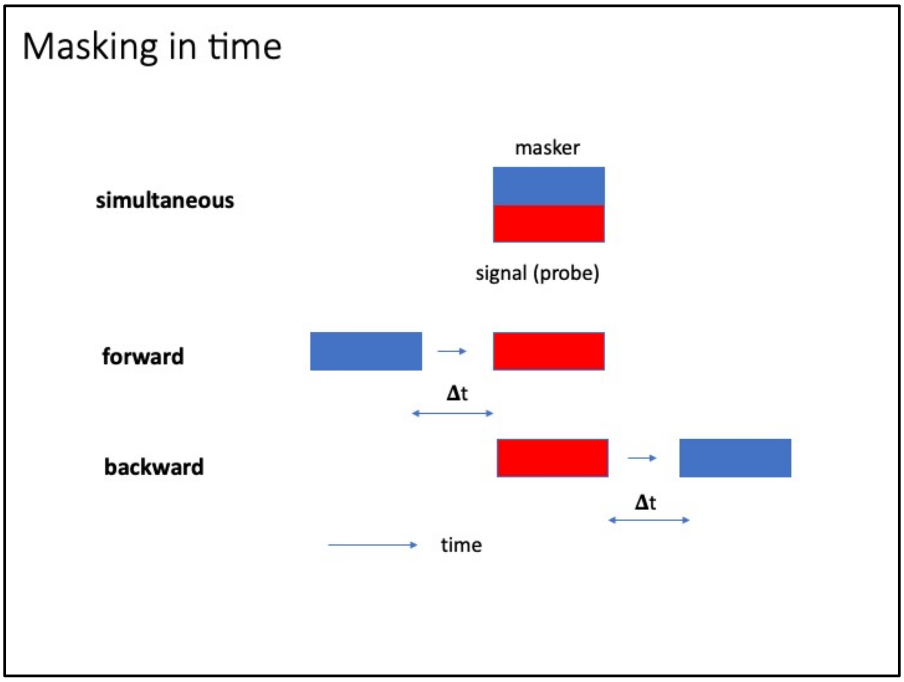


Masker occuring at the same time as the signal (probe) has obviously larges effect on the probe threshold (simultaneous masking). However, when the masker is presented befor the probe, the masking effect is still there, as long as the interval between the msaker and the probe is not too large (forward masking). Even the masker presented after the probe has some effect on the probe threshold (backward masking). The forward masking last longer (about 200-300 msec.) The significant backward masking interval is shorter (not more than 40 msec).

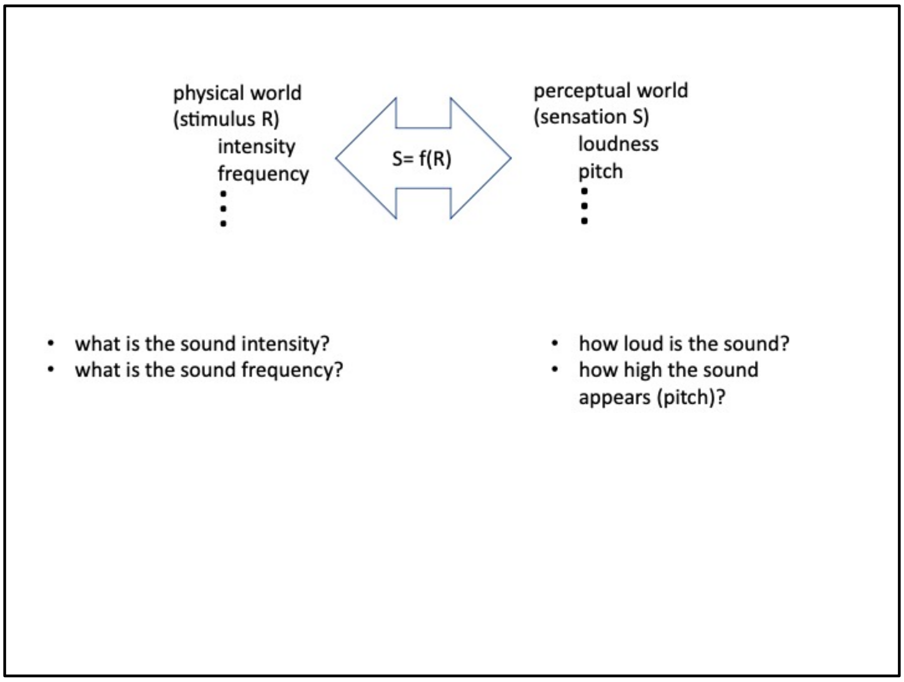
Four dimensions of pure tones (harmonic signals)

1. frequency
2. intensity
3. length
4. *phase (can be ignored unles interested in sound direction in binaurak heari*

Physical dimensions of intensity and frequency
have their perceptual correlates

frequency [Hz] – pitch [Mel]
intensity [W/m^2] – loudnes [Sone]

Pure tones have four ohysical dimensions, frequency, intensity, lengths and phase. The first two have their clear perceptual correlates. Perception of time is important in music. Ear is relatively insesitive to absolute phase (Ohh's law of hearing).

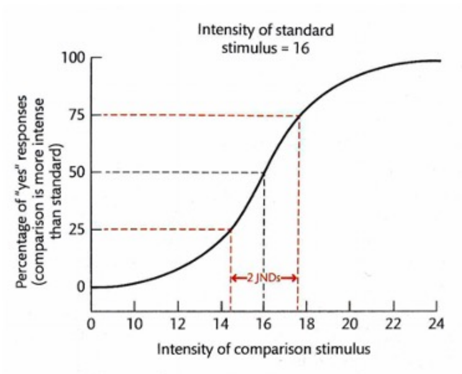


The question how is a physical stimulus R reftlected in a sensation S in human perceptual system, that is what is the so called psychometric fiunstion S=f(R) is a reasonable one to ask. For aucoustic stimuli that may be how is frequency of a signal reflected in a perception of how high or lhow low is a tone, or how loud is a sound of a given intensity. We will mention two methods to adress the question. One involves first to learn what are minimal differences on a pair of stimuli, the second method is directly asking the experimental subjects for a magnitude estimation of a difference between two sounds.

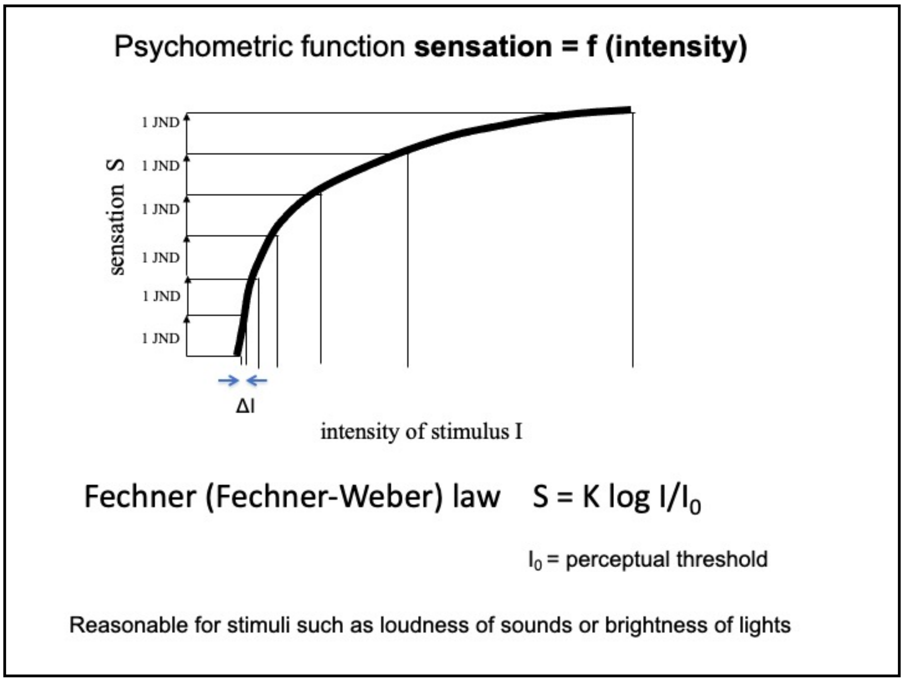
Discrimination

- Just Noticeable Difference (JND)

- How similar (different) are two different stimuli?
  - how much they need to differ to be discriminated as not being the same?

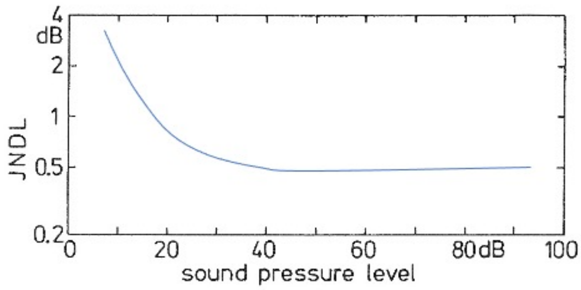


There is not much difference between the model for reporting presence or absence of a stimulus and discriminating between two stimuli using the so called "method of constant stimuli", where the subject must respond which of the two stimuli is stronger. However, the response curve here starts at 50% when the subject is guessing if there is a difference between two stimuli or not, an the so called "just noticeable difference " (JND) is typically set at the 75% response level.



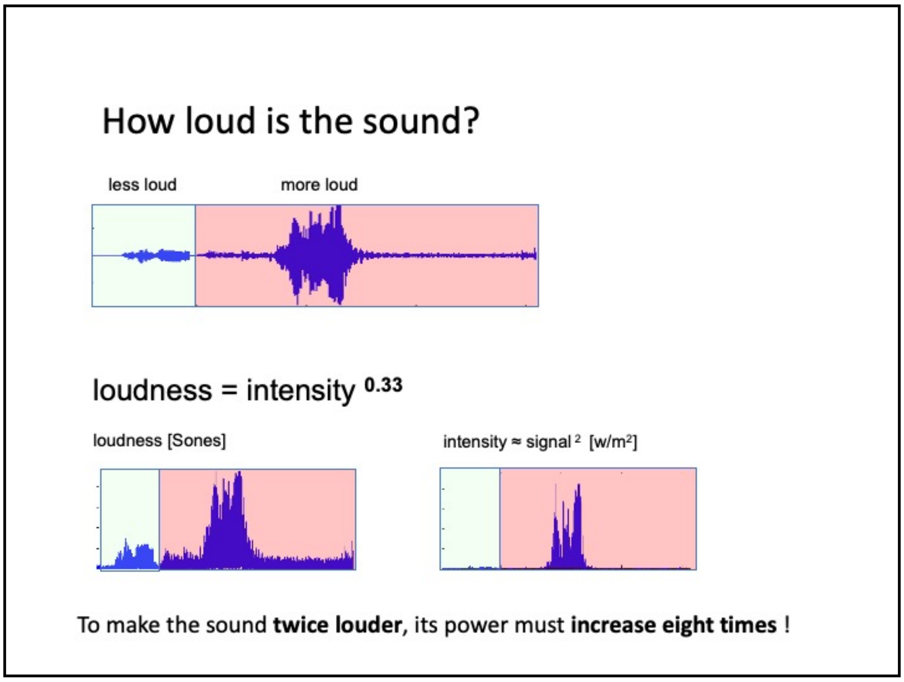
Response to a stimulus is not a linear function of the stimulus. Instead, it follows the so called psychometric function, which is in general unknown. One way of deriving this psychometric function was proposed by Fechner, who proposed that the psychometric function can be derived by stacking just noticeable differences (which, as we remember from Weber' s law, approximately follow relative changes in the stimulus intensity). Fechner suggested logarithmic dependency of the sensation on the stimulus intensity. This essentially says that the sensation is a compressive function of stimulus intensity and is reasonable for some stimuli such as loudness of sounds or brightness of lights. However, certain stimuli clearly do not obey this law. This, e.g. the 2 meter line appears twice long as 1 meter line, or 2 grams of salt in your food makes the food much more that twice saltier than 1 gram of salt would. Also the strict interpretation of Fechner's law suggest that no stimulus (zero stimulus intensity) implies infinitely negative sensation ☺.

Weber fraction (JND) for loudness



For white noise and intensities above 40 dB, the JND is less than 1 dB.

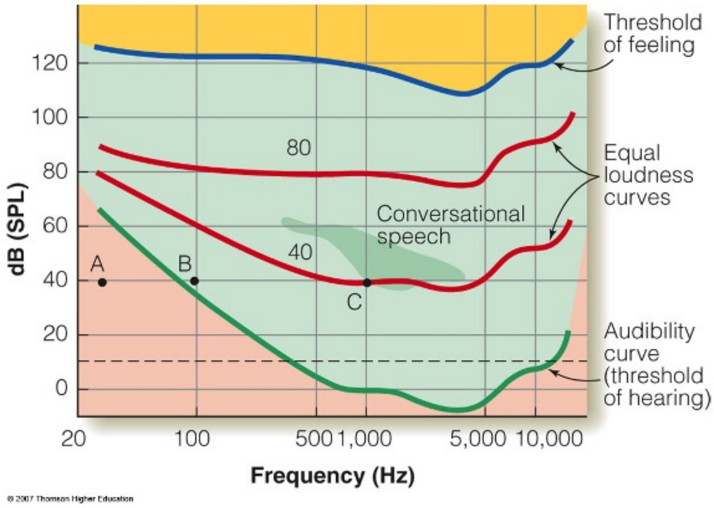
For white noise, which affects all frequencies equally, the JND is less that 1 dB. For pure tones, the situation is more complicated and the JND needs to be determined considering excitation patterns elicited by the tone.

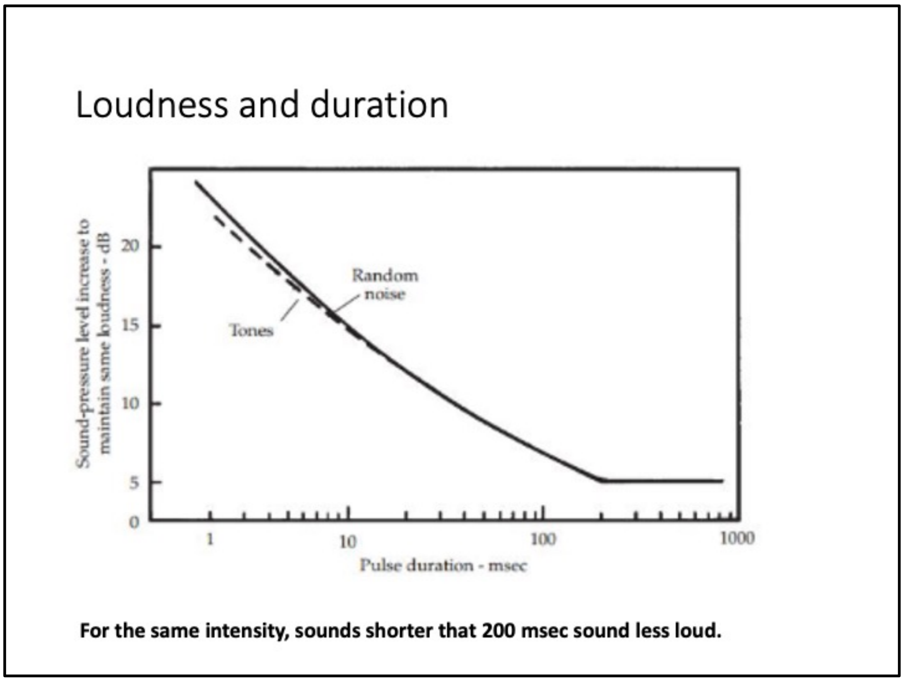


How much louder is one signal comparing to another? Clearly, the signal with larger intensity (power) is louder that the signal with less power, but how much louder? Experimental evidence shows that the loudness increases with the cubic root of the signal intensity (power law of perception, which is valid also for many other models of perception). That means, the loudness increases slower than the increase in intensity (approximately ten times – exactly eight times if the power 0.33 is considered) is needed to increase the loudness twice.

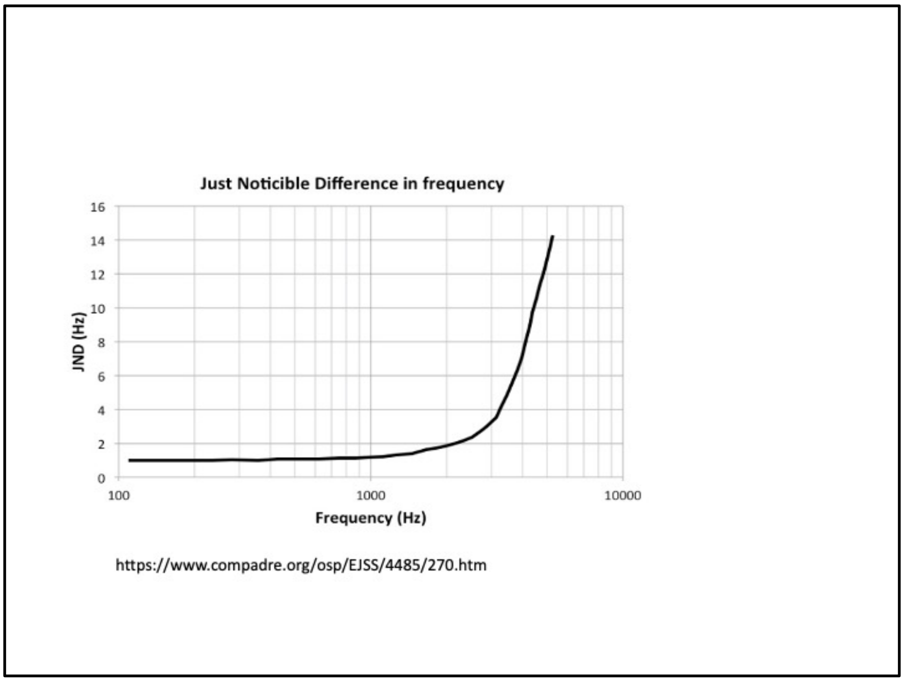
Equal loudness curves

100 dB – five orders of magnitude in acoustic pressure
(ten orders in magnitude in power)

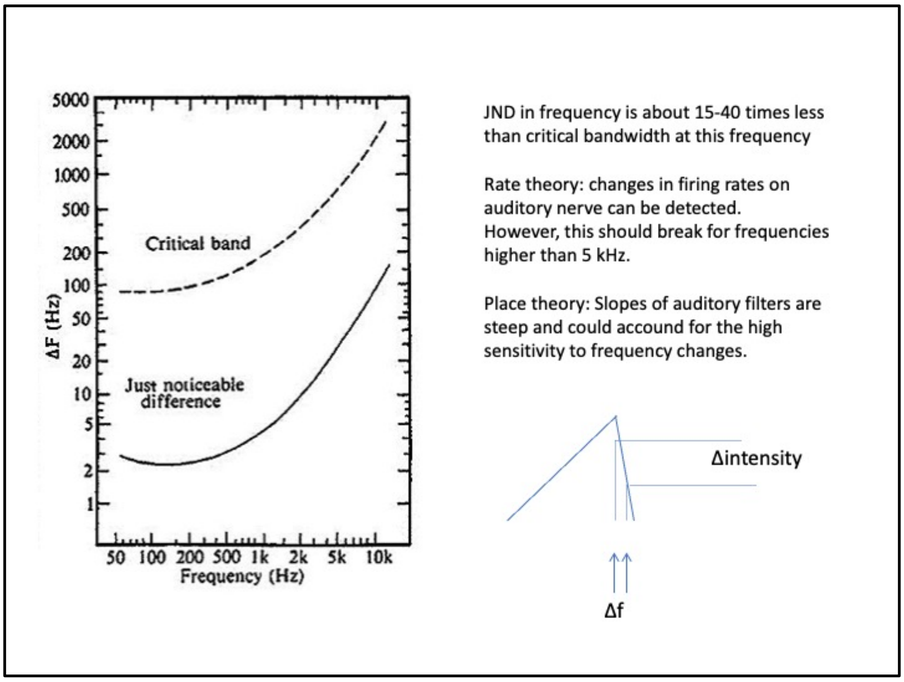




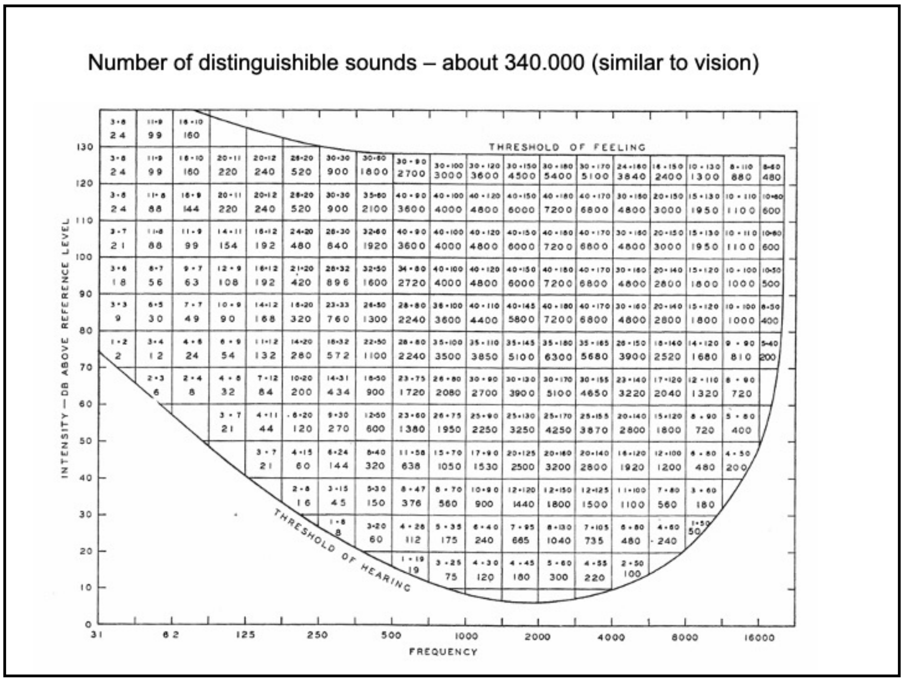
For the same intensity, sounds shorter that 200 msec sound less loud. (Remember, we have seen similar time span for sounds at the threshold of hearing).



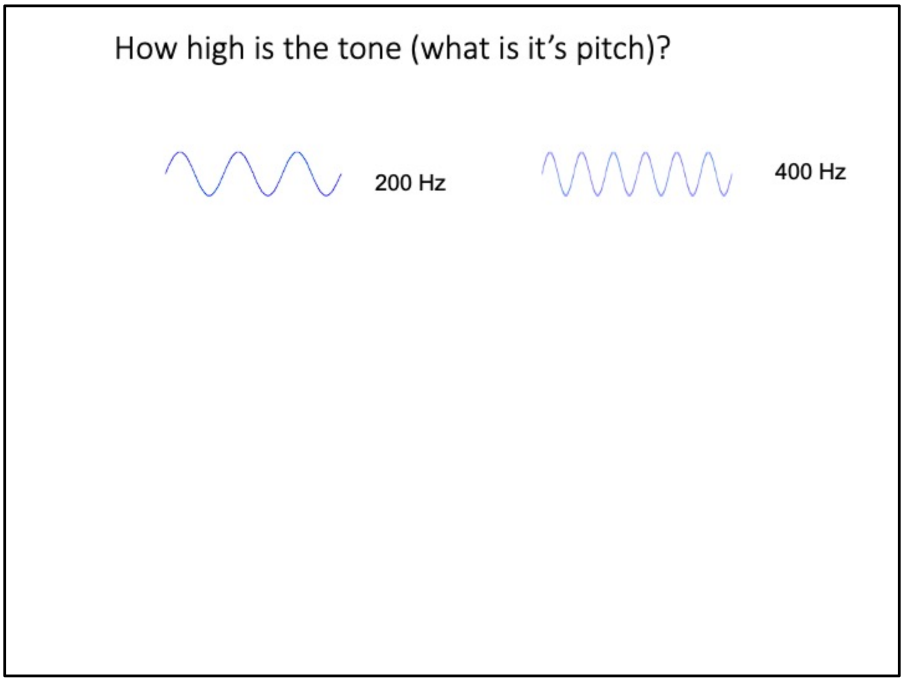
JND is constant (i.e. the Weber fraction Δfg/f for frequency is approximately constant only up to around 1 kHz (Fechner –Weber law does not hold). For frequencies above 1 kHz, the Weber fraction is approximately constant at about 0.3 – 1 % of the frequency. It varies with sound intensity, for larger intensities, the Weber fraction is smaller. For frequencies below about 500 Hz, the Weber fraction increases significantly, so for low frequencies, we cannot differentiate among sounds with different frequencies as well as we do for frequencies above 500 Hz.



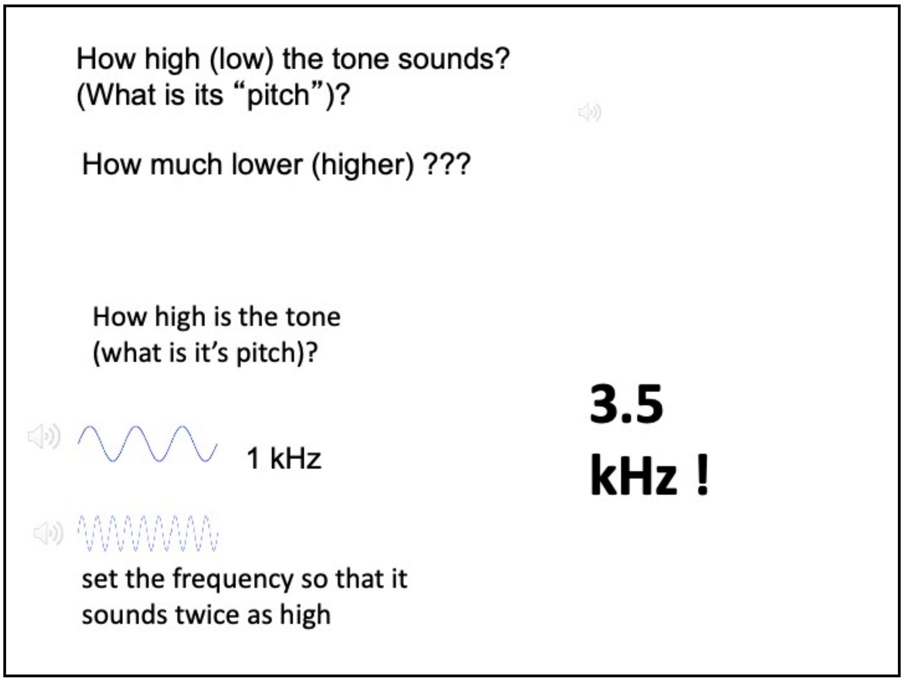
Frequency **resolution** indicates how well can different components of acoustic signal resolved and assign to different frequency channels. This is very different from frequency **discrimination**, which indicates how well can human hearing discriminate between two pure sounds with different frequencies. Resolution is indicated by critical bands. Discrimination is indicated by JND in frequency change, which is much smaller than critical bandwidth. Proponets of rate theory of hearing may remind that tone frequency is (up to 5 kHz) preserved in firing rates on auditory nerve and brain can in principle be sensitive to small changes in this firing rate. However, the JND in frequency remains small well beyond the 5 kHz (so this can be rejected). Place teory proponets could argue that even a small changes in frequency of the tone can be resolved on very steep slopes of critical band filters torards higher frequencies. THis is probably correct.



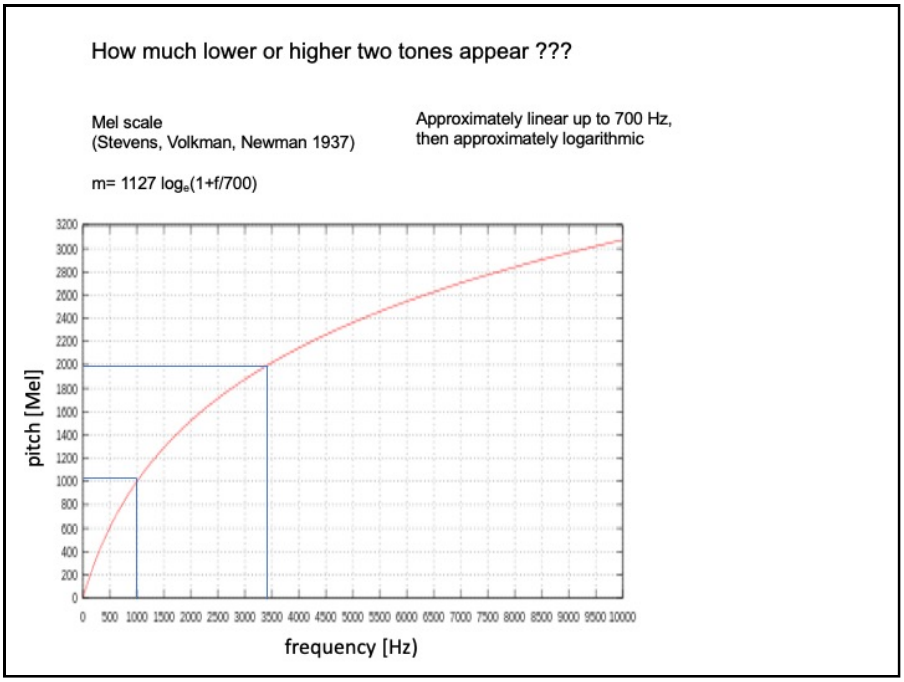
The tolal number of different signals in intensity-frequency plane would be around 330 000. The discriminability is highest around 2 kHz and at higher intensities.



Pich is perceived frequency of the tone. It is clear that the tone with higher frequency is perceived as being higher in pitch. However it is not clear how much higher the tone is.



Pitch refers to perceived tone of the stimulus. We all agree that some sounds sound "higher" and some "lower". This percept is related (among other things) to the frequency of the sound. High frequency sounds sound "higher" and low frequency sounds sound "lower". So a reasonable question is how much higher is one sound relative to another. This is given by experimentally-determined Mel scale.



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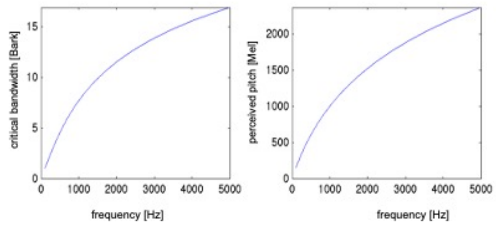
Critical bandwidth　　Pitch of a tone



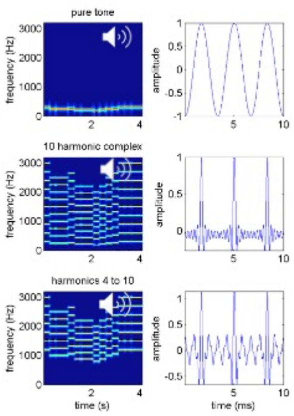
$b = 6*\sinh^{-1}(f/600)$　　$m = 1127 \log_e(1+f/700)$

b in Bark
(1 critical band is one Bark)

m in Mel
(tone at 1000 Hz is 1000 Mel)

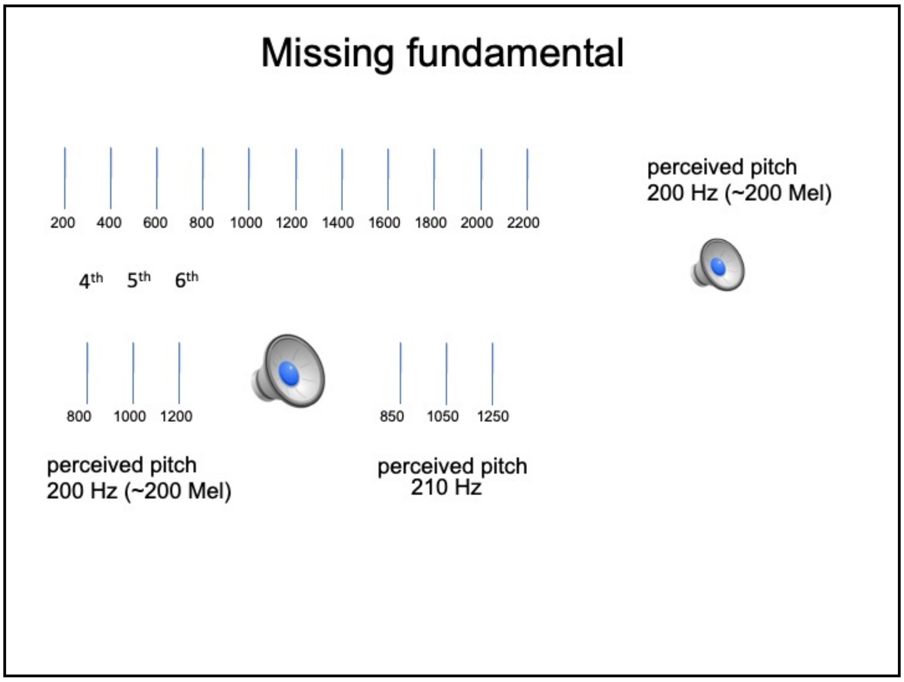
The pitch-frequency relation is described by Mel function. The mel finction is similar to the function describing criotical bands of hearing, even when it was derived by very different experiments.

Pitch perception
pitch ≈ periodicity



https://auditoryneuroscience.com/pitch/missing-fundamentals

Pitch perception is dependent on the sound periodicity of the complex signal and not on intensities of signal harmonics. The lower harmonics can be missing and the one pitch does not change. The depencei of the pitch in the signal periodicity was derived by parceptual experiments where one signal was played and experimental subjects were asked to adjust the frequency of the second tone so that it was twice (half) as high as the first tone.



Complex signals with many harmonic components also have pitch. This pitch is related to fundamental periodicity of the signal. When the signal is high-pass filtered, the pitch is still determined by a common denominator of the remaining components, even when the component with the perceived frequency is actually missing.

Interesting situation arises when all components of such high-pass filtered signal are artificially shifted by a constant amount . (Such a signal does not arise from natural vibrations since the components are non-harmonic but can be made artificially). In this case, the perceived pitch is ambiguous. Most subject report pitch that relates to the middle tone (10th harmonic of 204 Hz, and close to 9th and 11th harmonic) but some subject also report pitch of 185 Hz (not related to any exact real value of the shifted components which are still close to all 10th (1850 Hz – real 1840 Hz) 11th (2035 Hz – real 2040 Hz) and 12th (2220 Hz – real 2240 Hz) harmonics, of 185 Hz fundamental, or 227 Hz, with it harmonics "close", i.e. being 1816 Hz (real 1840), 2043 Hz (real 2040) and 2270 Hz (real 2240 Hz). Perception is "forgiving" while it tries to make sense of a signal which is not realistic in nature.

Perceived pitch and duration

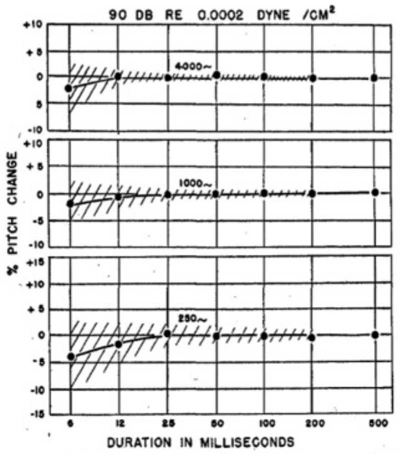
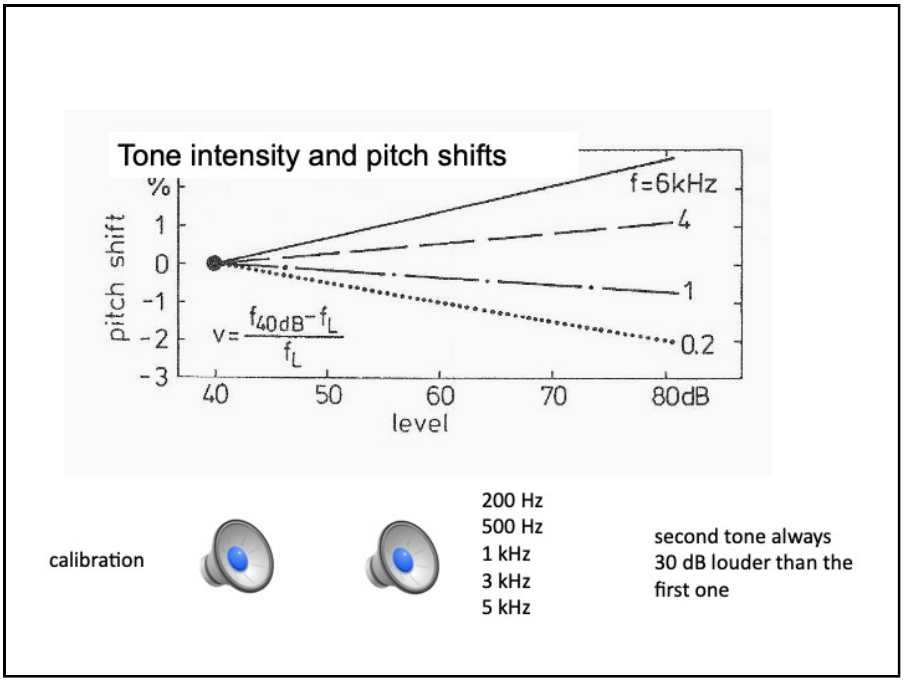


FIG. 3. The relation between tonal duration and changes in apparent pitch, as determined by the method of average error

For tone durations < 200 msec, perceived pitch is lower and error in estimation is increasing

Doughty, J. M., & Garner, W. R. (1948). Pitch characteristics of short tones. II. Pitch as a function of tonal duration. *Journal of Experimental Psychology, 38*(4), 478–494.

Perceived pitch of the tone also depends on the length of the tone. For tones shorter that 200 ms, the perceived pitch is somehow lower and the estimets from different experiments are more variable (for detaile, look up [Doughty, J. M., & Garner, W. R. (1948). Pitch characteristics of short tones. II. Pitch as a function of tonal duration. *Journal of Experimental Psychology, 38*(4), 478–494] - BTW – the authors were from JHU).



Pitch also depends on intensity of the tone. Higher intensity tones of high frequencies sound higher in pitch. Higher intensity tones of low frequencies sound lower in pitch.