I645 Human Perceptual Systems and its Models

Report 1

Explain functions, mechanisms, and nonlinearities of the human auditory system

Name: Cheng Haowei

Student ID: 2110415

Introduction:

Hearing is one of the most important human senses. Language, communication, exploration of the world, alerting to danger, etc. all need to be established with the help of hearing. Once the auditory system is damaged, people's daily life will be seriously affected.

The human auditory system is a complex and dynamic system that is crucial for our ability to perceive and interpret sound. It is composed of a series of specialized structures that work together to process and encode sound information, which is then transmitted to the brain for further processing. In this report, I will discuss the key functions, mechanisms, and nonlinearities of the human auditory system, and how these components work together to enable us to hear and understand the sounds in our environment.

The main functions of the auditory system include detecting and discriminating sounds, locating their sources, and encoding and transmitting information to the brain. The mechanisms involved in the auditory system include transduction, which involves converting sound waves into electrical signals, and encoding, which involves transforming these signals into meaningful information. The human auditory system is also characterized by several nonlinearities, including its ability to adapt to changing levels of sound intensity and filter out background noise, which is essential to our ability to perceive and understand a wide range of sounds in our environment.

In this report, I will explore each of these key components of the human auditory system in more detail, and demonstrate how they work together to allow us to hear and interpret sound.

1. Functions of the auditory system:

(1) Outer ear

The function of the outer ear is to collect and funnel sound waves into the middle ear. The outer ear consists of the pinna, which is the visible portion of the ear, and the ear canal. The pinna is shaped in such a way as to help collect sound from different directions and funnel it into the ear canal (shown in Figure 1). The ear canal amplifies sound waves, further increasing their intensity before they reach the middle ear. This amplification of sound is important for our ability to hear soft sounds and to distinguish between sounds that are close together in frequency [1]. The outer ear also helps to protect the delicate structures of the middle and inner ear from damage by blocking out large objects and providing a moist environment that helps to prevent damage from dryness.

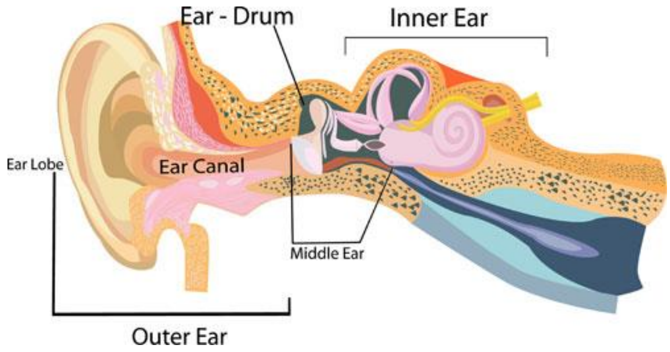

Figure 1. Parts of the ear

(2) Middle ear

The function of the middle ear is to transmit sound from the outer ear to the inner ear. The middle ear is an air-filled cavity that contains three small bones called the ossicles, the malleus, the incus, and the stapes. These bones work together to convert sound waves from the air in the ear canal into mechanical vibrations that are transmitted to the inner ear (shown in Figure 2). The middle ear also acts as a buffer, protecting the inner ear from excessively loud sounds.

The mechanical vibrations of the ossicles are transmitted to the oval window, which is the opening to the inner ear. The oval window is connected to the fluid-filled cochlea, which is responsible for converting mechanical vibrations into electrical signals that are sent to the brain for processing [2]. This process of converting sound from the air into electrical signals is critical for our ability to hear and understand sound.

In addition to transmitting sound, the middle ear also plays an important role in maintaining equal pressure on both sides of the eardrum. The middle ear is connected to the throat via the Eustachian tube, which helps to equalize the pressure in the middle ear and prevent damage to the eardrum [3]. The middle ear also contains the tensor tympani and stapedius muscles, which help to control the movements of the ossicles and reduce the transmission of loud sounds to the inner ear.

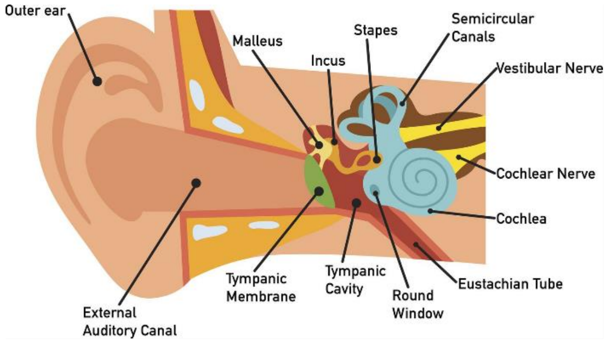

Figure 2. Middle ear

(3) Inner ear

The function of the inner ear is to convert mechanical vibrations from the middle ear into electrical signals that are sent to the brain for processing. The inner ear, also known as the cochlea, is a spiral-shaped structure that is filled with fluid. The cochlea is divided into three main parts: the vestibular system, the basilar membrane, and the spiral organ (also known as the Organ of Corti)(shown in Figure 3).

The vestibular system is responsible for detecting changes in head position and movement and providing our brain with information about balance and spatial orientation. The basilar membrane is a specialized structure that vibrates in response to sound and separates the fluid in the cochlea into different regions. The spiral organ, located on the basilar membrane, contains hair cells that are stimulated by the vibration of the membrane [4].

When the hair cells are stimulated, they produce electrical signals that are sent to the auditory nerve and then on to the brain. These electrical signals are interpreted by the brain as sound. The inner ear also helps to filter out background noise and separate sounds based on their frequency, allowing us to distinguish between different sounds and understand speech.

The inner ear plays a critical role in our ability to hear and understand sound, and damage to the inner ear can result in hearing loss or balance problems. The intricate structure of the inner ear and its complex functions make it one of the most fascinating and important components of the human auditory system.

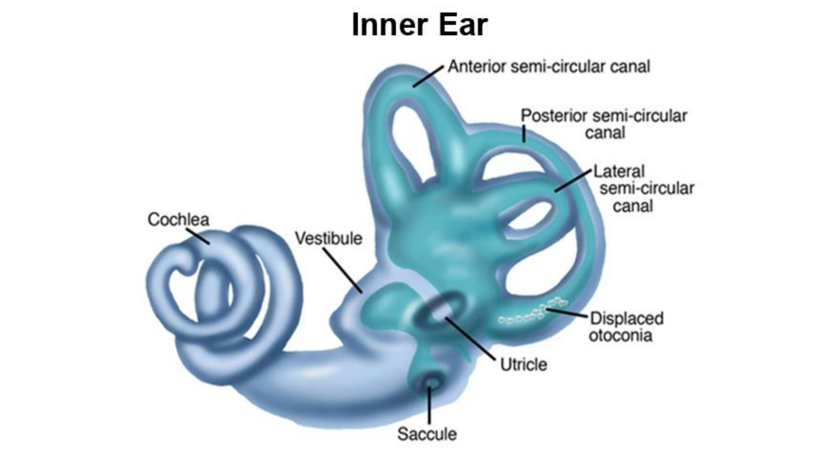

Figure 3. Inner ear

2. The mechanisms of human auditory system

The human auditory system operates through a series of interconnected processes and structures that work together to translate sound into electrical signals that can be understood by the brain. First collecting sound with the outer ear and channeling it into the ear canal, where it is further amplified. Then, the middle ear bones(ossicles) take these amplified sound waves and convert them into mechanical vibrations, which are sent to the inner ear. The minimum detectable level of sound to reach pinna corresponds to an energy flow(or intensity) of 10−12 W/m2 in a sound pressure wave (threshold of hearing). Then, due to its shape, the most sensitive frequencies are ranging from 1000 to 4000 Hz.

Once in the inner ear, the cochlea is responsible for converting these mechanical vibrations into electrical signals. This is achieved by hair cells in the spiral organ, which responds to the movement of the basilar membrane by producing electrical signals. These signals are then carried to the brain by the auditory nerve, where they are interpreted as sound.

Finally, the brain processes this information to allow for the differentiation of different sounds and the understanding of speech. The auditory system can adapt and respond to different stimuli, such as adjusting the sensitivity of the hair cells to environmental sounds and contracting the middle ear muscles in response to loud noises for protection. The complexity and interplay of these mechanisms make the human auditory system capable of hearing a wide range of sounds and speech [5].

3. The nonlinearities of human auditory system

(1) Frequency selectivity

The basilar membrane in the cochlea of the inner ear is designed to be mechanically selective to different frequencies of sound. This is because the width and stiffness of the basilar membrane vary along its length, with the base of the membrane being wider and stiffer, and the apex being narrower and more flexible. As a result, different frequencies of sound are resonant at different locations along the basilar membrane, and this allows the auditory system to process sounds with different frequencies as distinct signals (shown in Figure 4).

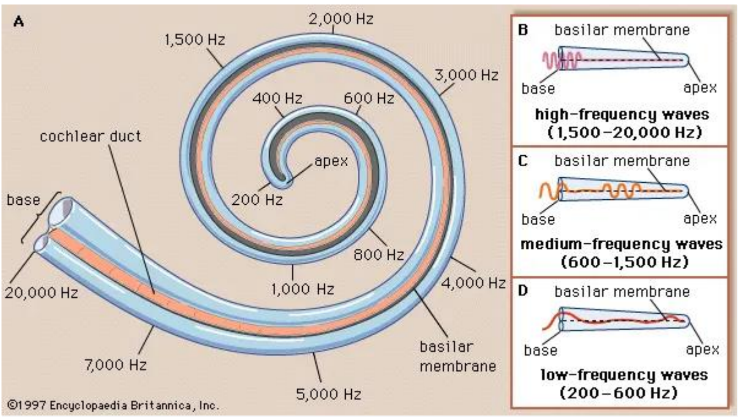

Figure 4. Transmission of sound within the basilar membrane

The frequency selectivity is also reflected in the neural encoding of sound. Neurons in the auditory nerve and in the auditory cortex are tuned to different frequencies, and the distribution of these neurons across the auditory pathway is arranged in a way that reflects the frequency selectivity of the basilar membrane [6]. This ensures that different frequencies of sound are preserved as they are transmitted from the ear to the brain.

While the frequency selectivity of the human auditory system is an important aspect of our perception of sound, it is not perfect. There are limitations to the system's ability to selectively respond to different frequencies, and these limitations can vary between individuals and can change with age.

(2) Nonlinear compression

When the intensity of a sound increases, the hair cells in the cochlea become less sensitive, and the middle ear muscles can contract to reduce the transmission of sound to the cochlea. This nonlinear compression helps to prevent damage to the inner ear and ensures that quiet sounds can still be heard, even in the presence of loud sounds [7].

(3) Spontaneous rate:

The spontaneous rate of the human auditory system refers to the baseline rate of neural activity in the auditory nerve and the auditory cortex when no sound is presented. This baseline rate of neural activity is an important aspect of the auditory system, as it provides a reference point for the auditory system to compare against when sound is being presented. It is important for our perception of sound because it influences how we perceive sounds that are presented at low levels. For example, if the spontaneous rate of the auditory system is high, it becomes more difficult to perceive sounds that are presented at low levels, as these sounds will not produce a large enough change in the neural activity to be detected [8]. On the other hand, if the spontaneous rate of the auditory system is low, it becomes easier to perceive sounds that are presented at low levels, as these sounds will produce a larger change in neural activity. It is interpreted as evidence of an active process within the cochlea, limited from growing indefinitely in amplitude by an amplitude-limiting nonlinearity.

Conclusion

The human auditory system is a complex and dynamic system responsible for processing auditory information. The outer ear collects and directs sound waves to the middle ear, which amplifies the sound and transmits it to the inner ear. The inner ear contains the cochlea, which is responsible for transforming sound waves into neural signals that can be interpreted by the brain. The mechanisms of the auditory system are nonlinear and involve a series of intricate transformations that result in the perception of speech and other sounds.

Despite the extensive research on the human auditory system, there are still many aspects that remain poorly understood. For example, the precise nature of the nonlinearities involved in speech perception is still being researched, and the development of more accurate models is ongoing. Additionally, there is limited knowledge about how the auditory system adapts to changes in the acoustic environment and how it processes sounds in noisy conditions. Further research is needed to improve our understanding of the human auditory system and to develop new strategies for improving speech perception in individuals with hearing difficulties.

Reference

[1] Dobie, R. A., Van Hemel, S., & National Research Council. (2004). Basics of sound, the ear, and hearing. In Hearing Loss: Determining Eligibility for Social Security Benefits. National Academies Press (US).

[2] Onchi, Y., 1961. Mechanism of the middle ear. the journal of the acoustical society of America, 33(6), pp.794-805.

[3] Voss, S.E., Rosowski, J.J., Merchant, S.N. and Peake, W.T., 2000. Acoustic responses of the human middle ear. Hearing research, 150(1-2), pp.43-69.

[4] Wu, D.K. and Kelley, M.W., 2012. Molecular mechanisms of inner ear development. Cold Spring Harbor perspectives in biology, 4(8), p.a008409.

[5] https://www.zhihu.com/question/20790368/answer/16812055.

[6] Kemp, D.T., 1979. Evidence of mechanical nonlinearity and frequency selective wave amplification in the cochlea. Archives of oto-rhino-laryngology, 224(1-2), pp.37-45.

[7] Milekhina, O.N., Nechaev, D.I., Popov, V.V. and Supin, A.Y., 2017. Compressive nonlinearity in the auditory system: Manifestation in the action of complex sound signals. Biology Bulletin, 44, pp.603-609.

[8] Yates, G.K., 1991. Auditory-nerve spontaneous rates vary predictably with threshold. Hearing research, 57(1), pp.57-62.