Pitch

The perceptual correlate of frequency: the perceptual dimension along which sounds can be ordered from low to high.

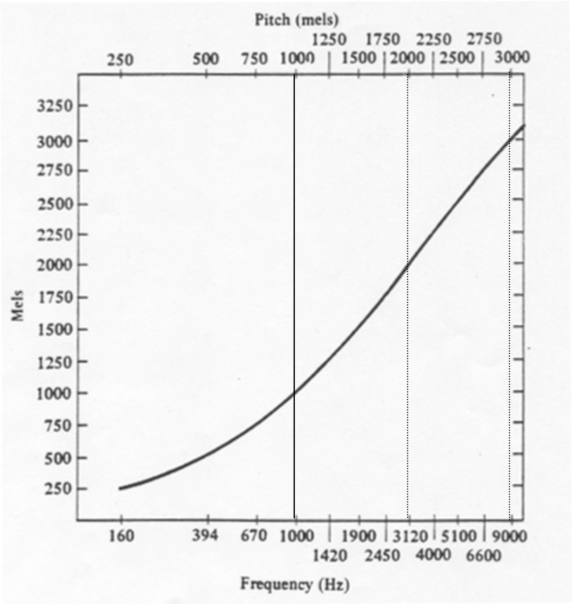
The bottom line

Pitch perception involves the integration of spectral (place) and temporal information across the spectrum.

Scales of pitch

There have been some attempts to develop scales of pitch.

mel scale



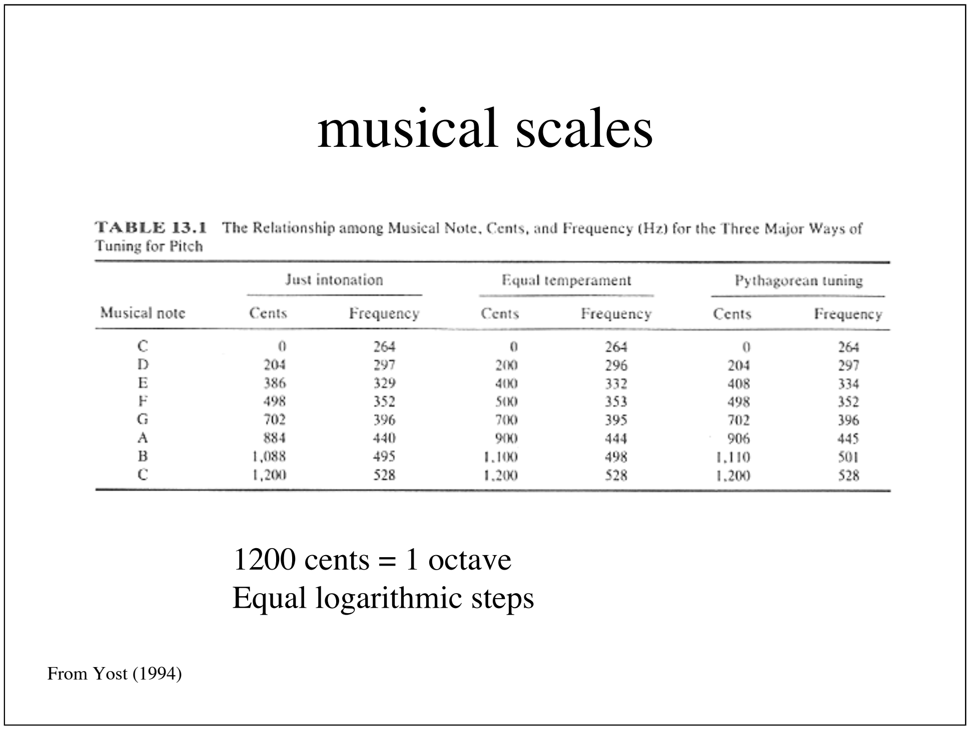
From Gelfand (1998)

Stevens used magnitude estimation to establish the mel scale. The pitch of 1000 Hz is 1000 mels. A sound that sounds half as high would have a pitch of 500 mels, while a sound that sounds twice as high would have a pitch of 2000 mels. Notice that the frequency that is twice as high as 1000 Hz is 3120 Hz and the one that is 3 times as high is 9000 Hz. The relationship between frequency and pitch is not simple.

Pitch has two qualities

- Pitch height
- Pitch chroma
  - Octave equivalence

The idea of the mel scale is frequently criticized because it ignores one aspect of pitch altogether. Pitch height is the quality of pitch that continues to get higher as the frequency is increased. Pitch chroma is the cyclic quality of pitch: sounds that are separated by an octave have a similar pitch quality. We say that octaves are equivalent in that sense.



musical scales

TABLE 13.1 The Relationship among Musical Note, Cents, and Frequency (Hz) for the Three Major Ways of Tuning for Pitch

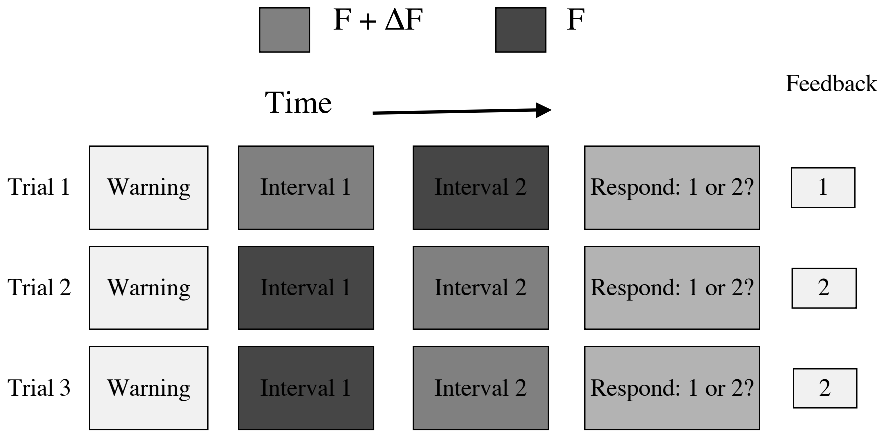
	Just intonation		Equal temperament		Pythagorean tuning	
Musical note	Cents	Frequency	Cents	Frequency	Cents	Frequency
C	0	264	0	264	0	264
D	204	297	200	296	204	297
E	386	329	400	332	408	334
F	498	352	500	353	498	352
G	702	396	700	395	702	396
A	884	440	900	444	906	445
B	1,088	495	1,100	498	1,110	501
C	1,200	528	1,200	528	1,200	528

1200 cents = 1 octave
Equal logarithmic steps

From Yost (1994)

For that reason some people prefer to describe pitch in terms of musical scales. The unit of the scale is the octave, where an octave is a doubling of frequency. Each octave is broken into 1200 logarithmically equal steps called cents. This table shows the values of notes in the Western musical scale in cents and in frequency. Notice that the exact pitch of the notes is not generally agreed upon; there are different versions of the scale. That means that different people “hear” the steps in scale as being correctly spaced at different frequencies.

2AFC Frequency Discrimination



▨ F + ΔF ■ F

Time →

					Feedback
Trial 1	Warning	▨ Interval 1	■ Interval 2	Respond: 1 or 2?	1
Trial 2	Warning	■ Interval 1	▨ Interval 2	Respond: 1 or 2?	2
Trial 3	Warning	■ Interval 1	▨ Interval 2	Respond: 1 or 2?	2

Which one was higher?

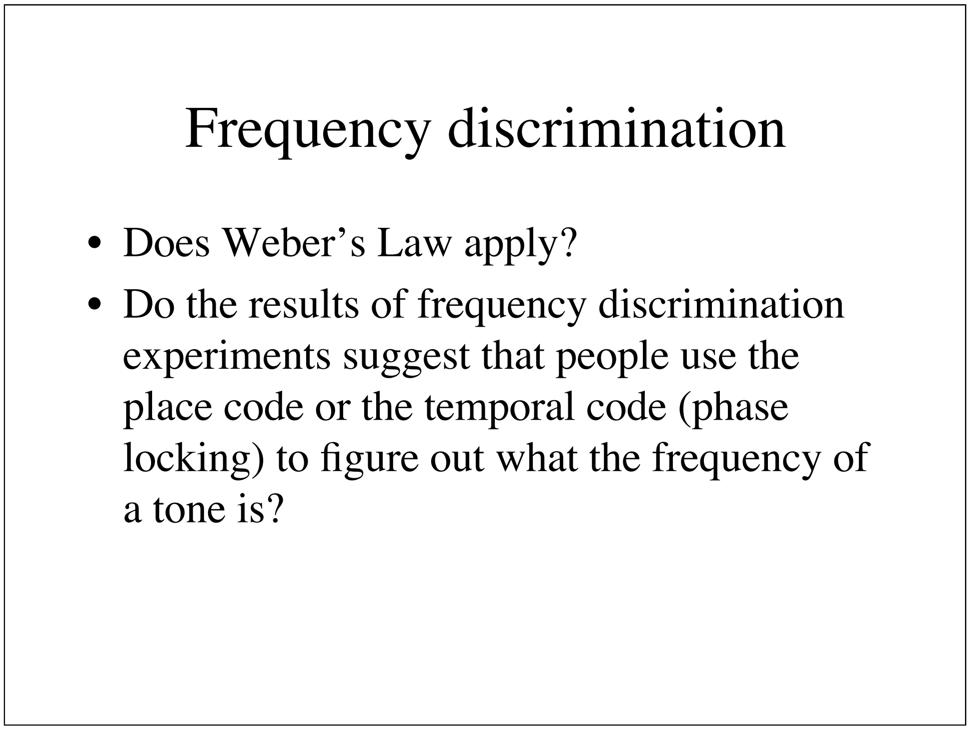
Vary ΔF to find a threshold

In psychoacoustics, pitch scales have received less attention than other aspects of pitch perception. Pure-tone frequency discrimination is one task that has been used to assess the accuracy of people’s pitch perception. On each trial, the listener receives a warning that the trial is starting, then hears two “intervals”. In one interval the frequency of the tone is F; in the other it is F + ΔF, randomly chosen. The listener chooses the interval that contained the higher tone, and the difference between the two tones in frequency, ΔF, can be manipulated to find a threshold.

Terms for frequency discrimination threshold

- ΔF
- frequency DL, DLF, FDL
- ΔF/F, Weber Fraction
- jnd for frequency

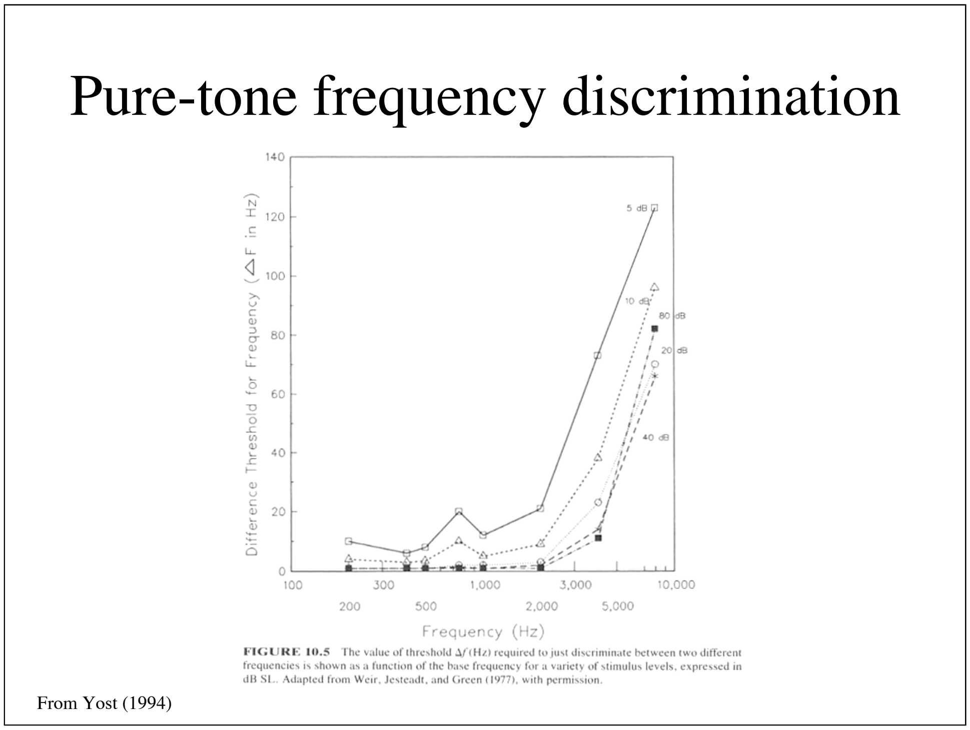
There are various terms for the frequency discrimination threshold.



Frequency discrimination

- Does Weber’s Law apply?
- Do the results of frequency discrimination experiments suggest that people use the place code or the temporal code (phase locking) to figure out what the frequency of a tone is?

Two major questions about frequency discrimination have been of interest .

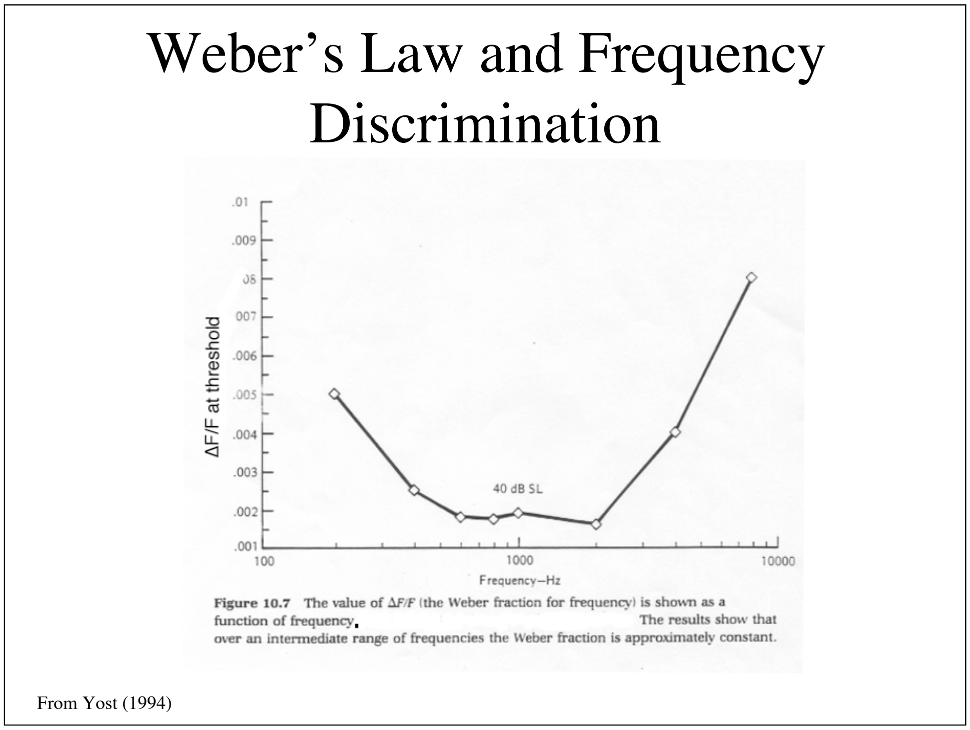


Pure-tone frequency discrimination

FIGURE 10.5 The value of threshold Δf (Hz) required to just discriminate between two different frequencies is shown as a function of the base frequency for a variety of stimulus levels, expressed in dB SL. Adapted from Weir, Jesteadt, and Green (1977), with permission.

From Yost (1994)

Each curve shows the jnd for frequency as a function of frequency, each curve at a different sensation level. Once the level of the tone reaches about 40 dB SL, level isn't very important. At frequencies below about 2000 Hz, the jnd is quite small, a Hz or two. At higher frequencies, the jnd increases with increasing frequency.

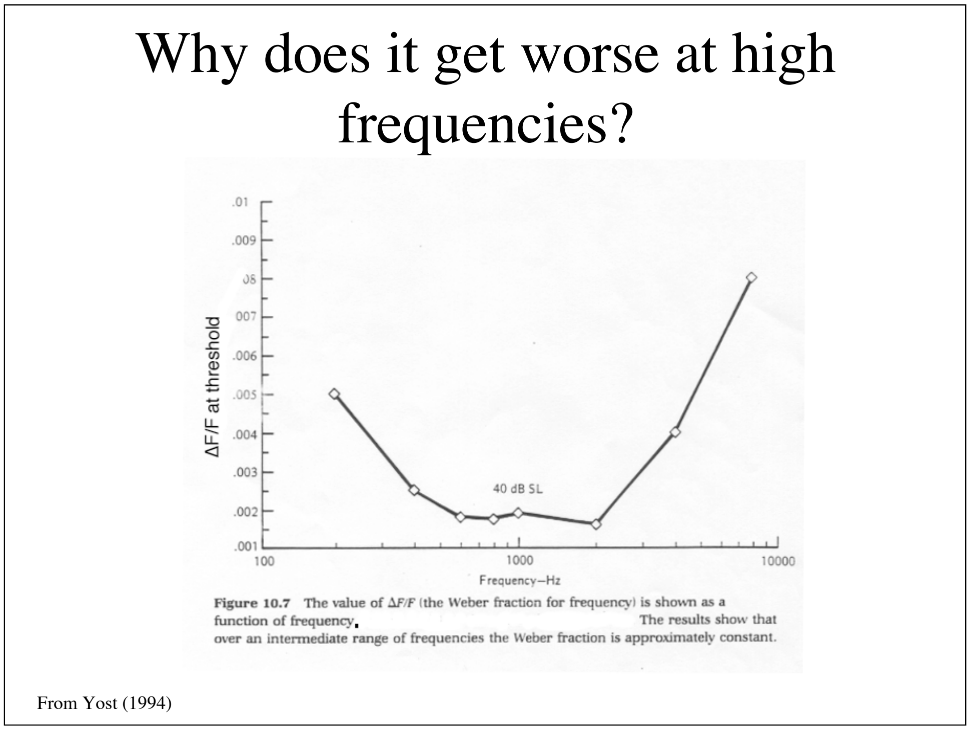


Weber's Law and Frequency Discrimination

Figure 10.7 The value of ΔF/F (the Weber fraction for frequency) is shown as a function of frequency. The results show that over an intermediate range of frequencies the Weber fraction is approximately constant.

From Yost (1994)

Does Weber's Law hold? In the midrange of frequency, the Weber fraction, ΔF/F is pretty much constant. At higher and lower frequencies it is worse.

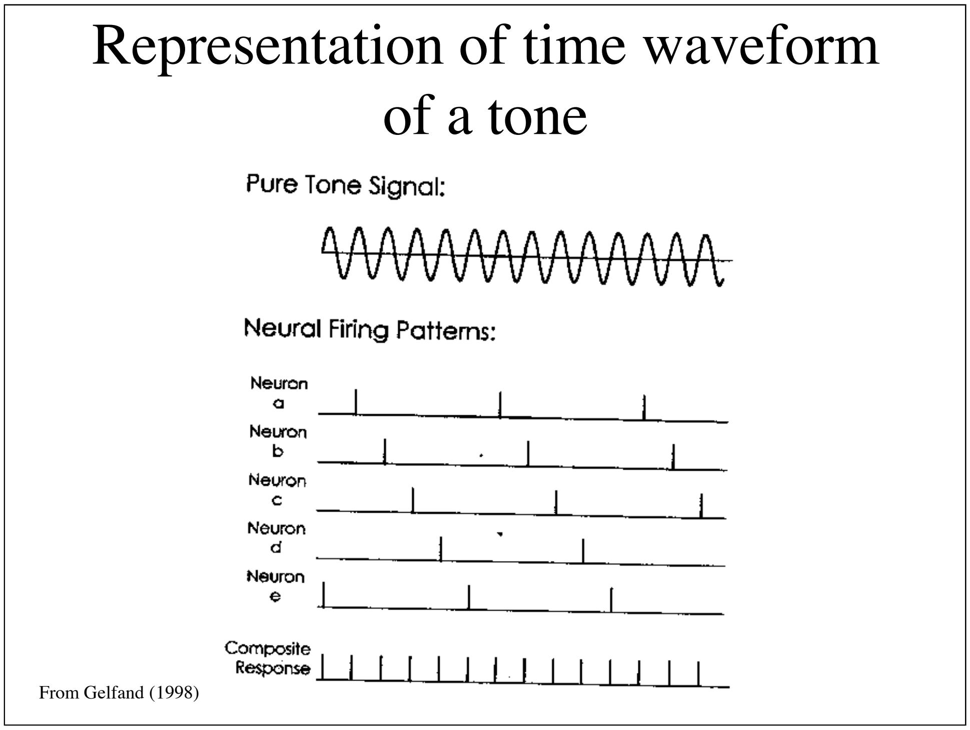


Why does it get worse at high frequencies?

Figure 10.7 The value of $\Delta F/F$ (the Weber fraction for frequency) is shown as a function of frequency. The results show that over an intermediate range of frequencies the Weber fraction is approximately constant.

From Yost (1994)

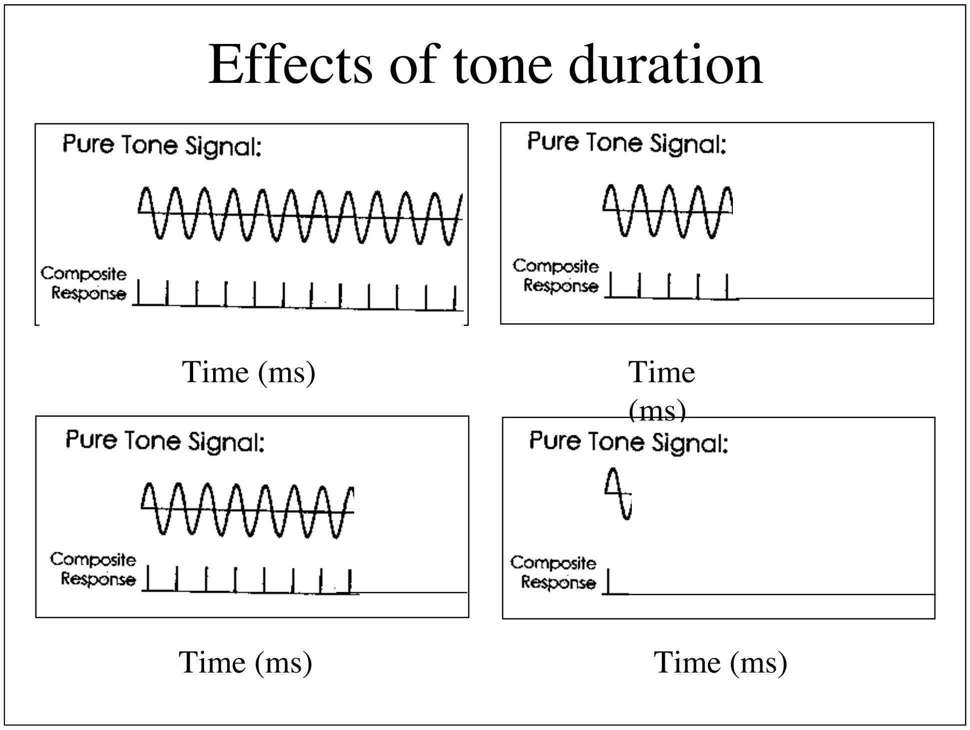
One explanation for the difference between low-ish frequencies and high frequencies is the code that is used to represent frequencies in these frequency ranges. While phase-locking could be used to represent a low frequency, only the place code is available to code high frequencies (over 5000 Hz, and phase locking starts to deteriorate above 1000 Hz or so).



Representation of time waveform of a tone

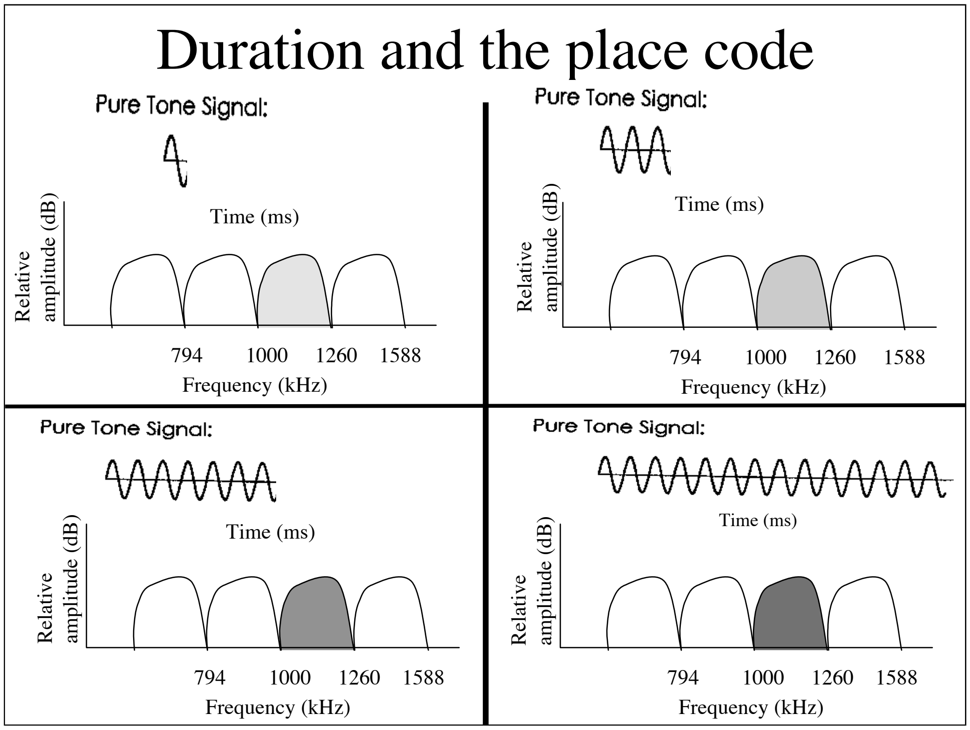
From Gelfand (1998)

Remember that the representation of the time waveform of sound depends on combining responses across nerve fibers to determine the interval between peaks in the waveform. Moore suggested that one way to tell whether different codes are used for low and high frequencies would be to see what would happen if you varied the duration of the tone.



Effects of tone duration

Consider that as the duration of the tone gets shorter and shorter, the information available to the auditory system to calculate that interval gets degraded severely.



Duration and the place code

As far as the place code is concerned, you might expect more activity as the duration of the tone is increased, but the task is always to figure out which one of those auditory nerve fibers is responding. So duration may not have such a dramatic effect on the place code.

Prediction

Shortening the duration of the tone should have a bigger effect on frequency discrimination if frequency is being coded temporally.

Effects of duration of pure-tone

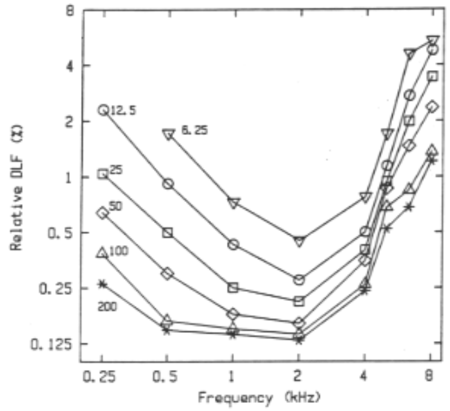


FIG. 5.3 Values of the DLF plotted as a function of centre frequency and expressed as a percentage of centre frequency (log scale). The number by each curve is the duration of the tone pulses in ms. Notice the sharp increase in the size of the DLFs which occurs around 5 kHz.

From Moore (1997)

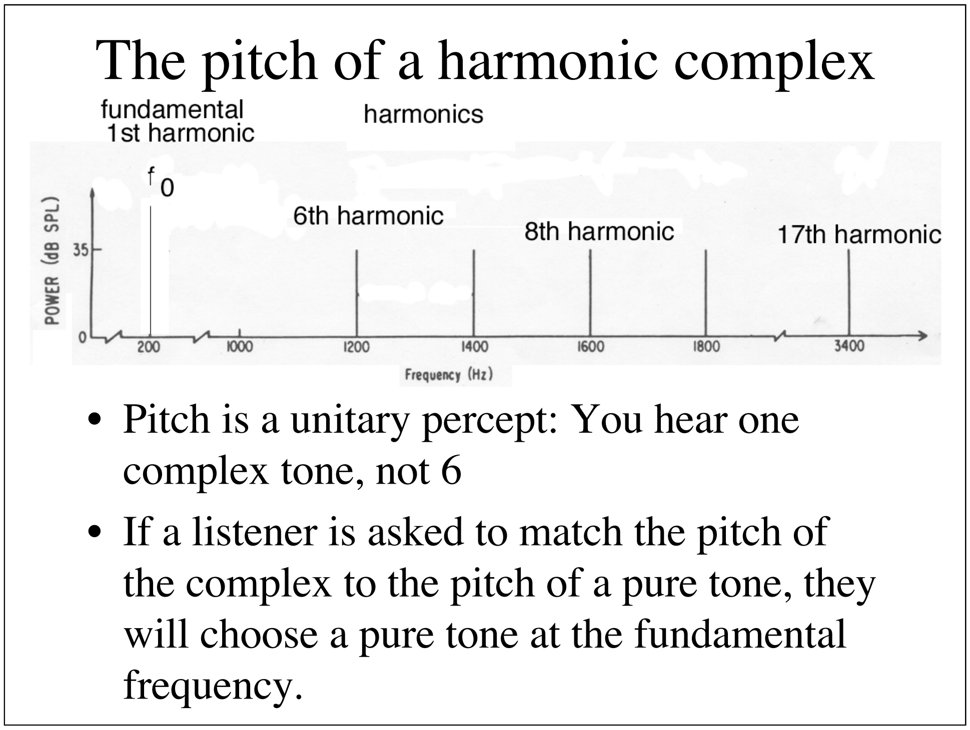
Moore’s results are consistent with this prediction. Each of these curves represents the Weber fraction as a function of frequency for a different tone duration. As the duration gets shorter, the jnd gets worse. But this effect is more pronounced at low frequencies, where the temporal code is thought to be used.

These and other findings suggest that a temporal code (phase-locking) is used to code low frequency tones, but that the place code is used to code high frequency tones

But notice that we do better, relatively speaking, with the temporal code. People use whatever works best.

Well, tones are fine, but..

Most sounds are complex. How do we perceive the pitch of complex sounds?

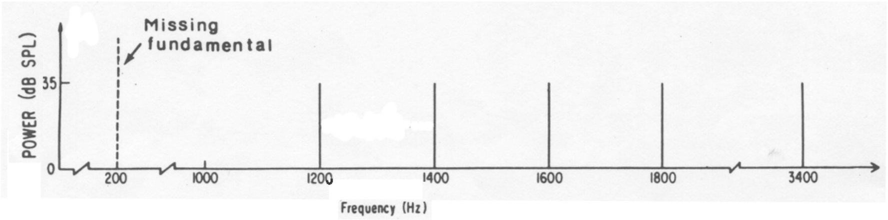


The pitch of a harmonic complex

- Pitch is a unitary percept: You hear one complex tone, not 6
- If a listener is asked to match the pitch of the complex to the pitch of a pure tone, they will choose a pure tone at the fundamental frequency.

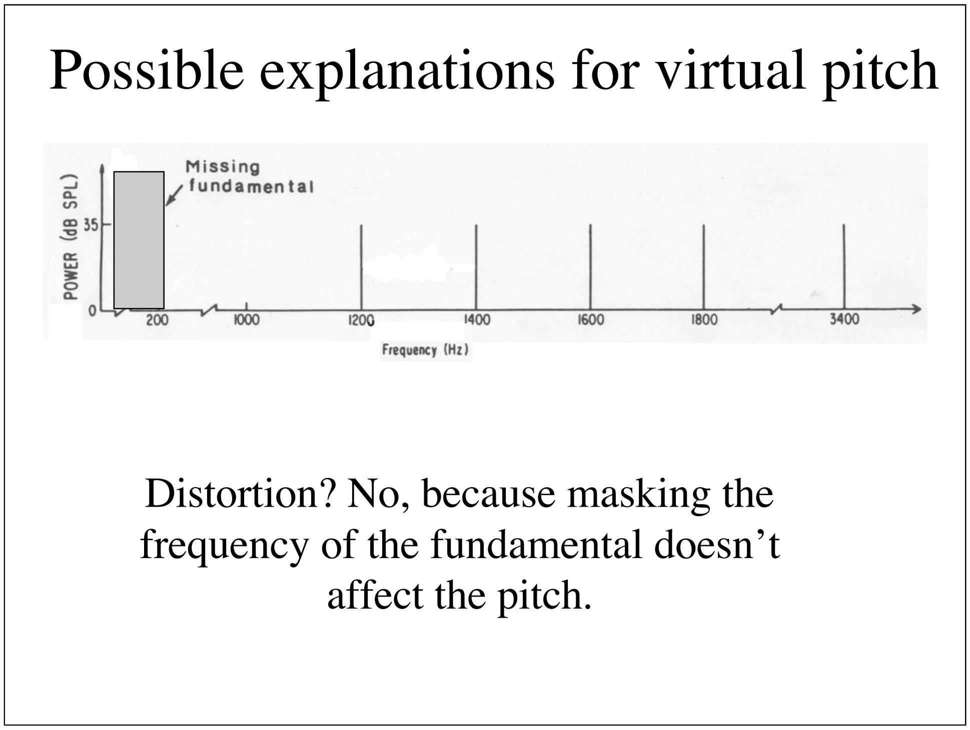
Many sound sources (e.g., voices, musical instruments) produce complex sounds with harmonically related components.

In fact, if you present the harmonics alone, you still hear the pitch of the fundamental



- Pitch of the missing fundamental
- Virtual pitch
- Residue pitch
- Low pitch

The pitch that you hear when the fundamental is missing goes by various names.

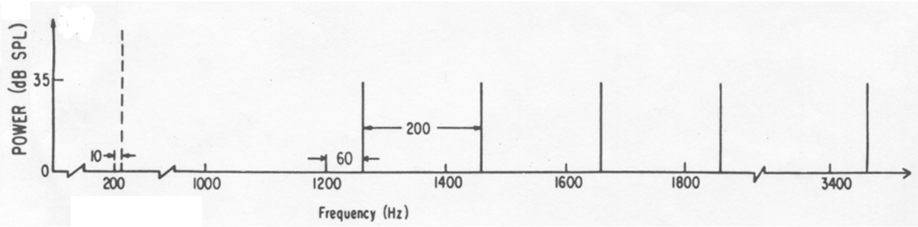


Possible explanations for virtual pitch

Distortion? No, because masking the frequency of the fundamental doesn’t affect the pitch.

One theory was that the ear is producing distortion products at $f_{i+1} - f_i$ which would be the frequency of the fundamental and that we are hearing that distortion.

Possible explanations for virtual pitch

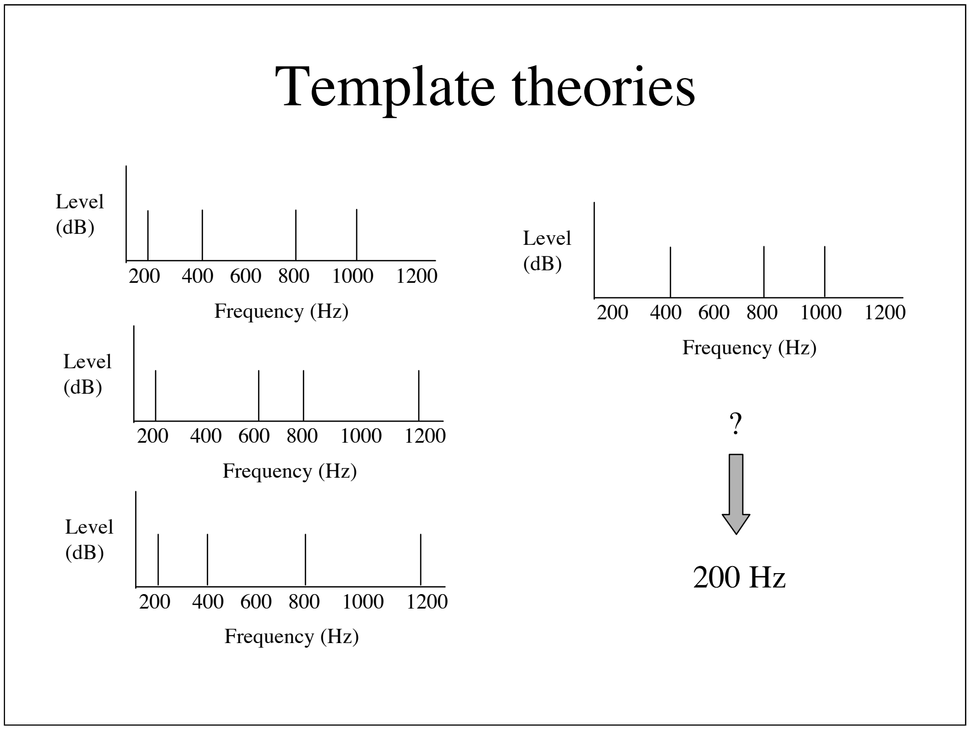


The system isn’t just taking the difference between harmonic frequencies, because shifting the harmonics, but keeping the difference the same, changes the pitch.

Another theory was that the pitch of complex is just the frequency difference between the harmonics.

Two classes of theories of complex pitch

- Template (pattern) theories
  - Place code
- Temporal theories
  - Temporal code (phase locking)



Template theories

The idea behind template or pattern recognition theories is that when we hear periodic sounds, the fundamental is in there, and some harmonics are there, although not always the same ones. But over many experiences with sound you learn a pattern, these harmonics go with that fundamental. So when you hear a sound you compare what you hear with what you have heard in the past and pick the fundamental pitch that matches the best. Even when the fundamental isn’t there the harmonics match best with the pattern or template for the fundamental.

Temporal theories

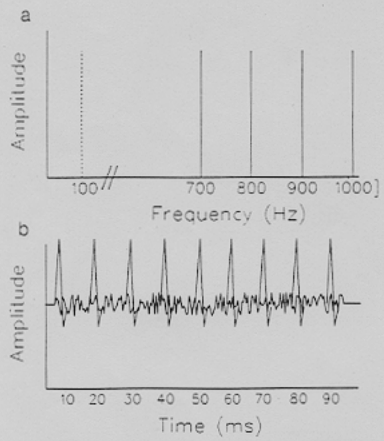
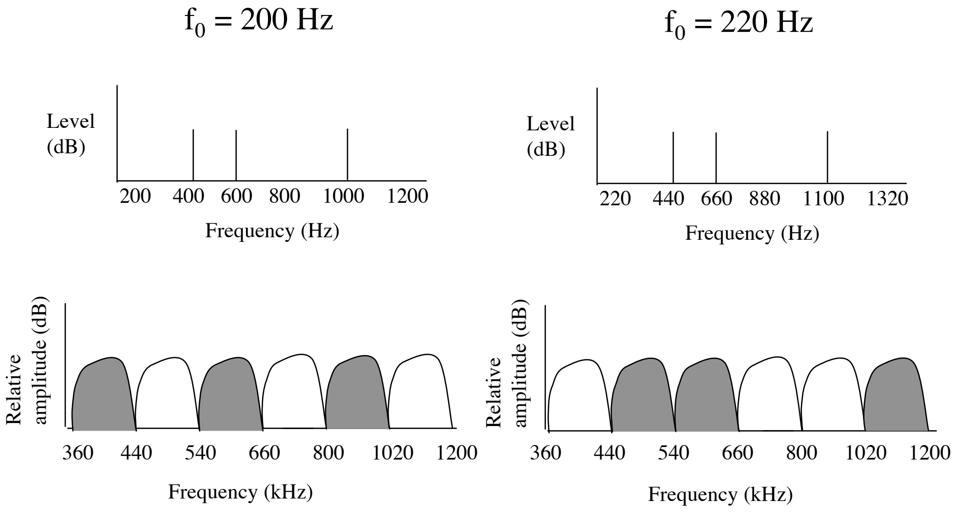


FIGURE 13.3 Amplitude spectrum (13.3a) and time domain (13.3b) description of a complex stimulus of tones of 700. 800. 900. and 1.000 Hz added together with the same starting phase. The dotted line represents the pitch perceived at 100 Hz. though there is no energy at 100 Hz. The time between the major peaks in 13.3b is 10 msec or the period of 100 Hz.

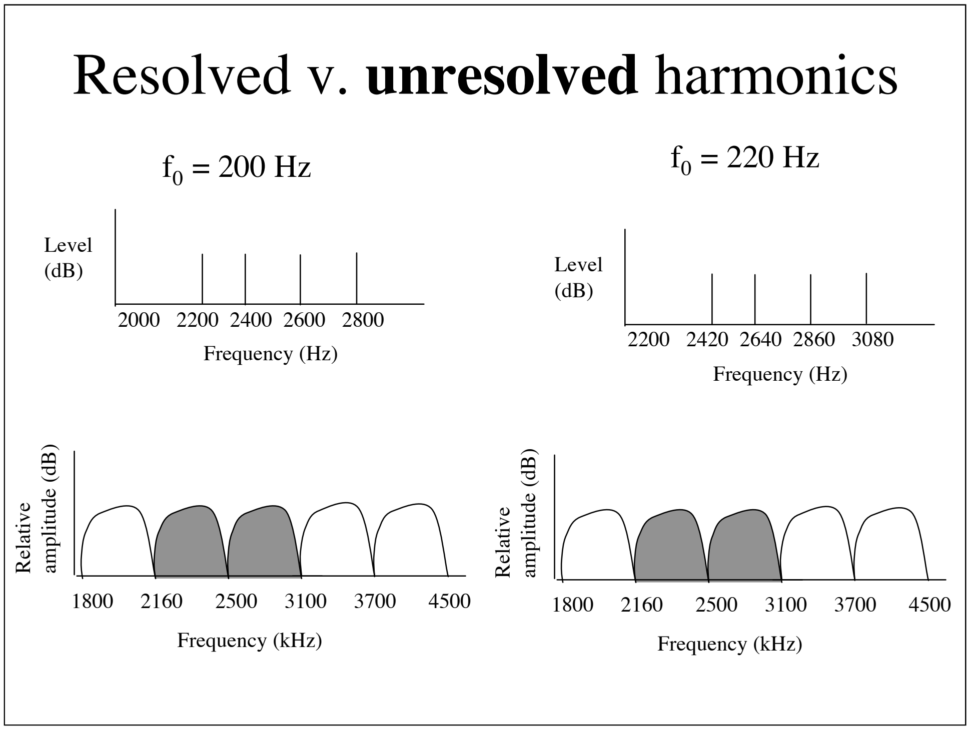
From Yost (1994)

Temporal theories point out that when you combine the harmonics of a given fundamental, even when the fundamental isn’t there, the combined time waveform repeats at the rate of the fundamental frequency. As we know, auditory nerve fibers will be phase-locked to the high positive peaks in the time waveform-- which are at the period of the fundamental. These theories say that that is the information you use to assign a pitch to the complex.

Resolved v. unresolved harmonics



To understand the results of studies that test these theories you have to understand the difference between resolved and unresolved harmonics. Resolved harmonics fall into different auditory filters. A different set of harmonics will create a different activity pattern across auditory filters.



Resolved v. **unresolved** harmonics

Unresolved harmonics pass through the same auditory filter. Different sets of harmonics could create the same pattern of activity across auditory filters. So if you hear different virtual pitches when the harmonics are unresolved, then you can’t be using a template or pattern to do that because the pattern is the same. You could be using temporal information because the combined waveform of the harmonics repeats at the rate of the fundamental frequency.

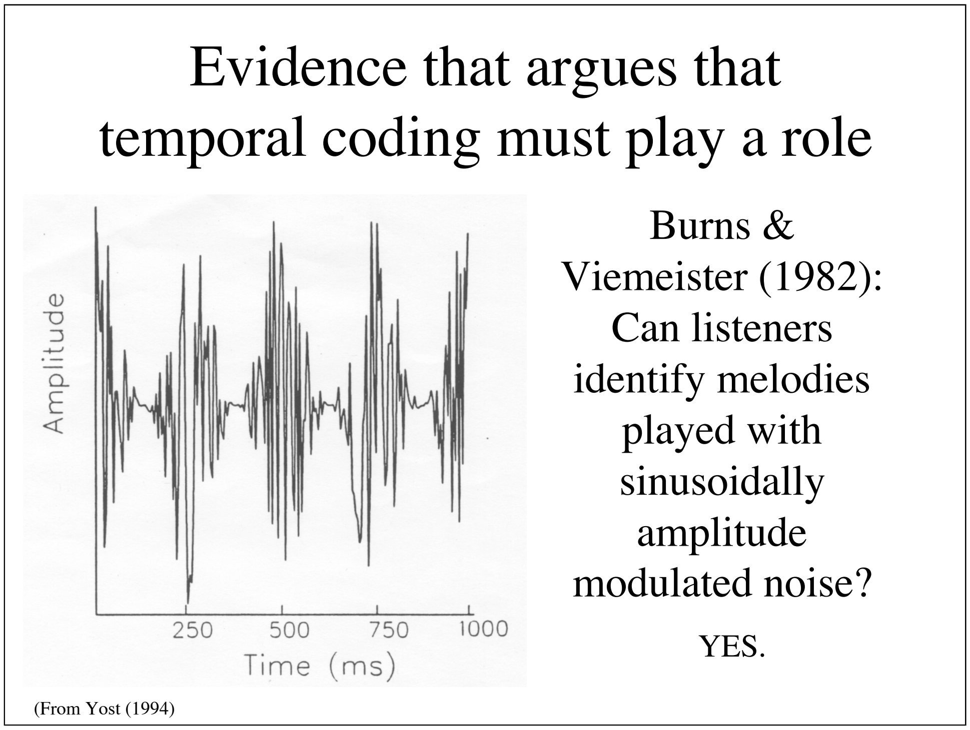
Remember that auditory filters are wider (in terms of linear Hz) at high frequencies. So generally unresolved harmonics will occur at high frequencies. So this would be a case where we areusing phase-locking to low-frequency modulations of a high-frequency carrier to identify sound.

Also notice that this situation is the opposite of the frequency dependence observed for pure-tone frequency discrimination, where the place code was the only code for a high frequency. Now we are using phase locking in high-frequency nerve fibers to identify the pitch.

Template v. temporal theories: Evidence

- Existence region of virtual pitch: Occurs even when all harmonics are unresolved (albeit weaker), but also when all are resolved.
- Dominance region: Resolved harmonics are more important in determining pitch

Studies that show that resolved harmonics produce stronger impressions of pitch than unresolved harmonics support template theories. But because virtual pitch does occur when all harmonics are unresolved, it is clear that temporal information is also being used.



Evidence that argues that temporal coding must play a role

Burns & Viemeister (1982): Can listeners identify melodies played with sinusoidally amplitude modulated noise?

YES.

(From Yost (1994)

A sinusoidally amplitude modulated noise does not create a spectral "pattern"; it elicits about the same activity over the whole basilar membrane. But we know that auditory nerve fibers will phase-lock to the amplitude modulation. But SAM noise has a pitch that corresponds to the rate of amplitude modulation that is strong enough that people can identify melodies played with SAM noise.

Is pitch peripheral?

- Both the place code and the temporal code in the auditory nerve response are used in pitch perception.
- But pitch perception must involve neural, central processes too
  - Where are the templates stored and compared?
  - How are place and temporal information combined?

Pitch perception must involve central processing.

Conclusions

- Both spectral (place) and temporal (phase-locking) information appear to be important in pitch perception.
- The situations in which spectral and temporal information are useful in determining pitch differ.
- There is no consensus on the appropriate scale of pitch.

Text sources

- Gelfand, S.A. (1998) Hearing: An introduction to psychological and physiological acoustics. New York: Marcel Dekker.
- Moore, B.C.J. (1997) An introduction to the psychology of hearing. (4th Edition) San Diego: Academic Press.
- Yost, W.A. (1994) Fundamentals of hearing: an introduction. San Diego: Academic Press.