CENTRO DE INVESTIGACIÓN EN TECNOLOGÍAS DE AUDIO
PONTIFICIA UNIVERSIDAD CATÓLICA DE CHILE

PITCH (PERCEPCIÓN DE ALTURAS)

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Octubre 2011

Discriminación de frecuencia

Demonstration 17. Frequency Difference Limen or JND (2:16)

The ability to distinguish between two nearly equal stimuli is often characterized by a *difference limen* (DL) or *just noticeable difference* (jnd). Two stimuli cannot be consistently distinguished from one another if they differ by less than a jnd.

The jnd for pitch has been found to depend on the frequency, the sound level, the duration of the tone, and the suddenness of the frequency change. Typically, it is found to be about 1/30 of the critical bandwidth at the same frequency.

In this demonstration, 10 groups of 4 tone pairs are presented. For each pair, the second tone may be higher (A) or lower (B) than the first tone. Pairs are presented in random order within each group, and the frequency difference decreases by 1 Hz in each successive group. The tones, 500 ms long, are separated by 250 ms. Following is the order of pairs within each group, where A represents (f,f+Δf), B represents (f+Δf,f), and f equals 1000 Hz:

Group	Δf (Hz)	Key	Group	Δf (Hz)	Key
1	10	A,B,A,A	6	5	A,B,A,A
2	9	A,B,B,B	7	4	B,B,A,A
3	8	B,A,A,B	8	3	A,B,A,B
4	7	B,A,A,B	9	2	B,B,B,A
5	6	A,B,A,B	10	1	B,A,A,B

A = low high
B = high low

Commentary

"You will hear ten groups of four tone pairs. In each group there is a small frequency difference between the tones of a pair, which decreases in each successive group."

References

- B.C.J.Moore (1974), "Relation between the critical bandwidth and the frequency difference limen," J. Acoust. Soc. Am. 55, 359.

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- "Frequency discrimination as a
- E.Zwicker (1970), "Masking and psychological excitation as conseque[illegible] of the ear's frequency analysis," in *Frequency Analysis and Periodicity Detection in Hearing*, ed. R.Plomp and G.F.Smoorenburg (Sijthoff, Leiden).

Demostración 17

Discriminación de frecuencia

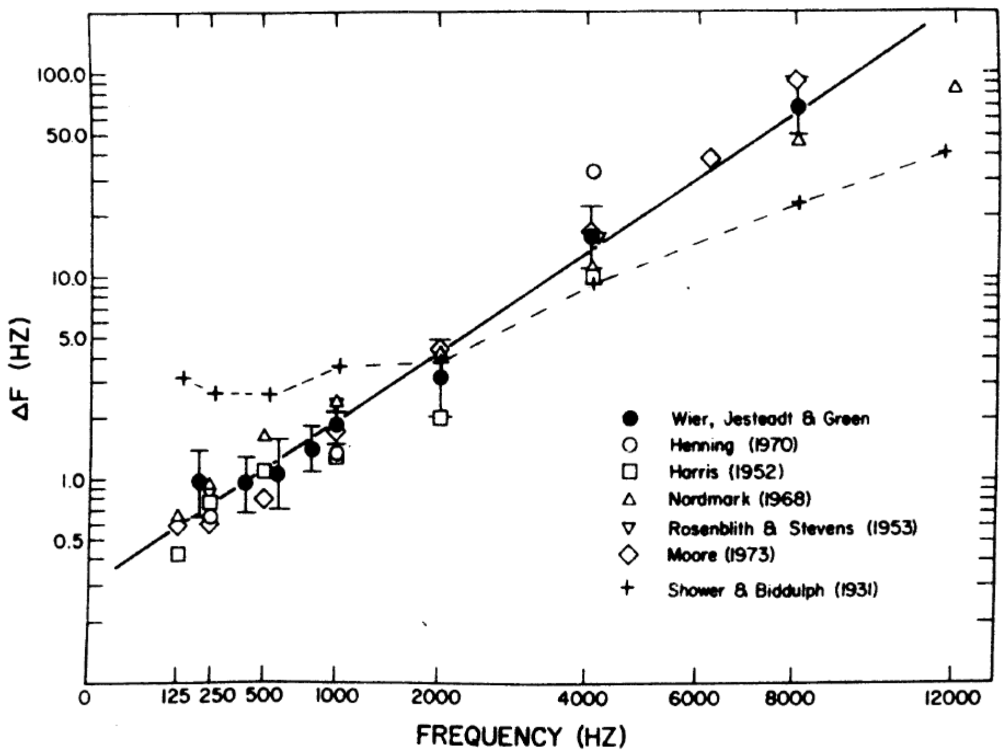

FIG. 2. Data and function from this experiment for 40 dB SL. Data of other authors are for stimulus levels from 30 to 50 dB SL. All the data are for pulsed sinusoids except Shower and Biddulph. Data for Nordmark (1968) have been multiplied by $2\times\sqrt{2}$ to account for differences in procedure (see Wier, Jesteadt, and Green, 1976; Jesteadt and Wier, 1977).

Wier, C.C., Jesteadt, W., and Green, D.M. (1977). "Frequency discrimination as a function of frequency and sensation level," J. Acoust. Soc. Am., 61, 178-184.

Discriminación de frecuencia y pérdida auditiva

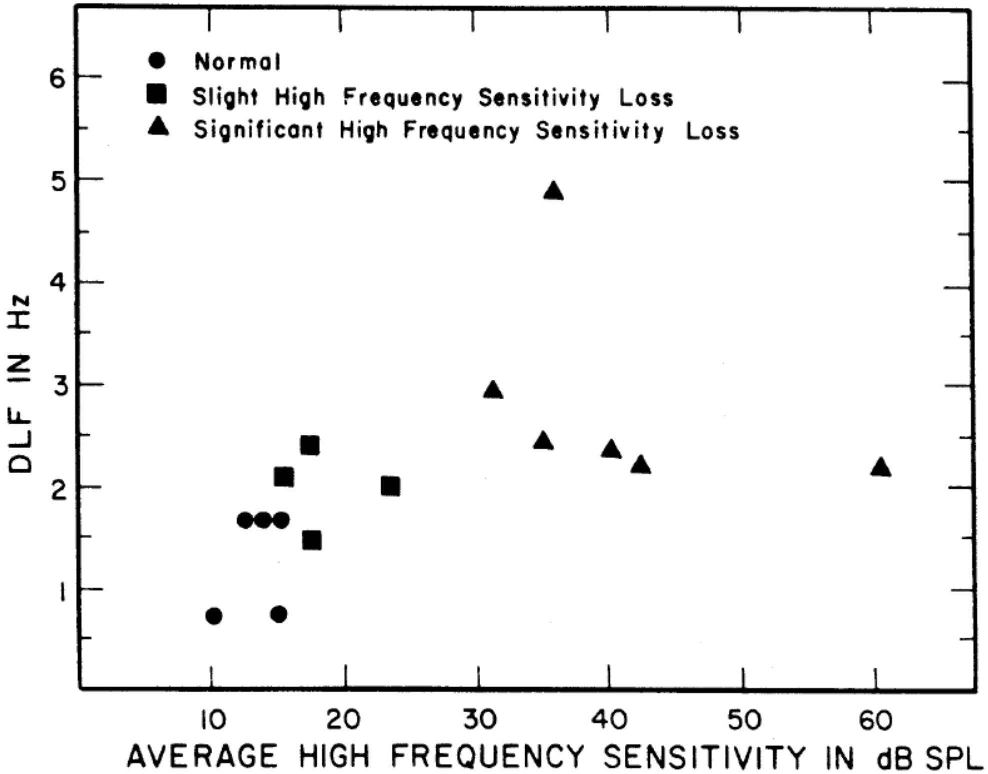

FIGURE 6. DLFs at 1200 Hz as a function of average high frequency sensitivity for 2.0, 3.0, 4.0, 5.6, and 8.0 kHz tones. The figure symbols refer to the listener groups of Figure 5.

Turner, C.W., and Nelson, D.A. (1982). "Frequency discrimination in regions of normal and impaired sensitivity," J. Speech and Hear. Res. 25, 34-41.

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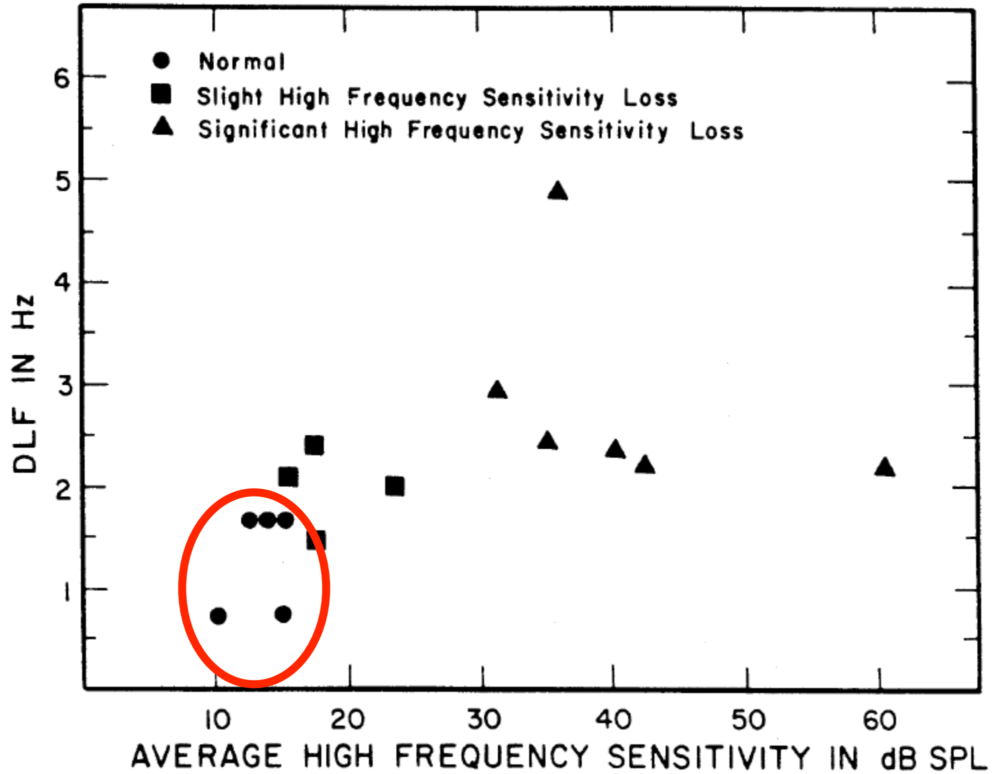
Discriminación de frecuencia y pérdida auditiva



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Discriminación de frecuencia y pérdida auditiva

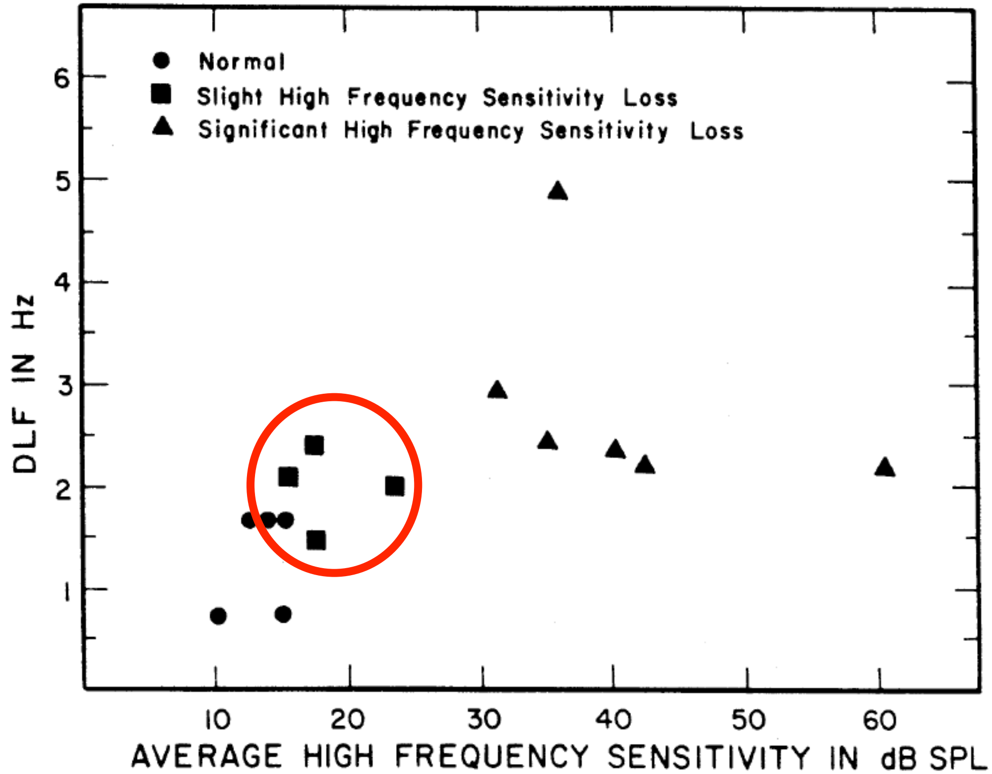

FIGURE 6. DLFs at 1200 Hz as a function of average high frequency sensitivity for 2.0, 3.0, 4.0, 5.6, and 8.0 kHz tones. The figure symbols refer to the listener groups of Figure 5.

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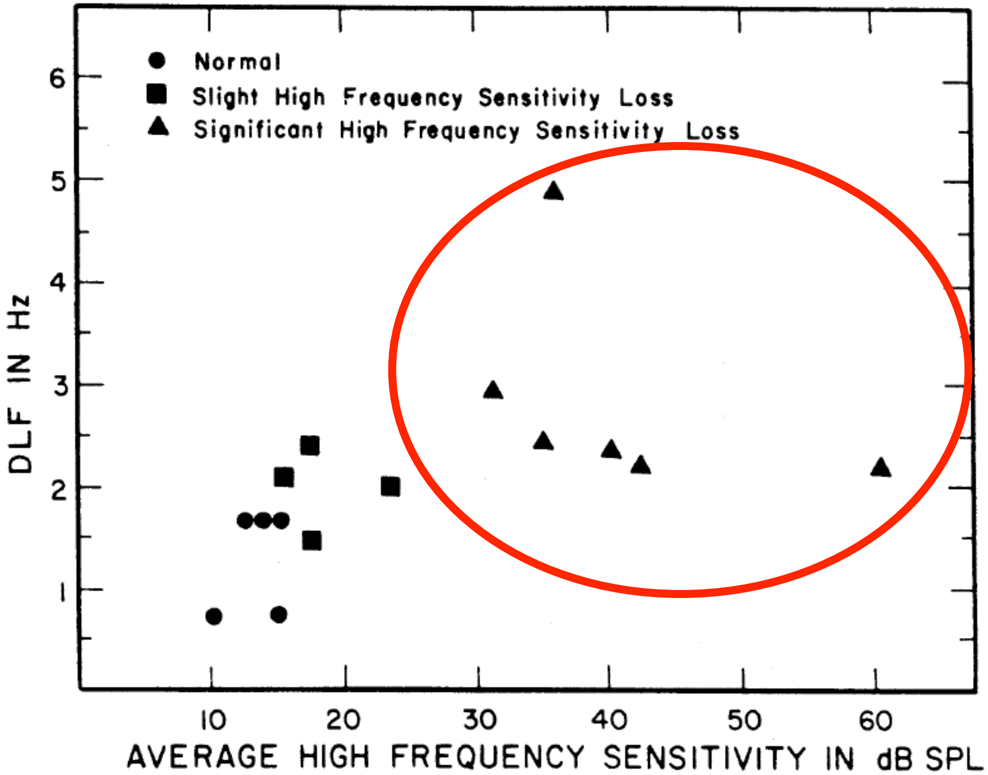
Discriminación de frecuencia y pérdida auditiva



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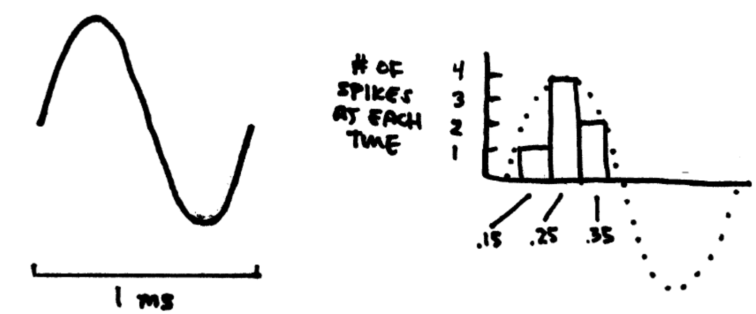
Turner, C.W., and Nelson, D.A. (1982). "Frequency discrimination in regions of normal and impaired sensitivity," J. Speech and Hear. Res. 25, 34-41.

Bloqueo de fase (Phase locking)



NEURAL SPIKE	TIME OF SPIKE	CYCLE #
	0.25 ms	1
	0.35 ms	2
	0.25 ms	3
	0.25 ms	4
	0.15 ms	5
	0.25 ms	6
	0.35 ms	7

Bloqueo de fase (Phase locking)

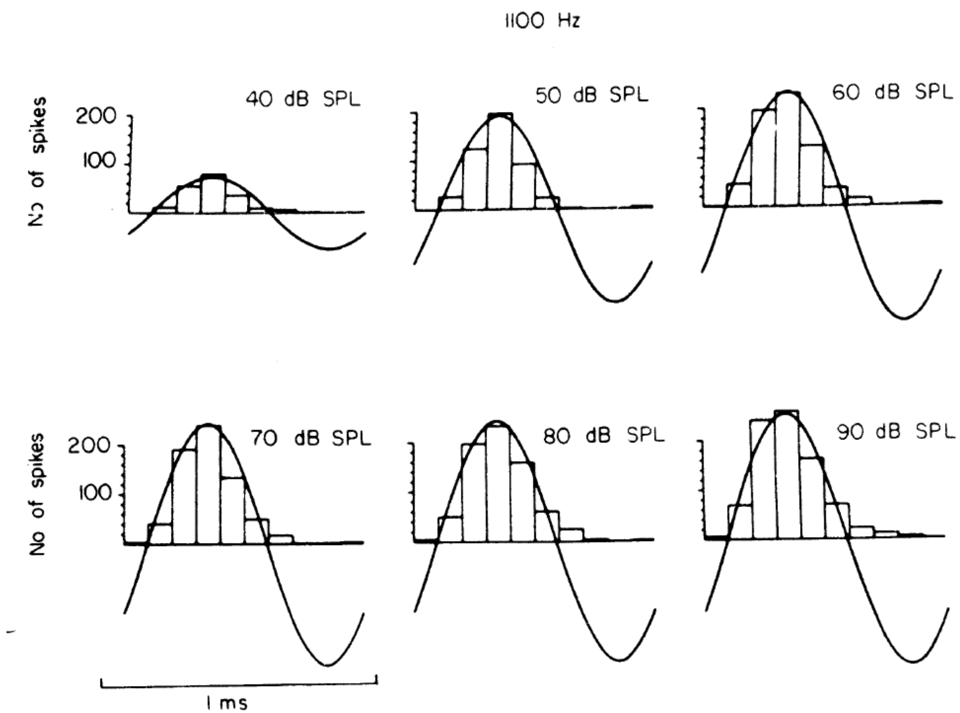
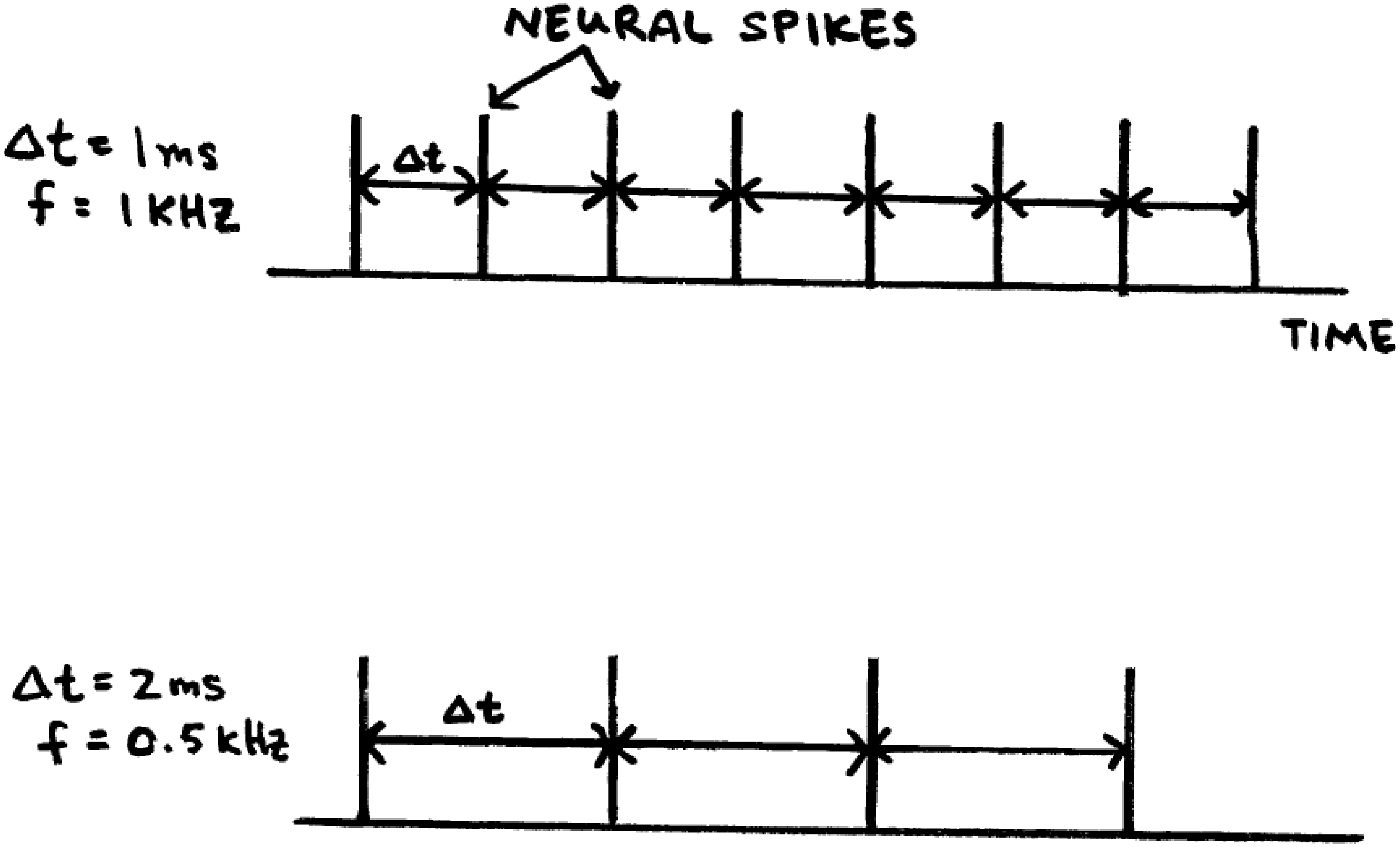


Fig. 4.8 Period histograms of a fibre activated by a low-frequency tone indicate that spikes are evoked in only one-half of the cycle. The histograms have been fitted with a sinusoid of the best fitting amplitude but fixed phase. Note that although the number of spikes increases little above 70 dB SPL, meaning that the firing is saturated, the histogram still follows the sinusoid without any tendency to square. From Rose *et al*. (1971, Fig. 10).

Rose, J.E., Hind, J.E., Anderson, D.J., and Brugge, J.F. (1971). Some effects of stimulus intensity on response of auditory nerve fibers in the squirrel monkey. J. Neurophysiol. 34, 685-699.

Teoría temporal



Límite del bloqueo de fase (Phase locking)

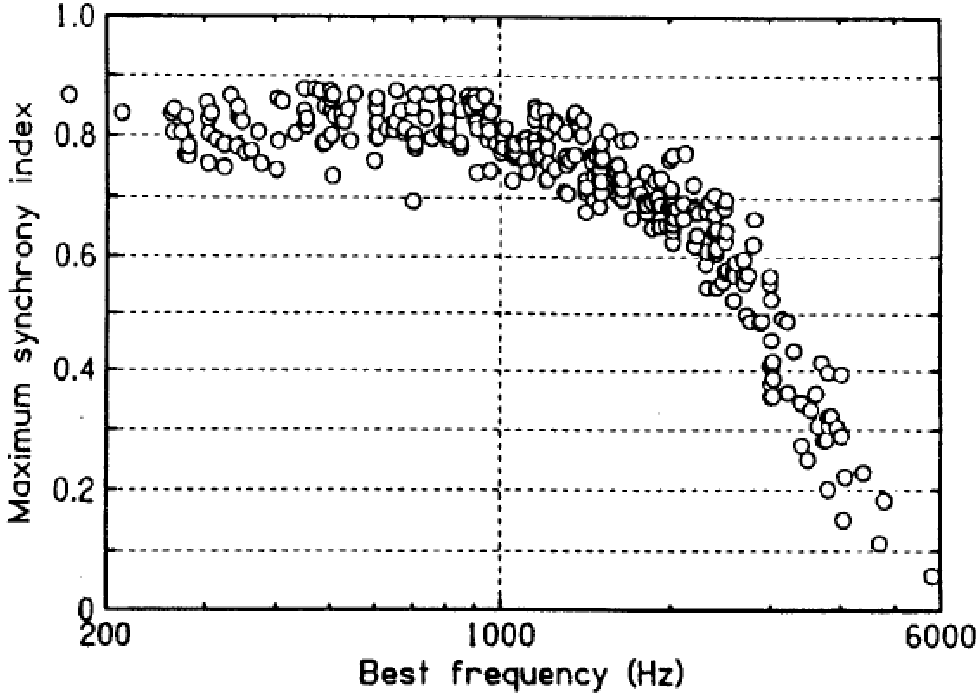


Fig. 10: Synchrony coefficient for 315 neurons as measured by D.H. Johnson who provided data for this plot; Courtesy AIP Press.

Johnson, D.H. (1980). "The relationship between spike rate and synchrony in responses of auditory-nerve fibers to single tones." J. Acoust. Soc. Am. 68, 1115-1122

Teoría del lugar

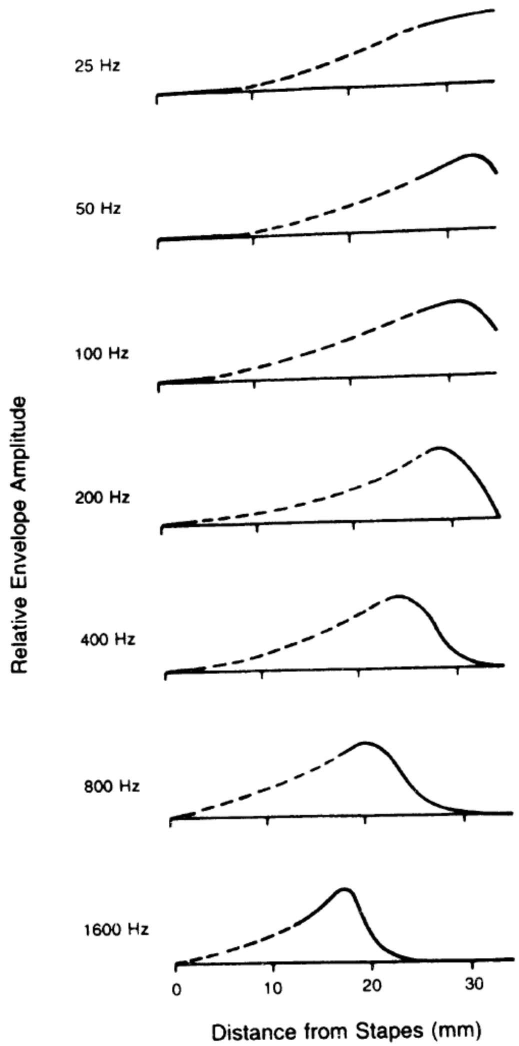


FIG. 1.9 Envelopes of patterns of vibration on the basilar membrane for a number of low-frequency sinusoids. Solid lines indicate the results of actual measurements, while the dashed lines are von Békésy's extrapolations. From von Békésy (1960), used with the permission of McGraw-Hill.

von Bekesy, G. (1960). *Experiments in Hearing* McGraw-Hill, New York.

Pitch de ruido de amplitud modulada

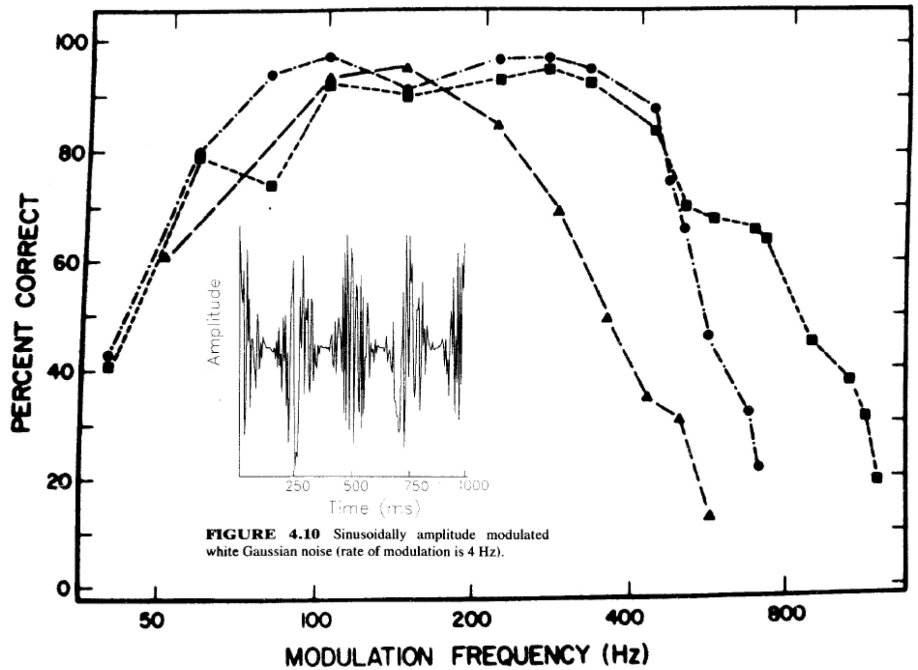


FIG. 1. Existence region for the pitch of AM noise. The ordinate is percent correct responses in musical interval recognition; chance performance corresponds to 20% correct. The abscissa is the modulation frequency of the higher frequency note of the tritone. The interval separation was 300 cents and the modulation index was 1.0. Symbols indicate observers (●, I2; ▲, I3; ■, I4).

Burns, E.M., and Viemeister, N.F. (1976). "Nonspectral pitch," J. Acoust. Soc. Am., 60, 863-869.

August Seebeck

Sirena de Seebeck

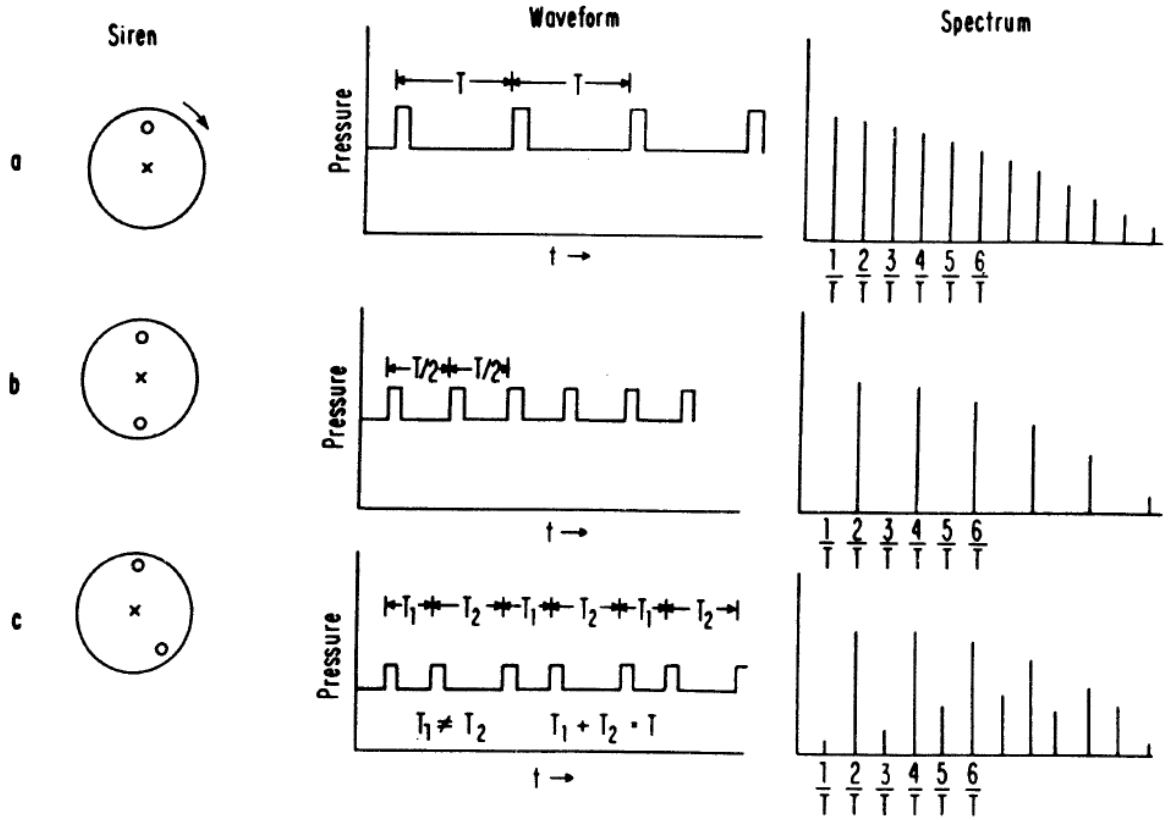
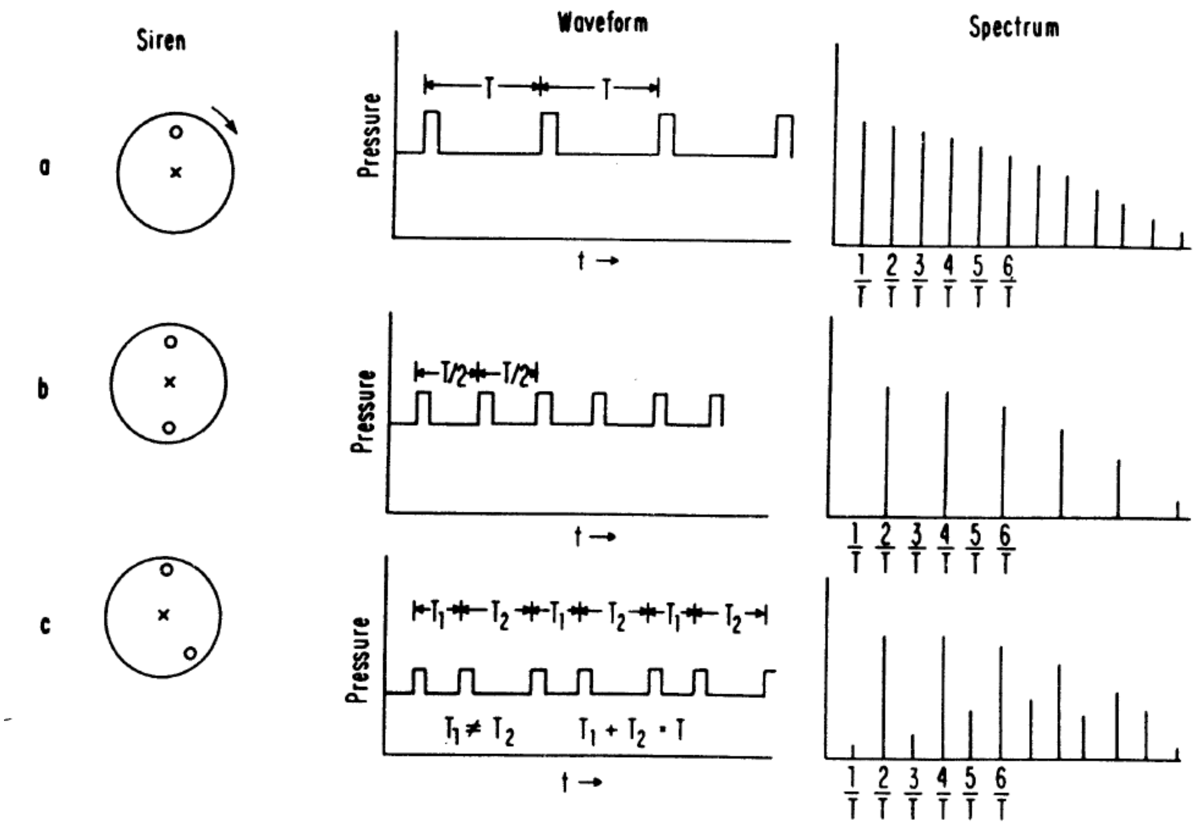


Figure 6.4. Seebeck's siren experiment. The sirens, the waveforms, and the spectra of the sounds are shown in columns of the figure. See text for a discussion of the experiment.

Seebeck, A. (1841). "Beohachtungen uber einige Bedingungen der Entstehung von Tonen. Annalen der Physik und Chemie, 53, 417-436.

Sirena de Seebeck



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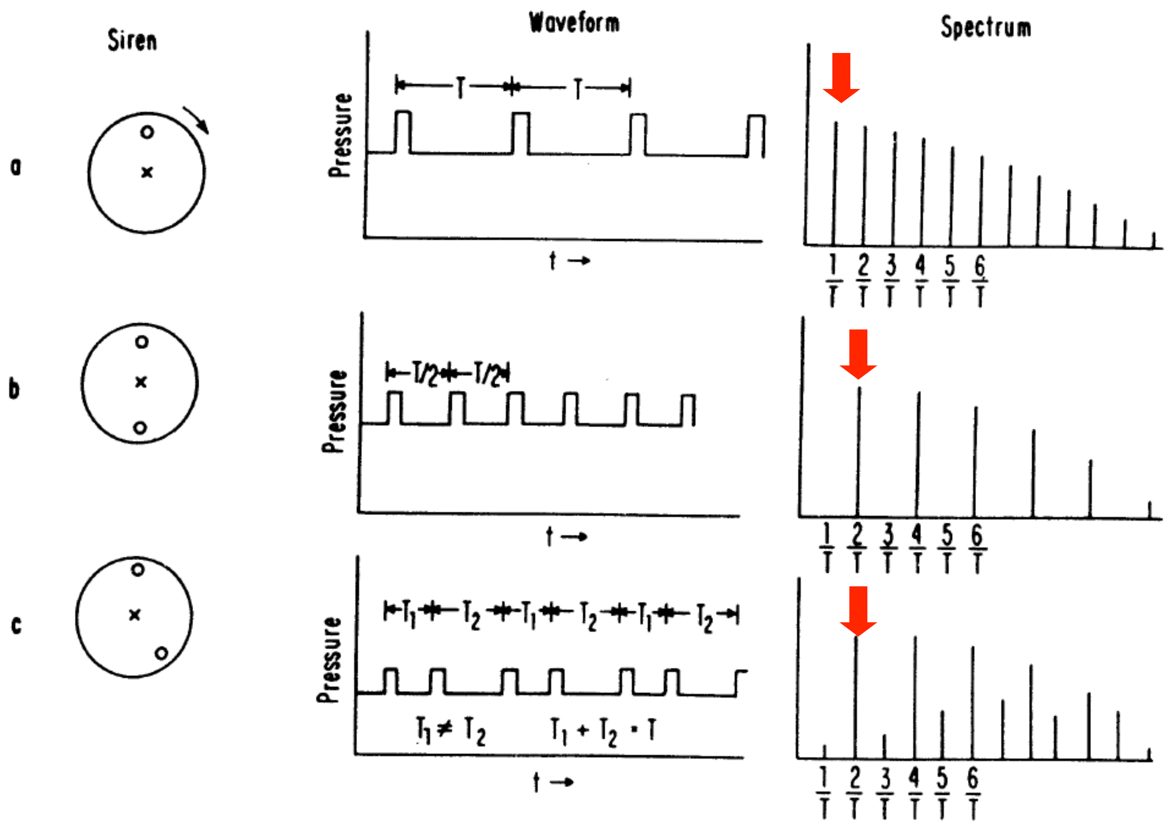
De acuerdo a la teoría del lugar, el pitch se basa en el menor componente de frecuencia con mayor amplitud (typicamente la fundamental).

Sirena de Seebeck



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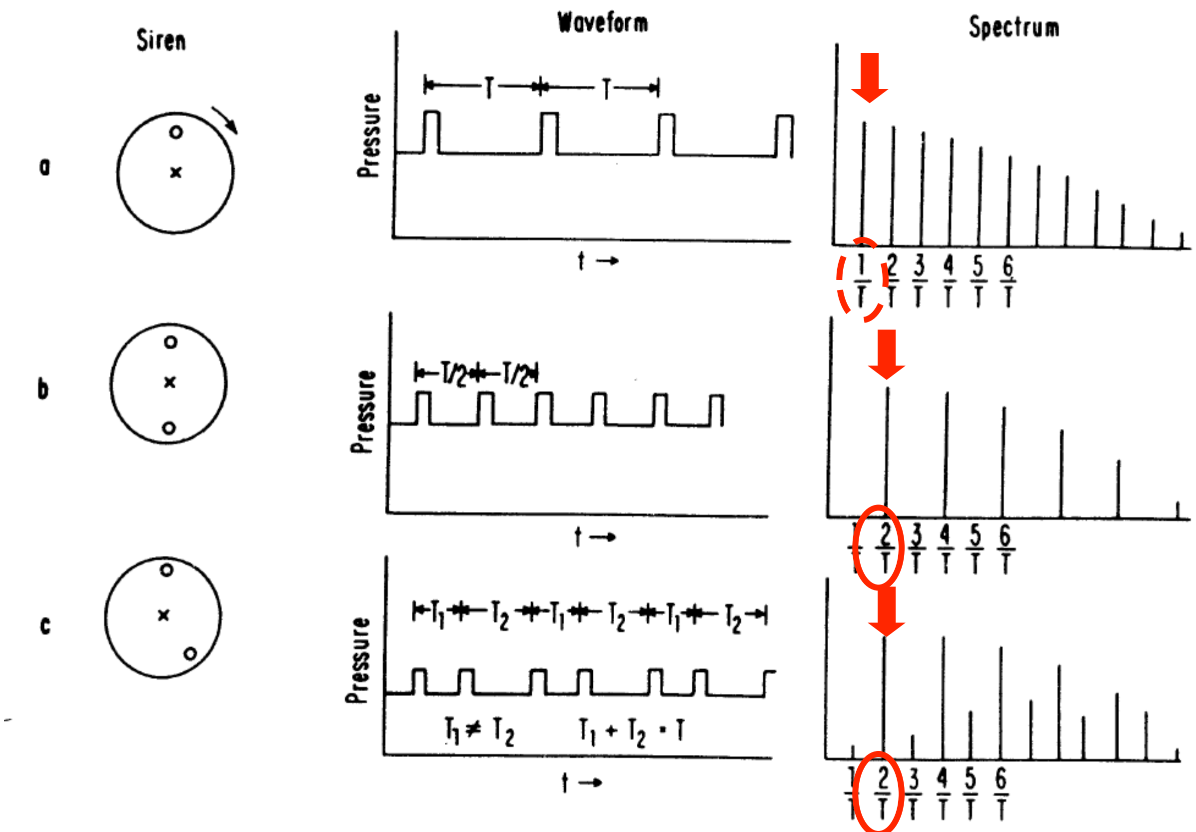

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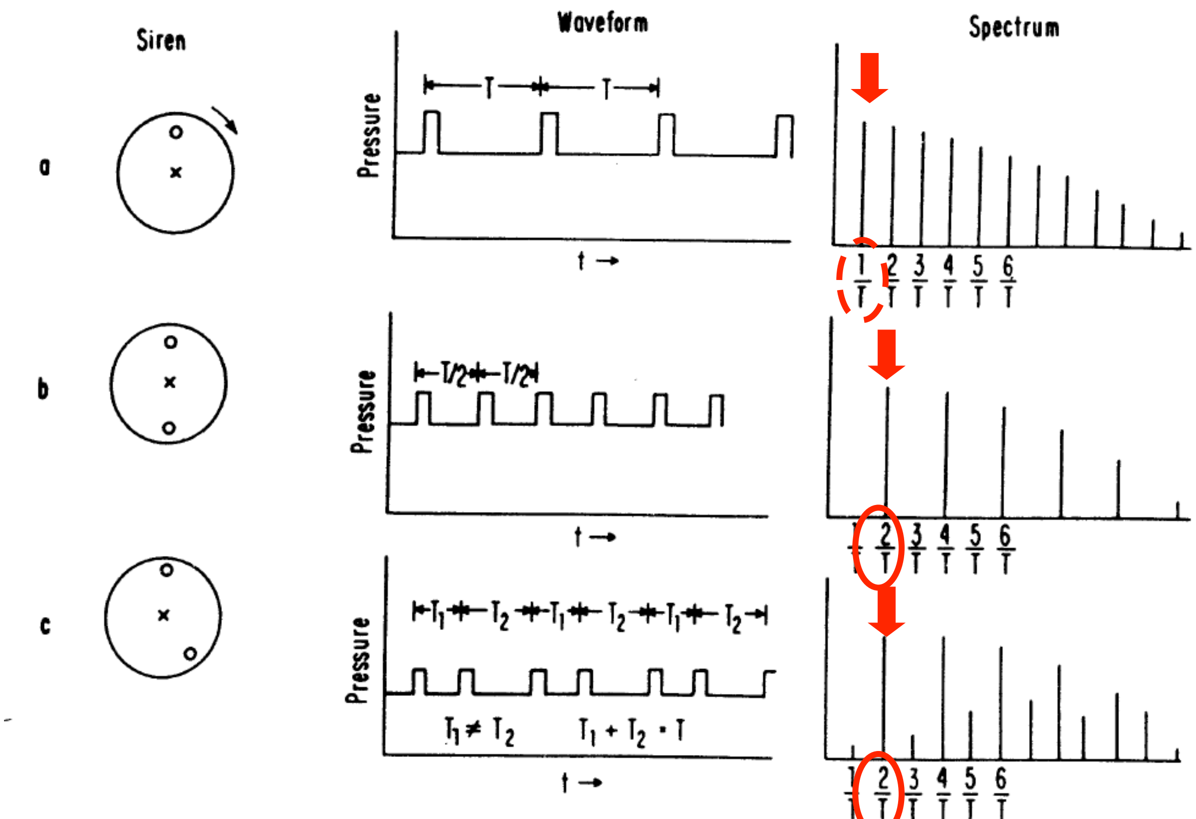

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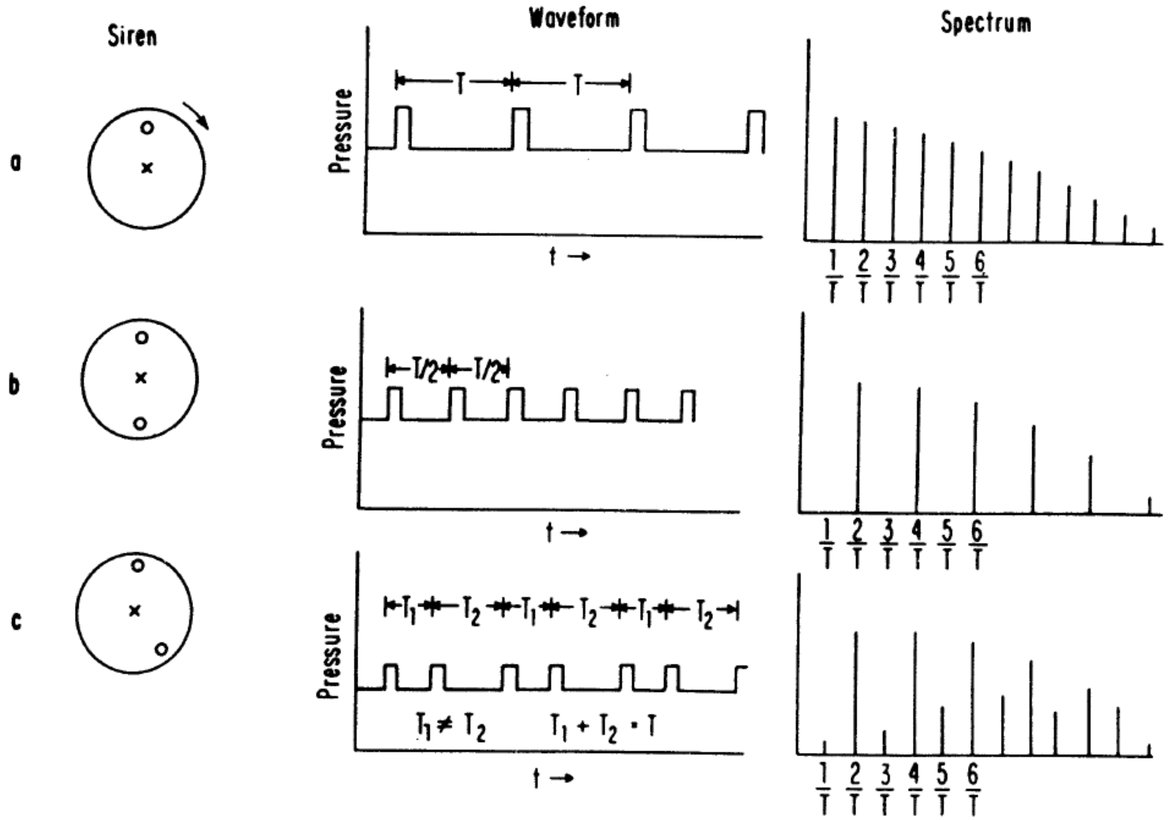
Entonces, b y c deben tener el mismo pitch

Sirena de Seebeck



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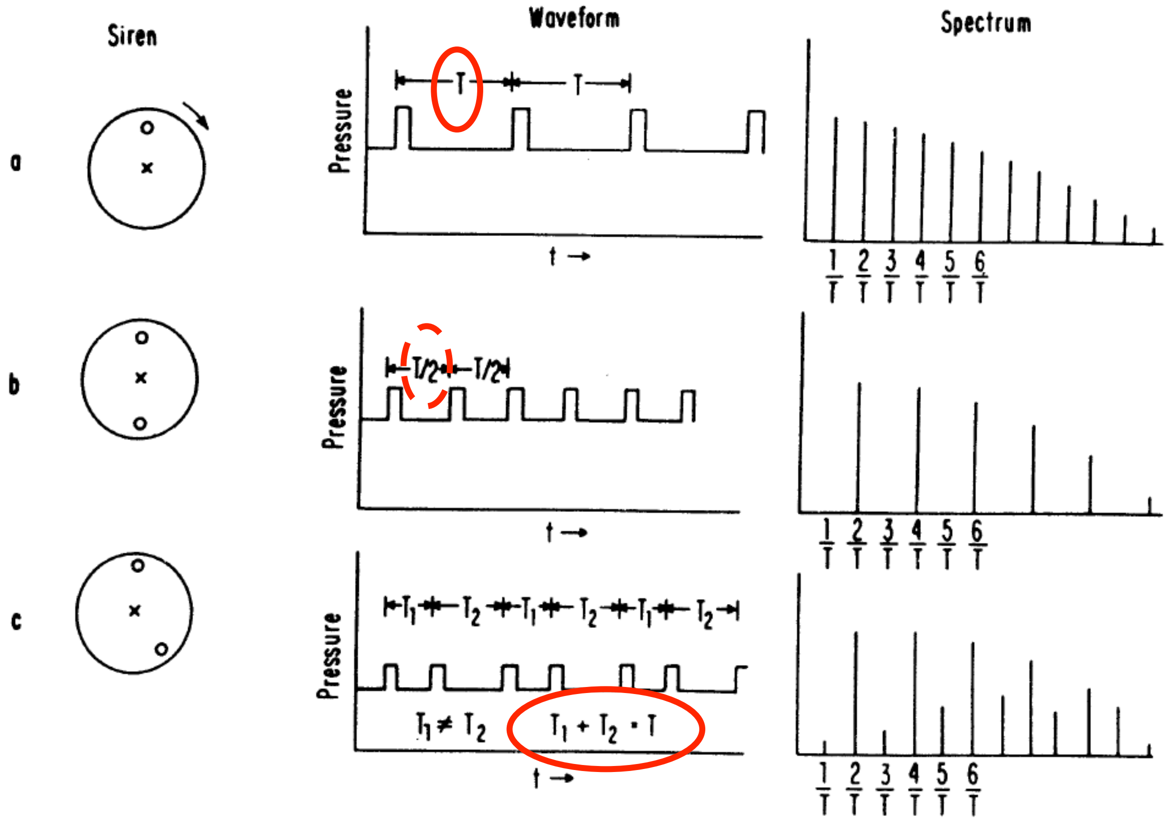
De acuerdo a la teoría temporal, el pitch se basa en el período de la onda.

Sirena de Seebeck



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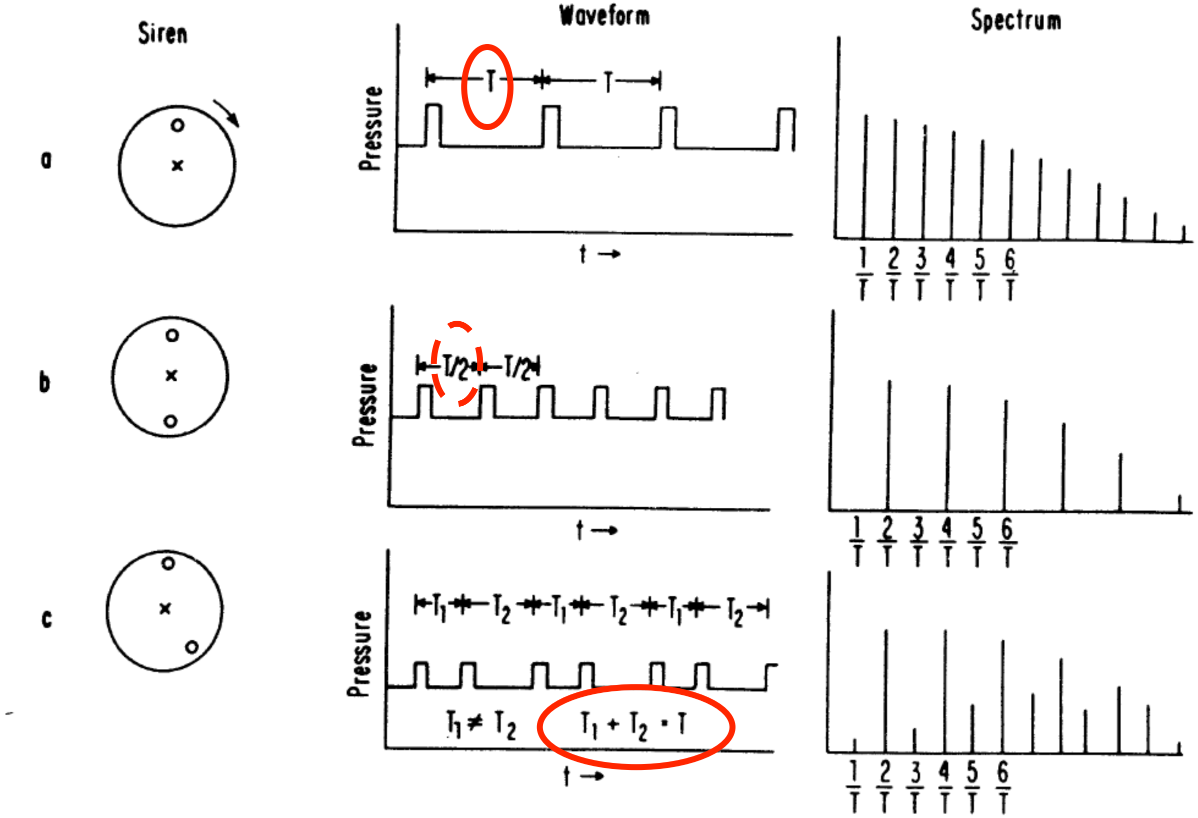

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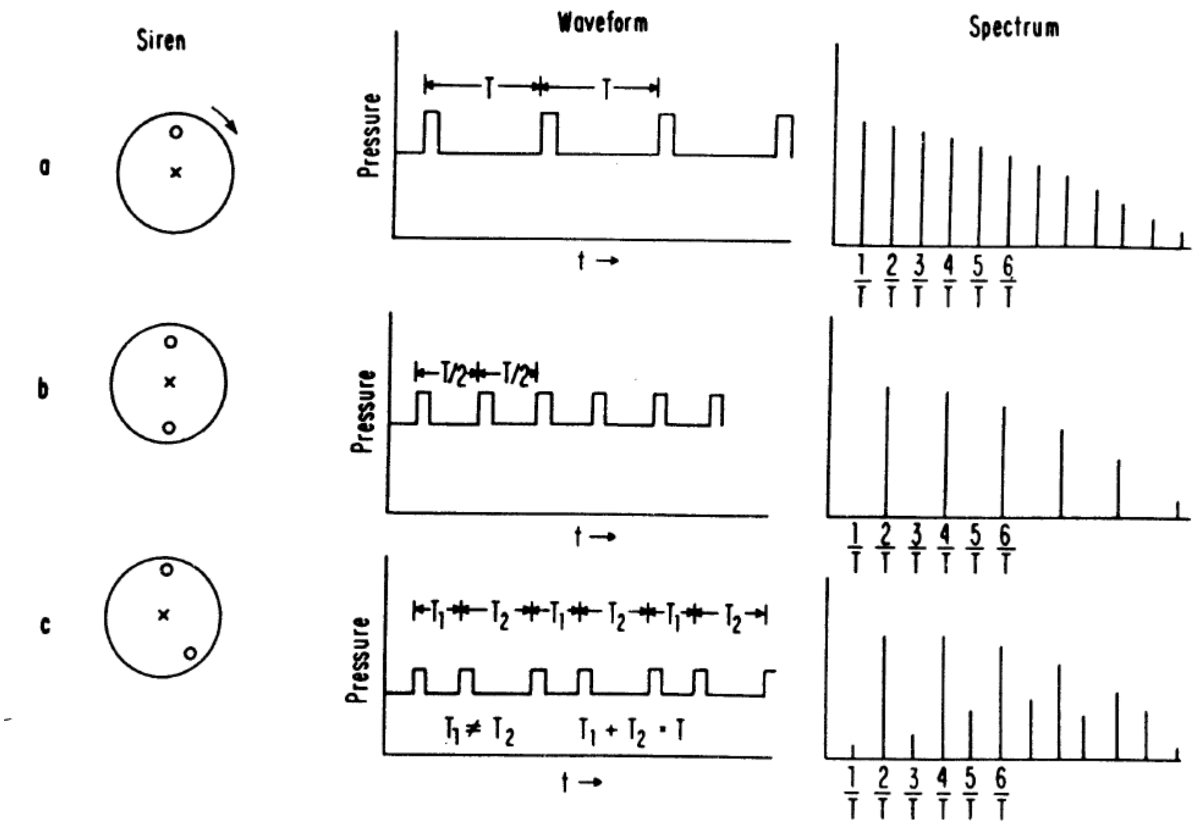
Entonces, a y c deben tener el mismo pitch

Sirena de Seebeck



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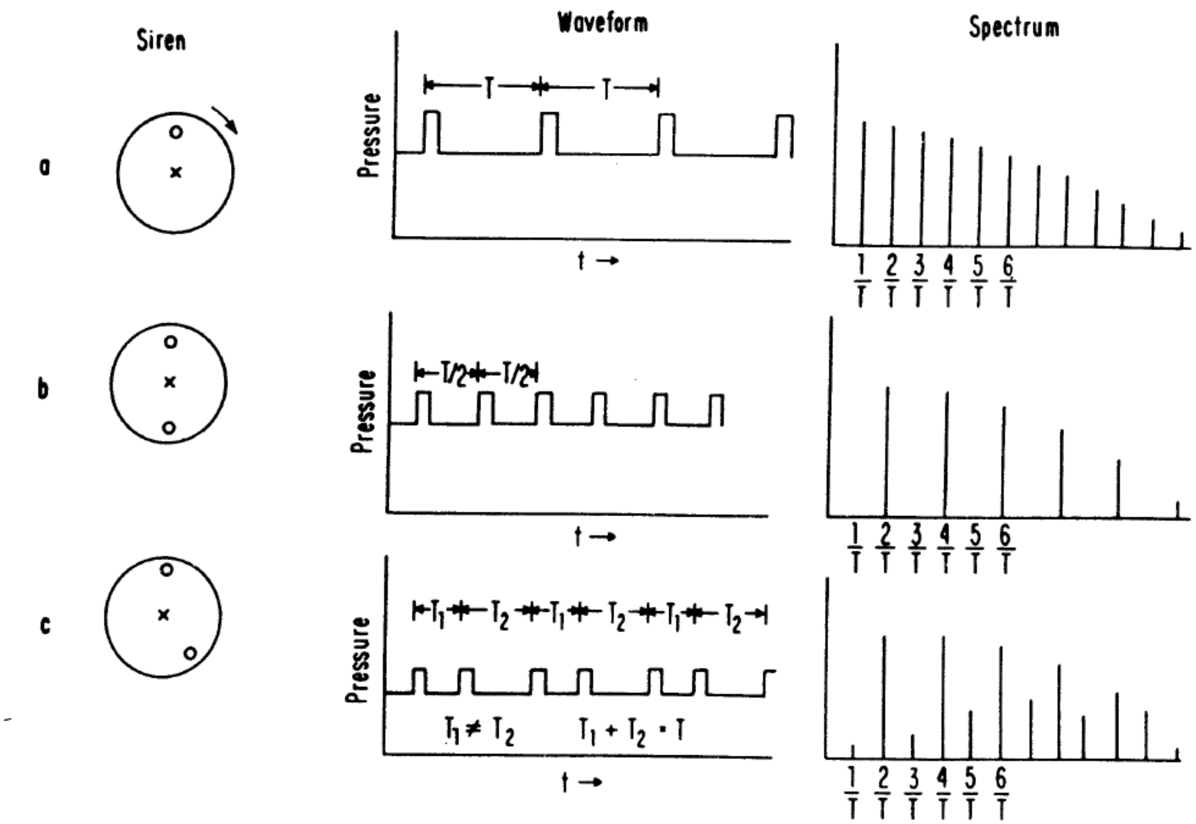
Teoría del lugar:
b and c.

Teoría temporal:
a and c.

Sirena de Seebeck



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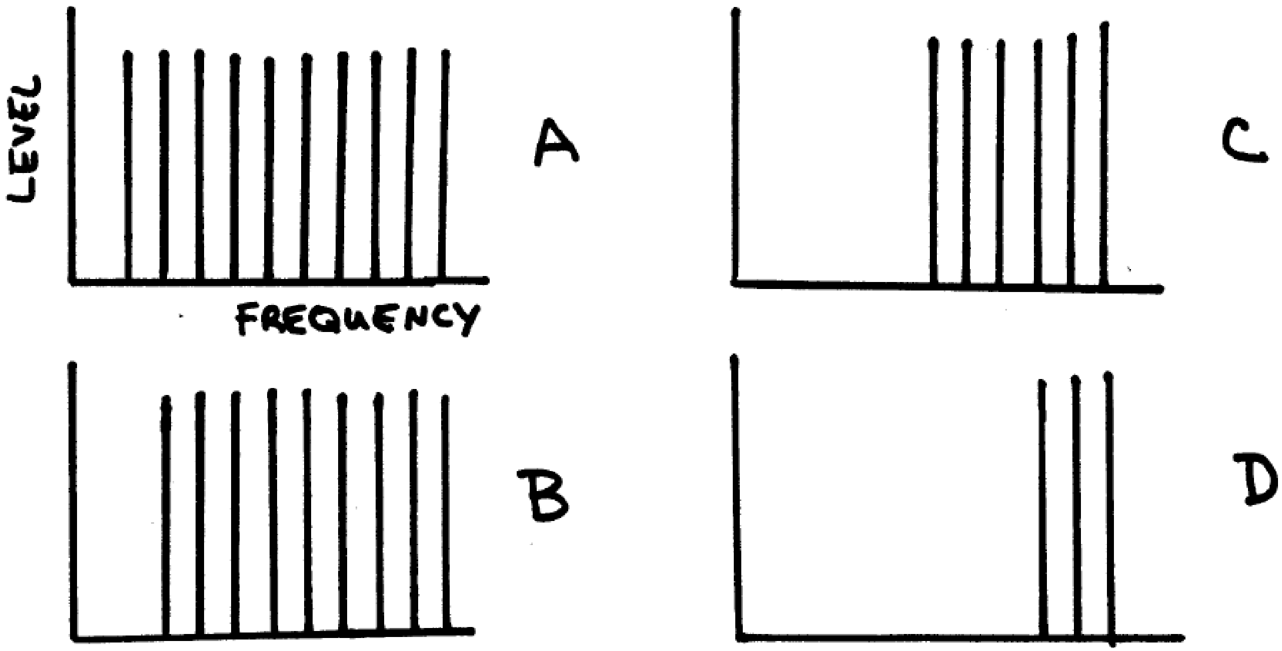
Teoría del lugar:
b and c.

Teoría Temporal:
a and c.

Tono Virtual

A: Todos los armónicos presentes
B: 1 armónico removido (la fundamental)
C: 4 armónicos removidos
D: 7 armónicos removidos



Tono Virtual

Demonstration 20. Virtual Pitch (0:41)

A complex tone consisting of 10 harmonics of 200 Hz having equal amplitude is presented, first with all harmonics, then without the fundamental, then without the two lowest harmonics, etc. Low-frequency noise (300-Hz lowpass, -10 dB) is included to mask a 200-Hz difference tone that might be generated due to distortion in playback equipment.

Commentary

"You will hear a complex tone with 10 harmonics, first complete and then with the lower harmonics successively removed. Does the pitch of the complex change ? The demonstration is repeated once."

References

- A.J.M.Houtsma and J.L.Goldstein (1972), "The central origin of the pitch of complex tones: evidence from musical interval recognition," J. Acoust. Soc. Am. *51*, 520-529.
- J.F.Schouten (1940), "The perception of subjective tones," Proc. Kon. Ned. Akad. Wetenschap *41*, 1086-1093.
- A.Seebeck (1841), "Beobachtungen über einige Bedingungen der Entstehung von Tönen," Ann. Phys. Chem. *53*, 417-436.

Tono Virtual o Missing Fundamental

Evidencia en contra de la teoría del lugar (Schouten, 1940)

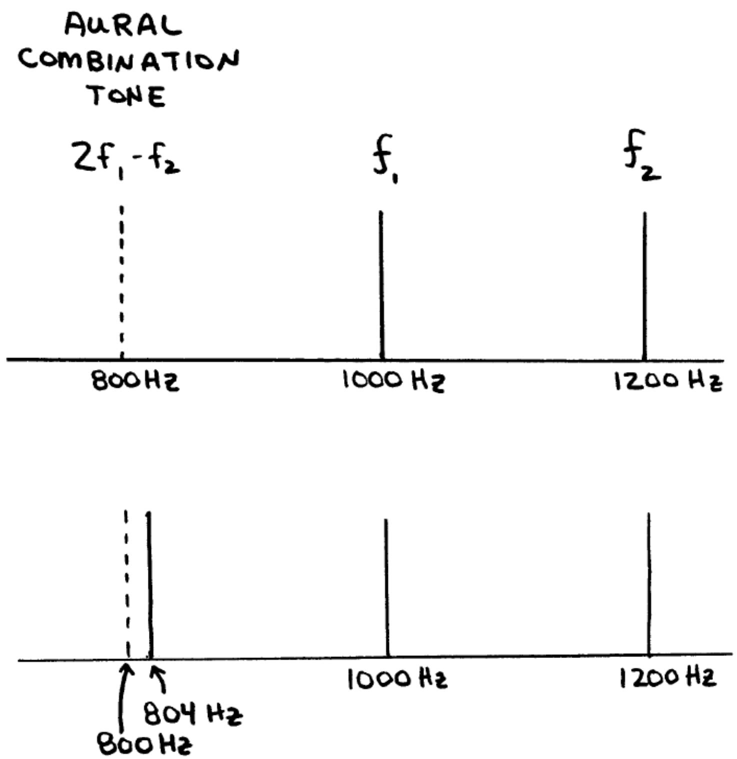
- Escucha cerca del umbral
- Enmascaramiento
- Pitch shift

Evidencia en contra de la teoría temporal

- Región dominante
- Cross-ear pitch

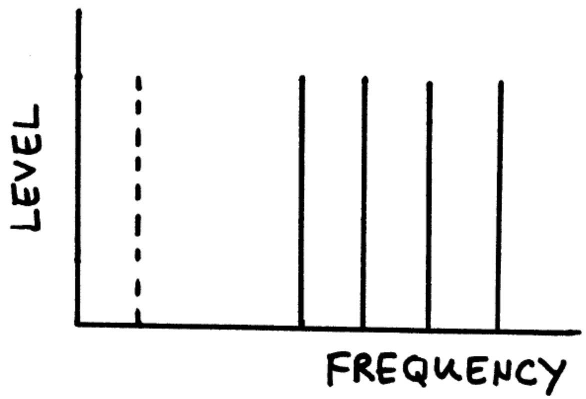
No-linearidad auditiva

…distorsion producida por el sistema auditivo mismo

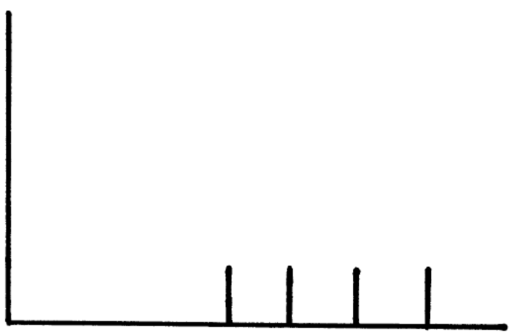


Demostración 34

Tono Virtual : Escucha cerca del umbral



Sonidos de alta intensidad producen distorsión.



Sonidos de baja intensidad no lo hacen.

Los auditores pueden detectar un tono virtual aún con sonidos de baja intensidad, por lo tanto el tono virtual no se debe a la distorsión.

Tono Virtual: Enmascaramiento

Demonstration 22. Masking Spectral and Virtual Pitch (1:28)

This demonstration uses masking noise of high and low frequency to mask out, alternately, a melody carried by single pure tones of low frequency and the same melody resulting from virtual pitch from groups of three tones of high frequency (4th, 5th and 6th harmonics). The inability of the low-frequency noise to mask the virtual pitch in the same range points out the inadequacy of the place theory of pitch.

Commentary

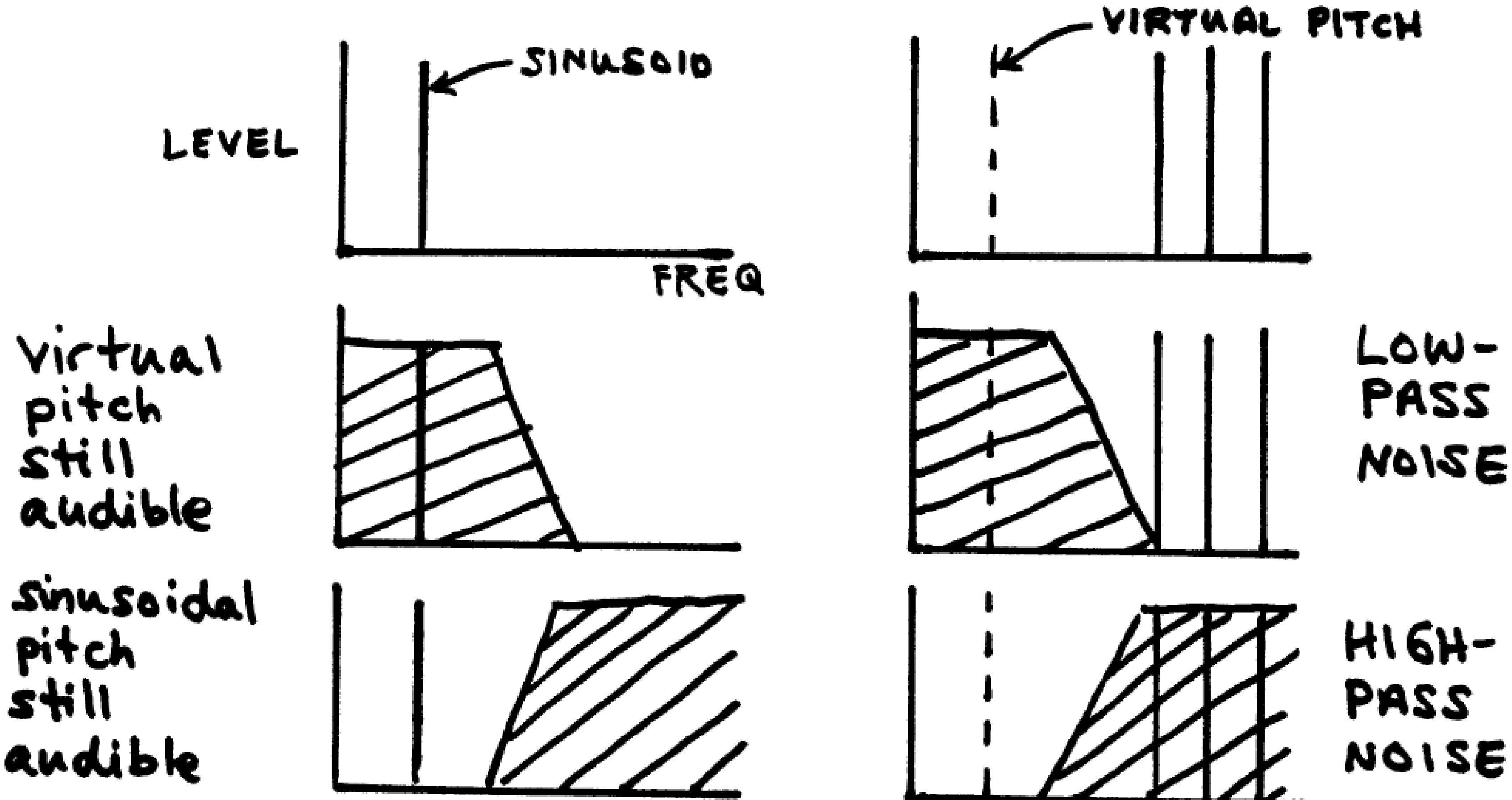
> "You will hear the familiar Westminster chime melody played with pairs of tones. The first tone of each pair is a sinusoid, the second a complex tone of the same pitch."
> "Now the pure-tone notes are masked with low-pass noise. You will still hear the pitches of the complex tone"
> "Finally the complex tone is masked by high-pass noise. The pure-tone melody is still heard".

References

- J.C.R.Licklider (1955), "Influence of phase coherence upon the pitch of complex tones," J. Acoust. Soc. Am. *27*, 996 (A)
- R.J.Ritsma and B.L.Cardozo (1963/64), "The perception of pitch," Philips Techn. Review *25*, 37-43.

Demostración 22

Tono Virtual: Enmascaramiento



Tono Virtual: Pitch shift

Demonstration 21. Shift of Virtual Pitch (1:08)

A tone having strong partials with frequencies of 800, 1000, and 1200 Hz will have a virtual pitch corresponding to the 200-Hz missing fundamental, as in Demonstration 20. If each of these partials is shifted upward by 20 Hz, however, they are no longer exact harmonics of any fundamental frequency around 200 Hz. The auditory system will accept them as being "nearly harmonic" and identify a virtual pitch slightly above 200 Hz (approximately $\frac{1}{3}(\frac{820}{4}+\frac{1020}{5}+\frac{1220}{6}) = 204$ Hz in this case). The auditory system appears to search for a "nearly common factor" in the frequencies of the partials.

Note that if the virtual pitch were created by some kind of distortion, the resulting difference tone would remain at 200 Hz when the partials were shifted upward by the same amount.

In this demonstration, the three partials in a complex tone, 0.5 s in duration, are shifted upward in ten 20-Hz steps while maintaining a 200-Hz spacing between partials. You will almost certainly hear a virtual pitch that rises from 200 to about $\frac{1}{3}(\frac{1000}{4}+\frac{1200}{5}+\frac{1400}{6}) = 241$ Hz. At the same time, you may have noticed a second rising virtual pitch that ends up at $\frac{1}{3}(\frac{1000}{5}+\frac{1200}{6}+\frac{1400}{7}) = 200$ Hz and possibly even a third one, as shown in Fig. 2 in Schouten et al. (1962)

In the second part of the demonstration it is shown that virtual pitches of a complex tone having partials of 800, 1000, and 1200 Hz and one having partials of 850, 1050, and 1250 Hz can be matched to harmonic complex tones with fundamentals of 200 and 210 Hz respectively.

Commentary

"You will hear a three-tone harmonic complex with its partials shifted upward in equal steps until the complex is harmonic again. The sequence is repeated once".
"Now you hear a three-tone complex of 800, 1000 and 1200 Hz, followed by a complex of 850, 1050 and 1250 Hz. As you can hear, their virtual pitches are well matched by the regular harmonic tones with fundamentals of 200 and 210 Hz. The sequence is repeated once"

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References

- J.F.Schouten, R.L.Ritsma and B.L.Cardozo (1962), "Pitch of the residue," J. Acoust. Soc. Am. 34, 1418-1424
- G.F.Smoorenburg (1970), "Pitch perception of two-frequency stimuli," J. Acoust. Soc. Am. 48, 926-942.

Demostración 21

Tono Virtual: Pitch shift

First demonstration
(all values are in Hz)

3-tone complex			fundamental	pitch	expected from distortion
800	1000	1200	200	200	200
820	1020	1220	20		
840	1040	1240			
860	1060	1260			
880	1080	1280			
900	1100	1300	100		
920	1120	1320			
940	1140	1340			
980	1180	1380			
1000	1200	1400	200	200/241	

Second demonstration

800	1000	1200	200
850	1050	1250	210

Tono Virtual: Pitch shift

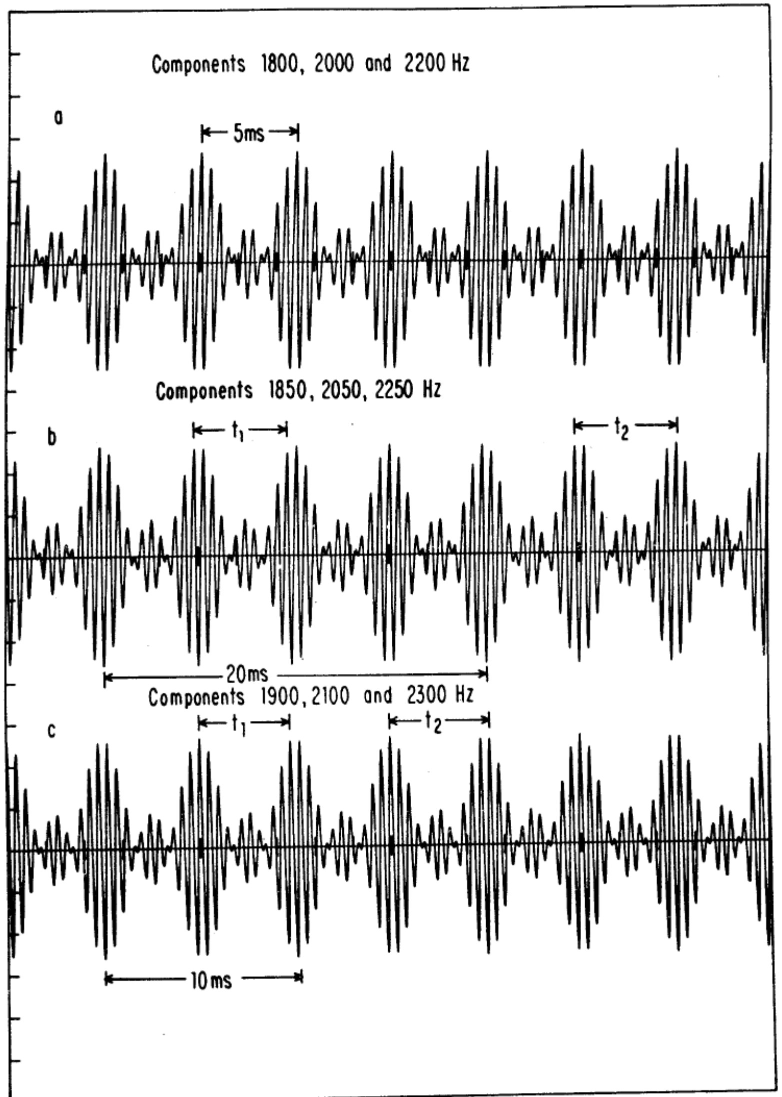

Figure 6.7. The waveforms produced by the three components in typical pitch-shift experiments. The frequencies of the components are indicated in the panels of the figure, the periods of the successive panels are 5, 10, and 20 msec as indicated. The pseudo periods marked t_1 and t_2 are used in some theoretical account to explain the pitch-shift results.

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Tono Virtual o Missing Fundamental

Evidencia en contra de la teoría del lugar (Schouten, 1940)

- Escucha cerca del umbral
- Enmascaramiento
- Pitch shift

Evidencia en contra de la teoría temporal

- Región dominante
- Cross-ear pitch

CITA

Tono Virtual: Región Dominante

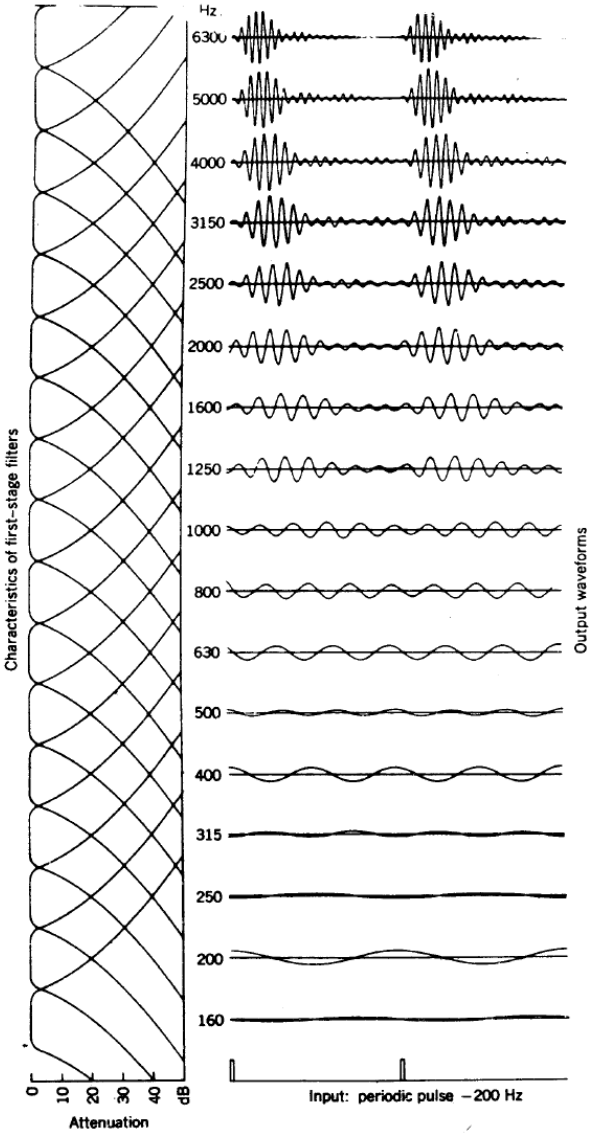


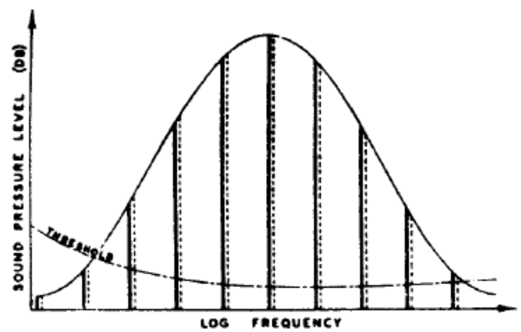
Figure 6.5. Illustrative waveforms at the output of a bank of filters similar to the ear's critical bands, after Plomp (1966). The input to the bank of filters is an impulse repeated 200 times per second. The response of the filters is shown in the right side of the figure. The frequency characteristic of the filters is shown in the left side of the figure. The center frequency of the filter increase from the bottom of the figure to the top. The bandwidth is proportional to the center frequency (constant Q). At low frequencies the output is essentially a single sinusoid; at higher frequencies the output is a combination of several sinusoids and the periodicity of the input is evident. From *Experiments on Tone Perception* (p. 128) by R. Plomp, 1966. Unpublished dissertation. Reprinted by permission.

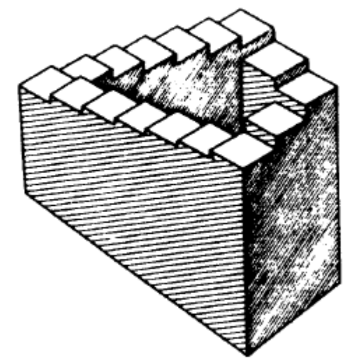
Tono Virtual: Cross-ear pitch

Pitch y circularidad

Demonstration 27. Circularity in Pitch Judgment (1:20)

One of the most widely used auditory illusions is Shepard's (1964) demonstration of pitch circularity, which has come to be known as the "Shepard Scale" demonstration. The demonstration uses a cyclic set of complex tones, each composed of 10 partials separated by octave intervals. The tones are cosinusoidally filtered to produce the sound level distribution shown below, and the frequencies of the partials are shifted upward in steps corresponding to a musical semitone ($\approx$6%). The result is an "ever-ascending" scale, which is a sort of auditory analog to the ever-ascending staircase visual illusion.





Several variations of the original demonstration have been described. J-C. Risset created a continuous version. Other variations are described by Burns (1981), Teranishi (1986), and Schroeder (1986).

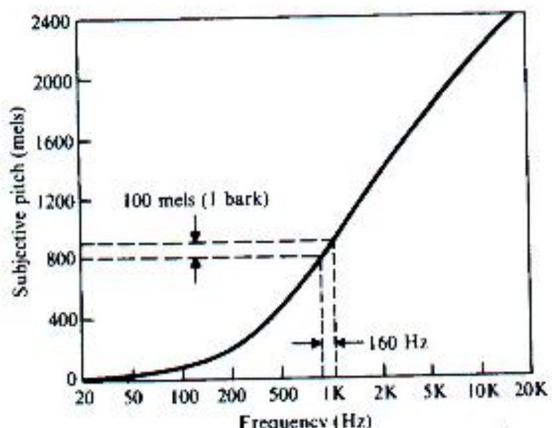
Demostración 27

Shepard, R.N. (1964). "Circularity in judgements of relative pitch," J. Acoust. Soc. Am., 36, 2346-2353.

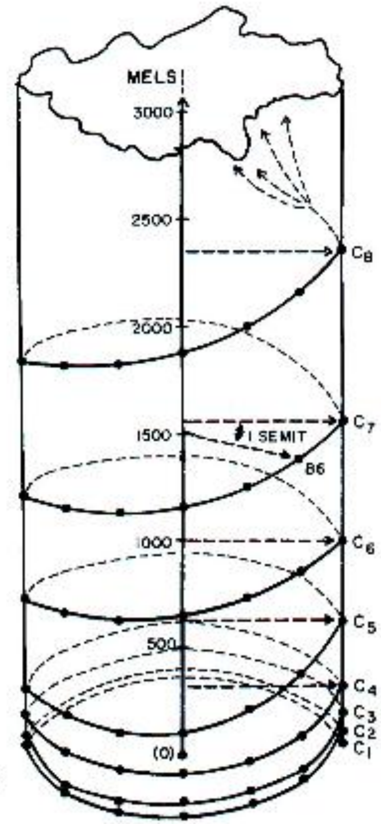
Representación del Pitch

Pitch

- At least two dimensions
  - Pitch Height
  - Pitch Chroma



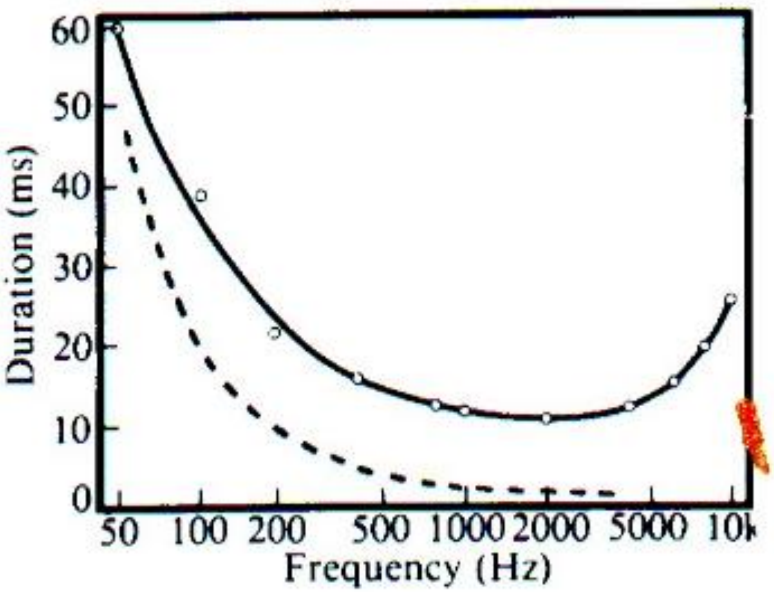
Mel : unit of pitch
Bark: unit of CB



Pitch y duración

Pitch and Duration

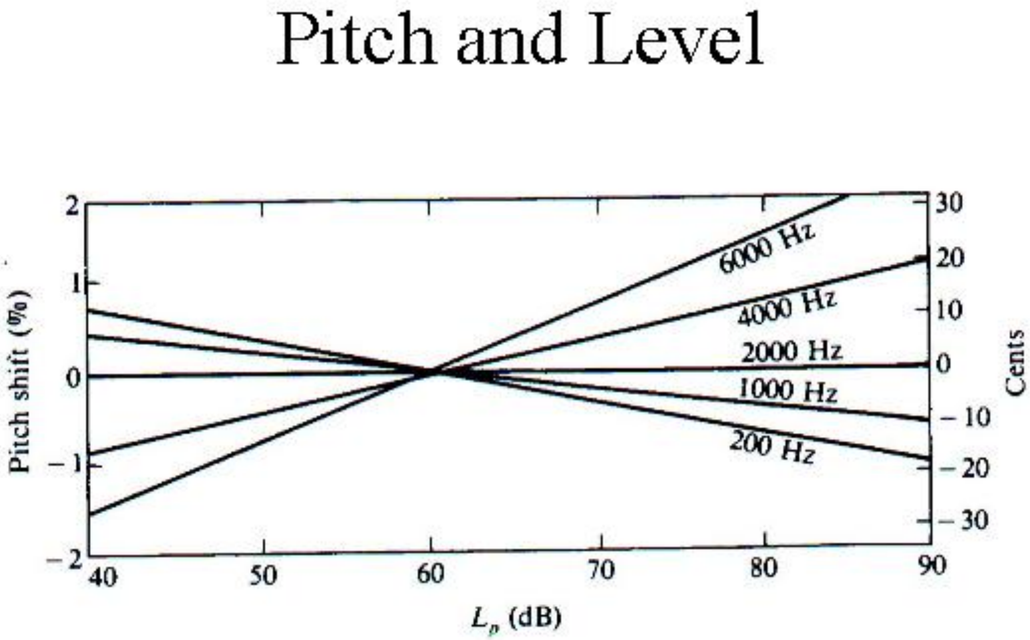
How much time do we need to hear a note in order to have an identifiable pitch?



Demostración 13

CITA

Pitch e intensidad



Demostración 12

Pitch sintético vs analítico

El sistema auditivo tiene la habilidad de escuchar sonidos complejos de dos modos diferentes:

En forma analítica: escuchamos los componentes de un sonido

En forma sintética u holística: escuchamos el sonido en forma global

Demostración 25

Sobre-estimación de la octava

El sistema auditivo tiende a sobre-estimar la octava, prefiriendo razones mayores a 2.0.

Esta preferencia no es totalmente entendida

Demostración 15

Escalas logarítmicas y lineales

El sistema auditivo organiza las frecuencias en escalas logarítmicas, no en forma lineal.

Demostración 18

Teorías modernas del pitch

El "procesador" de pitch…

- Primero estima frecuencias de componentes individuales de un sonido, tales como 1000, 1200, and 1400 Hz

- luego se da cuenta que esos componentes puden ser producidos por una frecuencia fundamental de 200 Hz.