Perception (PSY 4204) Christine L. Ruva, Ph.D.

Sound, The Auditory System, and Pitch Perception
CHAPTER 11

Overview of Questions

- If a tree falls in the forest and no one is there to hear it, is there a sound?
- What is it that makes sounds high pitched or low pitched?
- How do sound vibrations inside the ear lead to the perception of different pitches?
- How are sounds represented in the auditory cortex?

SOUND: Two Definitions

- **Physical Definition**: Sound is pressure changes in the air or other medium.

- **Perceptual Definition**: Sound is the experience we have when we hear.

Sound Stimulus Produced by a Loudspeaker.

- Loud speakers produce sound by:
  - The diaphragm of the speaker moves out, pushing _____
  - The diaphragm also moves in, pulling the _____
  - The cycle of this process creates alternating high- and low-pressure regions that travel through the air

Sine Waves Can be Described by Their Amplitude and Frequency

- **Pure Tone**: created by a **_____**.

- **Amplitude**: difference in pressure between high and low peaks of wave

- **Amplitude**: Perception of amplitude is _____

- Decibel (dB) is used as the measure of _____
- Number of Decibels (dB) = 20 logarithm (p/p_0)
  - **p** = sound pressure of the stimulus
  - **p_0** = standard sound pressure (usually set at 20 micropascals)

- **SPL** (_____) indicates that we have used the standard pressure of 20 micropascals as p_0 in our formula.

- Decibels are a _____of loudness and are related to _____.
- Loudness approximately _____ for every _____ increase in sound.

Sine Waves Can be Described by Their Amplitude and Frequency

- **Frequency** - number of _____ within a given time period.
  - Measured in _____ - _____ is 1 cycle per second
  - Perception of _____ is related to frequency
- People can hear frequencies between _____.

Pitch, Chroma, & Timbre

- **Tone height**: is the property of increasing pitch that accompanies increases in a tone's frequency. _____.
- **Tone Chroma**: Letters of notes on a musical scale (A, B, C, D, E, F, & G) repeat and notes with the same letter sound similar.
- **Octave**: Every time we pass the same letter on the spiral we have gone up an octave.
- Tones separated by octaves have _____ that are multiples of each other
- **Timbre**: If two tones have the same _____ but sound different, this is a difference of timbre.

Specifying the Frequencies of Complex Sound Stimuli

- Most environmental stimuli = **complex sounds**
- **Additive Synthesis for creating a complex tone**
  - The starting point for creating a complex tone by additive synthesis is a single _____ (one frequency), which is called the _____ _____ of the complex tone.
  - **Harmonics**: are _____ that are added to the fundamental frequency, each tone has a frequency that is a multiple of the fundamental.

- For a **440 Hz** fundamental, the frequency of the 2nd tone/2nd harmonic is _____, and the 3rd tone/3rd harmonic is _____.
- The pattern of pressure changes for a complex musical tone consists of the sum of these components.

Complex Periodic Sounds – continued

- Effect of missing fundamental frequency
  - Removal of the first harmonic results in a sound with the same perceived pitch, but with a different _____.
    - This is called periodicity pitch.

SOUND AS A PERCEPTUAL RESPONSE: THE EXPERIENCE OF HEARING

- The range of hearing for humans is between _____**.**
- **Audibility Curve**: this indicates how sensitivity changes across the frequencies that we can hear by plotting the threshold for _____ versus _____.
- We are **most sensitive** at frequencies between _____, the range of frequencies that is most important for _____.
- The **area above the green curve** is called the _____ because we can hear tones that fall within this area.
- **Threshold for feeling**: As we approach this curve tones become _____ and can cause _____ to the auditory system.

LOUDNESS

- The loudness of pure tones depends on both _____
- **Equal Loudness Curves**: These curves indicate the number of decibels that create the same perception of loudness at different frequencies (40 and 80 dB, SPL).
- At _____, all frequencies don't sound equally loud. Frequencies below 400 Hz (bass notes) and above 12,000 Hz (the treble notes) are inaudible at _____.

AUDITORY SYSTEM: STRUCTURE & FUNCTION
3 Basic Tasks Before We Can Hear

- Sound stimulus must be delivered to the receptors.
- Transduction:
- These electrical signals must be processed so they can indicate qualities of the sound such as pitch, loudness, timbre, and location.

THE OUTER EAR: Pinnae and Auditory Canal

- **Outer ear**: consists of the pinnae and auditory canal
  - **Pinnae**: _____
  - **Auditory Canal**: The canal and its _____ protects the delicate _____ at the end of the canal and helps keep this membrane and the structures in the middle ear at a relatively constant _____.
- The resonant frequency of the canal amplifies frequencies between 1,000 and 5,000 Hz.
- **Resonance** occurs when sound waves that are reflected back from the closed end of the auditory canal interact with sound waves that are entering the auditory canal.
  - This interaction reinforces some of the sound's frequencies, the frequency reinforced the most is called the _____ of the canal.

THE MIDDLE EAR

- The **middle ear** is a 2 cubic centimeter cavity separating inner from outer ear.
- This cavity contains the _____, the **3 smallest bones in the body**.
  - Malleus - moves due to the _____
  - Incus - transmits vibrations of _____
  - Stapes - transmit vibrations of incus to the _____ of the cochlea

Why are the ossicles necessary?

- **Outer** and **middle** ear are filled with _____
- **Inner** ear filled with _____ that is much denser than air
- Pressure changes in air transmit poorly into the denser medium
- Ossicles act to _____ for better transmission to the fluid

THE INNER EAR: COCHLEA

- **Cochlea**: is the main structure of the inner ear (35 mm long).
- The liquid of the Cochlea is set into vibration by the movement of the _____ against the _____.
- **Cochlear Partition**: extends almost the entire length of the cochlea separating the **scala vestibuli** and the **scala tympani**.

Inner Ear: Organ of Corti

- Contains the receptors, called _____
- It sits on top of the basilar membrane
- It is covered by the tectorial membrane
- **Hair Cells**: the _____.
- **Transduction takes place by**:
  - **Inner hair cells**: The _____ generates the electrical signal that is transmitted to fibers in the auditory nerve.
  - Cilia bend in response to movement of organ of Corti and the tectorial membrane.
- When the _____ bend in one direction the cell _____ and when it bends in the other direction the hair cells _____.
- Each time the cell depolarizes it _____, and each time it hyperpolarizes _____.

FREQUENCY ANALYSIS IN THE COCHLEA AND AUDITORY NERVE
2 Possible Ways Neurons Might Signal Frequency

- By _____ are firing (_____)
- By _____ these fibers are firing - the _____.

FREQUENCY ANALYSIS IN THE COCHLEA AND AUDITORY NERVE

- **Békésys' Place Theory of Hearing**: the frequency of a sound is indicated by the place along the _____ at which nerve firing is highest.

- **Békésy** observed the basilar membrane reaction to different frequencies by:
  - boring a hole in the ear of a _____
  - Building a _____ of the cochlea using the physical properties of the basilar membrane

Békésys' Place Theory of Hearing

- The **_____** of the basilar membrane (by the stapes) is **3 to 4 times _____** than its **apex** and the base is **100 times _____** than the apex.

- This knowledge led to models of the cochlea that revealed that pressure changes in the cochlea cause the basilar membrane to vibrate in a traveling _____.
- **Envelope** of the traveling wave
  - Indicates the point of maximum displacement of the _____
  - Hair cells at this point are stimulated the most strongly leading to the nerve fibers firing the most strongly at this location
  - Position of the peak is a function of _____

Physiological Evidence for Place Coding

- **Tonotopic Maps on the Cochlea**: a map of frequencies along the length of the cochlea that was developed by measuring the electrical response of the cochlea to different frequencies.
  - The **apex** of cochlea responds best to _____ and the **base** responds best to _____.

Physiological Evidence for Place Coding

- **Hair Cell and Auditory Nerve Fiber Firing**: microelectrode recording from individual hair cells and auditory nerve fibers.
- Measuring the level in dB SPL necessary to elicit a small response at each frequency yields a **frequency tuning curve**.
- **Characteristic Frequency**: the frequency to which the hair cell is most sensitive.
- **Psychophysical tuning curves**, which are determined by measuring perception of different frequencies, look very similar to the neural curves obtained from measuring hair cells and auditory fibers.

Basilar Membrane's Response to Complex Tones

- Each component of a **complex tone** activates a different area of the basilar membrane.
- The auditory system performs a type of _____ on complex tones breaking the complex tone into its harmonics and responding to each harmonic.
  - Thus the cochlea is called a _____

Updating Békésy's Place Theory

- Békésy used basilar membranes _____ and his results showed no difference in response for _____ that people can distinguish.
- New research with live membranes shows that the entire _____ respond to sound by slight tilting and a change in length.
  - For this reason these cells are called the _____.

Signaling Frequency by the Timing of Nerve Firing

- **Phase locking**
  - Nerve fibers fire in bursts
  - Firing bursts happen at or near the peak of the sine-wave stimulus
  - Thus, they are "locked in phase" with the wave
  - Groups of fibers fire with periods of silent intervals creating _____
- Information for frequency is then transmitted through a series of structures to the cortex, resulting in our perception of sound.

Frequency Analysis in the Cortex

- Much of the timing information provided by the phase-locking is lost by the time the signal reaches the cortex.
  - This is because while the nerve fibers phase-lock to frequencies up to about _____, neurons in the cortex phase-lock only up to about _____.

Place and Temporal Coding for Pitch

- Place coding is effective for the _____.
- Temporal coding with phase locking is effective up to _____.

Pathway from the Cochlea to the Cortex
The Auditory Pathways

- The auditory nerve carries the signals generated by the inner hair cells away from the **cochlea** and toward the **auditory receiving area** in the cortex **(A1).**
- **SONIC MG**:
  SON = _____
  IC = _____
  MG = _____

Auditory Areas in the Cortex

- Hierarchical processing occurs in the cortex
- Neural signals travel through the core, then belt, followed by the parabelt area.
- Simple sounds cause activation in the _____.
- Belt and parabelt areas are activated in response to more complex stimuli made up of _____.

What and Where Streams for Hearing

- ***What,*** or _____, starts in the anterior portion of the core and belt and extends to the prefrontal cortex.
- It is responsible for _____.
- ***Where****,* or _____, starts in the posterior core and belt and extends to the parietal and prefrontal cortices.
- It is responsible for _____**.**
- Evidence from neural recordings, brain damage, and brain scanning support these findings.

Hearing Loss and Cochlear Implants

- These will be covered during the presentations and will not be on your exams.