 – 1.9 ms. The calculated time in which the signal runs via the basilar membrane and the cochlear fluid for soft tones is 6 -7 ms. Loud tones make their way to the receptor in a time that is different to that of soft, amplified tones. According to the travelling wave theory, splitting of information occurs.

In stapedotomy, the piston substitutes only the piston motion of the stapedial base. The absence of the rocking motion of the stapes in stapedotomy results in the absence of transfer of high-frequency waves.[8]

The presence of physiological rocking motion of the stapedial base in the case of higher frequencies either hinders or eliminates formation of a travelling wave on the basilar membrane. The reason for this is the motion of the base along either the transverse or the longitudinal axis of the base. When one half is generating sound waves forward, at the same time, the other half of the base is generating same-frequency reverse waves that run in the

opposite direction. These waves are subjected to destructive interference. There is no wavecoding and the information is not transferred to the receptor. Hearing is preserved, the signal is conducted to the osseous capsule of the cochlea.

Speed of the sound wave in the fluid = 1450 m/s. At the frequency of 1000 Hz wave length = 1450 : 1000 = 1.45 m = 145 cm Active length of the basilar membrane = 3 cm. Period of the sound wave 1000 Hz = 1 ms – the wave travels 1 length of the wave = 145 cm. During one period of the wave one wave amplitude peak occurs – this is related to energy transfer. One 1000 Hz wave peak occurs every 145 cm – resonating over 3 cm of the basilar membrane. In resonance, the driving force of the wave depends on the wave amplitude. It is unlikely that one peak of a longitudinal wave in the fluid that occurs once every 48 lengths of the basilar membrane could convey all the information contained in the sound wave onto the transverse wave of the basilar membrane. We hear frequencies of 100 Hz – when the length of the wave is 14.5 m – one peak of the wave in the fluid occurs every 483 lengths of the basilar membrane. We hear frequencies of 50 Hz – when the length of the wave = 2900 cm – in humans, it takes 966 lengths of the basilar membrane for one maximum amplitude of the longitudinal wave in the cochlear fluid. For mammals whose basilar membrane is 5 mm long, it takes six times more lengths of the basilar membrane = 5796 for generating a maximum wave amplitude.

The 80 dB, 1000 Hz signal forwarded to the outer auditory canal with the duration time of 0.5 ms is received by the receptor.[9,10] At the frequency of 1000 Hz in the cochlear fluid half of the wave period = 72.5 cm. At 10 000 Hz in the cochlear fluid at 0.5 ms, this is a quarter of the wave period = 7.25 cm. Part of the longitudinal wave period in the cochlear fluid provides no grounds for a resonance between the longitudinal wave and the transverse wave of the basilar membrane in humans, which ensures all the information is transferred to the receptor.

In wave motion, inertia is proportional to frequency squared and directly proportional to amplitude and vibrating mass. In wave motion, inertia = (2π x frequency) 2 x amplitude x mass g x mm/s 2. In the middle ear and the inner ear, there are vibrating elements that have mass, speed and acceleration. This indicates that inertia is significant in hearing, even more when it is assumed that the signal reaches receptor via the cochlear fluid and the basilar membrane.

The theory provides no explanation for the frequency of contractions in outer auditory cells up to 200 kHz. Tests that attempted to prove OHC contraction frequency were conducted improperly. Isolated auditory cells were stimulated with electricity. The role of ion channels of the cell wall that determine the duration of a single full auditory cell depolarisation cycle 3-4 ms was disregarded. The times for the absolute and relative refraction of ion channels restrict cell contraction frequency.

The tip-links mechanism – there is no possibility to convey the information on the harmonics, phase shifts and quantitative. Cadherin tip links cannot be responsible for the molecular, mechanically-activated potassium ion channel gating mechanism. Without information transfer there is no hearing.

Discussion

The travelling wave theory proposed by Bekesy in 1928 fails to correctly explain many mechanisms that the hearing process comprises.[11] Development of various sciences, studies conducted by research centres worldwide and analyses of the current theory of hearing indicate that there is a need for seeking the truth about hearing. Slowly, a new philosophy of hearing is born – proposed and published under the name of the “submolecular theory of hearing”.

The main idea of the new theory is the transmission of auditory information encoded in a sound wave in the form of quantified energy directly to the receptor. The elimination of numerous energy transformations on the way ensures swift and unflawed transmission of information, as confirmed by experimental studies.[12]

Based on the claim that each point in material environment reached by sound wave energy becomes a source of a new sound wave, it has been assumed that the energy received by the auricle, the tympanic membrane and the auditory ossicles, primarily the stapedial base, transmits the energy of the wave to the surroundings, the osseous capsule of the cochlea. In this respect, the resonance of the longitudinal wave with the transverse wave plays no role. Energy is not transformed into the transverse wave, as it does not work in fluids. It is necessary that energy is retransformed from transverse to longitudinal in accordance with the previous theory. The new theory states that the information is transferred by means of a sound wave without mass displacement. Provided it is in motion, the cochlear fluid moves with the sound wave amplitude. There are neither laminar flows nor turbulent flows, described in the travelling wave theory – whirlpools in the cochlear fluids are described. The hydrodynamics of fluids is one of the key foundations of Bekesy's theory. Fluid flows are incapable of coding quantified energy, harmonics, phase shifts, or quantitative.

Another important difference in the new theory pertains to the mechanism of direct transfer of sound wave energy to the receptor.

This takes place on a molecular and electron level. Sound wave energy acts on sound-sensitive molecules causing conformational changes of particles. These molecules receive energy and code the auditory information. The additional molecule energy taken from a sound wave generates conformational changes that affect the mechanically-activated potassium ion channel gating mechanism. Conformers that are created by the acting sound wave energy are responsible for opening and closing potassium channels.

The ability of auditory cell receptors to receive sound wave energy of a specific frequency is genetically determined. Receptors that receive high-frequency waves are situated in the area of the base of the cochlea. The closer they are to the cochlear cupula, the lower the frequency of the waves received by receptors. Each auditory cell has an individual or group connection to the centre and on this basis, knowing the transmission pathway, the centre identifies wave frequency.

The third difference compared to the previous theory pertains to the amplification of a signal heading to the centre. It is an intracellular amplification. Waves that are too weak to reach the centre are amplified. The amplification process takes place on a molecular level. Only a wave that has been received by a receptor is amplified.

The submolecular theory puts much weight on the work of an auditory cell, ion channels of the side and lower walls of an auditory cell and synapses, as well as describes phenomena that accompany hearing, such as temporal aggregation and spatial aggregation, lateral inhibition and postsynaptic inhibition, and receptor fields.

According to the new theory, the time it takes a signal to reach the receptor or the point where a test is conducted on the auditory nerve is consistent with experimental studies. There is no decrease in the energy on the pathway to the receptor.

The number of sound wave energy transformations on the way to the centre is lower by half. The new theory eliminates the conflict of the difference in the speed of the longitudinal wave and the transverse wave. This eliminates the issue of the difference in wave length, particularly at low frequencies, with the length of the basilar membrane.

Mechanical amplification is transformed to molecular, intracellular amplification. This emphasises the significance of inertia of vibrating elements that have mass in the ear. It explains the lack of high-frequency transmission after stapedotomy.

This provides an explanation for hearing after the basilar membrane is blocked in the course of a cochlear implant surgery due to partial deafness.

Fundamentals of the submolecular theory of hearing[13]

Molecules are made up of atoms connected with chemical bonds, covalent (atomic) bonds or ionic bonds. Ionic bonds are formed when atoms have significant differences in electronegativity. Some atoms give electrons away, other atoms accept electrons. By accepting an electron, they become a negative ion. For a chemical bond to be formed, there have to be at least two valence electrons of two elements.

A sound wave acts on particles (molecules) that are a sum of atoms that have mass expressed in Daltons. 1 u = 1.66 x 10 -24 g = 1/12 carbon atom mass. A Dalton is a unified atomic mass unit.

A change in the total energy of a molecule causes a shift in the angles of valence bonds, which are angles between adjacent valence bonds that can become smaller or greater with changes in energy.

A dihedral angle – a torsion angle – is a rotation on the axis of a noncovalent bond, the changing of which takes much less energy than for changing a valance angle. For this reason, changes in the geometry of a molecule take place mainly by means of changes in the dihedral angle. The number of possible molecule conformations is determined by the size of the molecule. For instance, for a molecule made up by 20 peptides, the number of possible conformations is 10^{20}.

For a 100-peptide molecule, the number of possible conformations is 10 100!. Native conformation is basic conformation with the lowest level of energy. Molecules are affected by specific-frequency harmonic vibrations all the time. These vibrations stem from all the vibrations of atoms of a molecule around their balance position

that overlap with the same phase for each atom, meaning that atoms reach maximum deflection at the same time. Chemical bonds are then shortened and elongated. When one of them becomes shorter, another becomes longer. What then occurs is bending vibrations, oscillation, changes in the angle values, and rocking of atoms or entire molecules. Oscillations affect rotation as the dimensions of the molecule change.

Potential energy of a molecule is related to chemical bonds; it is minimal when the length of every bond in the molecule is not under tension. The total energy of a molecule is the sum of translational energy, electronic energy, rotational energy, and oscillation energy. Translational energy is part of the inner energy of a molecule related to its own motion in space; energy such as kinetic energy of these motions.

With the optimal bond length preserved, the angle between the bonds can be changed. A change in angles triggers a change in the distances between some atoms, which changes the potential energy of the molecule.

Molecule conformation is also affected by Van der Waals bonds, electrostatic impact, determined by the charges of specific atoms.

Torsion angles – a change in these angles causes a change in energy; an angle between the atoms is rotated. This affects rotational energy of the entire molecule.

Oscillations and rotations have an impact on the energy of motion inside the molecule and the kinetic energy of the centre of the molecule mass. Oscillation cannot be strictly separated from rotation, since in oscillation, the length of a molecule changes, the length of bonds changes, and the moment of inertia of a molecule.

A sound wave should be considered a stream of a portion of energy in the form of multiplied quanta of energy. An atom has a total energy, that is, a sum of the kinetic energy of electrons and the potential proton-electron energy. An electron orbits with a specific constant energy. A change in the orbit for a more distant one or a closer one is accompanied by an emission or absorption of some portion of quantum energy. Each atom has a different total energy and every orbit has a different energy. Hydrogen electrons in a higher orbit are an excited state, a higher energy. Absorption of a quantum of energy results in a shift of an electron to a higher orbit and a higher energetic state. The atom is now an excited atom. The added energy must be exactly equal to the difference in the energy between the electron orbits, between energetic states. In turn, a return of an electron to a lower level causes the electron to be radiated in the form of electromagnetic radiation. An atom remains in the excited state briefly, 10 -8 s on average, and then frees itself of the excess energy and goes into a lower level of lower energy. In the course of moving to the lower level, the atom radiates a quantum of energy – it is an emission of a wave of a specific length.

When atoms that are constantly in motion collide, kinetic energy is transferred to the other atom. The latter absorbs the energy and goes to a higher-energy level – it is an excited level. Changes in electron states take place within attoseconds 10 -18 s. In this time, an electron cloud is changed. Particles that have single bonds are susceptible to conformational changes. A constant rotation of groups of atoms takes place round the bond. Such particles are shape-shifting. Each change in the shape requires external energy. Rotation is not permanent; as a result of the release of energy, the least-energy state is restored. A molecule that is not affected by any force is in a basic native state and has the lowest potential, global energy. The effect of external energy upsets this balance. Depending on the energy quanta, conformation changes of a molecule are incremental.

The time in which an excited particle goes back to its native state is relaxation time specified in femtoseconds. It is determined by the degree to which conformation changes These studies give us a better understanding of the mechanism behind the ever-precise reception and transfer of the information that a sound wave carries. A relaxation that is this fast is the condition for the formation of further conformational changes. This is important at sound frequencies up to 200 kHz (the bat). This transfer mechanism is binding on the path to the mechanically-activated potassium ion channel, as well as in an auditory cell where the information is conveyed by means of chemical reactions of transmitters of intracellular information.

1 femtosecond (fs) =10 -15 s = 0.000,000,000,000,001 of a second!

A molecule sensitive to a certain kind of energy of specific frequency receives this information but cannot cumulate energy in the molecule permanently. It has to get rid of that energy fast. The molecule strives to reach the native state as soon as possible. The energy cannot disappear, it has to be forwarded – to the neighbour. Excitation of a molecule, much as its relaxation, takes place within several femtoseconds. This allows high frequencies to be transferred. One period of vibrations of atoms and molecules is 10 -15 second long. A molecule has the capacity to add more molecules. A supramolecular complex is created, capable of receiving external energy, resulting in conformational changes in the complex and the possibility for work to be done; it can affect the gating of potassium ion channels dependent on a sound wave.

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Conflicts of interest

The author declares there is no conflict of interest.

References

1. Skarżyński H, Skarżyński PH. New strategy for partial deafness treatment 18 years of own experience. *Nowa Audiofonologia*. 2014;3(5):9–16.
2. Kwacz M, Marek P, Borkowski P, et al. A three-dimensional finite element model of round window membrane vibration before and after stapedotomy surgery. *Biomech Model Mechanobiol*. 2013;12(6):1243–1261.
3. Wysocki J, Kwacz M, Mrówka M, et al. Comparison of round window membrane mechanics before and after experimental stapedotomy. *Laryngoscope*. 2011;121(9):1958–1964.
4. Szymański M, Rusinek R, Zadrożniak M, et al. Vibrations of the human tympanic membrane measured with Laser Doppler Vibrometer. *Otolaryngologia Polska*. 2009;63(2):182–185.
5. Hudspeth AJ. Hearing: mechanical amplification in the ear. *Neuron*. 2008;59(4):530–542.
6. Dong W, Olson E. Detection of Cochlear Amplification and Its Activation. *Biophysical Journal*. 2013;105(4):1067–1078.
7. Kemp DT. Otoacoustic emissions travelling waves and cochlear mechanisms. *Hear Res*. 1986;22:95–104.
8. Skarżyński H, Mrówka M, Młotkowska-Klimek P. *Stapedotomia u chorych z małą rezerwą słuchową*. Audiofonologia vol. XXV. 2003.
9. Martinson K, Zieliński P, Kamiński T. *Dyskryminacja czasu trwania ultrakrótkich impulsów akustycznych*. Postępy Akustyki, Otwarte Seminarium Akustyki, Instytut Fizyki Jądrowej, Kraków. 2018.
10. Majka M, Sobieszczyk P, Gębarowski R. *Subsekundowe impulsy akustyczne: Wysokość skuteczna i prawo Webera Fechnera w różnicowaniu czasów trwania.* Instytut Fizyki Jądrowej PAN, Kraków. 2014.
11. Guinan Jr J, Solt A, Cheatham M. Progress in Cochlear Physiology after Bekesy. *Hear Res*. 2012;293(1-2):12–20.
12. Myjkowski J. Submolecular Theory of Hearing. *HSOA Journal of Otolaryngology, Head and Neck Surgery*. 2022;8(1):1–6.
13. Piela L. *Idee chemii kwantowej*. PWN Warszawa. 2022. p. 1300.