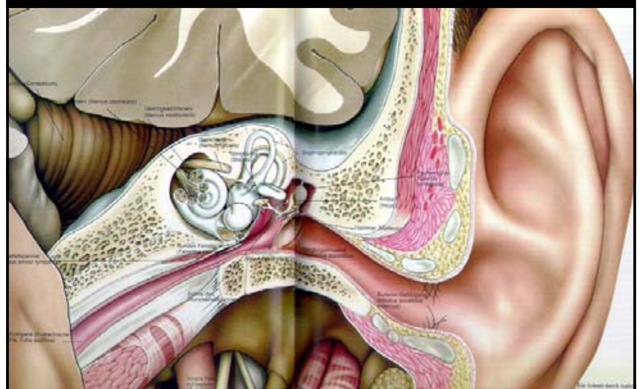
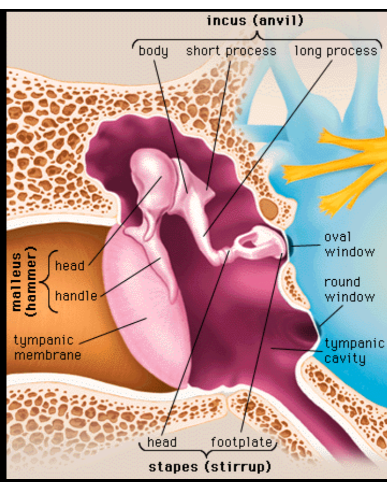
PSY-2007S

Auditory Experimentation

week 4 – Stevens' subjective scaling method

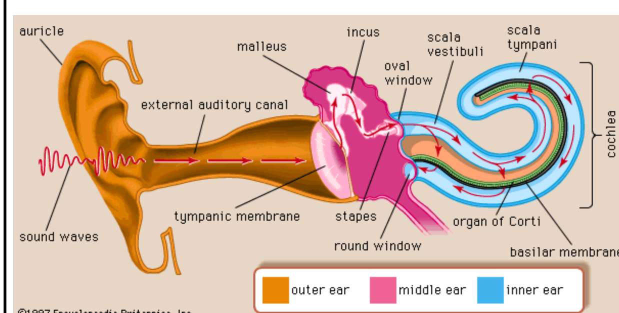


The middle ear



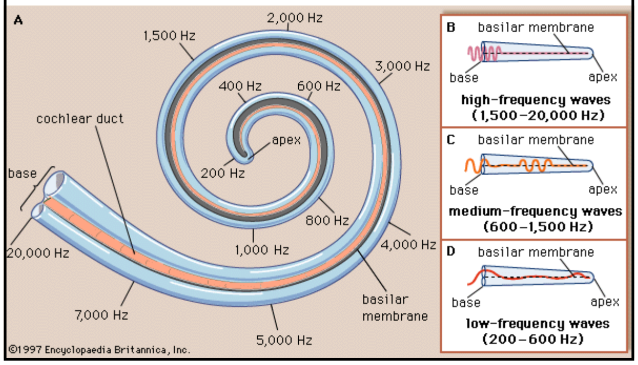
The inner ear

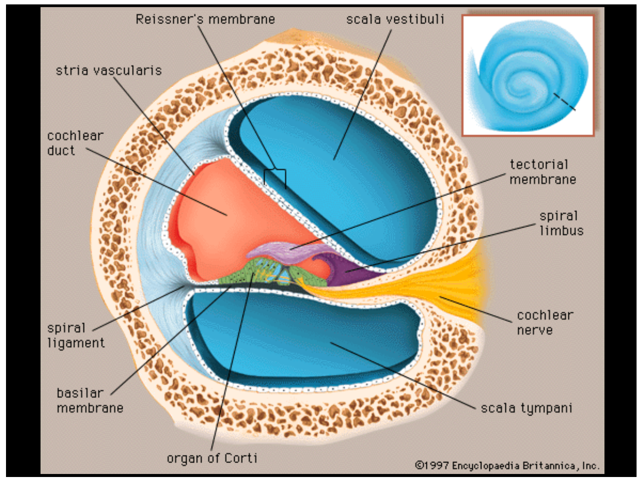
Vibrations at the oval window send pressure waves through the cochlea that move the basilar membrane.



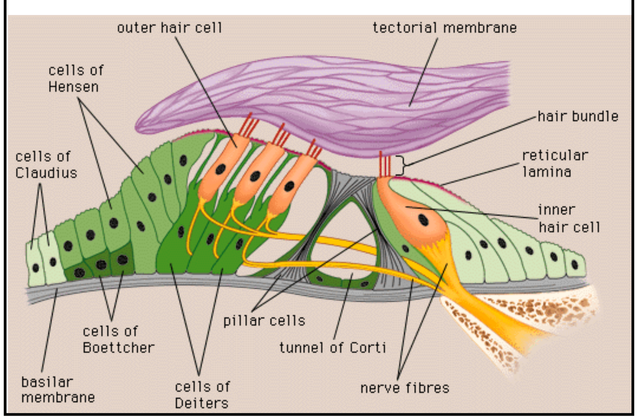
The basilar membrane

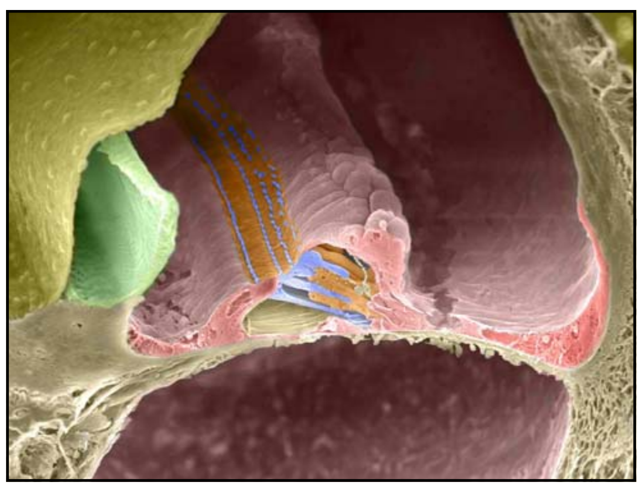
Length: 32mm, width at base: 0.04mm, width at apex: 0.5mm



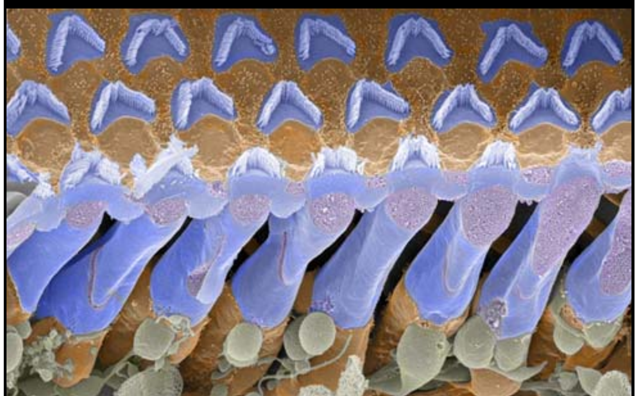


The organ of Corti





Hair cells



Loudness and sound intensity

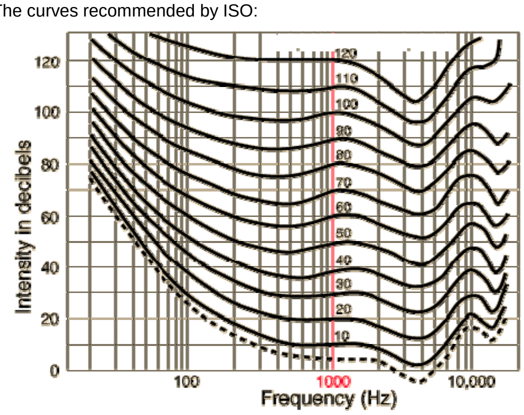
The most intense sound we can hear without immediately damaging our ears is about 120dB above the faintest sound we can hear.

This is a ratio of 1,000,000,000,000 : 1

Source	Intensity	Level	Times > T
Threshold of Hearing	$1*10^{-12}$ W/m^2	0 dB	10^0
Rustling Leaves	$1*10^{-11}$ W/m^2	10 dB	10^1
Whisper	$1*10^{-10}$ W/m^2	20 dB	10^2
Normal Conversation	$1*10^{-6}$ W/m^2	60 dB	10^6
Busy Street Traffic	$1*10^{-5}$ W/m^2	70 dB	10^7
Vacuum Cleaner	$1*10^{-4}$ W/m^2	80 dB	10^8
Large Orchestra	$6.3*10^{-3}$ W/m^2	98 dB	$10^{9.8}$
iPod at Maximum Level	$1*10^{-2}$ W/m^2	100 dB	10^{10}
Front Row at Festival Concert	$1*10^{-1}$ W/m^2	110 dB	10^{11}
Threshold of Pain	$1*10^{1}$ W/m^2	130 dB	10^{13}
Military Jet Takeoff	$1*10^{2}$ W/m^2	140 dB	10^{14}
Instant Perforation of Eardrum	$1*10^{4}$ W/m^2	160 dB	10^{16}

Hearing curves and minimum audible field

The curves recommended by ISO:



Loudness scaling

Loudness is a subjective quantity and we can not measure it directly.

We can use tricks to get around this problem. For instance we can ask a test person to match the loudness of one tone to that of another tone, or tell us whether one tone is perceived louder than another. We can also use JNDs to try to construct a curve that relates loudness to sound intensity (Fechner's idea).

The easiest way is to ask the test person for a direct rating.

Magnitude estimation

Can we attach numbers to our sensations?

Awarding points or stars, applause and applause meters, etc.

Stevens' scaling experiments

Surprisingly, this works best when the test person is free to use whatever numbers they like.

"You will be presented with a series of stimuli in random order. Your task is to tell how intense they seem by assigning numbers to them. Call the first stimulus any number that seems appropriate to you. Then assign successive numbers in such a way that they reflect your subjective impression. There is no limit to the range of numbers you may use. Try to make each number match the intensity as you perceive it."

Stevens' scaling experiments

For all results of these magnitude estimation experiments, Stevens found that a simple power function best described the relation between stimulus and sensation:

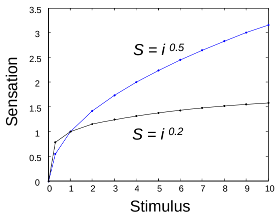
$$S(i) = C * i^{a}$$

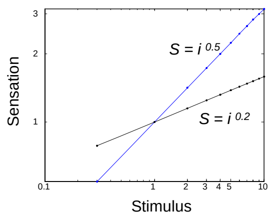
In words: The sensation S is proportional to the stimulus intensity I raised to a power a.

S(i)	Sensation evoked by stimulus intensity i
i	stimulus intensity
C	constant proportionality factor
a	exponent

Power laws

Power law curves are straight lines when plotted on a log scale:





Loudness scaling

For loudness S is proportional to sound pressure raised to the 0.6 power:

$$S = C\, i^{0.6},$$

where C depends on the frequency.

Loudness doubles for about a 10 dB increase in sound pressure level. Other investigators have found that the exponent varies with tone frequency and spectral content. Some investigators find the exponent to be as great as 1, which leads to a loudness doubling for a 6dB increase in SPL (Warren, 1970).

The sone scale

Orchestra range (dB)	Sones
100	64
90	32
80	16
70	8
60	4
50	2
40	1

Exponents for different perceptions

Loudness	0.67	Sound pressure of 3000 Hz tone
Lightness	1.2	Reflectance of gray papers
Visual length	1	Projected line
Redness	1.7	Red-gray mixture
Taste	1.4	Salt
Taste	0.8	Saccharine
Discomfort, cold	1.7	Whole body irradiation
Discomfort, warm	0.7	Whole body irradiation
Heaviness	1.45	Lifted weights
Electric shock	3.5	Current through fingers

What does it mean?

The power law can be seen in different ways:

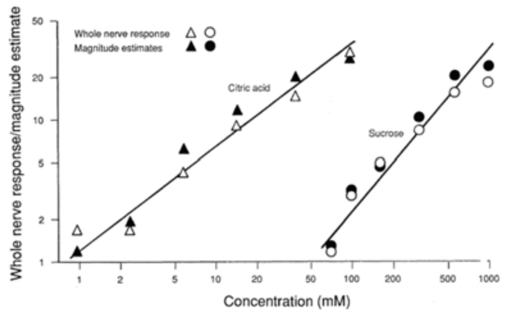
(i) purely as a useful description or characterization of sensation

(ii) as a definitive measure of sensation

(iii) a belief that the power law is realized in elementary neural function.

(The last one is the strongest: there is a region somewhere in the brain where the activity is coupled to the stimulus via a power law and this reflects subjective experience!)

Recording of whole gustatory nerve in humans during middle-ear surgery. Magnitude estimates of the taste of different concentrations of citric acid and sucrose were also measured.



Pitch

…the attribute of an auditory sensation in terms of which sounds may be ordered on a scale from low to high.

With exception of pure tones, pitch is not a simple function of spectral content.
It is more closely related to the repetition rate of a sound in a range from 30 to 5000Hz (the limits of musical pitch).
For a pure tone, this corresponds to the frequency; for a complex tone it usually (but not always) corresponds to the fundamental frequency.

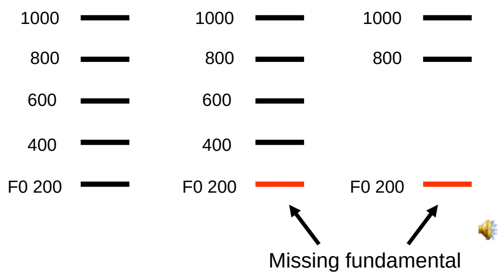
Frequency is the most important, but not the only, contributor to the sensation of pitch. Other contributors to pitch include intensity, spectrum, duration, envelope, and the presence of other sounds.

Pitch

Sounds with very different spectra but the same repetition rate often have similar pitches:

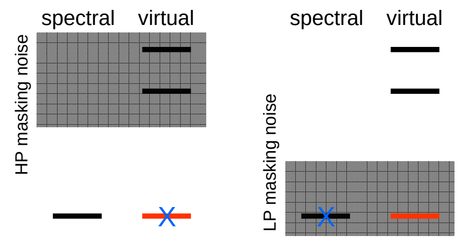
Harmonic complexes

The pitch of a harmonic complex is heard at the fundamental frequency, F0



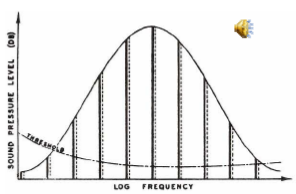
Masking spectral and virtual pitch

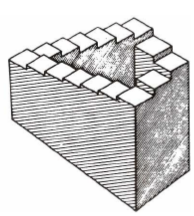
Masking noise of high and low frequency masks out a melody carried by single pure tones of low frequency and the same melody resulting from virtual pitch from groups of three tones of high frequency (4th, 5th and 6th harmonics).



Circular pitch illusion

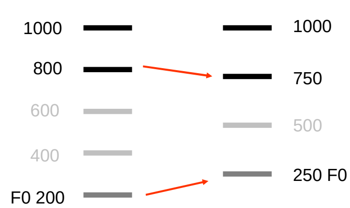
Shepard's (1964) illusion of pitch circularity: A cyclic set of complex tones, each composed of 10 partials separated by octave intervals. The tones are co-sinusoidally filtered to produce the sound level distribution shown below, and the frequencies of the partials are shifted upward in steps corresponding to a musical semitone (~6 %).





Analytic vs. Synthetic Pitch

Do you hear the individual harmonics (analytic) or the overall pitch, F0, of a complex tone (synthetic)?



The two theories of pitch extraction