Auditory Sensitivity: Absolute Thresholds

MAF – pressure measured in the free field where a listener's head would be. The sound source is directly in front of the listener.

MAP – pressure measured in the ear canal. Thresholds are measured in one ear only.

Differences in the two measures are due to some binaural advantage, outer-ear filtering (mid frequencies), and physiological noise (low frequencies).

See Moore, B.C.J (1997). An introduction to the psychology of hearing. 4th edition. Academic: London.

Auditory Sensitivity (2)

Hearing Level (dB HL)

Threshold of hearing, relative to the average of the normal population.

For example, the average threshold at 1 kHz is about 4 dB SPL. Therefore, someone with a threshold at 1 kHz of 24 dB SPL has a hearing level of 20 dB HL.

Audiograms

Audiograms measure thresholds in dB HL, and are plotted "upside-down" (see graph). Measurements usually made at octave frequencies from 250 Hz to 8000 Hz.

See Gelfand (1997)

Threshold microstructure: Individuals show peaks and dips as large as 10 dB over very small frequency differences - probably due to OHCs and "cochlear amplifier".

Temporal Integration

- Audiometric thresholds and international threshold standards are measured using long-duration tones (> 500 ms).

- Detectability of tones with a fixed level decreases with decreasing duration, below about 300 ms.

- The total *energy* in a tone at threshold stays about constant for durations between about 20 and 200 ms.

Intensity (W/m²)

Duration (ms)

Area = total energy
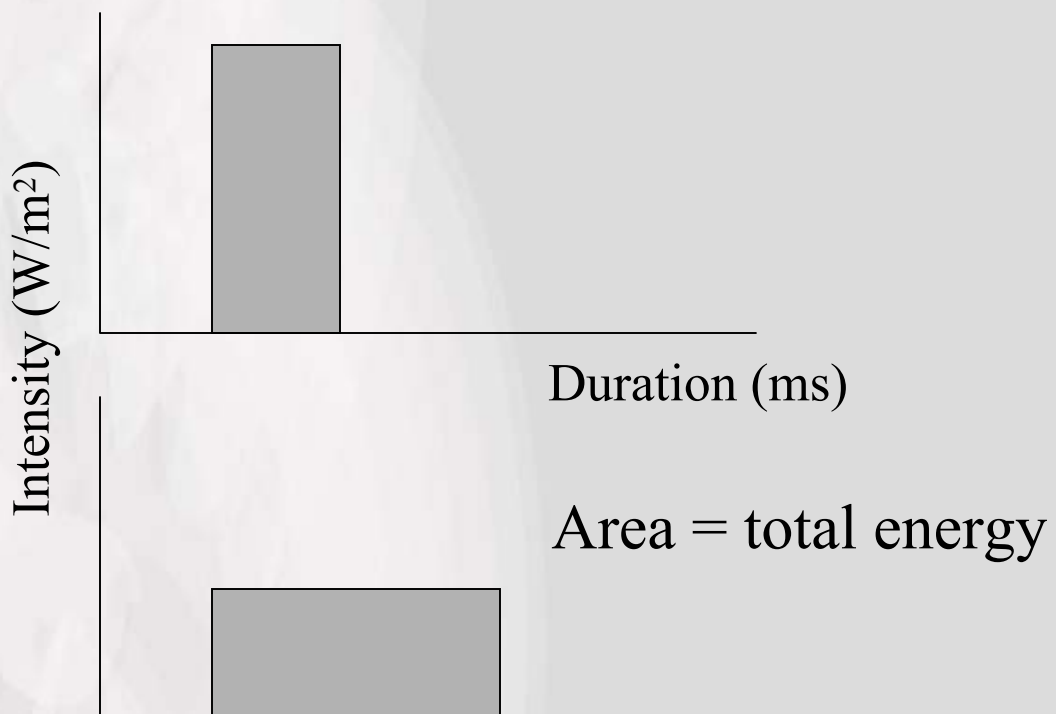
Equal-loudness Contours

1 kHz is used as a reference. By definition, a 1-kHz tone at a level of 40 dB SPL has a *loudness level* of 40 **phons**. Any sound having the same loudness (no matter what its SPL) also has a loudness level of 40 phons.

Equal-loudness contours are produced using loudness matching experiments (method of adjustment or method of constant stimuli).

Filters are used in loudness meters to compensate for the changes in loudness as a function of frequency:

- dB(A) = 'A' weighting: 40 phon curve (approx.)
- dB(B) = 'B' weighting: 70 phon curve (approx.)
- dB(C) = 'C' weighting: essentially flat - high sound levels.

Problems of Equal Loudness Contours

Judging the relative loudness of two different sounds is difficult and subject to many biases, e.g. the range effect (e.g. Gabriel et al. 1997; Acustica 83:670):
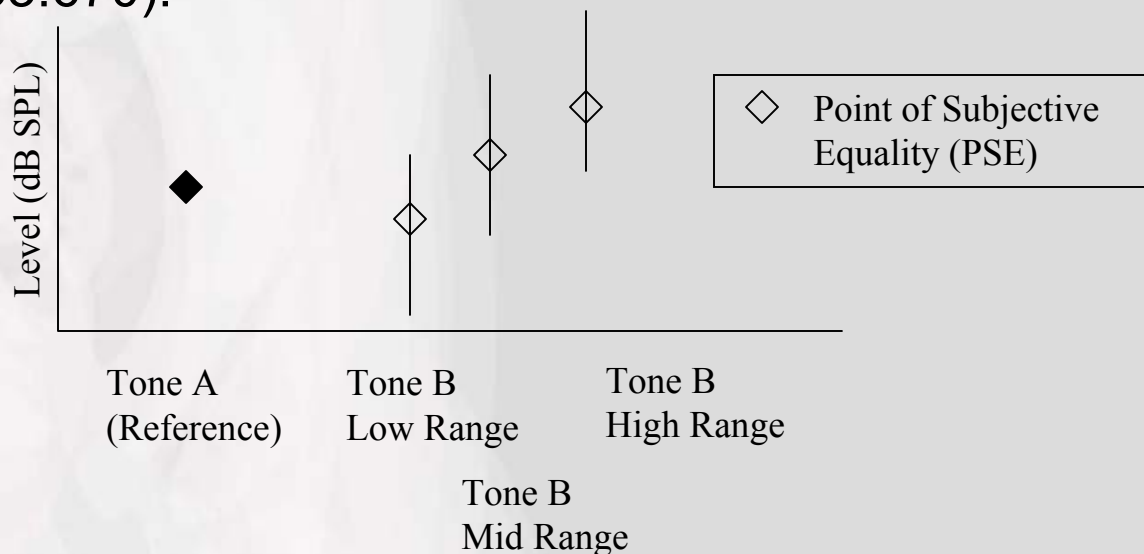
Not yet clear if this is a sensory or nonsensory effect.

Using a small frequency difference reduces the range effect, but increases the likelihood of a cumulative error.

Loudness Scaling

A number of techniques can be used to estimate loudness:

- Magnitude estimation: Assign a number to the loudness of a sound
- Magnitude production: Adjust the level of a sound to match a number
- Ratio estimation: What is the loudness ratio of two sounds? (e.g. half, quarter, two, four, etc.)
- Ratio production: Adjust the level of the second tone so that it is half/quarter/twice as loud as the first tone.

Underlying assumption is that the assigned numbers (or ratios) are proportional to percept.

- Cross-modality matching: Compare loudness with, say, line length. Transitivity seems to hold (Hellman and Meiselman, 1990; JASA 88:2596).

Stevens' power law

Based on a number of different experiments, the psychologist S.S. Stevens concluded that loudness could be described as a power law:

$$L = kI^{0.3}$$

(L = Loudness, I = Intensity, k is a constant)

So, a 10-dB increase in level gives a doubling in loudness.

This provides the basis for the loudness scale, measured in **Sones**.

A 1-kHz at 40 dB SPL is defined as having a loudness of 1 Sone. So, a 1-kHz tone at 50 dB SPL has a loudness of about 2 Sones (twice as loud).

Loudness level grows more rapidly at low levels, at very low and high frequencies, and in masked conditions ("partial masking").

Models of Loudness
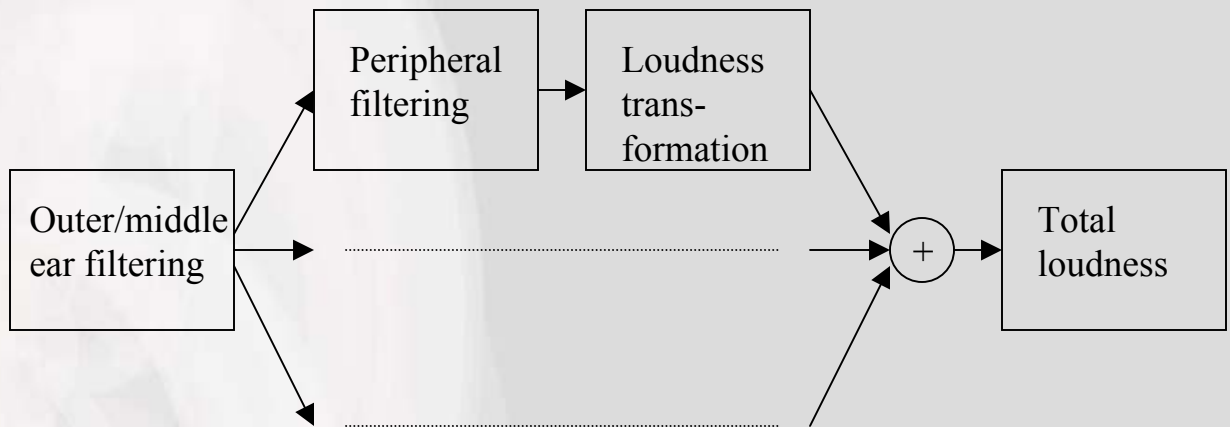
Problems measuring loudness

Loudness judgments are very difficult to make. We are not accustomed to making judgments about our perception - only about the sound sources themselves.

This leads to the judgments being easily influenced by external (or internal) biases, and results can be variable.

One study (Warren, 1970), using each subject for just one judgment, found a different relationship:

$$L = kI^{0.5}$$

Thus, there is plenty of room for skepticism about measure and scales of loudness.

Loudness Recruitment

Sensorineural hearing impairment often leads to raised absolute thresholds, but the same uncomfortable loudness level.

This steeper growth of loudness is known as "loudness recruitment".

Possible physiological basis in the basilar-membrane nonlinearity, and the cochlear amplifier (Moore and Oxenham, 1998; Psych. Rev. 105:108-124):

See Ruggero and Rich (1991)

Loudness Summation and the Critical Band

- The increase in loudness beyond a critical bandwidth can be explained in terms of nonlinearity: $A^{0.3} + B^{0.3} > (A+B)^{0.3}$

- Loudness summation is greatly reduced in hearing-impaired listeners, in line with predictions based on loss of cochlear nonlinearity.

Demonstration from the ASA/IPO CD (Track 7).

Intensity Discrimination: Weber's law

Weber's law (which holds approximately for a number of sensory modalities) states that:

The just-detectable change in stimulus intensity (jnd or DL) is proportional to the intensity

or $\Delta I/I$ = Constant

In terms of a level change in dB, the jnd remains constant (e.g., a change of 1 dB is just detectable, no matter what the original level).
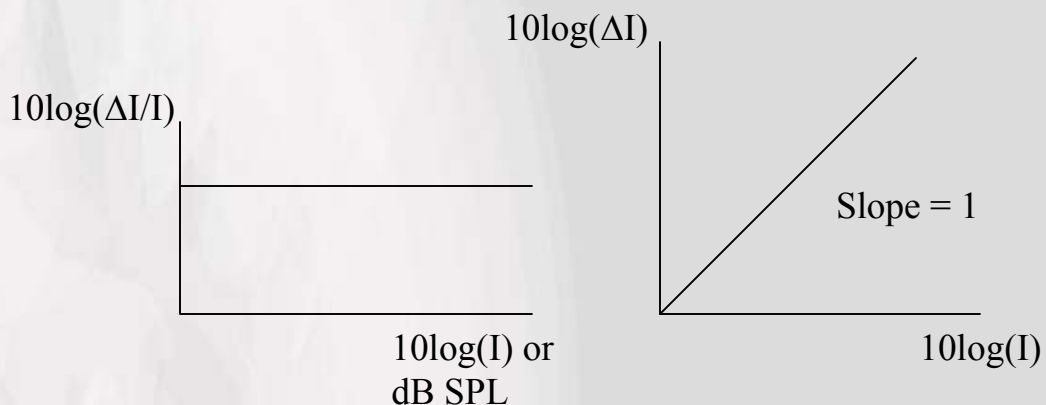
Fechner's law

Postulates that the jnd should always represent the same change in loudness. A loudness scale should therefore be derivable by counting intensity jnds.

$$dL = dI/\Delta I$$

Therefore, loudness (L) can be derived by integration:

$$\int_0^L dL = \int_{I_0}^I \frac{dI}{\Delta I}$$

Weber's law states that $\Delta I = kI$. So

$$\int_0^L dL = \int_{I_0}^I \frac{dI}{kI}$$

or

$$L = \frac{1}{k}\ln(I/I_0)$$

So loudness should be a logarithmic function of intensity (i.e., a dB scale).

Who's right, Fechner or Stevens?

Fechner's Error?

- Some consequences of a logarithmic loudness function:
  - The change from 10 to 20 dB should be the same as the change from 60 to 120 dB.
  - If loudness additivity holds, two tones at 70 dB should sound as loud as one tone at 140 dB
- What if the jnd does not represent a constant change in loudness? How could this be?
- The jnd is determined by two things:
  - 1) Perceptual distance (change in loudness)
  - 2) Internal noise

Fechner assumed (incorrectly) that internal noise is constant.

Noise in the auditory nerve can be approximated as having Poisson distribution (Variance = Mean). But this doesn't predict Weber's law either. Other noises (memory, etc.)?

The "Near-Miss" to Weber's Law and the Dynamic Range Problem

Weber's law holds for intensity discrimination of broadband noise. For tones, and other narrowband stimuli, discrimination *improves* at high levels, leading to a slope of around 0.9, instead of 1 (Rabinowitz et al., 1976; JASA 59:1506).

On the other hand, we know that most auditory nerve fibers have saturated at levels of 50 dB SPL or below.

How does the auditory system code intensities over such a large level range?

- Off-frequency listening

- Temporal information
  - Increase in synchrony with level (limited to frequencies at which phase locking occurs < 4kHz)
- Low-and medium spontaneous-rate fibers
  - Higher thresholds, but greater dynamic range

Intensity discrimination of noise in bandstop noise

6   14   kHz
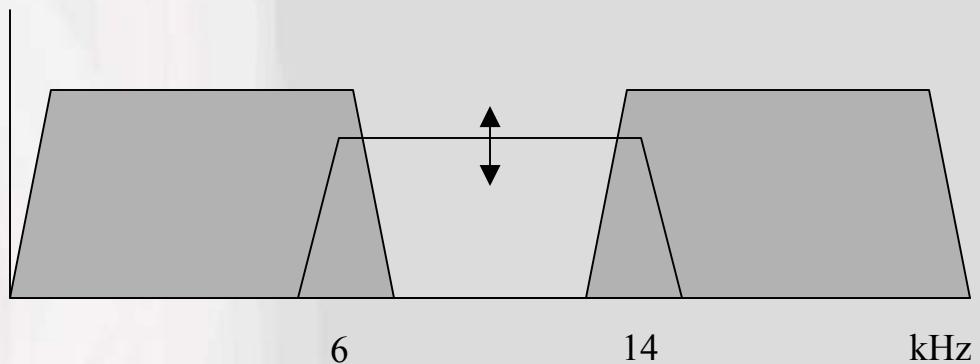
Viemeister's (1983: Science 221, 1206-8) experiment showed that good intensity discrimination could be obtained even when off-frequency listening and phase locking were unlikely. He explored possible role of low spontaneous-rate fibers.