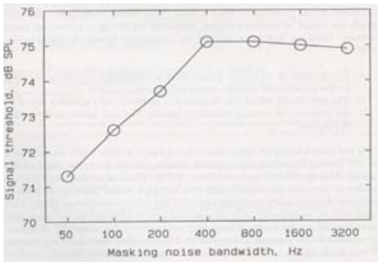
Fletcher



Based on Fletcher, 1934 and Schoonveldt and Moore (1989)

Critical Bands

- Early experimenters (e.g. Fletcher) thought that masking of a tone by broadband noise was independent of the noise bandwidth until the bandwidth became smaller than some critical value.
- The ear acts as a collection of parallel filters, each with its own characteristic bandwidth. (Critical Bandwidth or CB)

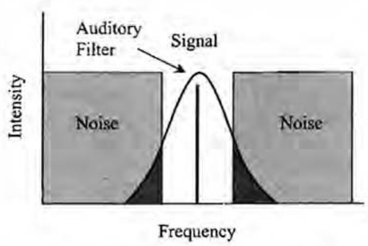
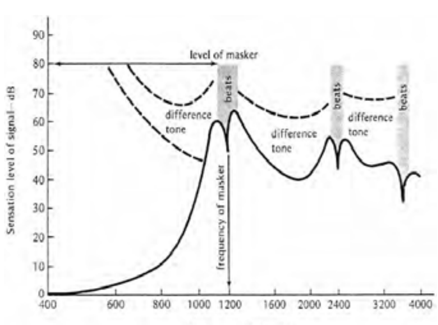


FIG. 5.11. A schematic illustration of the spectrum of the stimulus used by Patterson (1976). The area of the dark shading is proportional to the noise energy passed by the auditory filter centered on the signal frequency. As the width of the spectral notch is increased, the noise passed decreases, and the signal becomes easier to detect (hence, threshold decreases). Based on Moore (2003, Figure 3.3).

Considerations in Simultaneous Masking Experiments

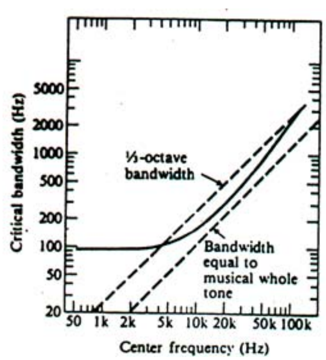
- Beats
- Non-linearities in the hearing mechanism
  - Combination tones
  - Aural harmonics

Early measurements



Wegel and Lane 1924

Critical Bandwidths



Center frequency (Hz)	Critical bandwidth (Hz)
100	90
200	90
500	110
1,000	150
2,000	280
5,000	700
10,000	1,200

Based on Zwicker 1961

Estimating the shape and size of the filters

- Fletcher used an approximation to the filter's shape as a rectangle.
- Rectangular approximations came to be known as Equivalent Rectangular Bandwidths (ERB)

Equivalent Rectangular Bandwidth (ERB)

$$ERB = ((6.23x10^{-6} xf_c^2) + (93.39x10^{-3} xf_c) + 28.52)$$

- f_c is center frequency
- It is an approximation that describes the filters as ideal rectangular filters

ERB = 24.7(0.004.37f_c + 1)

(Glasberg and Moore 1990)

Where f_c is in Hz.

CF and ERB

- Typically, the bandwidth of a filter is around 10% to 15% of the center frequency.

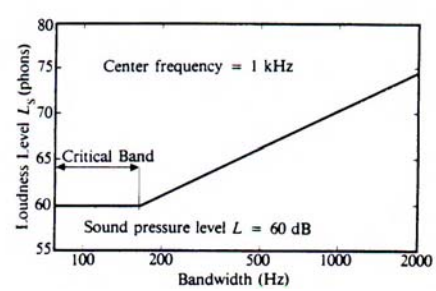
Bark scale and Critical Bands

- The range of audible frequencies is divided into approximately 24 frequency regions based on the Critical Bands (also known as Bark)
  - Corresponds to a division in the basilar membrane of 0.9-1.3mm each, regardless of center frequency (Greenwood, 1961. Moore 1986)
- In the midrange frequencies, the bands are close to 1/3octave wide.
- Barks band edge frequencies and center frequencies
  - 0, 100, 200, 300, 400, 510, 630, 770, 920, 1080, 1270, 1480, 1720, 2000, 2320, 2700, 3150, 3700, 4400, 5300, 6400, 7700, 9500, 12000, 15500
  - 50, 150, 250, 350, 450, 570, 700, 840, 1000, 1170, 1370, 1600, 1850, 2150, 2500, 2900, 3400, 4000, 4800, 5800, 7000, 8500, 10500, 13500

Threshold of detectability

- In any filter, a signal may be detected when it is above some threshold.
- For medium frequencies, it corresponds to a signal to noise ratio of 1:2.5 or -4dB
  - The signal will be detected if its level is not more than 4dB below that of the noise in the filter.

Loudness and Bandwidth



Masking

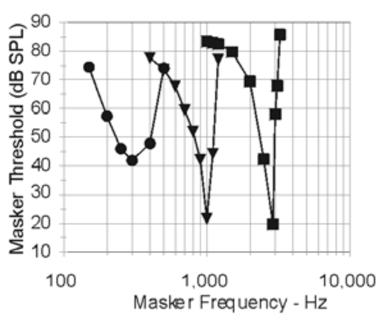
- The process by which the threshold of audibility for one sound is raised by the presence of another (masking) sound
- The amount (usually in dB) by which the threshold of audibility of a sound is raised by the presence of another (masking) sound.

American Standards Association 1960

Masking

- Masking of two tones
  - Masker: The tone or signal which causes the masking
  - Maskee or Signal: Tone which is masked
- Possible explanation: masking occurs because the threshold of hearing of the signal is shifted when in presence of the masker.

Psychophysical Tuning Curves (PTC)



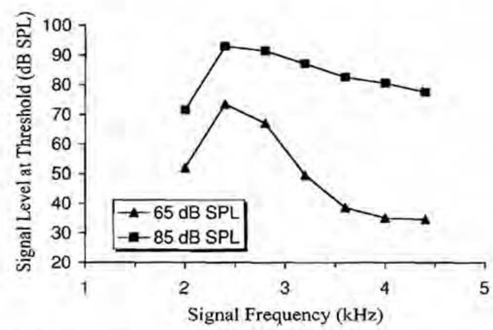
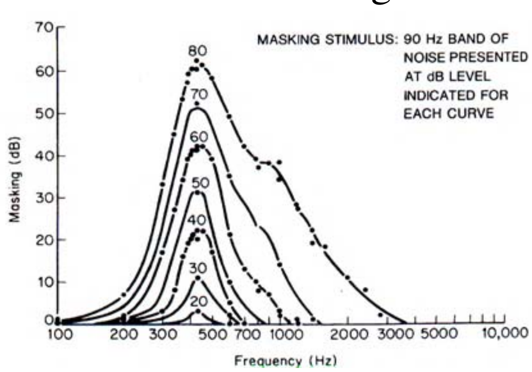


FIG. 5.13. An illustration of the upward spread of masking. The curves show the threshold level of a pure-tone signal in the presence of a 2.4-kHz pure-tone masker, as a function of signal frequency. Thresholds are shown for two levels of the masker (see legend). Threshold is highest (masking is greatest) when the signal frequency is equal to the masker frequency. As the masker level increases the signal threshold increases, although the increase is greatest on the high-frequency side of the masking pattern. Data are from an unpublished study by Oxenham, reported by Oxenham and Bacon (2004).

Simultaneous Masking Curves

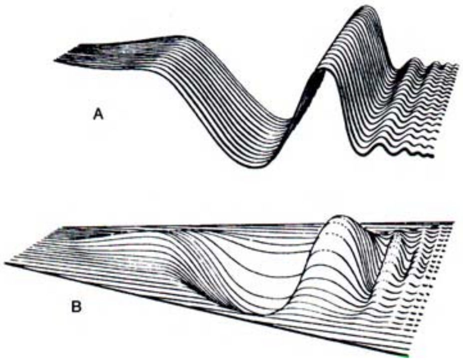


From Egan and Haske, 1950

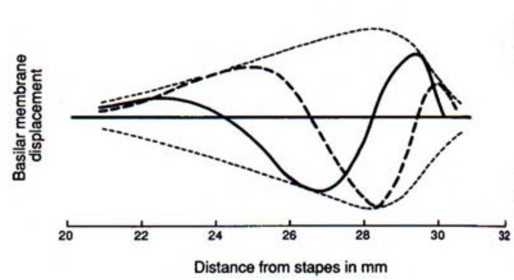
Assymetry of Masking

- A pure tone masks tones of higher frequency more efficiently than tones of lower frequency

Basilar Membrane

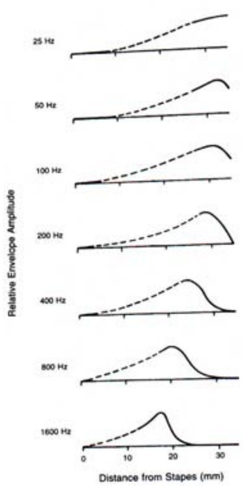


Basilar Membrane



Basilar Membrane

Upward Spread



Forward and Backward Masking

- Masking can also occur when the tone (signal) and the masker are not simultaneous.
- Forward Masking
  - Masking of a tone by a sound that ends a short time (e.g. 20-30ms) before the tone begins
- Backward Masking
  - Masking of a tone by a sound that begins sometime later (e.g. 10ms later)

Forward and Backward masking

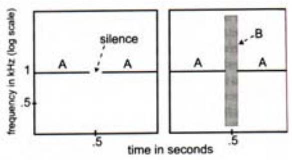
- Forward masking suggests that recently stimulated sensors are not as sensitive as fully-rested ones
- Backward masking may occur at higher levels of processing

Apparent Continuity

- Vision

Apparent Continuity

- Auditory



Other masking characteristics

- Forward masking is greater the smaller the delay between the two signals
- The rate of recovery from forward masking is greater for higher masker levels. Decays to zero in all cases, after 100 - 200 ms
- Forward masking increases with increased masker duration… until about 50ms.
- Forward masking depends on the signals used.

Some possible explanations for forward masking

- Response of the basilar membrane continues after the end of the masker. (“ringing”)
- Masker produces short-term adaptation or fatigue in the auditory nerve or higher centers in the auditory system
- Neural activity persists at some level in the auditory system.

Swamping or Suppression in Simultaneous Masking?

- “Swamping”
  - The masker produces a significant amount of activity in the auditory filters which swamps the information making the signal undetectable
- “Suppression”
  - When signal is well above or below the masker, the neural response to a tone may be suppressed by a tone that does not excite that particular neuron.

Equal Loudness Contour Curves Threshold of audibility