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Fallacies in Bekesy's Travelling Wave Theory

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Abstract

Improved and complemented over decades, the travelling wave theory proposed in 1928 by Bekesy still contains ambiguities and logical inconsistencies. The 1961 Nobel Prize awarded to Bekesy for explaining the mechanisms of hearing provides no justification for further existence of the travelling wave theory in its present form. This paper presents reservations made regarding key points of the theory of hearing that continues to be recognized Discrepancies concerning the reception, processing, and transmission of auditory information are discussed. A different path of the signal to the receptor is suggested. This entails a change in the amplification of the signal and the conversion of sound wave energy to an auditory cell response.

The transfer of sound wave energy coding auditory information is progressive according to physics and quantum chemistry. The transfer of auditory information to the receptor by means of a travelling wave, the cochlear fluid and the tip-links mechanism is subjected to critical assessment.

Keywords: Impedance, Resonance, Coding, Signal Amplification.

Analysis of the Mechanisms of Hearing

Upon hitting any object, sound waves are reflected, absorbed, or transmitted. The angle of reflection is equal to the angle of incidence at which they hit a given surface. Energy absorption is determined by the angle of incidence. The human auricle has a diverse, cavernous surface that is conducive to wave energy absorption. Reflected waves are dispersed with only a small part of the reflected rays directed to the external auditory canal [1].

The waves absorbed by the auricle are transmitted by the skin of the auricle to the auricular cartilage. The material constant of the cartilage called specific acoustic resistance is lower for the cartilage than for the skin and the connective tissue. Lower resistance means that a wave is transmitted quicker. On its way from the air to the auricle, a sound wave changes direction in which the wave propagates due to the difference in the velocity of the wave in that environment. The frequency of the transferred wave remains unchanged. The energy of the acoustic wave absorbed by the auricle is transmitted onto the surroundings, the temporal bone, in line with the law of acoustics, "each point reached by the sound wave becomes the source of a new sound wave".

The vibrations transmitted by the auditory ossicles of the middle ear are channelled by ligaments and joints to the bone capsule of the tympanic membrane. The most significant impact on the transmission of sound wave energy onto the bone labyrinth of the cochlea is exerted by the stapedial footplate vibrating in the oval window.

According to vibrometric studies, a 90 dB (amplitude of 500 nm) sound wave hitting the tympanic membrane on the side of the tympanic cavity has the amplitude of 80 dB (amplitude of 100 nm). It is hard to agree with the thesis that a wave that hits the tympanic membrane or a wave that is transmitted by the ossicles of the tympanic cavity upon reaching the fluid of the vestibular duct is amplified 44 times = 33 dB [2]. The questionability of this thesis for such amplification is evidenced by vibrometric studies of wave amplitude on the stapedial footplate on the side of the inner ear and in the initial section of the fluid of the vestibular duct:

The studies were conducted for a 90 dB (500 nm) input wave [3,4]

Frequency—the base ----- the vestibule:

1000 Hz--------5.09 nm--------0.275 nm
4000 Hz--------1.37 nm--------0.00886 nm
8000 Hz--------0.0905 nm-----0.00153 nm

With constant intensity of a wave that is hitting the tympanic membrane, a change in frequency to high causes a drastic decrease in high-frequency wave energy measured in the cochlear fluid. The reason behind this disproportion lies in the structure of the oval window, the mechanics of the annular ligament, and the rocking motion of the stapes at high frequencies. During rocking motion of the stapes, vibrations of the stapedial footplate transmit sound wave energy via the annular ligament to the bone of the oval window capsule. High frequencies trigger rocking motion of the malleus caused by the structure of the tympanic membrane that are transmitted to the stapes. The sound wave energy transferred onto the bone labyrinth of the cochlea is subjected to constructive interference with the energy of waves previously transmitted from the auricle and the ossicles of the middle ear onto the bone. The combined wave energy is heading straight to the receptor at the speed of 4000 m/s. The proof lies in the time for this distance, 1.5 ms, from the external auditory canal to the point at which the EcoG measurement was taken.

Bekesy assumed that upon hitting water, sound wave energy is reflected in 99.9%. According to his supposition, a sound wave that is heading from the air to the cochlear fluid is reflected to the same extent. A sound wave inside the ear does not hit water directly. It hits the flexible tympanic membrane of low impedance that absorbs and transfers up to 80% of the incident sound wave energy. This fact is confirmed by laser Doppler vibrometry. For a wave of 90 dB, 3 kHz (amplitude of 500 nm) hitting the tympanic membrane, testing on the tympanic cavity side showed a wave with the amplitude of 100 nm, corresponding to 80 dB. It is hard to agree that in the middle ear, this wave is amplified 44 times, that is, by 33 dB. The difference in the area of the tympanic membrane and the stapedial footplate, with the former being 17 times bigger, allegedly amplifies the wave energy 17 times. In stapedotomy, there is a difference in the area of the tympanic membrane and the active surface of the piston whose diameter is 0.4 mm, with the former being 100 times bigger, and no wave amplification occurs. With the piston diameter of 0.6 mm, the area is 50 times bigger and there is no wave amplification either [5].

Sound wave energy is proportional to the wave amplitude squared. If the lever mechanism of the middle ear reduces wave amplitude in a ratio of 1.3:1, then it can increase the strength but it does not increase the amplitude of the wave, it does not increase the energy transmitted to the sound wave.

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