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Inertia in the Ear

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Abstract

The energy of the sound wave reaching the receptor via the Bekesy traveling wave theory was analyzed. In wave motion, the vibrations of a vibrating element that transmits sound waves and has mass are associated with the occurrence of the phenomenon of inertia. In the middle ear, such vibrations involve the middle ear ossicles that conduct sound waves to the oval window. According to Bekesy's theory, in the inner ear the vibrations of elements having mass concern the basilar membrane with the organ of Corti, the cochlear fluids and the tip-link apparatus. The calculations were performed by AI.

In the following section, attention was drawn to the additional inertia generated by the mechanism of amplifying quiet sounds by 40-50 dB – according to the traveling wave theory.

Keywords: Bekesy Traveling Wave Theory; Ear; AI

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Inertia in the Ear

Every body in motion, having mass and acceleration, is subject to the law of inertia [1]. The measure of inertia is the mass of a body. In wave motion, inertia is directly proportional to the oscillating mass and to the amplitude, and proportional to the square of the frequency. This is confirmed by the formula for calculating inertia in wave motion: $(2 \text{ pi x frequency})^2$ x amplitude x mass $g/mm/s^2$. The mass of the vibrating element of the middle ear is taken into account for the calculation: The hammer 25 mg, the incus 30 mg, the stirrup 3 mg [2], the stapedius muscle, the tensor tympani muscle, the tympanic membrane, the joint connections, the chorda tympani, the arterioles and the nerves – all together form a conglomerate vibrating up to a certain frequency. A weight of 70 mg was assumed for calculations. Frequencies from 100 Hz to 10,000 Hz were analyzed. The wave amplitude was calculated according to Robert Resnick and David Halliday data: For the loudest sounds, displacement amplitudes are of the order of 10^{-5} m. The weakest sound with a frequency of 1000 Hz that a young person can still hear has a pressure amplitude of 2.8×10^{-5} Pa.

The displacement amplitude corresponding to this sound is 8 x 10-12 m. After rounding, this is 10-11 m, 0.01 nm, which is 10 x smaller than the size of atoms (10-10 m).

According to the above data, it was assumed that:

The amplitude of this wave's deflection in nanometers corresponds to the sound wave in dB.

Decibels (dB)	Wave Amplitude (nm)
0	0.01
20	0.1
40	1
60	10
80	100
100	1000
120	10,000
140	100,000

For the analysis of inertia in the middle ear, the vibrating mass was assumed to be 70 mg. Calculations of inertia in wave motion are tedious; I outsourced the work to artificial intelligence. I obtained the following results:

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Decibels (dB)	Wave Amplitude (nm)	Frequency (Hz)	Inertia (N)
20	0.1	100	2.77×10^{-9}
20	0.1	1000	2.76×10^{-7}
20	0.1	10,000	2.76×10^{-5}
40	1	100	2.76×10^{-8}
40	1	1000	2.76×10^{-6}
40	1	10,000	2.77×10^{-4}
60	10	100	2.76×10^{-7}
60	10	1000	2.76×10^{-5}
60	10	10,000	2.76×10^{-3}
60	10	2400	1.59×10^{-5}
80	100	100	2.77×10^{-6}
80	100	1000	2.76×10^{-4}
80	100	10,000	2.76×10^{-2}
100	1000	100	2.76×10^{-5}
100	1000	1000	2.76×10^{-3}
100	1000	10,000	0.276
120	10,000	100	2.76×10^{-7}
120	10,000	1000	0.0276
120	10,000	10,000	2.76

These calculations confirm the thesis that high frequencies are conducted through the ossicles of the middle ear as a sound wave, which has no mass and is not subject to inertia [3]. Bekesy, observing the vibrations of the ossicles, noticed that above 2400 Hz the vibrations of the ossicles were invisible (microscopic observations).

Conclusion

Inertia in wave motion is directly proportional to the oscillating mass and amplitude, and proportional to the square of the frequency of the sound wave.

The amplitude of the sound wave increases 10 times – the inertia increases 10 times.

The frequency of the sound wave increases 10 times – the inertia increases 100 times.

An increase in frequency from 100 Hz to 10,000 Hz – with the same amplitude and mass – requires 10,000 times more energy to transport the sound wave on its way to the receptor.

When accepting inertia in the middle ear and additionally in the inner ear, this result increases much more. For example, the inertia in the inner ear was calculated for a total, assumed weight of the vibrating elements = 250 mg.

Mass	Decibels (dB)	Wave Amplitude (nm)	Frequency (Hz)	Inertia (N)
250 mg	40	1	100	98.7×10^{-9}
250 mg	40	1	1000	9.88×10^{-6}
250 mg	40	1	10,000	98.7×10^{-3}
250 mg	100	1000	10,000	0.988

The inertia of the middle ear adds up to the inertia of the inner ear – but only in Bekesy's traveling wave theory [4]. The submolecular theory does not recognize such problems. According to the submolecular theory, sound wave conducts information to the receptor without the participation of vibrations of vibrating elements having mass.

A sound wave does not have the mass necessary to generate inertia – there is no increase in energy necessary to transmit higher and higher frequencies. A sound wave is the movement of pressure, or energy, without moving the mass of the environment. The problem of inertia also concerns the mechanism of mechanical amplification in the inner ear, when the basilar membrane is pulled by the contracting OHCs. The mass of the basilar membrane connected to the organ of Corti, vibrating during the amplification of soft, high-frequency sounds, together with the cochlear fluids and the tip-link mechanism, generates an additional large inertia in the signal path of the amplified tones to the receptor. The electrochemical potential of chlorine and anions, and the conformational changes of prestin are not the source of such large and variable portions of energy for high amplified frequencies [5]. The summation of the inertia of the middle and inner ear at high frequencies is evidence of the existence of a different signal path to the receptor. This is the path postulated by the Submolecular Theory of Hearing. In the case of mammals that can hear up to 100 kHz (young cat, dolphin), the inertial range for frequencies between 100 Hz and 100 kHz is a million times. This situation is unacceptable in Bekesy's traveling wave theory, but is it still accepted?

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