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Review Article

A New Paradigm for the Hearing Theory

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Abstract:

The first part of the paper provides a general overview of the paradigm for the hearing theory. Attention was drawn to the need for creating a new paradigm and to the problems with its acceptance. It is necessary to supply good documentary evidence for the big change between the old, recognised paradigm and the new one, based on new assumptions, new science and solid evidence. The second part briefly describes, in bullet points, the most important problems of Bekesy's travelling wave theory which either have not been explained or described incorrectly.

I argue for the replacement of a century-old paradigm – viz. 'Bekesy's travelling wave theory' - with a modern paradigm of 'submolecular hearing theory', devoid of the misunderstandings contained in travelling wave theory.

Keywords: bone; cell; otolaryngology

Introduction

A paradigm is a generally recognised level of science in a certain field, which at a certain time is a source of knowledge on a given topic. A paradigm provides model solutions to problems and points the way to further research. It can be assumed that the development of science consists in the accumulation of knowledge as successive cyclical paradigms. Assumed are the four stages of a paradigm, following one after another: The first period covers the works on a paradigm emergence, gaining recognition and a long period of the paradigm's 'reign'. The second period is related to the progress in various sciences. Detected are more and more facts, theorems and conclusions of the paradigm which are incompatible with current knowledge. The paradigm is unable to explain new problems. The third period means a growing crisis, and analyses of its causes begin to create a new vision of hearing. A new paradigm on the hearing theory is emerging; it is based on new, modern foundations, significantly different from the previous one [1]. The fourth period, long and difficult, concerns the slow acceptance of the new paradigm, which sometimes takes a long time.

Adopting a new paradigm is very difficult for researchers, it causes resistance and takes years. While describing his own research pathway, Max Planck wrote: "A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die and a new generation grows up that is familiar with it". (Max Planck - Scientific Autobiography and Other Papers. New York 1949, pp.33-34). An interesting problem is the behaviour of researchers when they already realise that the current theory exhibits serious flaws and a new theory without such flaws is already on the horizon. A rational course of action would be to analyse carefully the competing theories and to evaluate the conclusions.

Scientists, finding anomalies and flaws in the current hearing theory, introduce some modifications, clarifications, corrections, which further intensifies the crisis and accelerates the acceptance of a new hearing philosophy - a new paradigm. As time goes by, despite the resistance of scientists, the problem of fitting the new paradigm to the laws of nature is overcome. A verification of paradigms is possible and advisable when the crisis of the current paradigm has created a new situation, giving rise to a new paradigm. A comparison of the two paradigms is particularly concerned with the compatibility with the laws of nature and the compatibility with the current knowledge of various different specialties. Subsequent analyses lead to the disclosure of further ambiguities in the existing theory. There must be a clear difference between the old and the new theory. The new theory must not contain the errors of the old theory; instead, it must provide a possibility of new research to confirm the new theory. The results of experiments have to be consistent with current knowledge. They should ensure conditions for solving problems hitherto neglected such as inertia in the ear, the signal path to the receptor, the problem of resonance of the longitudinal wave with the transverse wave of the basilemma, while maintaining the full range of information transmitted to the receptor. There is a lack of a good description of the operation of the auditory receptor and the auditory cell itself. Scientists, recognising the current paradigm of hearing, confirmed by the Nobel Prize in 1961, are not willing to analyse the veracity of the assumptions of the old theory – viz. the travelling wave, dating back to the turn of the 20th century, nor to analyse all the mechanisms described by this theory - and contained in the recognised paradigm. Authors of textbooks do not create a new paradigm. By using the accumulated knowledge, they create a historical description of previous paradigms (theories), focusing on the current paradigm. There is no room in the textbook for an emerging new paradigm, even when its acceptance has been many years in the making. The

first critical comments on the travelling wave theory were published in 2003 in Otolaryngologia Polska [2]. Submolecular theory has been discussed since 2000.The paradigm is slowly gaining acceptance as it proves to be more effective and accurate in describing and solving difficult problems either overlooked or described incorrectly. In defence of the old theory, scholars are performing various studies to make the current paradigmatic theory more detailed. Examples are studies on the basilemma or the tip-links mechanism. Such studies are presented in textbooks and numerous published scientific papers. An in-depth analysis of the current hearing theory indicates that there are anomalies in the description of the mechanisms that make up the reception, processing and transmission of auditory information. The accumulation of these problems, their description, and the search for their solution will lead to the creation of a new philosophy of hearing, a new paradigm. In particular, it is difficult to persuade older scientists to adopt the new paradigm; they are convinced that the paradigm they adhere to solves all problems correctly. They defend it irrationally. Changing a paradigm sometimes requires changing an entire generation of scientists. Older scientists do not fully accept the new theory. These comments do not apply to all senior scientists. There are already more 'elders' supporting the new philosophy of hearing. The conversation is easier with younger scientists. Defenders of the old theory refer to textbook knowledge, accepted by scientists as a dogma. As history has it, in some branches of science, a paradigm shift occurred after several decades. A favourable situation arises when the difference between paradigms is considerable and the new paradigm does not contain any of the errors of its predecessor. The adoption of a new paradigm results in an approximation to the truth about hearing, and provides an opportunity of solving problems that are new and those that have either not been solved, or poorly described. There are 2 methods of evaluating theories being compared. The comparative method involves assessing the consistency of theories with the laws of nature and examining the results of experiments and tests. The second one – falsification method – consists in finding and comparing the errors of each theory. The final evaluation of the paradigms being compared cannot be based on evidence alone. The two methods should complement each other. A comparative analysis of Bekesy's travelling wave theory with the submolecular theory of hearing. The results of the comparison between the two theories provide a basis for postulating a paradigm shift in hearing theory to a new one.

Notes on Bekesy's travelling wave theory, considered in the comparative and falsification methods of comparing the two paradigms:

1. The travelling wave theory fails to recognise that some of the energy absorbed by the auricle is transmitted through continuity to the temporal bone and to the receptor. This is important in the case of animals in recognising the direction from which the wave is coming. The current theory recognises mainly reflected waves, directed into the external auditory canal.
2. The acceptance of the thesis that a wave falling directly on water is reflected in 99.9% constituted the basis for recognising an amplification in the middle ear. The sound wave falls on the elastic eardrum and the energy is then conducted to the ossicles of the middle ear, and a part of the energy is conducted to the temporal bone. The part of the energy conducted through the middle ear ossicles, and especially the stirrup plate, is conducted to the cochlear housing bone, undergoes constructive interference with the energy conducted from the auricle and eardrum, and is then conducted directly to the receptor. The part of the sound wave energy from the stirrup is conducted to the cochlear fluid. This part also includes as well degraded energy, running through the cochlear canals to the round window, where it is subject to annihilation. This part of the energy is not involved in the transmission of information to the receptor. The energy which keeps on reaching the ear cannot be accumulated, but it is converted into another form of energy.
3. Wave amplification in the middle ear: The lever mechanism reduces the amplitude of the wave in a ratio of 1.3:1. The energy of the wave is proportional to the square of the amplitude or the square of the sound pressure. Where does the wave amplification come from? The difference in area of the eardrum and the area of the stirrup plate in a ratio of 17:1 is said to amplify the sound wave 17 times. The difference in the area between the eardrum and the piston that replaces the stirrup plate in the procedure of stapedotomy in a ratio of 100:1 or 50:1 (depending on the diameter of the piston), will not amplify the sound wave. Doppler laser vibrometry tests do not confirm any amplification in the middle ear. If a wave of 1000 Hz, 90 dB = 500 nm, acting on the eardrum in the middle ear has 80 dB = 100 nm, on the stirrup plate 11.7 nm and in the fluid of the vestibular canal 0.27 nm - this does not agree with the statement of scientists - (audiology [3]) that in the middle ear the amplification is 44 times and 50% of the incident energy on the eardrum is conducted to the inner ear.
4. No explanation - when the stirrup plate makes a rocking motion at high frequencies, at the same time a part of the plate generates a forward movement of the fluid; instead, the other part of the plate generates a backward movement. How is auditory information transmitted through the cochlear fluid? How is formed a travelling wave with 100% information transmission?
5. The sound wave in the cochlear fluid is a longitudinal wave. A wave on the basilemma is a transverse wave. There is no explanation of how wave vectors perpendicular to each other can resonate and carry 100% of the information, even within tenths of a millisecond [4, 5].
6. There is no correspondence between the resonant sound wave and the basilemma's natural vibration in mammals capable of hearing up to 100 kHz. The mechanisms of hearing are the same. They can hear perfectly.
7. The resonance capacity of the man's basilemma was incorrectly determined. The mass of the organ of Corti and fluid attenuation on both the sides of the basilemma were not taken into account [6]. The correspondence of the intrinsic vibrations of mammalian basilemmas with the received frequencies up to 100 kHz was not checked, either.
8. No account has been taken of a law of physics, viz. that resonance is impossible when the attenuation of the forcing wave is greater than the energy of the forcing wave. This situation occurs during the reception of a threshold wave. Hearing works. The theory ignores this.
9. How is explained the reception of a sound signal with a duration of tenths of a millisecond, while resonance takes time and one or 2 periods of the wave cannot convey auditory information [5].
10. There is no analysis of the difference between the speed of a sound wave in a liquid and the variable speed of a travelling wave which depends on the frequency of the wave. This has a very bad effect on the transmission of information, especially of multitones with harmonic components.
11. There is no explanation for the variable compression of the sound wave in the transmission of all information: amplitude, frequency, harmonics and product. This is due to a large difference in the speed of the waves encoding the information, and the reception of the frequency by the receptor at different locations along the basilemma.
12. There is no explanation of how the cochlear fluid flows the can encode and convey all information. Do fluids vibrating at different

frequencies have mass falling under the law of inertia? Is this an exception [7,8]. How does the laminar flow of a fluid can encode harmonics and phase shifts? Without this information, there is no hearing.

13. A reduction in amplitude of a 90 dB and 800 Hz sound wave between the ear canal and the round window is approximately 1000 times. A wave has an amplitude of 500 nm in the ear canal, and at the round window - 0.5 nm. The energy of the wave is proportional to the square of the amplitude. There is no elucidation of how a threshold wave with an amplitude of 0.01 nm at the entrance disappears on its way to the receptor. The path to the round window is not the path to the receptor, but more than half of this path in the atrial tract is the path to the receptor. It can be assumed that the amplitude of the wave on the path to the receptor fades by about 100 times [9].
14. If we should assume that this wave on its way through the fluids to the receptor decreases only 100 times, then a wave having 0.0001 nm is supposed to tilt or bend the hairs of the auditory cells with a thickness of 100-500 nm! Can a wave with an amplitude of 0.01 nm at the entrance, decreasing 100 times, be perceived by the human receptor? Why can a human hear a 0.01 nm wave? The barn owl's ear receives waves with an amplitude of 0.001 nm that reach the receptor, but not through the cochlear fluid. Can the flow of fluid in the cochlea, a million times smaller than the diameter of an auditory cell hair, tilt it? Bend it? Can it tighten the cadherin fibres and transmit all the information to the receptor? You can't use a 1 cm diameter twig to tilt or bend a 10 m diameter tree!
15. If rather the cochlear fluid flows, not sound waves, carry information - so according to the theory under consideration- the fluid has a certain velocity, acceleration and mass. Nature acknowledges inertia in such a case. This problem is not analysed in this theory.
16. Tip-links mechanism [10]: No explanation of how the pulling performed by the cadherin filament on the molecular structure of the receptor causes to regulate the mechanism responsible for gating potassium ion channels. How does the protein filament encode harmonics and phase shifts at frequencies up to 100 kH?
17. It was assumed that an OHC contraction of up to 100,000/s was possible because of an erroneous study involving electrical current stimulation of an isolated OHC. The action of cell wall ion channels - which exert decisive influence on the cell depolarisation rate, required to produce cell contraction - was deliberately excluded [11].
18. There is no answer as to whether simultaneous depolarisation and contraction of the entire auditory cell is possible. This is in conflict with the operation of the ion channels of the cell wall.
19. Adopting the thesis of high frequencies of OHC contraction as of a whole cell is in conflict with the thesis of mechanical amplification of silent tones due to OHC contraction. An amplified tone requires additional time to transmit the amplified information to the receptor [12].
20. Assuming the possibility of limited depolarisation of the auditory cell wall offers a possibility of frequent depolarisations, but excludes the described mechanical amplification of quiet sounds.
21. The mechanism of the decision to control the amplification of quiet sounds is not given nor described. Each contraction of the OHC pulls at the basilemma and amplifies the sound? Reception of loud tones also causes depolarisation and contraction of the cell.
22. In order for a quiet tone to be amplified, the quiet tone must be perceived. The auditory cell has afferent innervation. Information is conveyed to the centre. What is the purpose of transmitting the same information after amplification at this stage? Other waves cannot be amplified in this way. Mechanical amplification of the signal requires additional time, and, in the case of multitones, separation of quiet tones from loud ones. The quiet ones, already received, are amplified and via a separate path with a delay transmitted to the centre? Nature could not accept such an illogical method. It is a scientist's invention [13].
23. If one accepts the thesis of mechanical amplification of a quiet signal already received, the pulling at the contracting OHCs across the basilemma interferes with the transmission of information conveyed to the centre at that time. Is there a summation of information transmitted by two different waves? Current transmission of information cannot be stopped in order to amplify a wave already received. This wave, amplified alone or together with another wave, is supposed to stimulate the IHC. How does the IHC pass on so mixed up information?
24. Amplification of quiet received signals which are too weak to reach the centre, exists like in other sensory organs. It is an intracellular, molecular, regulated amplification [14].
25. An auditory cell is 50 μm long. During contraction the length decreases by 4% = 2000 nm. One end of the cell moves and pulls at the basilemma by 1000 nm! An amplitude increased by 1000 nm corresponds to an increase of 100 dB. This means that the amplification of a quiet sound is theoretically 100 dB! Why is the reported amplification of quiet sounds only as high as 40-50 dB?
26. A quiet tone, having 20 dB at the entrance, is - according to theory - amplified 44 times in the middle ear, then amplified by 40-50 dB (by 100 dB) in the inner ear, and finally we can hear this tone as 20 dB?
27. The signal pathway time from the ear canal to stimulate the receptor potential in the ECoG test is 1.5-1.9 ms. The calculated path time of this signal, leading through the basilemma and cochlear fluids is 4-5 ms. These are two different signal pathways.
28. 28 As the theory has it, there is one mechanosensitive potassium channel per 2 hairs. With such a high demand for potassium ion at high frequencies and high intensities, this number of mechanosensitive channels seems too low. There is a need to ascertain the actual density of these channels per 1 mm2of the auditory cell membrane covering also the membrane of the auditory cell hairs.
29. 6,000 ions can pass through the potassium channel in 1 ms. The number of ions passing through is controlled by the information contained in the sound wave. The process of conformational changes of the receptor proteins is responsible for this mechanism. The main role is played by the sound-sensitive proteins which convert the mechanical energy of the sound wave into encoded energy, transmitted by molecules to the gating apparatus of the mechanosensitive potassium channels. Does a protein filament have the ability to control the conformational changes of the receptor's sound-sensitive molecules, and the conformers acting on the receptor's activating and inactivation gates? Can such an action be fulfilled by a tip-links mechanism driven by cochlear fluid flows?
30. If a cadherin filament can somehow open the ion channel, how is the channel closed in line with the energy of the sound wave. To suggest that this role is played by myosins (J. Hudspeth) is unacceptable. Myosins are too slow to handle high frequencies. In addition, all but one of the myosins step slowly, in one direction only, which precludes any control of ion channel openness.
31. If the resonance of waves at the basilemma is responsible for frequency discrimination, how then are recognised frequencies between, for example, 100 and 1000 Hz? The wavelengths for these

frequencies are 14.5 m and 1.45 m. These values will not fit on a basilemma of 0.032 m.

32. Why does the travelling wave theory exclude direct action of sound wave energy on the auditory receptor, for which the relevant stimulus is sound wave energy? This is how sound waves are perceived in insects which have neither cochlear fluid nor basilemma.
33. The travelling wave theory does not explain the reception of auditory information after immobilisation of the basilemma with electrodes inserted into the eardrum in cochlear implant surgery in the case of partial deafness. The pathway to the receptor through the fluids and the basilar membrane is interrupted, but hearing is preserved for a part of the pre-surgery hearing.
34. There is a lack of high frequency conduction and reception after stapedotomy. There is no explanation of the reason for this situation. A hypothesis was put forward that the reason was too small the surface area of the diameter piston, amounting to 0.4 mm. The diameter of the piston was increased to 0.6 mm and 0.8 mm, resulting in an increase of the active area of the piston by 0.1256 mm2 to 0.5024 mm2. The active area of the piston was increased by 400%, with no effect on the conduction of high-pitched tones. There is another reason for this problem, explained by the new hearing theory.
35. The paradox of the theory to be explained: The cochlear canals along their length from the base of the cochlea to the cupola constrict from 4.3 mm to 1.7 mm. The basilemma which separates them from each other becomes wider in same direction from 0.25 mm to 0.75
36. mm. It needs verification whether the 0.25 mm wide basilemma can separate 17 times wider fluid spaces with different electrolyte concentrations. In this way, the dimensions of the basilemma were matched to the basilemma's own oscillations. This needs further research.
37. The quantisation of the energy of a sound wave involves the transfer of separated from each other packets of energy encoding information, which means that the transfer of energy occurs by leaps and bounds and portions are multiples of the smallest portion of energy, viz. quantum. How does the flow of a fluid can ensure the transfer of portions of energy encoding all the information contained in a sound wave, where the energy of the wave is only converted to the movement of the mass of the fluid [15]?
38. Spontaneous otoemission. While investigating a spontaneous otoemission, the receptor potential and action potential of the auditory nerve should be investigated. An OHC contraction occurs after depolarisation of the cell, which leads to an action potential. Pulling at the flaccid basilemma immersed in fluid, without the possibility of tension, produces a sound heard in the external auditory canal. Similarly, one can release the tension of the violin, go underwater into a swimming pool and play melodies. You can listen to the melodies near the pool. If the theory of acoustic emission formation, given by Kemp, is true, the acoustic otoemission so produced in the ear can be studied on the bone because especially low frequencies are conducted very well through fluids, soft tissues and through a bone.
39. There is a network of afferent and efferent synapses on the membrane in the inferior part of the OHC; they play a key role in the transmission of information. It is rather unlikely that the basilemma might be pulled through such delicate structures with different frequencies and intensities. These structures, 50 nm in cross-section, are fluid-filled with receptors that receive information from transmitters and convey it then to the nerve cells of the spiral ganglion.
40. Bone conduction: According to the travelling wave theory, the energy of the sound wave from the bone is conducted to the cochlear fluid, causes a travelling wave and acts on the receptor as in air conduction. The pathway so determined is much longer. To check this, the receptor potential rise time must be measured. With a pathway through the basilemma and cochlear fluids, an amplification of silent tones would also be expected, further increasing the pathway time to the receptor. If a wave speed through bone = 3000-4000 m/s, wave speed through soft tissues = 1550 m/s, then the travelling wave speed = 2.9 - 50 m/s. The problem arises again with the compression of the transmitted information - fast in the bone, very slow in the travelling wave, conveyed successively to the cochlear fluids and the tip-links mechanism. What is the purpose of such a confusion with the transmission of information, just because of the lack of recognition that the receptor can directly receive information from the sound wave. It avoids thus multiple unnecessary energy transformations, exposing the transmission to an error.
41. According to the theory, frequency resolution is dependent on wave resonance and travelling wave formation at the basilemma. The highest wave excursion is supposed to excite the cochlear fluid flow and stimulate the receptor via tip-links at a suitable location at a certain distance from the oval window. High frequencies are received closer to the oval window. Low frequencies - near the cupola, instead. This is the principle of tonotopy, well-known for 100 years, but the mechanism is different. The mechanism described by Bekesy does not ensure that all information is transmitted. Where does the greatest waveform excursion at the basilemma arise in the case of multi- tones with numerous aliquots and phase shifts? How are generated a cochlear fluid flow and encoding of information in the fluid?
42. The creator of the travelling wave theory - von Bekesy - made incorrect assumptions. For his calculations, he assumed for simplicity that the cochlea is not spirally twisted but is a straight tube, where the fluid wave runs to the cupola and back to the round window on both the sides of the basilemma, which is supposed to cause a pressure difference on both the sides of the membrane and the formation of the travelling wave. He neglected the existence of Reissner's membrane. In this conception, the sound wave travels through the organ of Corti to the basilemma, without transmitting information to the receptor, because the purpose of the wave is to cause an undulation of the basilemma and to generate cochlear fluid flows acting on the tip-links mechanism. This is a very illogical signal pathway.
43. The mechanism of OHC contraction needs to be further clarified. The thesis, accepted after 2000, that prestine, a molecular motor which does not derive its energy from ATP, is responsible for OHC contraction, is not certain and in accordance with the law of conservation of energy. The energy for OHC contraction is supposed to come from the electrochemical energy of the cell membrane, which is normally used for another purpose. Conformational changes of prestine are supposed to be the source of energy to change the shape of the cell, but most importantly, to do the hard work of pulling at the basilemma loaded with the organ of Corti, fluid spaces, vessels and nerves, in addition at frequencies of up to 100 kHz. Energy cannot be created de novo [16]. The energy of the conformational changes of prestine alone cannot be the source of the energy with such different sound intensity- and frequency-dependent demands.

The New Hearing Paradigm

The new philosophy of hearing is contained in the 'Submolecular Theory of Hearing' [17]. All the theses of the new theory are consistent with the laws of nature. Evidence is collected from various scientific centres worldwide. The "submolecular' name of the theory was first proposed in 2000. The name

has to do with molecular mechanisms at the atomic and electron level, playing an important role in the reception and processing of auditory information. The difference between the two hearing theories relates to the signal pathway to the receptor, the role of wave resonance and the basilemma, the mechanism of reception and processing of information at the receptor, the transmission of information to the receptor by the sound wave, and the encoding of information by the sound wave rather than the cochlear fluid [18]. The new theory of hearing does not acknowledge the mechanical amplification of the sound wave, but describes a signal amplification in the inner ear. It does not recognise a tip-links mechanism. It accurately describes the work of the auditory cell [19]. The shortcomings of Bekesy's travelling wave theory as well as the submolecular theory were presented in numerous papers published from 2003 to 2025: google scholar Jan Myjkowski.

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