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NEW IMPORTANT EVIDENCE FOR THE SUBMOLECULAR THEORY OF HEARING

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INTRODUCTION

The theory of hearing that remains widely accepted today was published in 1928 by Georg von Bekesy under the name traveling wave theory. The basis of this theory was Helmholtz's 1859 theory of sound wave resonance with the basilar membrane, wave amplification in the middle ear, and the hydrodynamics of cochlear fluids. The signal pathway to the auditory receptor is proposed to involve resonance between the longitudinal wave in the cochlear fluid and the transverse wave generated by the natural vibrations of the basilar membrane. The basilar membrane of the inner ear plays a fundamental role in the reception and transmission of information to the receptor. In the 1980s, Bekesy's theory was supplemented with mechanical amplification of sound in the inner ear by contraction of the OHC.[1,2,3]

The fundamental difference of the Submolecular Theory of Hearing is the recognition of a different signal pathway to the receptor, especially for high frequencies.[4,5] Sound wave is the carrier of auditory information and acts directly on the sound-sensitive molecules of the receptor. It is an adequate stimulus for the hearing receptor. The basilar membrane does not play the role attributed to it by Bekesy's theory in recognizing sound frequencies. This function is performed by hair cells with hearing receptors that receive specific frequencies according to the principle of tonotopy, a phenomenon that has been recognized for a century. The new theory places great importance on the role of inertia in the middle and inner ear. It does not accept the concept of inner-ear amplification mediated by OHC contractions and their pulling on the basilar membrane. It presents the mechanism of intracellular amplification at the molecular level. It describes the function of the auditory receptor and the hair cell itself, as well as the processes involved in the reception and transmission of auditory information at the submolecular and electronic levels.[6] Another important piece of evidence supporting the submolecular theory of hearing is the analysis of the reception and transmission of sound waves to the auditory receptor.

The analysis concerns the sounds we hear and the frequencies of the sound waves in human speech as detected by the auditory receptor. The voice is generated in the larynx and undergoes various transformations on its way to the auditory receptor, including amplification, resonance, interference, and superposition, ultimately reaching the ear as a complex sound wave.[7] The larynx generates the fundamental frequency, F_0, with typical values of 200-250 Hz in women and 80-140 Hz in men. Every tone contains harmonic components, known as aliquots or formants. Each subsequent harmonic tone is a multiple of the frequency of the fundamental tone. The number of harmonics is theoretically unlimited. Very important: Each vowel, as well as each voiced and voiceless consonant, has its own characteristic fundamental frequency and a distinct set of harmonic components. For a male voice with a fundamental frequency of F_0 = 140 Hz, formant F_1 = 280 Hz, F_2 = 420 Hz, F_3 = 560 Hz, F_4 = 700 Hz, F_5 = 840 Hz The first three harmonic components are the most important for the human voice. The more harmonic components there are in a sound, the better the voice's timbre. In women, F_0 can range from 200 to 250 Hz resulting in different series of harmonic components.

What is important is the length of sound, i.e. its duration, and the duration of the pauses between individual letters, words and sentences. All of these features are subject to auditory encoding.

This information is associated with the transmission of quantized energy, with the amplitude of the sound wave determining the amount of energy transmitted. The energy of a wave is proportional to the square of the wave amplitude.

Phoniatrics indicates that the fundamental frequency is perceived simultaneously with its harmonic components. ***These sounds are perceived simultaneously – a phenomenon which is indisputable and experimentally verified.***[7] Auditory information — fundamental tones together with aliquots, particularly polytones — cannot be transmitted to the auditory receptor in accordance with Bekesy's traveling wave theory:

They are transmitted according to the submolecular theory.[8]

Rationale

1. The sound wave propagates through the perilymph fluid from the oval window to the round window, along the vestibular duct. The wave with a frequency of 200 Hz resonates with the natural vibrations of the basilar membrane close to the cochlear apex. There is no increase in the amplitude of this wave from the oval window to the point of resonance.

2. Each fundamental tone and its subsequent aliquots resonate at a different point on the basilar membrane, according to frequency. The dimensions of the basilar membrane defined by Bekesy are intended to ensure this. It is doubtful that the basilar membrane, 0.1 mm wide at the base of the cochlea, separates the cochlear canal and the tympanic canal, 4.3 mm wide. It should be noted that the basilar membrane is connected to the organ of Corti along its entire length. A tension-free membrane immersed in the highly damped cochlear fluid and carrying substantial mass is subject to the effects of inertia.

3. According to Bekesy, the velocity of the traveling wave varies from 2.9 m/s near the cochlear apex to 50 m/s at the base of the cochlea. Each wave frequency is perceived at a different time and point due to the path traveled and the varying speed of the traveling wave. The difference between the speed of the sound wave in the cochlear fluid and the speed of the traveling wave at the cochlear base is 29-fold, increasing to approximately 500-fold near the cochlear apex. In this proportion, according to Bekesy's theory, auditory information is compressed, which makes it difficult to encode information and further transmit it to the receptor.

4. The fundamental tone has a lower frequency than its own harmonic components. The 200 Hz fundamental tone has harmonic components of 400 Hz, 600 Hz, 800 Hz, 1000 Hz, etc., and is perceived with a delay, closer to the cochlear apex. The higher the frequency of a harmonic component, the earlier it is detected — according to the traveling wave theory — and the earlier it produces a deflection of the basilar membrane, closer to the oval window. If this mechanism is supposed to determine frequency perception according to Bekesy's theory, an even greater problem arises in the perception of polytones and musical sounds, such as those encountered in concerts.

5. According to Bekesy's theory, successive, progressively lower frequencies toward the cochlear apex produce the largest deflection of the basilar membrane due to resonance with the basilar membrane, which becomes three times wider and thicker, despite the cochlear canals separated by the basilar membrane also becoming three times smaller. According to the traveling wave theory, there can be 6 deflections during the perception of one sound with 5 aliquots. In the case of polytones, this number increases further.

6. Bekesy, justifying the mechanism of the formation of the traveling wave by the pressure difference on both sides of the basilar membrane, stated that the pressure in the vestibular duct is 20 dB higher than the pressure in the tympanic duct. He did not explain why deflections of the basilar membrane would occur contrary to the laws of physics — that is, from a region of lower pressure toward a region of higher pressure.

For his own calculations, he straightened the cochlea into a linear tube and omitted the Reissner's membrane from the model so that the sound wave could propagate along both sides of the basilar membrane.

This changes the physiology of the cochlea for computational purposes.

7. Amplification in the middle and inner ear: Vibrometric tests do not confirm amplification in the middle ear. A 1000 Hz sound wave at 90 dB, with an amplitude of 500 nm at the input, has an amplitude of 11.7 nm at the stapes plate. The submolecular theory of hearing does not accept the concept of mechanical amplification in the inner ear, especially of quiet, high-frequency tones. Amplification of a 20 dB tone by 40 dB. According to AI:
The initial level was 20 dB.
The final level is 60 dB = 20 dB + 40 dB
20 dB corresponds to 100 times the reference energy.
60 dB corresponds to 1,000,000 times the reference energy.
The ratio of the final energy to the initial energy is exactly 10,000.

To increase the level of a 20 dB signal by 40 dB, it is necessary to supply external energy that is 10,000 times greater than the initial energy of 20 dB.

8. It is questionable whether a traveling wave on the basilar membrane, which is firmly attached to the organ of Corti, could be observed through an opening made in the cochlear wall. The basilar membrane cannot vibrate freely. There is no fluid between the basilar membrane and the organ of Corti. The wave is generated within the supporting cells. The highest deflections of this wave are thought to encode auditory information, causing flows of cochlear fluid that bend or flex the hairs of the hair cells. Vibrations of the basilar membrane together with the organ of Corti cause vibrations of the hair cells together with their hairs. During vibration movements, the tensions of the tip-links and lateral-links change. There is no clear explanation of how fluid flows and thin cadherin links encode and transmit not only amplitude and frequency, but also, simultaneously, harmonic components, phase, length of sound, and accent. The receptor, which acts as a processor responsible for converting the mechanical energy of the sound wave into the energy of chemical bonds in the receptor's sound-sensitive molecules, cannot be regulated simply by pulling on a protein filament. Simple mechanics is not enough to explain such complex processes present in all living beings in the world.

The mechanisms presented by the Submolecular theory of hearing are consistent with what Nature has devised through trial and error over millions of years. The sound wave reaches the receptor, transmitting encoded auditory information. The specific stimulus for the hearing receptor for billions of years has been the energy of a sound wave, not fluid flows or pulling the receptor with a thread. This is how insects hear, such as the dragonfly, which lived millions of years before the dinosaurs. The ability of living beings to respond to sound wave energy is universal and common in Nature. According to submolecular theory, amplification of quiet sounds in the inner ear exists. This is intracellular amplification, at the molecular level. The signals received by the auditory hair cells — not the sound waves themselves — are amplified within the hair cell when their energy is too low to reach the brain. Signals are also amplified in the auditory nerve at the nodes of Ranvier.

CONCLUSIONS

Bekesy's traveling wave theory contains erroneous descriptions of the mechanisms of perception and processing of auditory information. There is not enough energy in the inner ear to mechanically amplify quiet, high-frequency sounds.

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