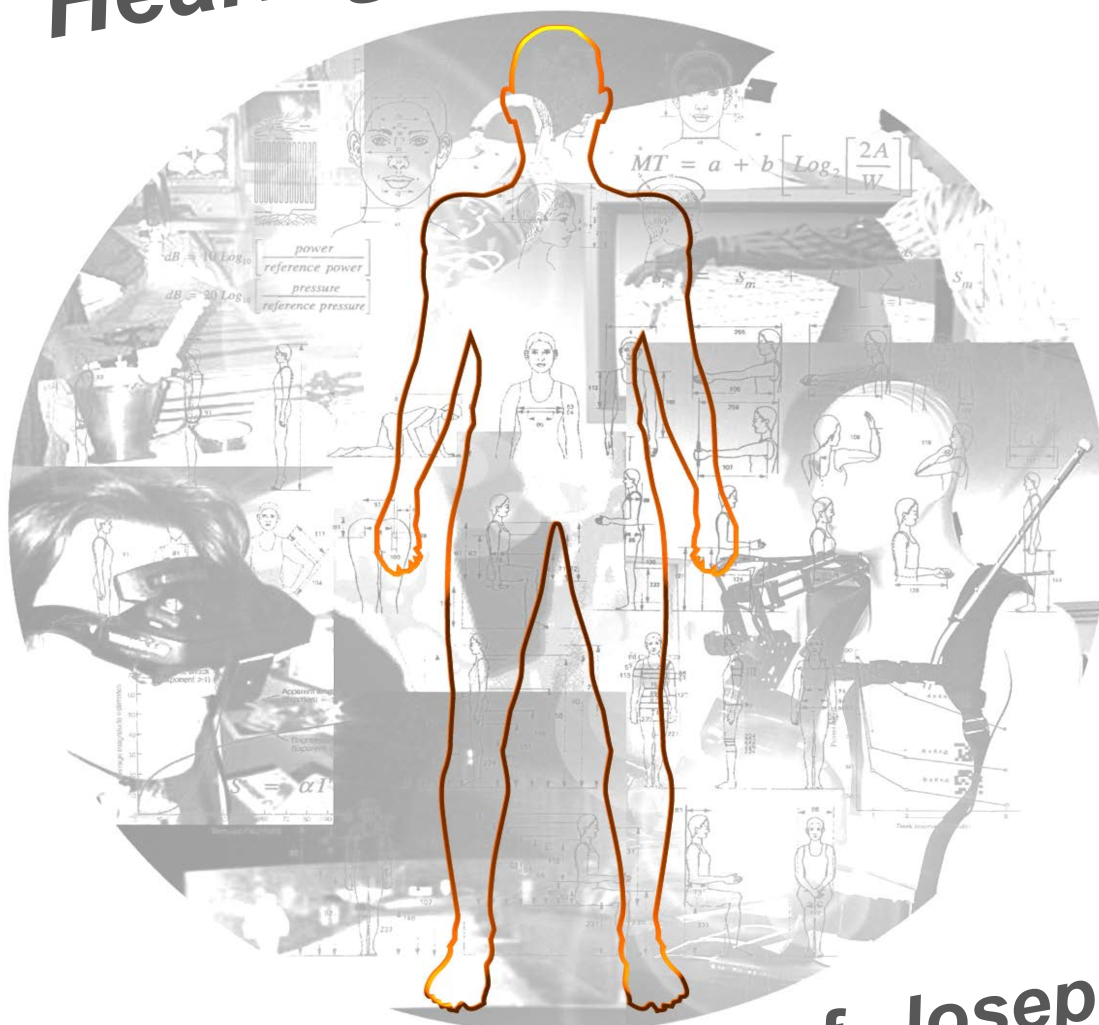
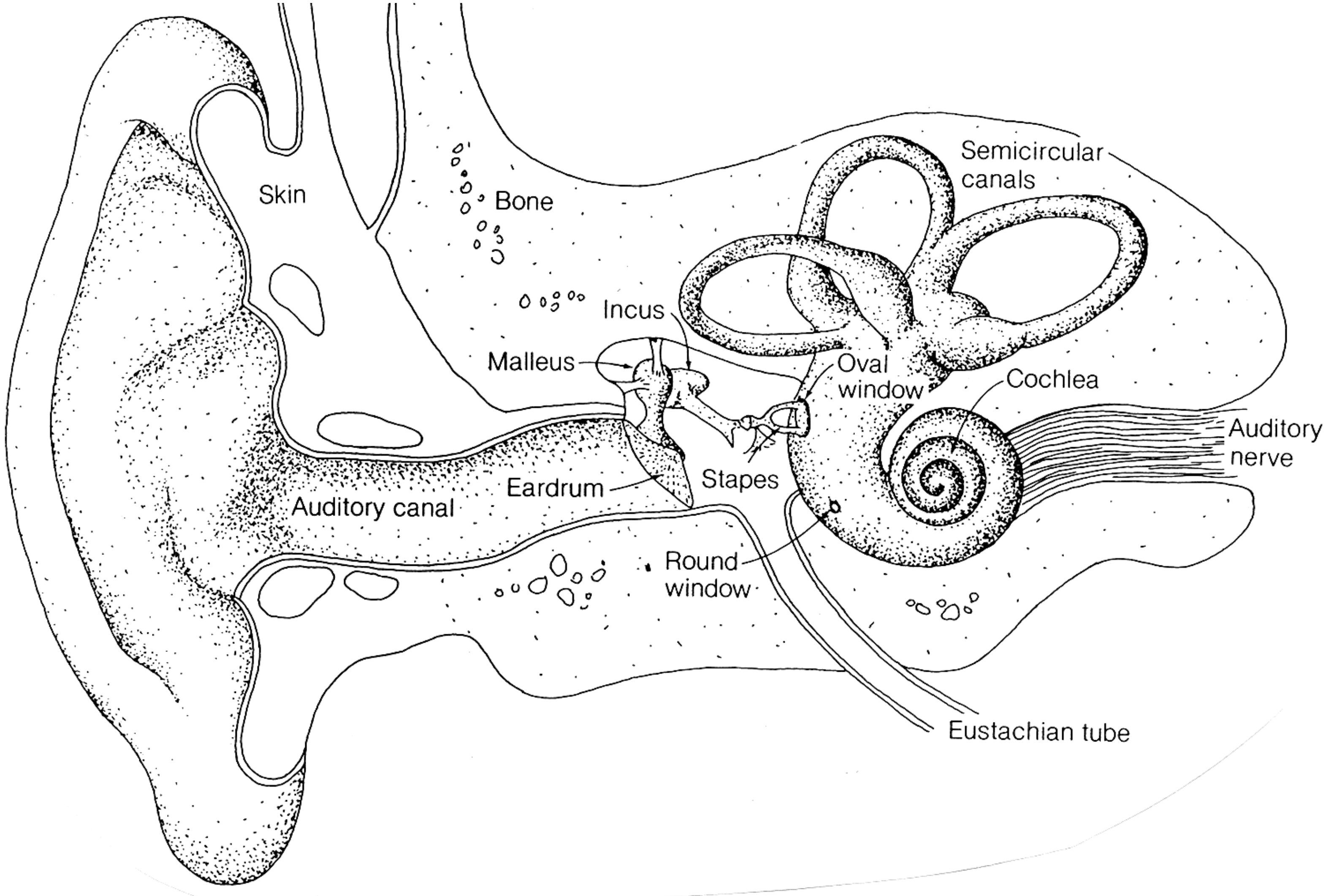
Hearing



Prof. Joseph Giacomin

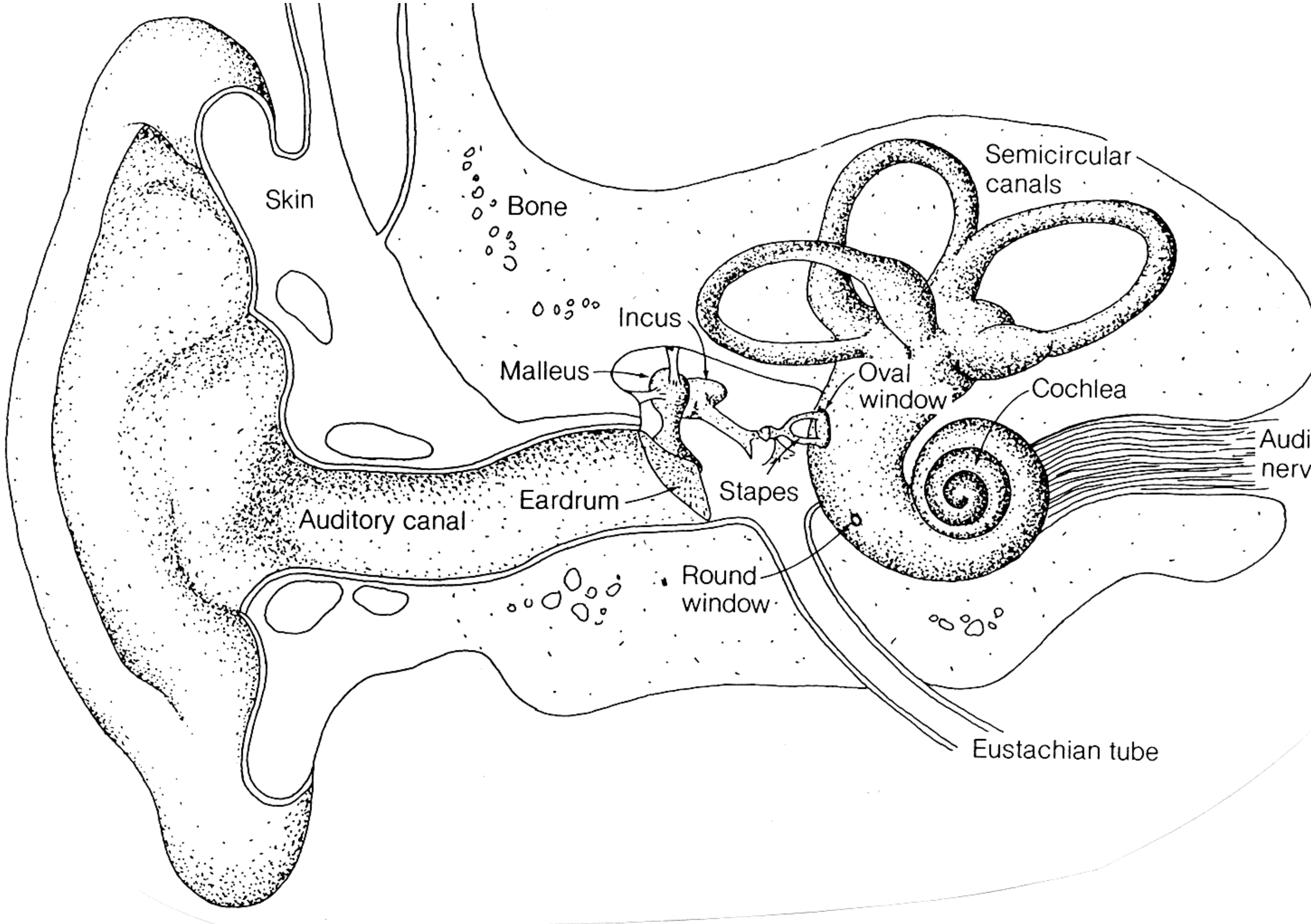


Outer Ear

Pinna: the fleshy outer part of the ear which directs sound inwards.

Auditory Canal: the passage leading towards the eardrum. Resonance effects in the auditory canal amplify sound at frequencies in the range from 1000 to 6000 Hz.

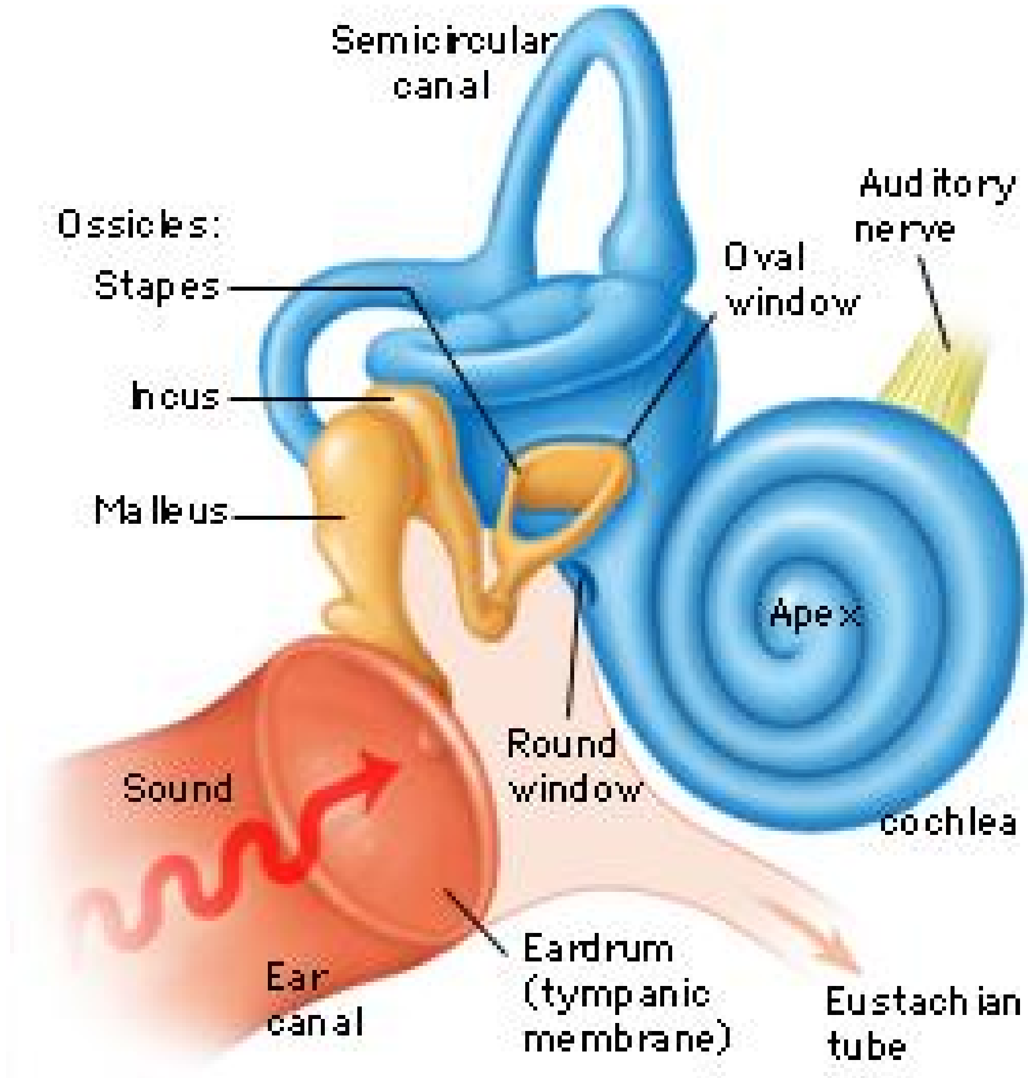
Eardrum (Tympanum): the membrane which vibrates following the pressure variations of the incoming sound waves.



Middle Ear

The middle ear consists of three tiny bones called the *ossicles* which transmit the vibration of the eardrum to the inner ear.

They are the malleus (hammer), the incus (anvil) and the stapes (stirrup).

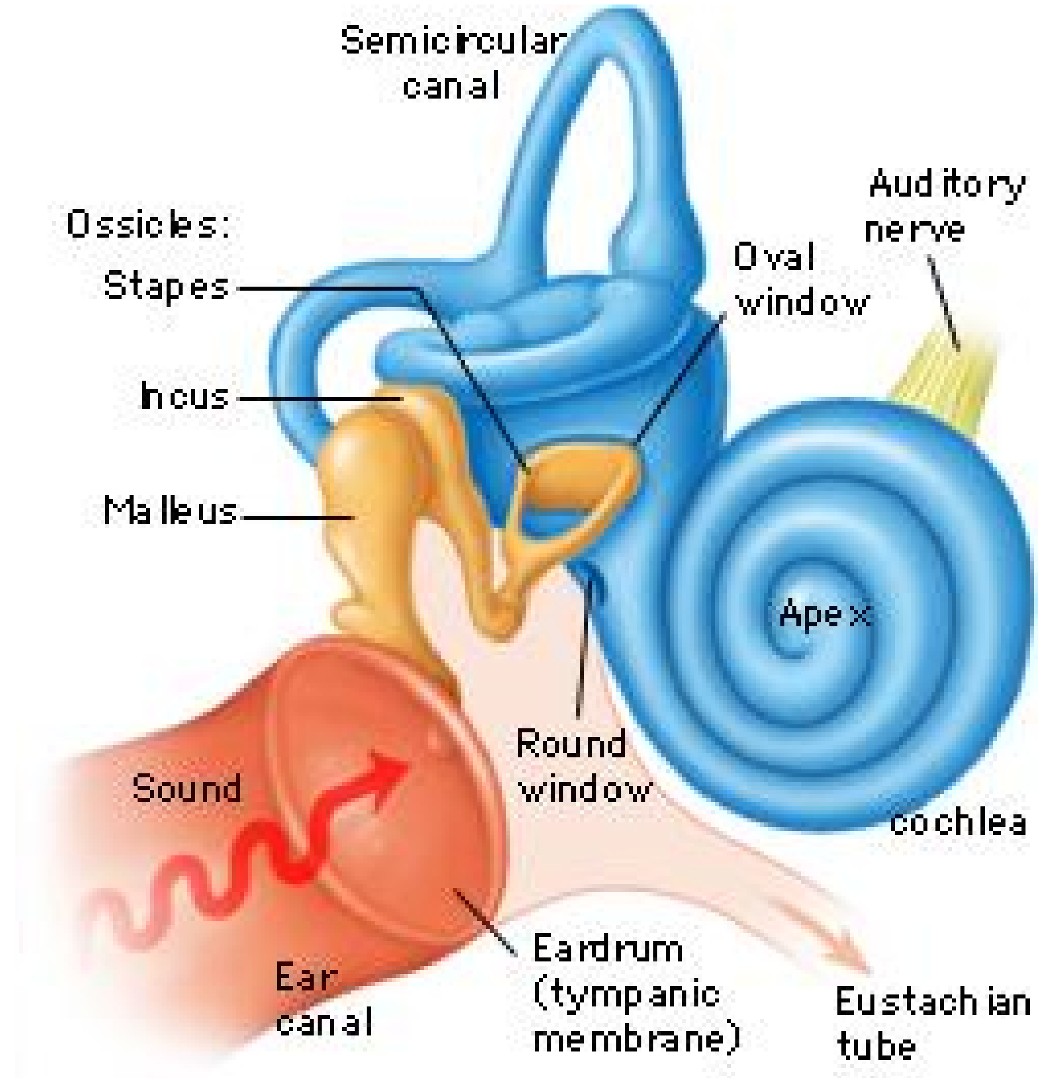


Middle Ear

The ossicles amplify sound in two ways:

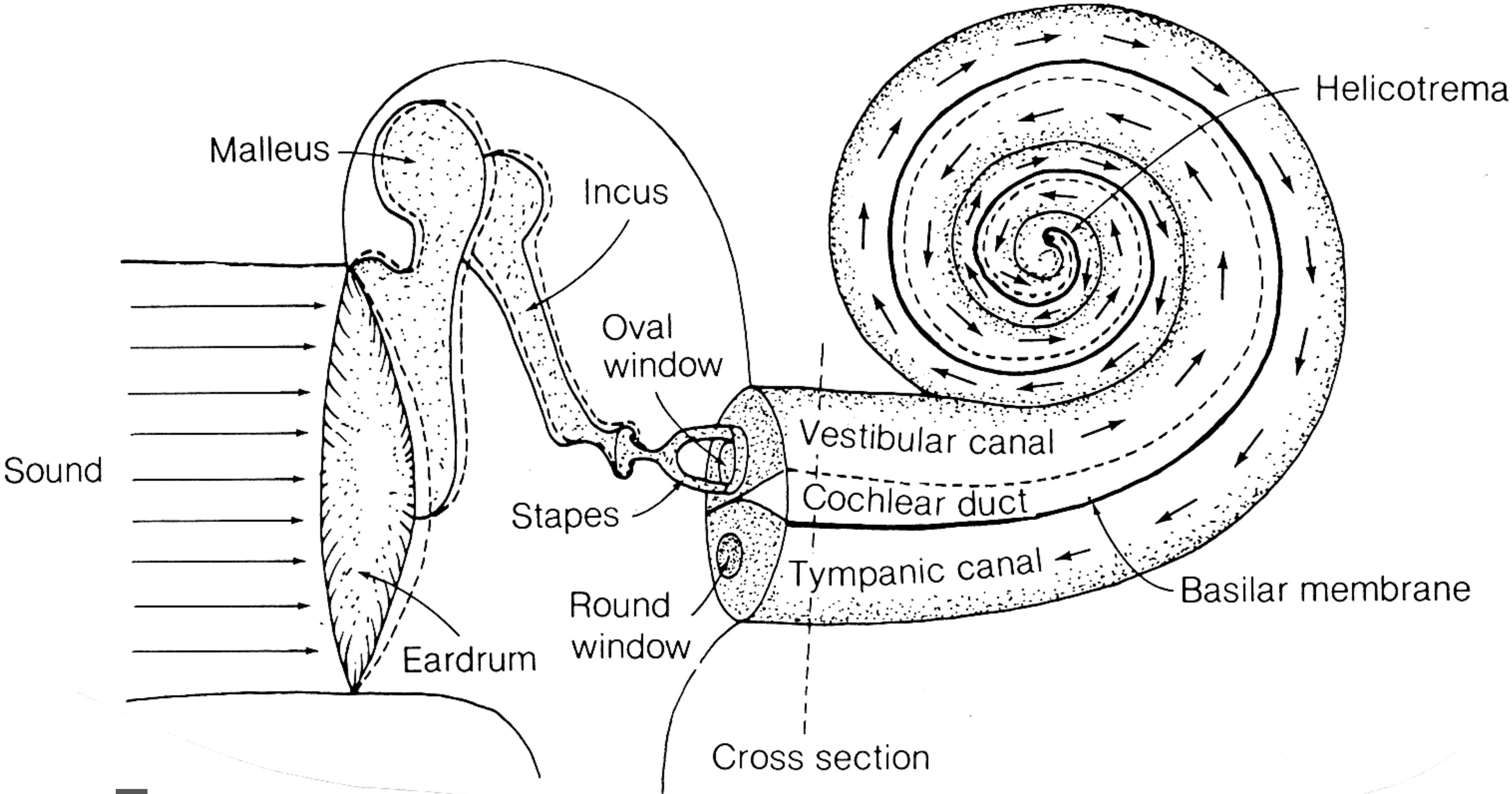
The system of lever arms approximately doubles the output movement amplitude at the oval window with respect to the input amplitude at the eardrum.

The area of the oval window on the cochlea is only 1/15 that of the vibrating area of the eardrum, thus the oval window sees a pressure amplification of 15 with respect to the eardrum even without the action of the lever arms.



Middle Ear

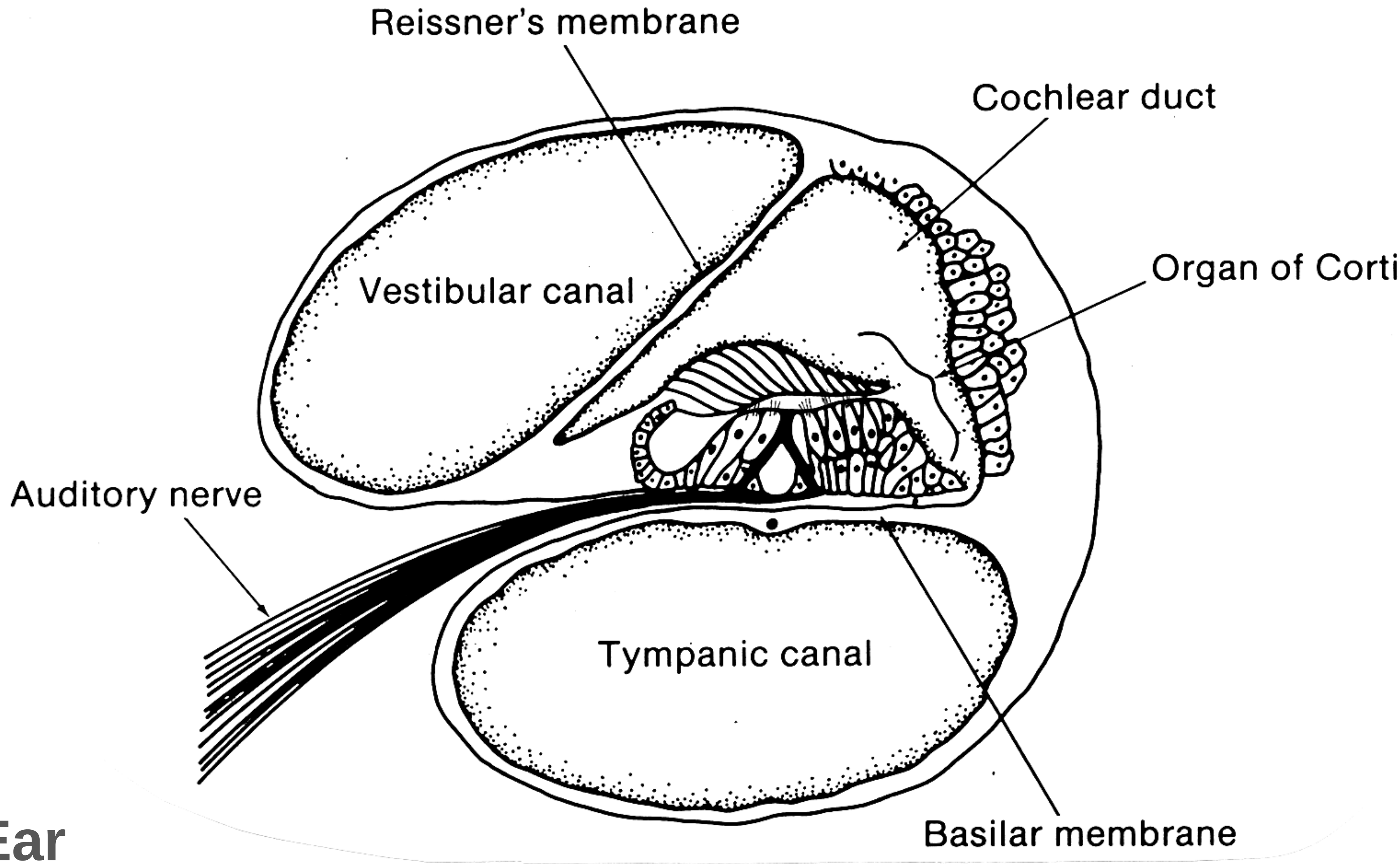
The ossicles protect the ear from intense sounds. When the movement amplitude is large, the geometry of the lever arms is such that the angle between the stapes and the oval window is reduced. Also, a reflex contracts a small muscle which is attached to the stapes, and another attached to the eardrum, such that the membrane is stiffened.



Inner Ear

The *oval window* receives vibration from the ossicles. It is at the end of one of the three canals which contain a fluid which resembles salt water.

Several sensory structures are present in the cochlear duct and it is here that the transduction of mechanical energy to electro-chemical nerve energy takes place.



The Ear

The *Organ of Corti* rests on the *Basilar Membrane* along its entire length and consists of about 23,500 receptor cells which have protruding steriocilia.

Mechanical stimulation of the steriocilia produces electro-chemical impulses.

Decibel Scale

Since the ear is a very sensitive organ special measures are used to represent the wide range of amplitudes that it can respond to.

Sound is normally considered in terms of its power. Two sound levels can be compared by determining how many powers of 10 (the logarithm) one sound exceeds the other by.

Each power of 10 is defined to be a unit of one bel.

For example, if one power level is one million times greater than another (10^6 times greater) we say that it is 6 bels greater.

Decibel Scale

The bel is a rather large unit when compared to normal hearing levels therefore it is common practice to work with units of decibels, which are one-tenth of a bel.

$$dB = 10\,Log_{10}\left[\frac{power}{reference\ power}\right]$$

where the reference power value is commonly taken to be 10^{-12} Watts.

Decibel Scale

No instrument directly measures the power of a sound source, thus the power is estimated from the sound pressure.

We therefore speak of the Sound Pressure Level (SPL) acting on the ear and its decibel value is

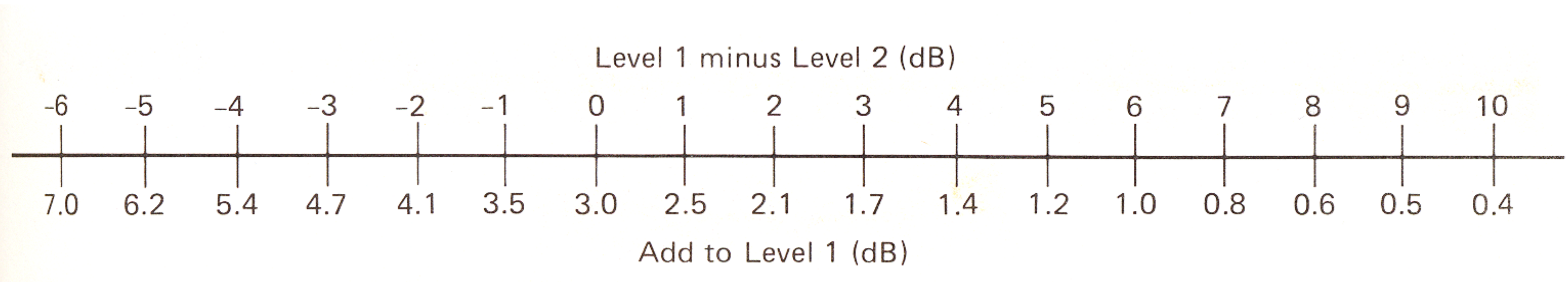
$$dB = 20\,Log_{10}\left[\frac{pressure}{reference\ pressure}\right]$$

The reference pressure is commonly taken to be 20 μ Pa, which is the average value of the perception threshold for sound measured in young adults at 1000 Hz.

Decibel Scale

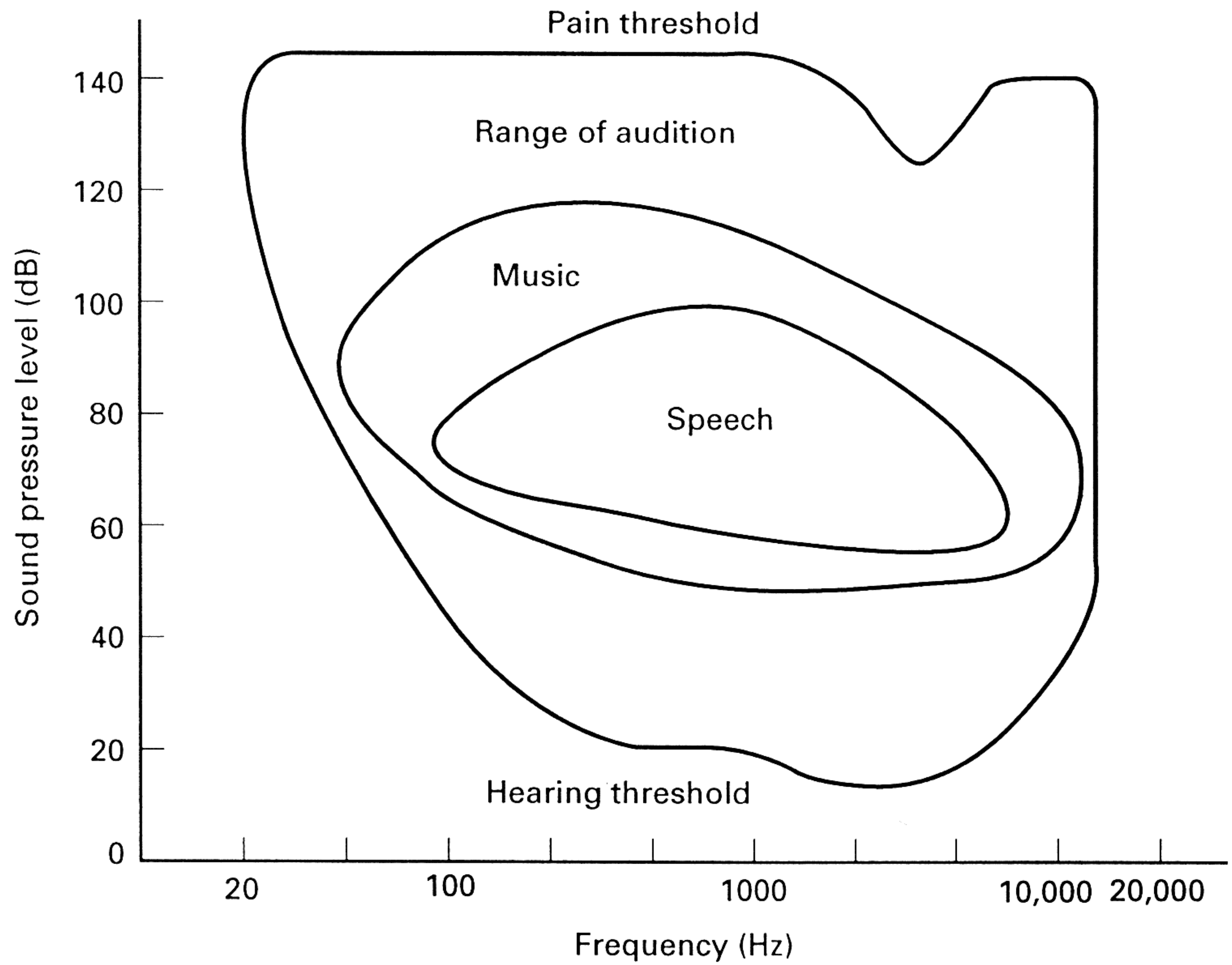
A word of caution regarding the use of decibel scales. Addition or subtraction of Sound Pressure Levels must be performed on the original pressure values, requiring the use of antilogs. Decibel values cannot simply be added together !

Decibel Scale



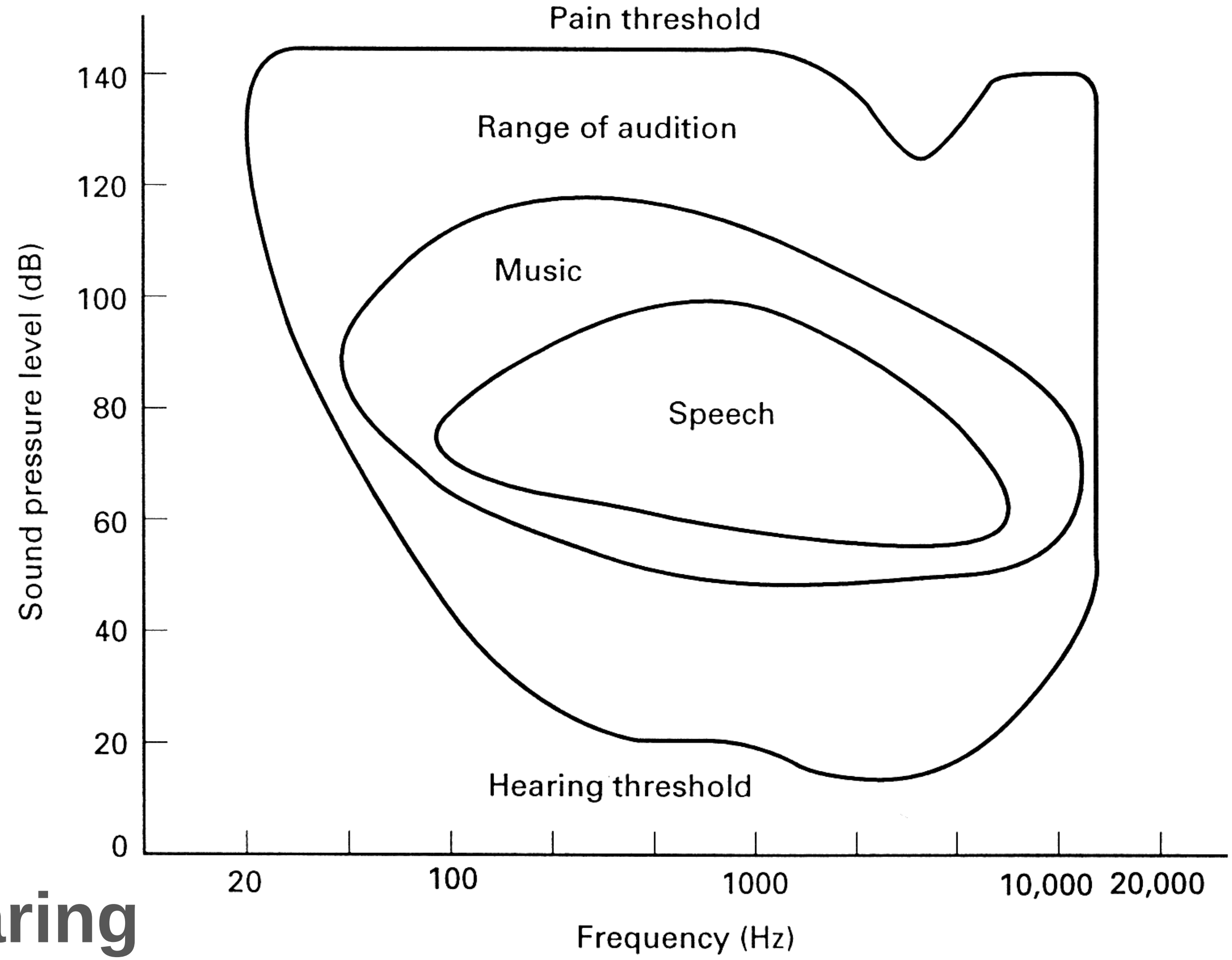
Nomograms can be used to simplify the task of adding decibel values. They provide the number of decibels that must be added to the larger value given the difference in decibels between the two sources.

As an example, two machines which each generate 100 dB of noise would, if operated in phase, generate a total noise of 103 dB (not 200 dB).



Range of Human Hearing

From the threshold of human perception to the threshold of human pain the range is about 140 decibels, i.e. 14 orders of magnitude of the sound power.



Range of Human Hearing

The frequency range of human hearing is from about 20 to 20,000 Hz.

Adults sense frequencies below 20 Hz only as vibration (infrasound).

Young children sense higher frequencies than adults, reaching up to 27,000 Hz.

The minimum frequency remains roughly constant with age, but the maximum drops. By age 60 the hearing loss for an 8,000 Hz pure tone is more than 40 dB.

Loudness

Loudness is a complex subjective experience which depends on both the intensity and the frequency of the sound.

Several numerical loudness indices have been developed, two early ones were the *phon* and the *sone*.

Loudness

The *phon* emerged from experiments involving pure tone sounds of fixed frequency and amplitude.

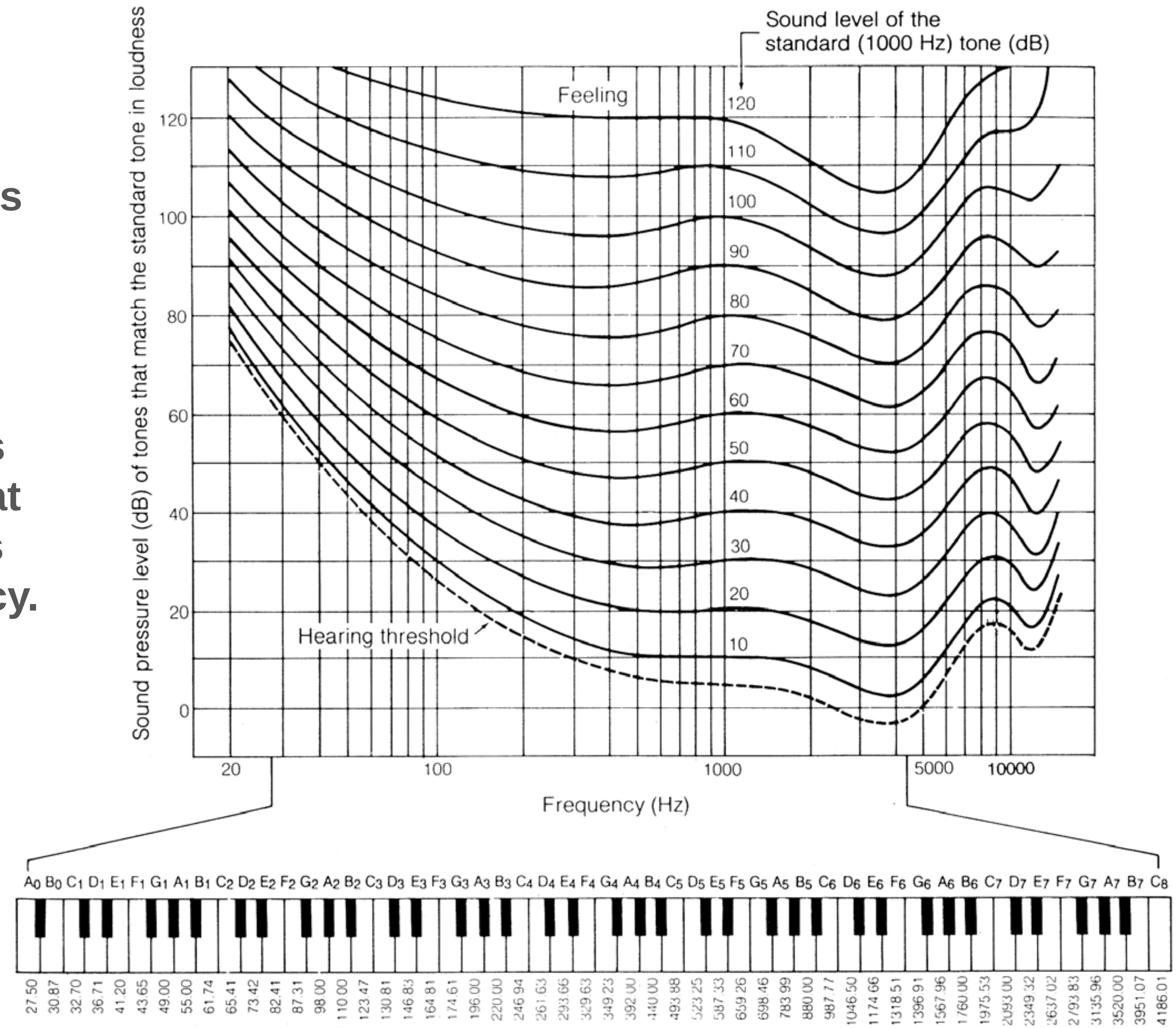
In each test the participant was presented a 1000 Hz pure tone as a reference, then the frequency was changed and the person was asked to adjust the amplitude of the new sound until it was of equal loudness.

Loudness

Testing many frequencies and many people lead to defining equal-loudness curves.

From the equal loudness curves it can be seen that human perception varies as a function of frequency.

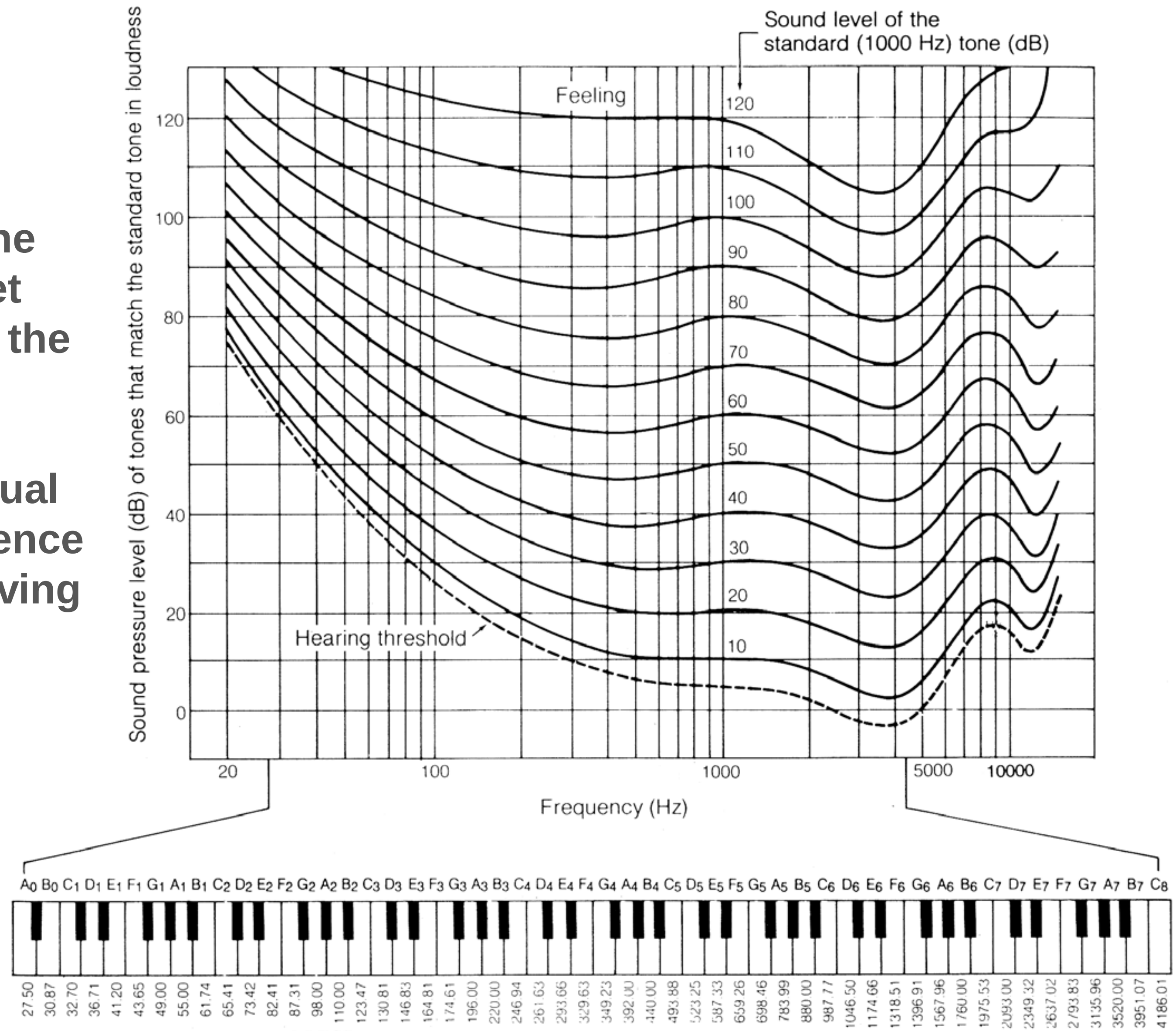
Humans are particularly sensitive to frequencies from 1000 to 6000 Hz.



Loudness

The *phon* was designated the unit of loudness and was set equal to the decibel level of the 1000 Hz reference tone.

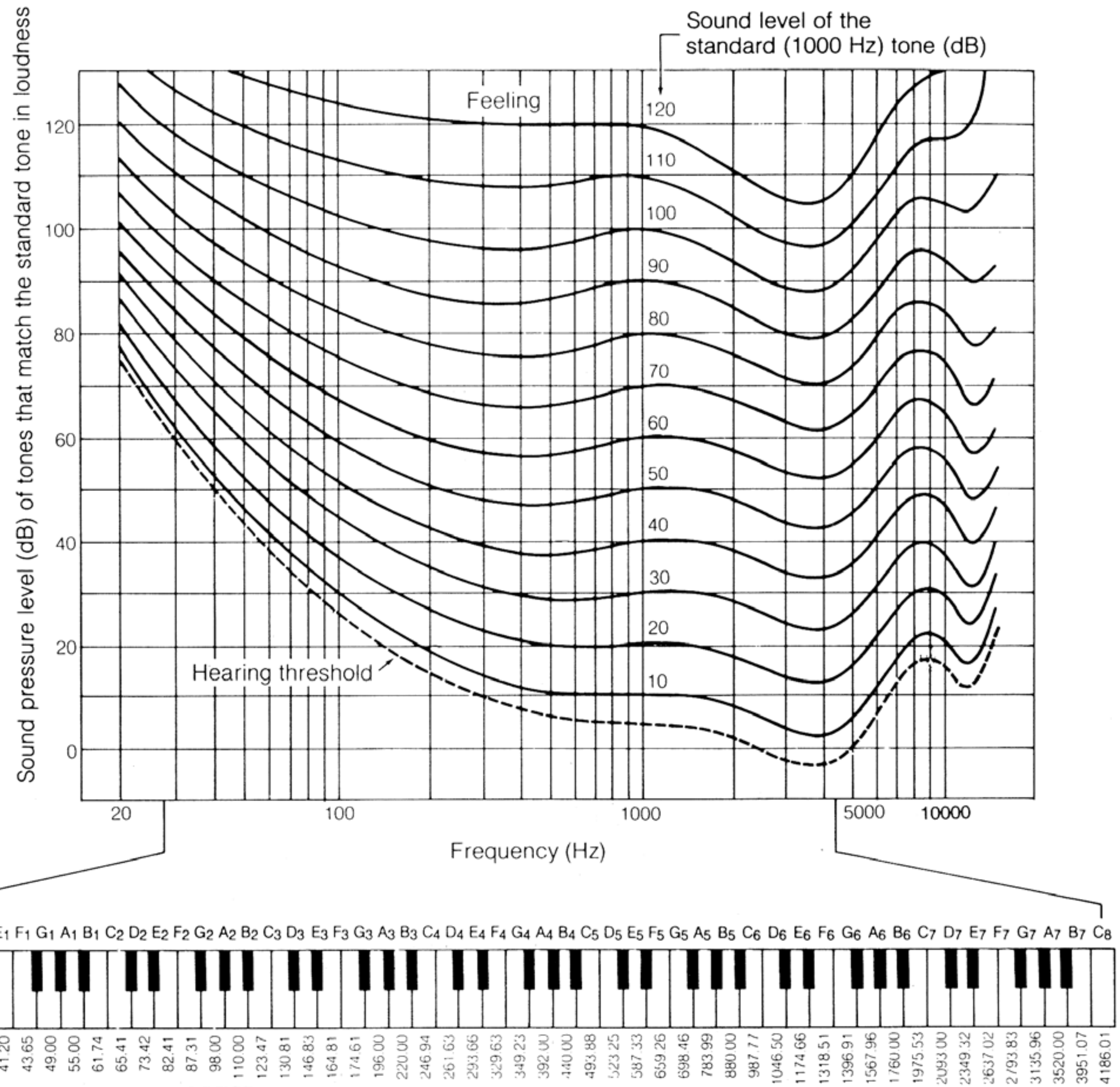
All tones judged to be of equal loudness to the 60 dB reference tone were designated as having a loudness of 60 phons.

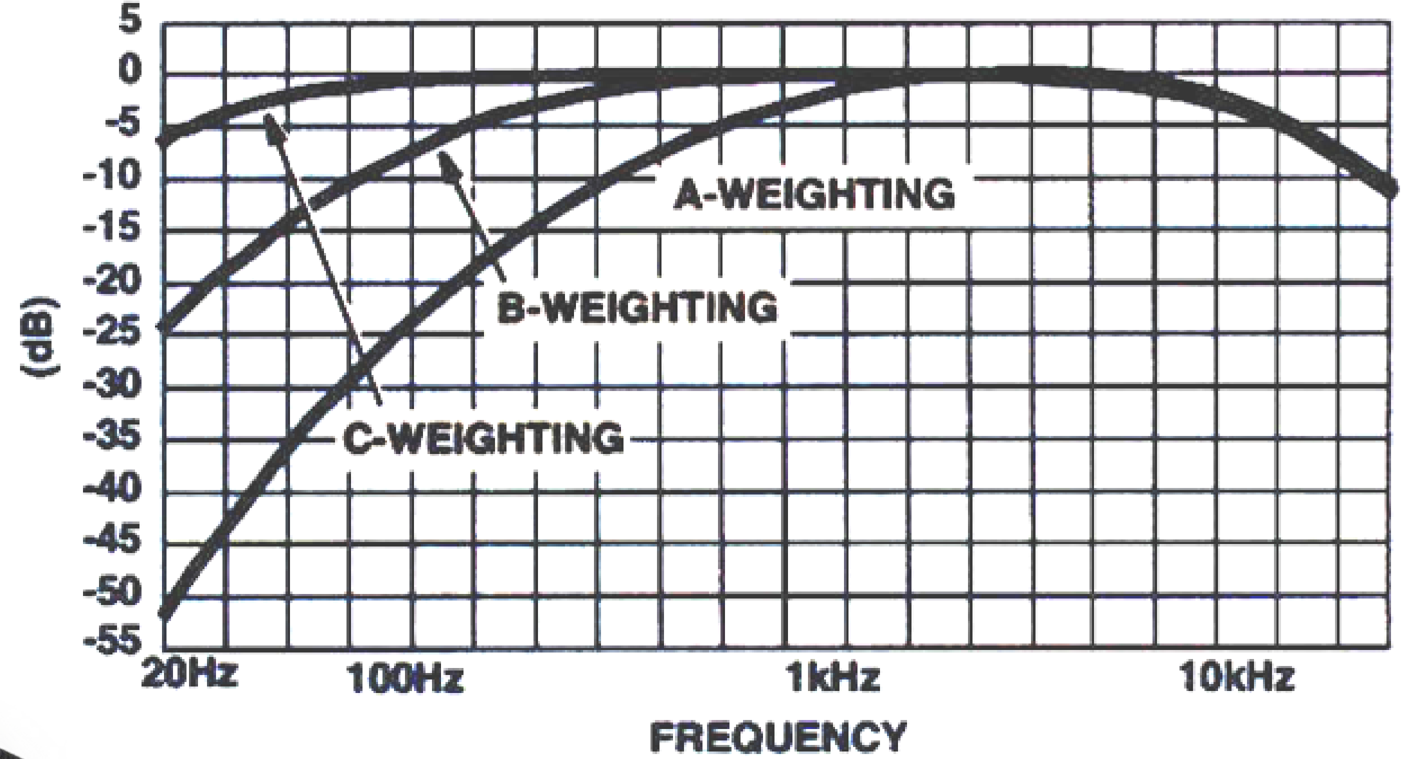


Loudness

The frequency weighting networks used in sound level meters are based on the phon curves developed by Fletcher and Munson.

The A and B frequency weightings are the 40 and 70 phon contours, but with some minor modifications to simply the required electrical filter network.





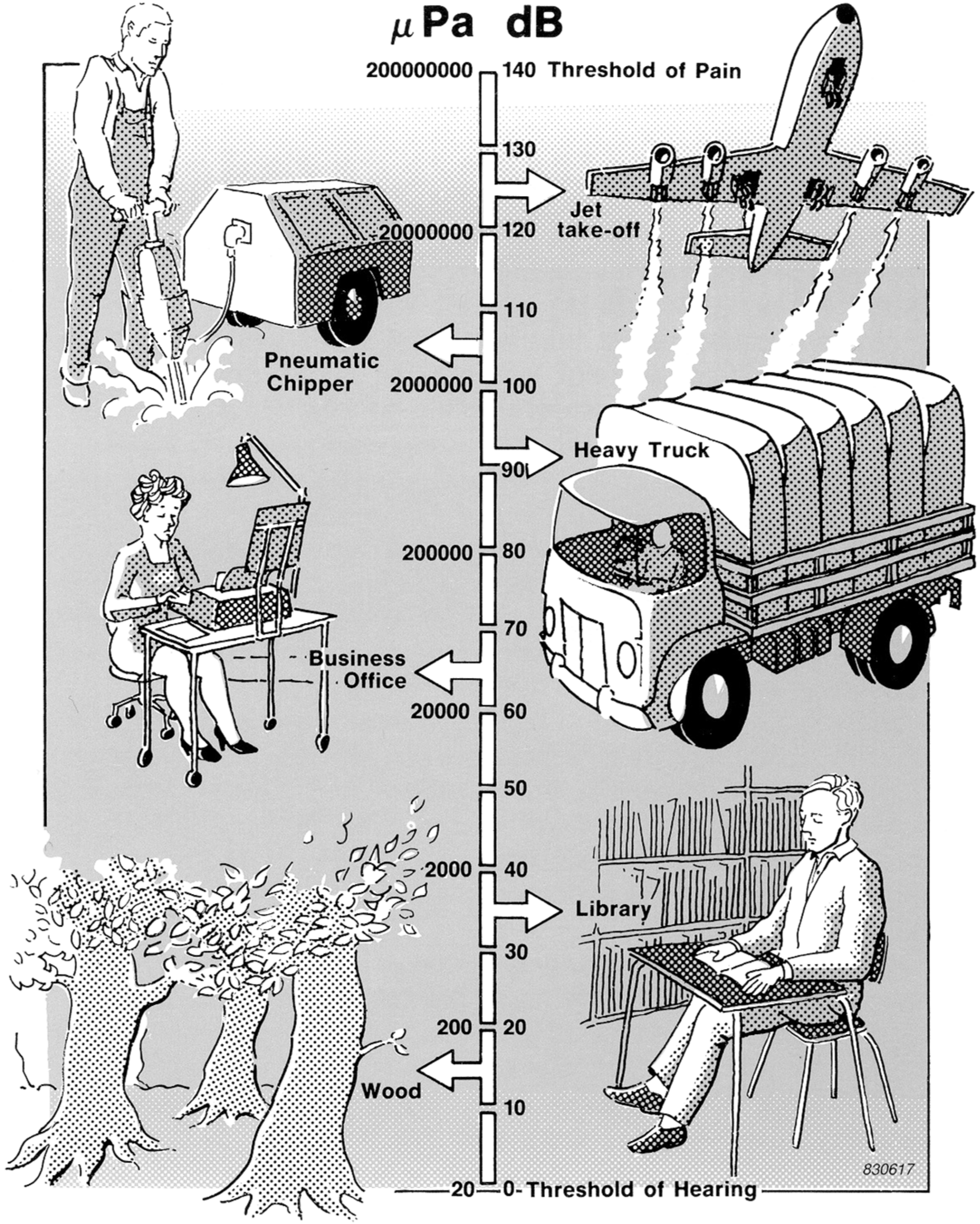
$$L_A = 10\,Log_{10}\left[\frac{p_A(t)}{p_{referecne}}\right]^2 \quad dB$$

dB(A) Loudness

Sound Pressure Level L_A is the sound pressure $p_A(t)$ measured using the frequency weighting A.

Decibel Scale

From the threshold of human perception to the threshold of human pain the range is about 140 decibels, i.e. 14 orders of magnitude of the sound power.



Annoyance

A term which is used to describe the effects of undesired sound is "annoyance".

Annoyance is a subjective quantity associated with the inappropriateness or unwantedness of the sound.

It is important to note that the loudness value of a given sound is only weakly correlated with its annoyance.

Sound Quality

A term which is used to describe the effects of desired sound is “sound quality”.

Sound quality is a subjective quantity associated with the appropriateness or desirability of the sound.

It is important to note that the loudness value of a given sound is only weakly correlated with its sound quality.

Design Classic: Kettle 9093

Kettle 9093 was designed by Michael Graves for Alessi and first sold in 1985.

It combine advanced mass production methods with a personal visual code which fuses influences from Art Deco to Pop Art and even the language of cartoons.

The most striking element of Kettle 9093 is the bird which sings when the water boils.

Design Classic: Harley-Davidson Sound

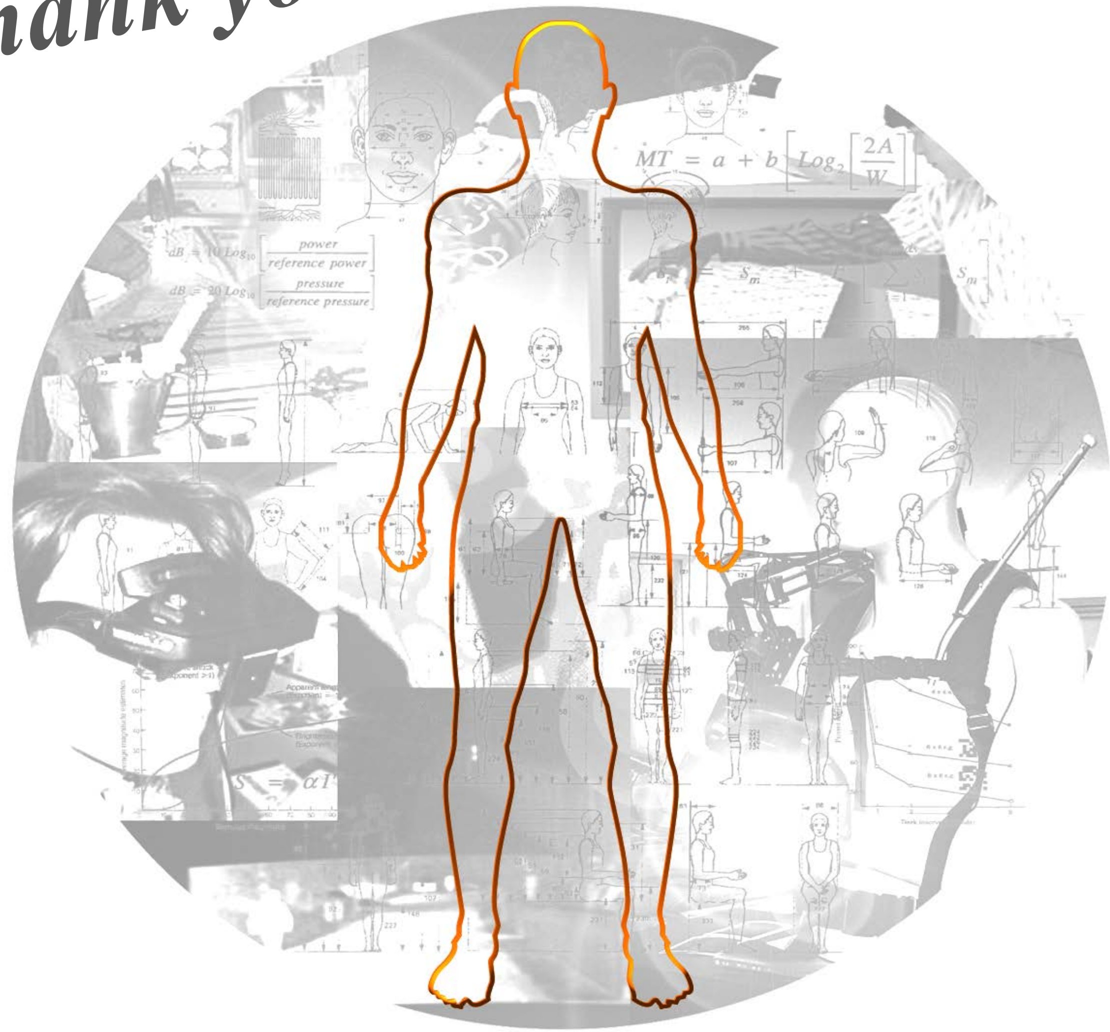
Harley-Davidson attempted to register as a trademark the distinctive engine "chug".

In February 1994 the company filed its application with the following description: "The mark consists of the exhaust sound of applicant's motorcycles, produced by V-twin, common crankpin motorcycle engines when the goods are in use".

Nine of Harley Davidson's competitors filed oppositions against the application, arguing that cruiser-style motorcycles of various brands use the same crankpin V-twin engine which produces the same sound.

After six years of litigation Harley Davidson withdrew the application.

Thank you.



$MT = a + b\left[Log_2\left[\frac{2A}{W}\right]\right]$
$dB = 10\,Log_{10}\left[\frac{power}{reference\ power}\right]$
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