Sereen Draghmeh

Hearing

Sound waves

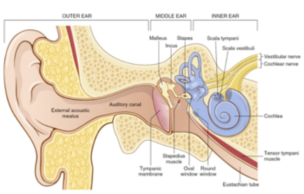
- **Waves** have **two characteristics** , **frequency** and **amplitude**
- **Sound waves** are **alternating high**- and **low-pressure regions traveling** in the **same direction through** a **medium**. They **originate from a vibrating object**.
- The **higher** the **frequency** of **vibration**, the **higher** is the **pitch** (**or** the **tone**)
    - **Measured via cycle per second or** the **Hz**
- The **larger** the **intensity** (or **amplitude**) of the **vibration**, the **louder** is the **sound**.
    - **Sound intensity** is **measured** in **decibels** (dB).
- An **increase** of **one decibel represents** a **tenfold increase in sound intensity**.
- **Most sounds** are **mixtures of pure tones**. The **human ear** is **sensitive** to **tones** with **frequencies between 20 and 20,000 Hz** (a cycle/sec) and is **most sensitive between 2000 and 5000 Hz.**
- The **usual range** of **frequencies** in **human speech** is **between 300 and 3500 Hz**, and the **sound intensity is about 65 dB.**

Sound	Loudness in Decibels (dB)	Comparison to Faintest Audible Sound (Hearing Threshold)
Rustle of leaves	10 dB	10 times louder
Ticking of watch	20 dB	100 times louder
Whispering	30 dB	1 thousand times louder
Normal conversation	60 dB	1 million times louder
Food blender, lawn mower, hair dryer	90 dB	1 billion times louder
Loud rock concert, ambulance siren	120 dB	1 trillion times louder
Takeoff of jet plane	150 dB	1 quadrillion times louder

- **Sound intensities greater** than **100 dB** can **damage** the **auditory apparatus**, and those **greater** than **120 dB can cause pain**.
    - **Don't memorize these numbers**

Hearing

- **Hearing** is the **ability** to **perceive sounds**.
- The **ear** is **divided** into **three main regions**:



    - (1) the **external ear**, which **collects sound waves** and **channels them inward**.
        - Functions as **collecting** the **sound waves** and to **determine** the **direction** of the **sound wave**
    - (2) the **middle ear**, which **conveys sound vibrations** to the **oval window**.
        - The **outer and middle ear together** are **called** the **conduction part** since its **responsible** to **transmit** the **soundwaves from the air** through the **external ear and the middle ear** to **reach** the **receptor cells in the cochlea**
        - And that's why if we have **problems** in **hearing** it can be **divided into 2 categories**, **either conduction** or **sensory (hearing impairment or hearing loss)**
    - (3) the **internal ear**, which **houses the receptors** for **hearing and equilibrium**.
        - The **cochlea part** is the **one responsible for the hearing**
            - The **receptor cells** here **aren't able to regenerate** so we have to project them

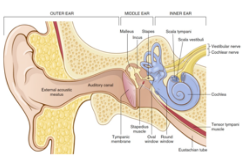
        - The **vestibular** is **more responsible** for the **balance**

Middle ear

- The **middle ear** is a **small**, **air-filled cavity** in the **petrous portion** of the **temporal bone**.
- It is **separated from** the **external ear by the tympanic membrane** and **from the internal ear** by a **thin bony partition** that **contains two small openings**: the **oval window** and the **round window**.
- **Extending across** the **middle ear** and **attached** to it by **ligaments** are **the three smallest bones** in the **body**, the **auditory ossicles**.
- The **bones are** the **malleus**, **incus**, and **stapes**.

Auditory transduction

- The **external** and **middle ears** are **air filled**, and the **inner ear**, which **contains** the **organ of Corti**, is **fluid filled**.
    - So the **conduction** in **this part** is **called air conduction** since the **medium is air**



- Thus **before transduction** can **occur**, **sound waves traveling through air must** be **converted into pressure waves in fluid** **(so amplification of these waves has to occur)**.
    - **Amplification occurs via two mechanisms**
        - due to the **mechanical part** of the **ossicles**
        - due to the **difference** in **surface areas of the tympanic membrane** and that of the **oval window**
            - in which the **surface area of the tympanic membrane** is **much larger** which **plays an important role** , since **when the surface area decreases** (as it **moves from** the **tympanic membrane** to the **oval window**) the **pressure will transmitted more causing amplification**
- The **acoustic impedance** of **fluid** is **much greater than that of air**.
- The **combination** of the **tympanic membrane** and the **ossicles serves** as an **impedance-matching device** that **makes this conversion**.

Middle ear

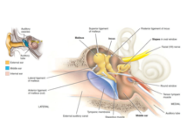
- **Besides** the **ligaments**, **two tiny skeletal muscles** also **attach to the ossicles**.
    - The **tensor tympani muscle**
        - which is **supplied by the mandibular branch** of the **trigeminal (V) nerve**
        - **limits movement** and **increases tension on the eardrum** to **prevent damage** to the **inner ear from loud noises**.
            - From its name we can conclude that it **tense the tympanic membrane** which is **important** in the **transmission** of **sound**

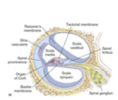
    - **waves**, since the **transmission of sound wont** be **very well from all the parts of the tympanic membrane if it is loose**
    - **keeps** the **tympanic membrane tensed**. This **tension allows sound vibrations** on any **portion of the tympanic membrane** to be **transmitted to the ossicles**.
  - The **stapedius muscle**
    - which is **supplied by the facial (VII) nerve**
    - is the **smallest skeletal muscle** in **the human body.**
    - By **dampening large vibrations** of the **stapes due to loud noises**, it **protects the oval window**.
- These **two muscles** are **important when there is loud sounds** since it **initiates** a **reflex called** the **attenuation reflex** which **reduces the intensity of lower frequency sounds**
- **When loud sounds** are **transmitted through the ossicular system** and **from there into the central nervous system**, a **reflex occurs after a latent period** of only 40 to 80 milliseconds to **cause contraction of the stapedius muscle** and, **to a lesser extent, the tensor tympani muscle**.
- The **tensor tympani muscle pulls the handle** of the **malleus inward** while the **stapedius muscle pulls the stapes outward.**
- These **two forces cause the entire ossicular system** to **develop increased rigidity**, thus **greatly reducing** the **ossicular conduction of low-frequency sound**.

Attenuation reflex

- This **reflex** can **reduce the intensity of lower frequency sound transmission by 30 to 40 decibels**, which is **about the same difference as that between a loud voice** and a **whisper**.
- The **function of this mechanism is**:
  - 1.to **protect** the **cochlea from damaging vibrations caused** by **excessively loud sound** and to **mask low-frequency sounds** in **loud environments**, and **allows** a **person to concentrate** on **sounds above 1000 cycles/sec**, where **most** of the **pertinent information** in **voice communication is transmitted**.
  - 2.to **decrease a person's hearing sensitivity** to **his or her own speech**.

Bone conductance



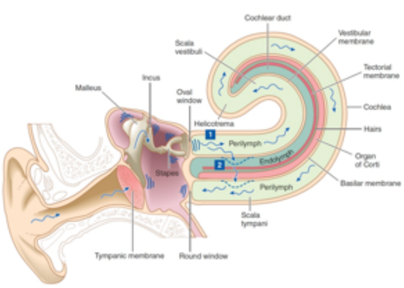


- **Because** the **inner ear**, the **cochlea**, is **embedded** in a **bony cavity in** the **temporal bone**, **called** the **bony labyrinth**, **vibrations** of the **entire skull** can **cause fluid vibrations** in the **cochlea**.
- **Therefore**, **under appropriate conditions**, a **tuning fork** or an **electronic vibrator placed on any bony protuberance** of the **skull**, but **especially** on the **mastoid process near** the **ear**, **causes** the **person** to **hear** the **sound**

- This is **cause when** the **vibration reaches** the **inner ear to** the **cochlea it is going to cause the fluid to also vibrate which will be perceived as sound**
- But of course its **not** the **same intensity as when** it is **travelled via air conduction since no amplification occurs when** its **just vibrations from the skull**

Inner ear

- The **inner ear** is **also called** the **labyrinth**.
- **Structurally**, it **consists of two main divisions**: an **outer bony labyrinth** that **encloses** an **inner membranous labyrinth**.
    - The **bony labyrinth** is a **series of cavities in the petrous portion** of the **temporal bone divided** into **three areas**:
        - (1) the **semicircular canals**
        - (2) the **vestibule**
        - (3) the **cochlea**.
    - The **membranous labyrinth**, a **series** of **epithelial sacs** and **tubes inside** the **bony labyrinth** that **have the same general form** as the **bony labyrinth** and **house the receptors for hearing and equilibrium.**
- The **cochlea**, which is a **spiral-shaped structure composed** of **three tubular canals** or **ducts**, **contains** the **organ of Corti.**
    - **The three tubular canals**
        - **Scala vestibuli**
        - **Scala tympani**
            - **What separates it from scala vestibuli** is a **membrane** called **vestibular membrane**
        - **Scala media**
            - **Has** a **dead end,** so its **not in communication with scala tympani** and **scala vestibuli (its isolated)**
            - **What separates it from tympani** is a **membrane called the basial membrane**
                - **Important** since it **contains** the **receptor cells, so signal transduction** of the hearing sensation **occurs here**

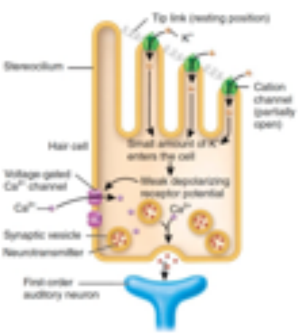


- The **organ of Corti contains** the **receptor cells** and is **the site of auditory transduction.**
- The **inner ear is fluid filled**, and the **fluid** in **each duct** has a **different composition**.
    - The **fluid** in the **scala vestibuli** and **scala tympani** is **called perilymph**, which is **similar** to **extracellular fluid (CSF).**
    - The **fluid** in the **scala media** is **called endolymph**, which **has a high potassium (K+) concentration**.
        - Thus **endolymph** is **unusual** in that its **composition** is **similar to** that of **intracellular fluid**, even **though**, **technically**, it is **extracellular fluid.**

- The **lengths** of the **basilar fibers increase progressively**, **beginning** at the **oval window** and **going from the base of the cochlea to the apex**.
- The **diameter** of the **fibers**, **however**, **decrease from the oval window** to the **helicotrema**, so **their overall stiffness decreases more than 100-fold**.
- As a **result**, the **stiff, short fibers near** the **oval window** of the **cochlea vibrate best at a very high frequency**, **whereas** the **long**, **limber fibers near** the **tip of the cochlea vibrate best** at a **low frequency**.

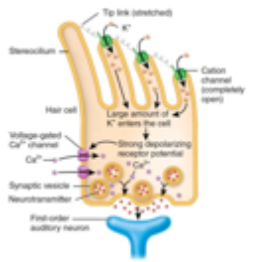
Organ of Corti

- As we said**,** at the **base of it** we have the **basilar membrane** while at the **top** we have the **tectorial membrane**
- The **organ** of **Corti lies** on the **basilar membrane** of the **cochlea** and is **bathed in the endolymph contained** in the **scala media.**
- **Auditory hair cells** in the **organ of Corti** are **the sites of auditory transduction**.
- The **organ** of **Corti contains two types of receptor cells**: **inner hair cells** and **outer hair cells.**
    - There are **fewer inner hair cells**, which are **arranged in single rows**.

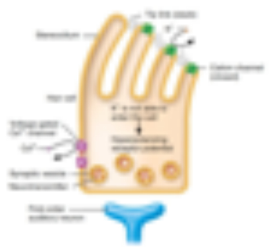


        - **More than 90 % of the nerve fibers transmitted** to **sensory neurons** is **form** the **inner hair cells**
        - Plus the **cilia here** are of **increasing length** (different lengths, like stairs) as depicted in this picture
        - On the **top** of each **cilia** we have **cation channels** they're **gates** are **attached** by **linking proteins** to the **next longer cilia**
        - **Resting stage:**
            - the **hair cells** are **resting** and are **straight** and this case, the **channels are partially open**, (the **most common concentration** of **cation** is in **endo lymph is potassium**) so the **potassium** will **enter causing weak depolarization**
            - this weak **depolarization** will **activate voltage gated calcium channels causing exocytosis** of the **neurotransmitter glutamate**, **activating** the **first order auditory neuron**
            - So the **resting state** in the **CNS** there is an **action potential** of **low frequency**
        - **Excitatory/Inhibitory :**
            - When there is a **stimuli** there is **going** to **be bending of the hair**, to **either way,** it can be
                - **towards** the **longest cilia**
                    - If it was **towards** the **longest cilia**, this will cause the **linking proteins** to **pull** the **potassium gates open** when **bending making them fully opened**

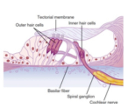
Sereer



- so **more potassium** will **enter causing a strong depolarization receptor potential** so **more neurotransmitter and glutamate release**
  - So it will **reach the CNS** as **more frequent action potential**
- **away** from the **longest cilia**



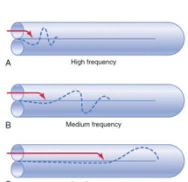
  - If it was **away** from the **longest cilia**, the **linking proteins** will **crumble causing total closure** of these **cation channels**
  - and so there is **no influx of potassium** so **hyperpolarization** so almost **no neurotransmitter coming** out to **synapse with** the **first order neuron** so **no impulse recaching the CNS**
- **Outer hair cells** are **arranged** in **parallel rows and are more numerous**.
  - Have **an important role** in the **hearing process**
  - the **function** of it exactly **isnt well understood**, **some say** it **can change the length of the cilia** which will **affect the movement of the membrane**, some also say it **causes sensitization of the inner hair cells**
  - **but they are important**
- **Cilia**, **protruding** from **the hair cells**, are **touching/embedded** in the **tectorial membrane**.
- **Thus** the **bodies of the hair cells are** in **contact** with the **basilar membrane**, and the **cilia** of the **hair cells are** in **contact** with **the tectorial membrane**.



- The **nerves that serve** the **organ of Corti** are **contained** in the **vestibulocochlear nerve (CN VIII)**.
- The **cell bodies** of **these nerves are located** in **spiral ganglia**, and **their axons synapse at the base of the hair cells**.

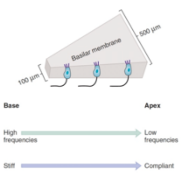
<u>Encoding of frequency</u>

- The **basilar membrane** is **not a uniform structure**, here the **basilar membrane starts** from the **base**, **from** the **oval window** and it **continues till the apex**
- At the **base**, the **basilar fibers** area **short** and **wide** as **we move towards the apex**
  - so for example In the **middle theyre longer and thinner**
  - at the **apex**, theyre the **longest and the thinnest**
- This is **important since** this **different characteristic of the fibers** can get **stimulated** by **different frequencies of the waves**



- So a **high frequency of the wave** will **stimulate** these **short stiff fibers**
- So the **CNS** when it **receives a signal** from a **certain area it will know** that **it's a high frequency or a low frequency sound (labeled line)**

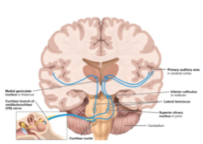
- So **depending** on **which part of the basilar membrane** the **frequency hits** it **will send that info** to the **CNS** and it **will know it's a medium frequency**
- **Encoding** of **sound frequencies occurs because different auditory hair cells** are **activated** by **different frequencies**.
- The **frequency** that **activates a particular hair cell depends** on the **position of that hair cell along** the **basilar membrane**.



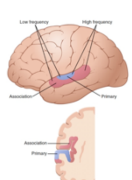
- The **base** of the **basilar membrane** is **nearest** the **stapes** and is **narrow and stiff**.
    - **Hair cells located** at the **base respond best to high frequencies**.
- The **apex** of the **basilar membrane** is **wide** and **compliant**.
    - **Hair cells located** at the **apex respond best to low frequencies**.
- Thus the **basilar membrane acts** as a **sound frequency analyzer**, with **hair cells positioned along the basilar membrane responding** to **different frequencies**.
- This **spatial mapping** of **frequencies generates** a **tonotopic map**, which then is **transmitted** to **higher levels of the auditory system**. **encoding** of **loudness**
- First, **as the sound becomes louder**, the **amplitude of vibration** of the **basilar membrane** and **hair cells also increases** so **that the hair cells excite** the **nerve endings** at **more rapid rates.**
- **Second**, as the **amplitude of vibration increases**, it **causes more and more of the hair cells** on the **fringes** of the **resonating portion** of the **basilar membrane** to **become stimulated**, thus **causing spatial summation of impulses**.
- **Third**, the **outer hair cells do not become stimulated significantly until vibration** of the **basilar membrane reaches high intensity**, and **stimulation of these cells presumably apprises** the **nervous system that the sound is loud**

Auditory pathway

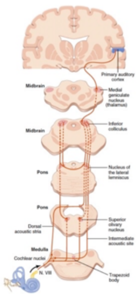
- A **characteristic** of this **pathway** is that there is **so many crossing of these fibers**.
- **Nerve fibers** from **the spiral ganglion of Corti enter** the **dorsal and ventral cochlear nuclei located** in the **medulla**.



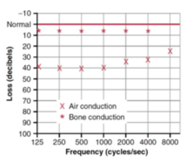
- At this point, **all** the **fibers synapse**, and **second-order neurons pass mainly** to the **opposite side** of the **brain stem to terminate** in the **superior olivary nucleus**.
- A **few second-order fibers** also **pass** to the **superior olivary nucleus** on **the same side**.
- **Signals** from **both ears are transmitted through** the **pathways of both sides of the brain**, with a **preponderance** of **transmission** in the **contralateral pathway**.



- **Many collateral fibers** from the **auditory tracts pass directly into** the **reticular activating system** of the **brain stem**. This **system projects diffusely upward** in the **brain stem and downward** into the **spinal cord** and **activates the entire nervous system** in **response** to **loud sounds**.
- **Other collaterals go** to the **vermis of the cerebellum**, which is **also activated instantaneously** in the **event of a sudden noise**.

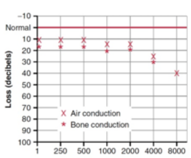


- A **high degree of spatial orientation** is **maintained** in the **fiber tracts** from the **cochlea all** the **way to the cortex.**
- **Destruction** of **both primary auditory cortices** in the **human being greatly reduces** one's **sensitivity for hearing**.
- **Destruction** of **one side only slightly reduces hearing** in the **opposite ear**; it **does** not **cause deafness** in the **ear because of many crossover connections** from **side** to **side** in the **auditory neural pathway.**
- **However**, it **does affect one's ability to localize the source** of a **sound because comparative signals** in **both cortices are required for sound localization**.
- **Lesions** that **affect the auditory association areas but not the primary auditory cortex do not decrease** a **person's ability to hear** and **differentiate sound tones**.
- However, the **person is often unable to interpret** the **meaning of the sound heard** (ex. Wernicke's area).



ination of the direction of sound

- To **distinguish whether some** has a **problem in the sensory or conductive part** we **have something called** an **audiogram** which is a **test which compares the air conduction to the bone conduction** in **which the air conduction is always better than** the **bone conduction** , but in this picture here the **bone conduction** here **seems higher** so the **problem** is in the **conductive p**art (e.g **calcification of the bone**, **perforated ear drum**, **fluids here**)



- While in this **picture** we can see a **decrease in conduction mainly at high frequency**, so we **reached the basilar membrane** (since it's the one that determine the high and low frequency) and so **we have a problem** in the **base of the basilar membrane** , **near** the **oval window** since **its the one that detects** the **high frequency sounds** and so there is **impairment there**
  - This is **typical for aging**
- A person **determines** the **horizontal direction from** which **sound comes by two principal** means:
  - (1) the **time lag between** the **entry of sound into one ear** and its **entry into the opposite ear**.
  - (2) the **difference between the intensities** of the **sounds** in the **two ears**.
- **These two mechanisms cannot tell whether** the **sound is emanating from in front of or behind** the **person or from above or below**.
- This **discrimination is achieved mainly** by the **pinnae**, **which act as funnels** to **direct** the **sound into the two ears**.
- The **shape** of the **pinna changes** the **quality of the sound entering the ear**, **depending** on the **direction from which the sound comes**.

- The **neural analyses** for **the direction detection process begin** in the **superior olivary nuclei** in the **brain stem**, **even though** the **neural pathways all the way from these nuclei** to the **cortex are required** for **interpretation of the signals**.