Academixs Journal of
Clinical Health Reports and Medical Science

Review Article

The Biophysical Function of the Human Outer Ear

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Received Date: 07.05.2021 **Accepted Date:** 13.05.2021 **Published Date:** 17.05.2021

Abstract
The ear transforms soft mechanical vibration of air particles into electrical signals, which reach the appropriate part of the cerebral cortex for processing by means of auditory nerves. The cerebellum interprets these complicated signals by determining pitch, tone, loudness, and placement of the sound source. We deduced the wave equation. The outer ear consists of the auricle and the external auditory canal. It is used to conduct air vibrations. Its bottom is closed by the eardrum, which absorbs sound vibrations. The waves can be classified in two big categories: longitudinal waves and transversal waves. Comparing the two forms, we can conclude that the phase velocity of longitudinal waves is always higher. Is a very interesting the dependence of sound quality on physical parameters. Loudness mainly depends on the sound pressure, but the duration and spectrum of the sound also influence the development of loudness sensation. The sense of pitch depends mainly on frequency, but shows a slight dependence on sound pressure and duration. When an ear is exposed to two or more different sounds, one can mask the other in the traditional sense.

Key Words: Human Outer Ear, Wave Equation, Sound Quality, Masking

Introduction
The simplest and clearest sound is the so-called sinusoidal sound. After a period x/c has elapsed from the initial perturbation of a point of the system, the instantaneous from the equilibrium position is

$$y = y_M \sin\left[\omega\left(t - \frac{x}{c}\right)\right]$$

where: y_M is the amplitude, ω is the angular frequency, t is the time and c is the travelling velocity of the oscillation.

The instantaneous velocity is

$$v = y_M \omega \cos\left[\omega\left(t - \frac{x}{c}\right)\right];\ y_M \omega = v_M$$

the instantaneous acceleration is

$$a = -\,y_M \omega^2 \sin\left[\omega\left(t - \frac{x}{c}\right)\right];\ y_M \omega^2 = a_M$$

tone of sound

$$p(t) = p_M \sin(2\pi t / T + \varphi)$$

where: p_M is the pressure amplitude, T is the period, φ is the phase [1].

Sounds perceived by two ears usually not identical. Sound waves from a source not exactly in front of an observer arrive at the left and right ears with different phases, at different times and with different amplitudes [2].

The Wave Equation
We speak of a sound wave if the disturbance caused by the sound source in the flexible medium propagates due to the properties of the medium. A sound wave is persistent if the vibration at the point of interference can be described by a periodic function. The frequency ν is determined by the wave source, and the velocity c and the wavelength λ are the elastic medium in which the wave propagates. It follows that the frequency is constant during propagation, while the propagation velocity and wavelength vary from medium to medium [3].

Hereinafter, we will confine ourselves to gas space, because the most significant chapter of mechanical waves is sound waves. The result obtained will also be valid for a liquid or solid state as far as the shape of the wave equation is concerned, but the properties of the medium must be duly taken into account [4]. In a gas space, the change in volume and density caused by the sound wave takes place at such a high rate that there is practically no time for heat exchange, so the wave propagation is treated as an adiabatic process. The Poisson equation is valid:

$$p \cdot V^{\gamma} = const,$$

where: p – pressure, V – volume, γ = Cp/CV – ratio of isobar to isochoric molar heat. With logarithm, then differentiation and Taylor decomposition (disregarding the whole mathematical derivation) we get:

$$\nabla^2 p = \frac{1}{c^2} \cdot \frac{\partial^2 p}{\partial^2 t}$$

It is a three-dimensional wave equation that gives the acoustic pressure in a flexible, homogeneous, and isotropic medium over space and time. With some modifications, we get to:

$$\nabla^2 \Phi = \frac{1}{c^2} \cdot \frac{\partial^2 \Phi}{\partial t^2}$$

The differential equation is the desired wave equation depending on the velocity potential of the particle [5]. This differential equation can be written for each sound wave.

The Anatomical Structure of the Outer Ear

The hearing analyser consists of two main systems: the peripheral hearing system, formed of the outer ear, the middle ear and the inner ear and the central hearing system, which contains the nervous pathways which ensures the transmission of the nervous influx and the hearing area where the information is analyzed and the hearing sensation is generated [6]. The peripheral hearing system achieves the functions of transmission of the sound vibration, the analysis of the acoustic signal and the transformation of the acoustic signal in nervous inflow and the generation of the nervous response [7].

The anatomical structure of the ear is shown in Figure 1. In humans, the organ of hearing, a device for absorbing acoustic stimuli, is hidden in the clavicle of the temporal bone. An amplifier is connected to the receptor device [8, 9]. The sound amplifier equipment is anatomically divided into two parts: the outer ear and the middle ear.

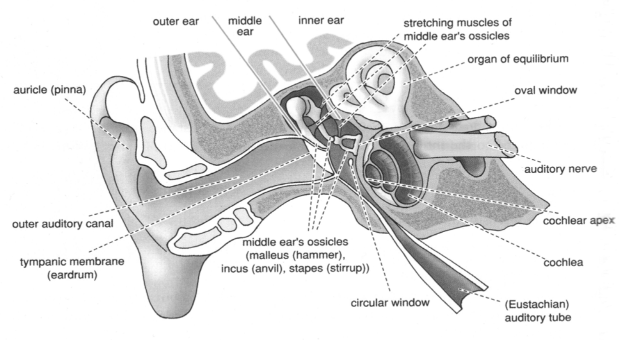

Figure 1: Anatomical structure of the ear

The outer ear consists of the auricle and the external auditory canal. It is used to conduct air vibrations. Its bottom is closed by the eardrum, which absorbs sound vibrations. The auricle is a shell-shaped paired organ located on both sides of the skull. Its outward-facing surface is depressed, concave, while the surface facing the skull is convex. On both sides there are imperfections on it. The rim of the auricle is called the helix, which arches around the auricle. Its root originates above the outer auditory canal, ending in the earlobe [10]. The helix leans against an arched ditch, in front of which a parallel protrusion can be seen. The beginning of this is also around the outer auditory canal, the end widens like a ditch. The auditory hole is surrounded by two lobes. The caudal formula of the cochlea is the earlobe, which is a soft-touch, skin fold without cartilage.

The external auditory canal starts in the middle of the eardrum and leads from the side to the middle, leading to the middle ear. It is approx. 22 to 26 mm long, 7 to 9 mm in diameter and approx. 1 cm3 in volume. We distinguish between external cartilaginous and internal bony parts. The cartilaginous part is a continuation of the cartilage of the auricle, while the bony auditory canal is formed by the os temporale. The wall of the external auditory canal forms an acute angle with the eardrum. Its inner surface is lined with skin folding over from the auricle, which also reaches the outer surface of the eardrum [11].

The external auditory canal is not completely straight, but is slightly bent in an S-shape. This curvature can be straightened by pulling the auricle backwards, upwards and outwards, and then the eardrum can also be examined on a living person with the help of a funnel. Hair follicles are also present at the auditory canal entrance. There are a number of sebaceous glands in the skin of the external auditory canal, the secretions of which are yellowish-brown in color (earwax), which, if they accumulate, can lead to hearing loss.

The outer ear begins to form intrauterally at 4–6 weeks of age, from the 6 dorsal tubers of the first gill arch. The final size is reached by the age of 9 [12]. Functions of the auricle: collecting sound, directing it into the ear canal and directing the sound to the eardrum, participating in directional hearing, the first station to compensate for the loss of sound stimulus, generating 6-8 dB amplification, participating in middle ear protection and evaporation. Blood supply. arterial part (carotis externa), venous part (temporalis superficialis). The following cerebral nerves are involved in its innervation: the trigeminal nerve (branch V.3), the facial nerve (VII) and the vagus nerve (X.). The external auditory canal physically acts as a resonator of ¼ wavelength. Its own resonant frequency is between 2,500-4,500 Hz [13]. This results in an increase in sound pressure of a few dB at the eardrum relative to the inlet of the auditory canal.

The skeleton of the auricle is made up of flexible cartilage that connects the connective tissue and outer skin to the skull bones [14]. The shape of the auricle is determined by the cartilaginous vase. It covers the cartilage skeleton as a direct continuation of the skin, head, and facial skin. Its shape and size vary from individual to individual. Under the skin, clinging to the cartilage, we find short muscles, which, however, are completely insignificant in terms of function in humans, but in some they are not completely diminished and are able to move the auricle. In old age, overproduction of growth hormone results in acromegaly and this results in an increase in the cartilage skeleton of the auricle in both women (5%) and men (18%).

The characteristics of the sound waves

The waves can be classified in two big categories:

– longitudinal waves when the oscillations of the particles take place in the direction of propagation of the wave;

he phase velocity c for longitudinal waves in a solid medium is given by the following formula:

$$c = \sqrt{\frac{E}{\rho} \cdot \frac{1}{(3-6)\mu}}$$

where: E - modulus of elasticity, ρ - density, μ - Poisson's ratio.

– transversal waves when the oscillations take place on a perpen¬dicular direction on the one of the propagation of the wave.

The phase velocity (c) of the transverse wave is calculated by the following formula:

$$c_l = \sqrt{\frac{E}{\rho_0 \cdot (3-6\mu)}}$$

Comparing the two formulas, we can conclude that the phase velocity of longitudinal waves is always higher. [15] Using the value interval of the Poisson number, the ratio of the velocities of the two phases changes in the following interval:

$$C_l / C_t \in [2, 15 - 9,7]$$

The sounds are longitudinal waves which propagate in continuous environments and if they reach the human's hearing organ, in certain conditions, they produce hearing sensations. The description and the characterization of the sounds is based on three main characteristics: height, intensity and quality, to which the following physical sizes correspond: frequency, amplitude and harmonic constitution [16].

The height of a sound is determined by the frequency of an acoustic wave (ν), namely the number of oscillations that the sound wave performs in the time unit. The higher the sound frequency, the „higher" the human ear perceives them [17, 18].

According to the frequency, the sounds classify as follows:

– infrasounds, $\nu < 16$ Hz;

– proper sounds, $16 \text{ Hz} < \nu < 20$ kHz,

– ultrasounds, $\nu > 20$ kHz.

The infrasounds and the ultrasounds cannot be perceived by the human ear.

The frequency range of hearing varies greatly from individual to individual; it is rare for a person to be able to hear the full hearing range of 16 to 20,000 Hz. The ear is relatively insensitive to low-frequency sounds; for example, at 100 Hz its sensitivity is roughly 1,000 times lower than at 1,000 Hz. The sensitivity of high-frequency sounds is greatest in infancy and gradually decreases throughout life, making it difficult for an adult to hear sounds above 12,000 Hz.

Loudness mainly depends on the sound pressure, but the duration and spectrum of the sound also influence the development of loudness sensation. The sense of pitch depends mainly on frequency, but shows a slight dependence on sound pressure and duration. Table 1 illustrates the dependence of sound sensation quality on physical parameters [19].

Table 1: Dependence of sound quality on physical parameters

Physical parameter	Subjective quality			
	Loudness	Base tone	Tone	Durability
Intensity	+++	+	+	+
Frequency	+	+++	++	+
Spectrum	+	+	+++	+
Duration	+	+	+	+++

+ = weakly dependent ++ = moderately dependent, +++ = highly dependent.

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$$C_l / C_t \in [2, 15 - 9,7]$$

The sound intensity I, is defined as sound energy E, which crosses the surface unit S, in the time unit t,

$$I = \frac{E}{S \cdot t} = \frac{P}{S}$$

where P is power and the measurement unit for the sound intensity is:

$$[I] = \frac{J}{m^2 s} = \frac{W}{m^2}$$

The sound intensity depends on the power of the sound source and the distance from the source, because the sound intensity decreases with the x distance, due to the absorption of the sound according to the relation:

$$I = I_0 e^{-\beta \cdot x}$$

where β is the absorption coefficient, which depends on the nature of the environment and it physical conditions [21].

The level of the intensity of the sound sensation depends both on the sound intensity and the frequency of sound. For sounds of the same frequency, the intensity of the sound frequency is given by Weber's law:

$$L = \log \frac{I}{I_0}$$

where I0 is the reference intensity. In order to define the reference intensity a sound with the frequency of 1 kHz is considered usually. The measure unit for the level of the sound intensity I, is called bel (B), (the intensity corresponding to zero bels) but the submultiple is used more often:

$$1dB = 10^{-1} B$$

in which case the level of the sound intensity is written:

$$L = 10\lg \frac{I}{I_0} (dB)$$

The level of the minimum sound intensity which causes sounds perceivable by the human ear is called sensitivity threshold. The level of the maximum sound intensity for which the sounds do not produce painful effects or temporary or permanent deafness is called painful sensation threshold. [22]. These two thresholds depend both on the sound frequency and the sound intensity. The human ear perceives sounds with intensities ranging between 0 and 140 dB. Table shows examples of sound intensity for various sound categories.

Sound	L (dB)
The leaves sre rusting	10
Low-toned conversation	30
Normal conversation	65
Street noise	90
Orchestral noise	100
Engined aircraft (at 3 m)	120

The human ear perceives two sounds which have the same intensity, but different frequencies, as two sounds of different intensity which shows the necessity of introducing a new sizes called hearing intensity (N). The hearing intensity represents the level of sound intensity measured in dB for a sound with a frequency of 1 kHz assessed by a normal physiological listener [23]. The measure unit for the hearing intensity is the phon.

One phon represents the intensity level of the sound with a frequency of 1 kHz and the sound intensity level of 1 dB.

The quality is another feature of the sound which allows it to differentiate two sounds which have the same frequency and the same sound intensity and this characteristic is determined by the type of sound source. The sound issued by a source is not a simple sound, but it is formed of several simple sounds which have different frequencies [24]. The sound with the lowest frequency is called fundamental sound and the other sounds whose frequency is equal with an integer multiple of the fundamental frequency, is called superior harmonic, the number and the energetic distribution of these harmonics determines the sound quality and allows us to distinguish the sounds from one another. The previously enumerated properties refer to the parameters which characterize the sound in itself. Since the sound must propagate to reach the hearing organ, the propagation parameters are also important [25]. They are: the speed of sound, the acoustic impedance, the reflection coefficient. The propagation speed v, of the sound depends on the propagation environment

$$v = \sqrt{\frac{E}{\rho}}$$

where: E – elasticity module and ρ environment density. For liquid environments the compressibility coefficient χ is used, which is the reverse of the elasticity module and the propagation speed can be written

$$v = \sqrt{\frac{1}{\chi\rho}}$$

Medium	Velocity of sound (m/s)
Air (20^0 C)	343
Water	1435
Glycerine	1750
Steel	5100
Copper	3400
Stone	5000
Lead	1300
Wood	3000–4000
Caoutchouc	45

The propagation of the sound waves determines pressure variations. The difference between the pressures existing in the environment is called sound pressure [26].

The acoustic impedance z is the size which is used in the case when the wave is not plan or there are energy dispersions, the pressure and the speed are not in the phase anymore. This size is given by the relation:

$$\Delta p = \rho \cdot v \cdot \upsilon$$

In these relations ρ is the environment density and v is the sound propagation of the sound and ν is the sound frequency.

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Masking

When an ear is exposed to two or more different sounds, one can mask the other in the traditional sense [27]. In the case of a simultaneous sound effect, the simultaneous masking is perhaps best explained by the fact that the hearing range of the weaker sound is raised by the louder sound, and the extent of this also depends on the frequency of the two sounds. Clear sounds, complex sounds, narrow and broadband noises can all mask other sounds in different ways.

Some interesting conclusions can be drawn from the relevant masking attempts:

1. Clear sounds that are closely related in frequency overlap more than sounds that are widely spaced in frequency.
2. A clear sound masks higher frequency sounds better than lower frequency sounds.
3. The higher the intensity of a masking sound, the wider the frequency threshold it is able to mask.
4. Narrowing by narrowband noise has the same properties as masking by a clear sound; again high frequency sounds are covered more effectively than those with a lower frequency than the masking noise.

References

1. Gamow G, Cleveland J M (1997) Physics. Pretince-Hall, Inc. Englewood Cliffs, N. J.
2. Cleri F (2016) The Physics of Living Systems. Springer.
3. Russell K H, Roth B J (2019) Intermediate Physics for Medicine and Biology. Elsevier.
4. Vincze J (1986) Medical Biophysics. Medical P. Budapest.
5. Vincze J, Vincze-Tiszay G (2020) The Biophysical Modeling of the different Regulations in the Human Organism. Intern. J. Inovat. Studies Med. Sciences, 4: 1-4.
6. Hamilton W J (2018) Textbook of human anatomy. Oxford P.
7. Cooper A (2015) Human Anatomy and Physiology, Albany Univ.
8. Vincze J (1990) Biophysics. 1th Ed. NDP P. Budapest.
9. Vincze J (2015) Biophysics. 5th Ed. NDP P. Budapest.
10. Vincze J (1996) The Biophysics is a Boderland Science. NDP P., Budapest.
11. Vincze J, Vincze-Tiszay G (2020) The Human Organism is a Biophysical-Biopsychological System. Technium, 2: 29-35.
12. Berne R M, Levy M N et all. (2014) Physiology. 7th Mosley, Elsevier.
13. Békésy G (1960) Experiments in hearing. McGraw-Hill Book Comp. New York, Toronto, London.
14. Vincze J, Vincze-Tiszay G (2020) Some Aspects of Sciences from the Biophysical Point of View. Int. J. Software & Hardware Engin. 8: 103-108.
15. Vincze J (2007) Interdisciplinarity, NDP P., Budapest.
16. Vincze J (2008) Biophysics of the Phonation and of the Hearing. NDP P, Budapest.
17. Rubin B A (2014) Fundamentals of Biophysics. Wiley, Scrivenes P.
18. Lin H C (2018) Advances in Oto-Rhino-Laryngology. Karger P.
19. Vincze J (2018) Medical Biophysics. NDP P., Budapest.
20. Hall J E, Hall M E (2020) Medical Physiology 14th Ed. N.Y.
21. Vincze J (2020) The Biophysical Modeling of the Apparatuses in the Human Organism. Lambert, Academic Publishing, Berlin.
22. Waigh T A (2007) Applied Biophysics: A Molecular Approach for Physical Scientists. Per. P.
23. Staudenmaier R (2018) Aesthetics and Functionality in Ear Reconstruction. Kindle Edition.
24. Vincze J, Vincze-Tiszay G (2020) The Biophysical Modeling of the „Seven-Dimensional" Man. Int. J. Recent Sci. Res., 5: 123-130.
25. Wu MY, Yiang GT, et all. (2018) Curent mechanistic concepts in reperfusion injury. Cell Physiol. Biochem. 2018; 46: 1650-1667.
26. Vincze J, Vincze-Tiszay G (2020) The Biophysical Adjustment in the Human Organism. J. Med. Res. Case Report, 2: 1-7.
27. Vincze J (2021) Biophysical Vademecum. NDP P, Budapest.

Citation: *Janos Vincze (2021) The Biophysical Function of the Human Outer Ear. Aca J Cli Hea Rep & Med Sci, Volume 1: issue 1: 1-5.*