Lecture 2-8: Perception of Intensity

Overview

1. **Objective and subjective attributes of a sound.** The field of **psychoacoustics** seeks to relate the subjective attributes of sounds to their objective physical properties. **Loudness** is related to the physical amplitude or intensity of the pressure variations. The perceived differences between **buzzy** sounds and **hissy** sounds are related to waveform periodicity. Our perceptions of **pitch** seem to be related to fundamental frequency. Our perceptions of **timbre**, **quality** or **colour** are strongly influenced by the spectral envelope of the sound
2. **Detection of pure (sinusoidal) tones.** We can map the **sensitivity** of our hearing mechanism using simple sinusoidal tones. The **detection** threshold, or the **threshold of audibility** maps out the physical intensity of tones that are just audible. This threshold varies with frequency, with greatest sensitivity (lowest threshold) between 1kHz and 4kHz, and limits to hearing of 20Hz to 20kHz, see figure 2-8.1. The **uncomfortable loudness level (ULL)**, sometimes called the **threshold of pain** maps out the physical intensity of tones that are loud enough to just cause discomfort. The threshold of pain varies much less with frequency than the threshold of audibility; this is probably because it is related to physical damage caused by high pressures in the cochlea. The **dynamic range** of hearing is the range of amplitude between audibility and discomfort. Both the threshold of audibility and the threshold of pain are **equal loudness contours**, that is, they map out a line of tones that have approximately equal perceived loudness. Other equal loudness contours can be drawn, for example, the line of tones that are all equally as loud as a 1kHz tone at 30dBSPL. We are sensitive to small amplitude changes in pure tones, the **just noticeable difference (JND)** for tones being about 1dB. This approximates to about 100 or so noticeable changes in loudness within the dynamic range at 4kHz.
3. **Plotting thresholds for clinical use.** Standard thresholds have been calculated for a group of normally hearing young adults. We can use these standard values to assess hearing. **Hearing loss (dBHL)** is just the difference between the measured threshold for a subject (in dBSPL) and the average normal threshold (in dBSPL) for a range of standard frequencies. Hearing loss measures are plotted on a graph called an **audiogram** in which positive numbers represent higher thresholds (i.e. worse than average hearing). When measuring hearing with loudspeakers rather than headphones we have to take into account the effect of the pinna, see figure 2-8.2.
4. **Peripheral auditory system**. The outer ear, or **pinna** is responsible for the collection of sound and makes subtle changes to the sound depending upon the direction from which it came; this helps us locate sounds in space. The **external auditory meatus** or ear canal ends in the **tympanic membrane** or eardrum. Movement of the eardrum in response to changes in air pressure causes movement of the drum and the **ossicular** chain connecting the drum to the **oval window** of the cochlea. The difference in size between the eardrum and the oval window causes an increase in the force applied to the cochlea, see figure 2-8.3. This is necessary because the cochlea is filled with fluid and is of high impedance (resistance to movement). Much of the shape of the threshold curve can be accounted for by the frequency responses of the pinna, ear canal and middle ear. These all tend to emphasise the middle range of frequencies between 1-4kHz, see figure 2-8.4. Thus tones at these frequencies are of greater amplitude at the cochlea than lower or higher frequencies.

Readings

At least one from:

- Hewlett & Beck, An introduction to the science of phonetics, Chapters 13 & 14: The mechanism of hearing & Loudness, pp 181-211. *Covers the essentials.*
- Rosen & Howell, Signals and Systems for Speech and Hearing (1st edition), Chapter 12: Application to Hearing. *Discusses filtering performed by outer, middle and inner ear.*

An especially good introductory book pertaining to many aspects of hearing, both psychological and physiological is: Yost, WA (2000) *Fundamentals of Hearing: An Introduction* (4th edition) Academic Press.

Learning Activities

You can help yourself understand and remember this week's teaching by doing the following activities before next week:

1. Write a description of how the outer and middle ears help to transmit sound vibrations to the inner ear. Be sure to highlight how each changes the sound signal as it passes through.
2. Sketch your own version of Figure 2-8.1 from memory. Be sure you know how to label the axes, the threshold of audibility and the threshold of pain.
3. Write an explanation in your own words of the terms: threshold of audibility, uncomfortable loudness level, dynamic range and just-noticeable difference.
4. Find a technical specification for a modern audiometer on the web and try to make sense of the description of its audio signal capabilities.

If you are unsure about any of these, make sure you ask questions in the lab or in tutorial.

Quick Quiz

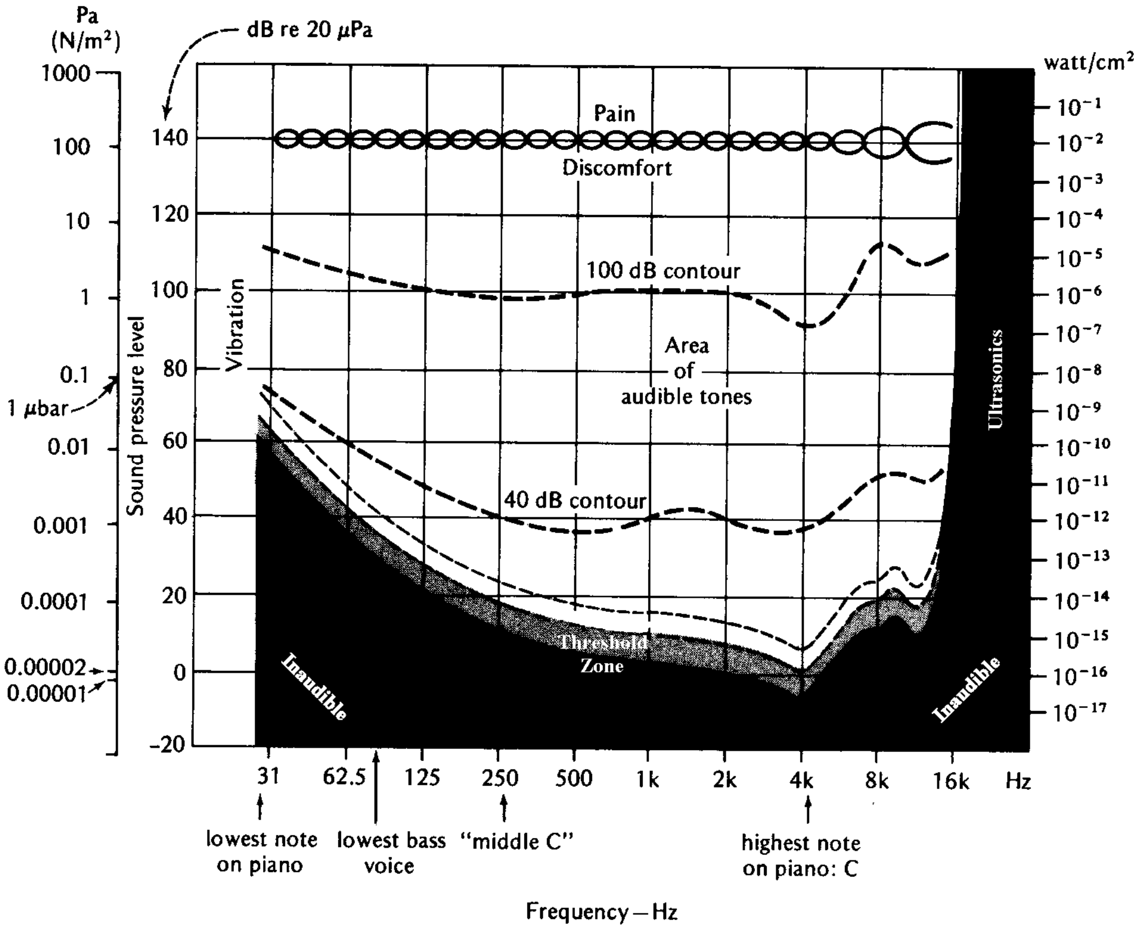
1. A graph of hearing thresholds, expressed in dB HL, as a function of frequency is called an ___________________________.
2. On the dB HL scale, 0 dB represents ________________________________.
3. A test to determine the relationship between stimuli and the sensations they produce is called a ___________________________ test.
4. The difference in dB between the thresholds of hearing and the uncomfortable loudness level is called the ______________________________.

Reflections

You can improve your learning by reflecting on your understanding. Here are some suggestions for questions related to this week's teaching.

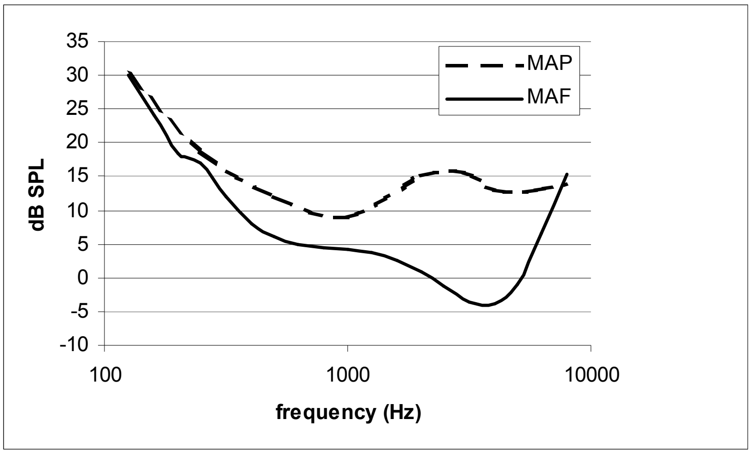
1. Trace the path of sound vibrations through all the anatomical components of the ear.
2. What is the pinna useful for? What is the Eustachian tube useful for?
3. What would happen to your sensitivity to sound if your ear drum and ossicular chain were removed?
4. Can you hear sounds underwater? Why can't you hear people speaking above the surface?
5. What is the difference between the dBSPL scale and the dBHL scale?
6. Why are we more sensitive to mid-frequency tones than to low-frequency or high-frequency tones?
7. What happens to your thresholds of audibility and of pain when you put cotton-wool in your ears?

Figure 2-8.1 Sensitivity of Human Hearing to Pure Tones



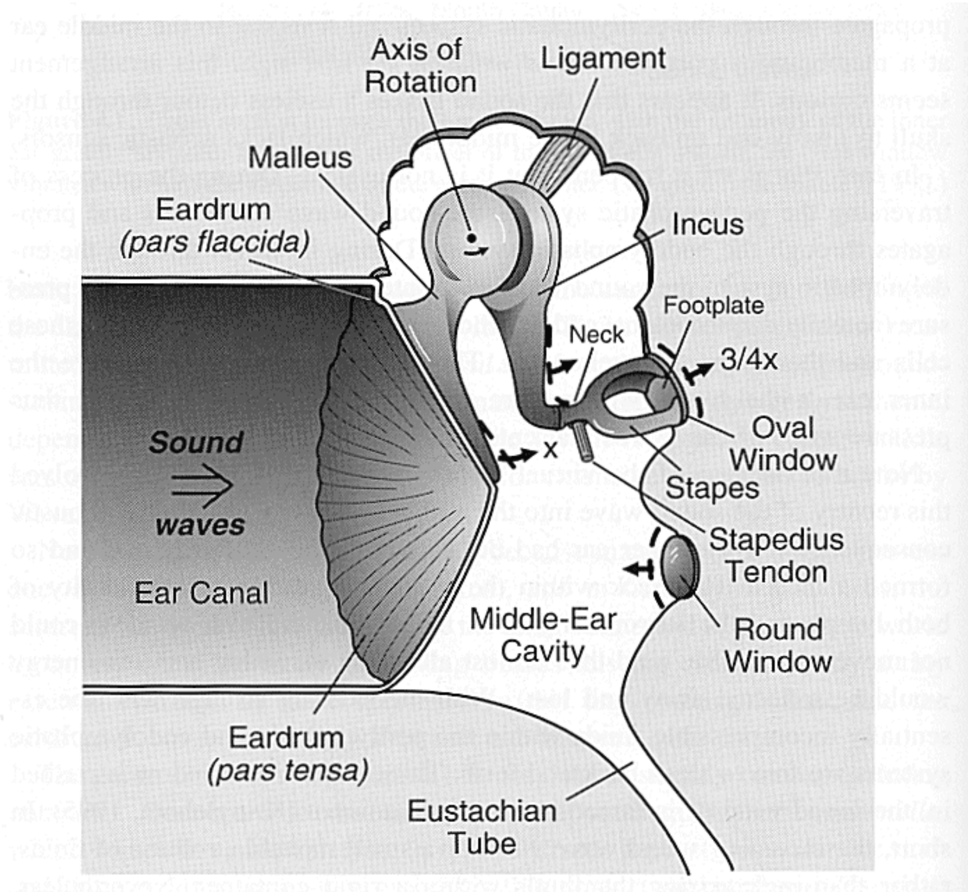
From: Davis, H., & Silverman, S. R. (**1978**) *Hearing and Deafness* (Holt, Rhinehart and Winston, New York).

Figure 2-8.2 Minimum Audible Field (MAF) vs Minimum Audible Pressure (MAP)



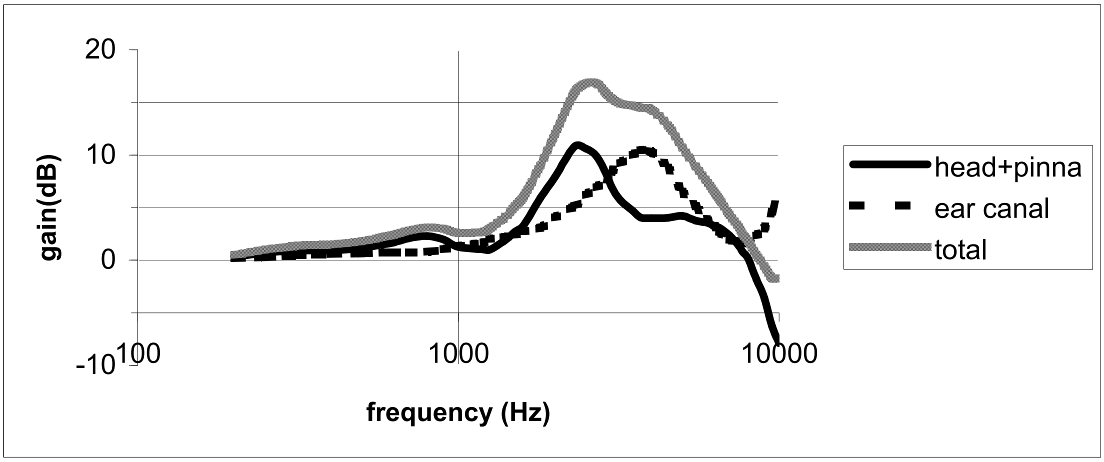
For MAP the pressure is measured in the ear canal at the observer's eardrum. For MAF we measure the pressure at the position of the listener's head, but without the listener present. Thus MAF measures benefit from the ear canal resonance and the acoustic effects of the head and pinna.

Figure 2-8.3 Action of Middle Ear



Cross-section through the human middle ear. Note the large difference in area between the ear drum and the oval window, a factor of about 20:1. From Geisler, C. D. (**1998**) *From Sound to Synapse: Physiology of the Mammalian Ear* (Oxford, New York).

Figure 2-8.4 Frequency response of outer ear and ear canal



Much of the shape of the threshold curve across frequency can be accounted for by transmission of sound into the cochlea.

Lab 2-8: Pure-Tone Audiometry

Introduction

Pure-tone audiometry (PTA) is a standard procedure used in clinics to measure the threshold of audibility for pure tones presented to a listener over headphones. Threshold measurements, made for an agreed set of frequencies, are expressed in dBHL (sometimes: dB ISO) and plotted on a graph called a pure-tone audiogram. In a clinic a calibrated audiometer is used to present the correct intensity for each tone such that 'normal hearing' (as described in 1964 by the ISO) registers as 0 dB HL (audiometric zero). In this experiment you shall take the roles of patient and technician in a pure-tone audiometric procedure using basic equipment that you will need to calibrate yourself.

Scientific Objectives

- to measure audiograms from a group of young adults with normal hearing

Learning Objectives

- to understand the relationship between dB SPL and dB HL units of intensity
- to demonstrate a particular method of threshold measurement ('10 down, 5 up')
- to illustrate the degree of normal variation in hearing thresholds
- to highlight sources of error in testing of hearing thresholds

Apparatus

The apparatus consists of a sine-wave oscillator connected to headphones through an attenuator box. The apparatus has been set up in the acoustic booths in the research laboratory. The apparatus has been calibrated so that the sound pressure level at the right headphone for an attenuation of 0 dB is known. YOU SHOULD NOT ADJUST THE OUTPUT LEVEL OF THE OSCILLATOR.

Method

You should work in pairs, one taking the role of client (patient) and one of tester (technician), then swapping roles to repeat. You should agree a signal for the client to indicate s/he has heard a tone.

Setup procedure:

1. Set the oscillator to the frequency under test, and the attenuator to 0 dB. Use the push button on the attenuator box to present a tone at the headphones.
2. Ensure the subject can hear the tone in the right ear only. Once the test is underway, please do not touch or adjust the headphones or watch the tester(!).

Measurement procedure ('10 down 5 up'):

1. Using the attenuator, decrease the level of the tone by 10 dB (2 clicks), and present the tone using the push button (for about 1 second). Repeat until the subject ceases to respond. The presentation level is now below the subject's threshold.
2. Increase the level of the tone by 5 dB (1 click) and present tone. Repeat until the subject responds again. The presentation level is now at or above threshold.
3. Decrease the level of the tone in steps of 10 dB until the subject ceases to respond.
4. Repeat 2. and 3. until the threshold level (lowest attenuator setting for a valid response) is the same three times in a row.
5. Record the dB setting on the attenuator.

Observations

1. Using the measurement procedure, test the following frequencies (Hz):

   1000, 2000, 4000, 8000, 125, 250, 500 & 1000 again

2. Convert your attenuator readings into dB SPL **using the calibration reading for your equipment**:

   Threshold level @ f Hz (dB SPL) = Calibration level @ f Hz (dB SPL) -
   Attenuator reading @ f Hz (dB).

   Where 'f' = 125, 250, 500, etc. Plot a graph of your threshold level in dB SPL against log frequency.

3. Convert your threshold levels in dB SPL to Hearing Level in dB HL using this table:

Frequency	125	250	500	1000	2000	4000	8000
dB SPL	30	19	12	9	9	9	10

   Hearing Level @ f Hz (dB HL) = Threshold level @ f Hz (dB SPL) -
   Average Threshold level @ f Hz (dB SPL).

   If your threshold level is louder than average you should get a positive number. If your threshold level is quieter than average you should get a negative number.

4. Plot your Hearing Level on the standard audiogram form supplied.

5. A professional audiometer will be available in the lab. Try out the bone conduction unit. How does this work? Why is it a useful supplement to headphones?

Concluding Remarks

What problem might arise if a client has very different thresholds in the left and right ears? How might you overcome this problem?

A WORD OF WARNING

We have tried to make this experiment realistic, but the apparatus is designed to explain audiometry rather than give accurate results. Since the testing conditions are less than perfect, our equipment and calibration methods non-standard, and your partner not a trained audiometric technician - **you should not take the results to be a reliable indicator of your hearing**. If you are concerned about your hearing you should arrange to visit the audiology department of your local hospital.

Examination Question

These is a question from a past exam paper. You may like to write an outline answer or discuss in tutorial.

1. Define the dB SPL and dB HL scales of sound pressure intensity. What kind of study is it necessary to conduct in order to define dB HL? Why does the absolute threshold for normal young listeners vary in dB SPL across frequency? [2003/4]