LICENCIATURA EN FISICA MEDICA

BIOFISICA

CAPITULO 10
Producción del Sonido, el Habla y la Escucha en el Ser Humano

ONDAS Y SU PROPAGACION

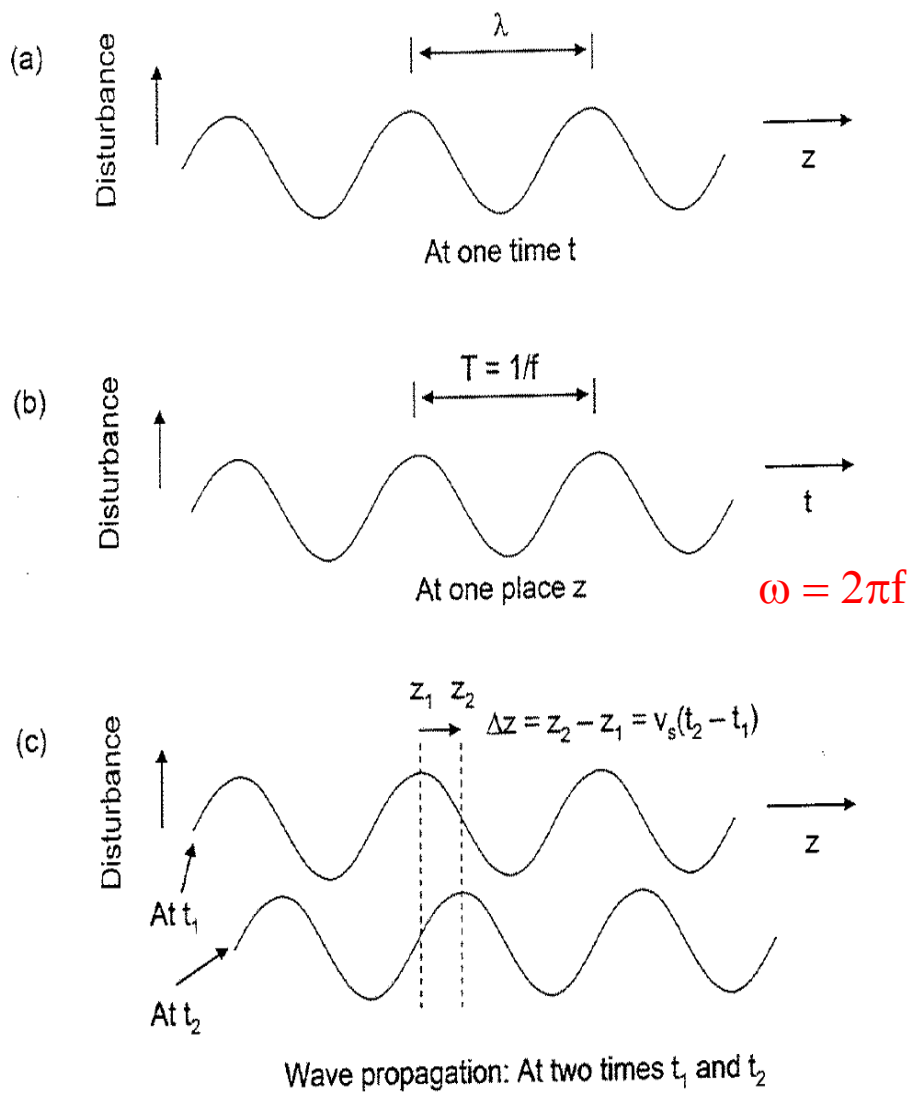


Fig. 10.1. Waves at (a) one time, (b) one place, and (c) two different times, showing wave propagation

ONDA DE PRESION Y PROPAGACION

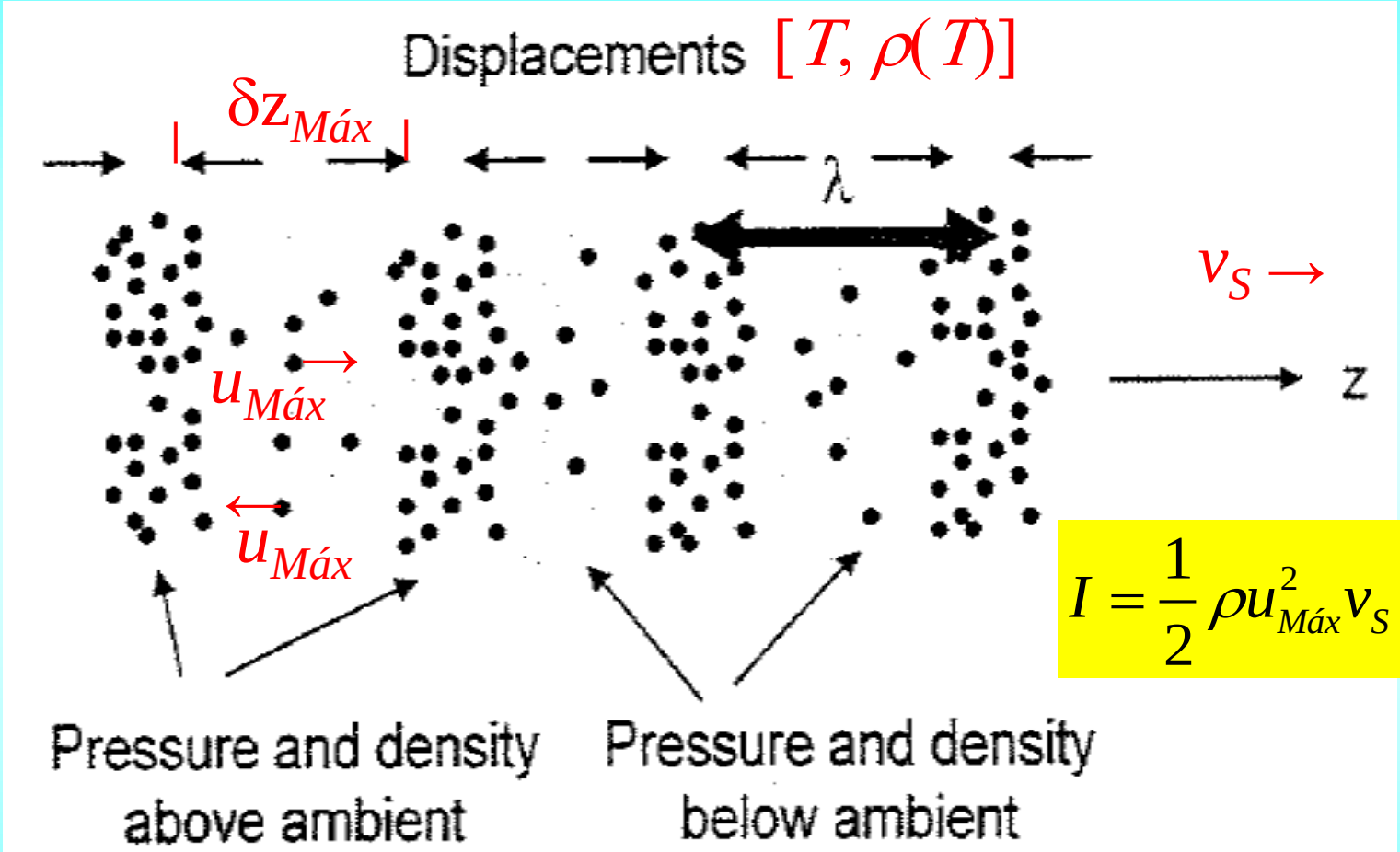


Fig. 10.2. Sound waves are compressional waves

$u_{Máx} = (\delta z_{Máx})\omega$ $\omega = 2\pi f$ v_S: velocidad del sonido

INTENSIDAD Y PROPAGACION

$$[I] = \left[\frac{1}{2}\rho u_{Máx}^2 v_S\right] = \frac{kg}{m^3} \times \frac{m^2}{s^2} \times \frac{m}{s} = \frac{kg \times m}{s^2} \times m \times \frac{1}{m^2 \times s} =$$

$$= \frac{N \times m}{m^2 \times s} = \frac{J}{m^2 \times s} = \frac{W}{m^2}$$

$$v_S = \sqrt{\frac{C_{Adiabático}}{\rho}} = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{\gamma RT}{m}}$$

$$\gamma = \frac{c_p}{c_v} = \begin{cases} 5/3 = 1,67 & \text{Gas de moléculas monoatómicas} \\ 1,4 & \text{Aire, mezcla de moléculas diatómicas} \\ 1 & \text{Gas de moléculas muy grandes} \end{cases}$$

INTENSIDAD, IMPEDANCIA Y PRESION

$$u_{Máx} = \left(\delta z_{Máx}\right)\omega$$

$$I = \frac{1}{2}\rho u_{Máx}^2 v_S = \frac{1}{2}\rho v_S \left[\left(\delta z_{Máx}\right)\omega\right]^2$$

$Z = \rho v_S$, Impedancia acústica

$$\left[Z\right] = \left[\rho v_S\right] = \frac{kg}{m^3} \times \frac{m}{s} = \frac{kg}{m^2 \times s}$$

$\left|P\right| = \left(\rho v_S\right)\omega\left|\delta z_{Máx}\right| = Z\omega\left|\delta z_{Máx}\right|$, Presión acústica

$$\left[\left|P\right|\right] = \left[Z\omega\left|\delta z_{Máx}\right|\right] = \frac{kg}{m^2 \times s} \times \frac{1}{s} \times m = \frac{N}{m^2} = Pa$$

$$I = \frac{1}{2}\rho v_S \left[\left(\delta z_{Máx}\right)\omega\right]^2 = \frac{1}{2} Z \left[\left(\delta z_{Máx}\right)\omega\right]^2 = \frac{P^2}{2Z}$$

CARACTERISTICAS ACUSTICAS DE LOS TEJIDOS Y ORGANOS

Table 10.1. Mass density, sound speed, and acoustic impedance. (Using data from [467, 489])

material	ρ (kg/m^3)	v_s (m/s)	Z ($= \rho v_s$) (kg/m^2-s)
air (20°C)	1.20	343	413
water	1.00×10^3	1,480	1.48×10^6
fat	0.92×10^3	1,450	1.33×10^6
muscle	1.04×10^3	1,580	1.64×10^6
bone	2.23×10^3	3,500	7.80×10^6
blood	1.03×10^3	1,570	1.61×10^6
soft tissue (avg.)[a]	1.06×10^3	1,540	1.63×10^6
lung	286	630	1.80×10^5

[a] The soft tissue value is representative of the skin, kidney, liver, and the brain.

INTENSIDAD EN deciBell (dB)

$$[I] = \frac{W}{m^2}$$

$$I = \frac{P^2}{2Z}$$

$I_{Ref\,(3000\,Hz)} = 10^{-12}\, W/m^2$, Mínima intensidad percibida

$$Z_{Aire} = 413\, kg/m^2\, s$$

$P_{Ref\,(3000\,Hz)} = 2,9 \times 10^{-5}\, Pa$, Mínima presión percibida

$$I\left(Bell\right) = log_{10}\left(I/I_{Ref\,(3000\,Hz)}\right)$$

$$I\left(deciBell\right) = 10 \times log_{10}\left(I/I_{Ref\,(3000\,Hz)}\right)$$

INTENSIDADES TIPICAS DE SONIDOS

Table 10.2. Typical sound intensities

	intensity (W/m^2)	intensity level (dB SPL)
sound barely perceptible, human with good ears	10^{-12}	0
human breathing at 3 m	10^{-11}	10
whisper at 1 m, rustling of leaves, ticking watch	10^{-10}	20
quiet residential community at night, refrigerator hum	10^{-8}	40
quiet restaurant, rainfall	10^{-7}	50
normal conversation at 1 m, office, restaurant	10^{-6}	60
busy traffic	10^{-5}	70
loud music, heavy traffic, vacuum cleaner at 1 m	10^{-4}	80
loud factory	10^{-3}	90
fast train, pneumatic hammer at 2 m, disco, blow dryer	10^{-2}	100
accelerating motorcycle at 5 m, chainsaw at 1 m	10^{-1}	110
rock concert, jet aircraft taking off at 100 m	$1 = 10^{0}$	120
jackhammer	10^{1}	130
shotgun blast, firecracker	10^{2}	140
jet engine at 30 m	10^{3}	150
rocket engine at 30 m	10^{6}	180

SPL≡ Sound Pressure Level

INTERACCION ACUSTICA EN UNA INTERFAZ

$$Z = \rho v_S$$

$$R_{Refl} = \left(\frac{1 - Z_2 / Z_1}{1 + Z_2 / Z_1}\right)^2$$

$$T_{Trans} = \frac{4 Z_2 / Z_1}{(1 + Z_2 / Z_1)^2}$$

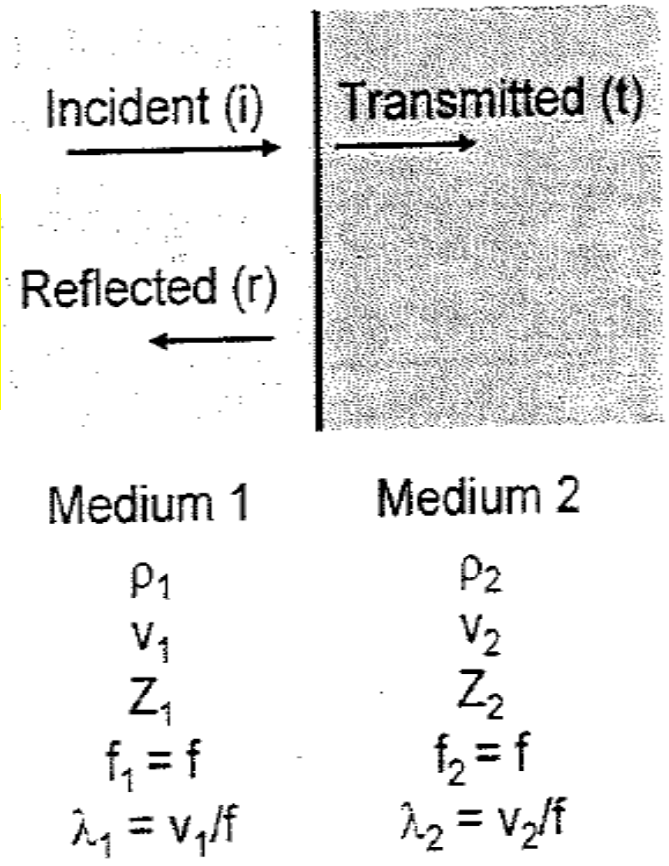


Fig. 10.3. Schematic of acoustic wave transmission and reflection

ALGUNAS INTERFACES BIOLOGICAS

Table 10.5. Representative fractions of reflected and transmitted acoustic energy at tissue interfaces. (Using data from [467, 489, 508])

tissue interface	reflected fraction (in %)	transmitted fraction (in %)
water/soft tissue	0.23	99.77
fat/muscle	1.08	98.92
bone/muscle	41.23	58.77
soft tissue/bone	43.50	56.50
bone/fat	48.91	51.09
soft tissue/lung	63.64	36.36
air/muscle	98.01	1.99
air/water	99.89	0.11
air/soft tissue	99.90	0.10

PROPAGACION Y ABSORCION

Como la amplitud de la onda A es proporcional a la presión acústica P

$$A(z)\alpha P(z)$$

y la presión acústica P de la onda disminuye al propagarse, resulta:

$$A(z) = A(z=0)exp\left(-\gamma_{Acústico} \times F \times z\right)$$

$\gamma_{Acústico}$, Coeficiente de absorción sonora,

$F = f^2$, Para líquidos puros,

$F \approx f$, Para tejidos blandos.

A la expresión de la absorción se la conoce como Ley de Beer, por su semejanza con la Optica.

COEFICIENTE DE ABSORCION DE TEJIDOS Y ORGANOS

Table 10.3. Amplitude absorption coefficient γ_{sound} for tissues. (Using data from [467])

tissue	γ_{sound} (s/m)
aqueous humor	1.1×10^{-6}
vitreous humor	1.2×10^{-6}
blood	2.1×10^{-6}
brain (infant)	3.4×10^{-6}
abdomen	5.9×10^{-6}
fat	7.0×10^{-6}
soft tissue (average)	8.3×10^{-6}
liver	1.0×10^{-5}
nerves	1.0×10^{-5}
brain (adult)	1.1×10^{-5}
kidney	1.2×10^{-5}
muscle	2.3×10^{-5}
crystalline eye lens	2.6×10^{-5}
bone	1.6×10^{-4}
lung	4.7×10^{-4}

It is multiplied by the frequency f (in Hz) to obtain the amplitude absorption coefficient per unit length.

COEFICIENTE DE ABSORCION DE ALGUNOS FLUIDOS

Table 10.4. Amplitude absorption coefficient γ_{sound} for fluids. (Using data from [467])

fluids	γ_{sound} (s^2/m)
water	2.5×10^{-14}
castor oil	1.2×10^{-11}
air (STP)	1.4×10^{-10}

It is multiplied by f^2, where f is the frequency (in Hz), to obtain the amplitude absorption coefficient per unit length. STP is standard temperature and pressure.

PRIMEROS MODOS RESONANTES DE UN CUERDA VIBRANTE

Cuerda fija en sus extremos de:

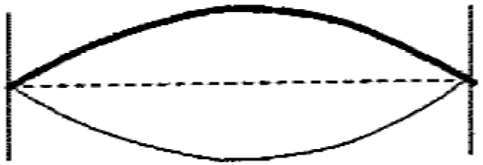
Longitud L

Radio r

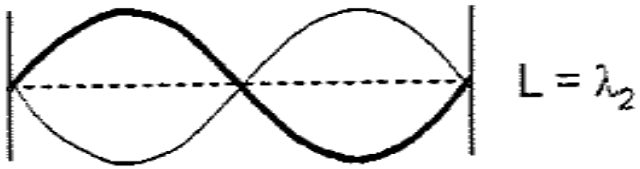
Densidad ρ

Masa lineal $\mu = \pi r^2 \rho$

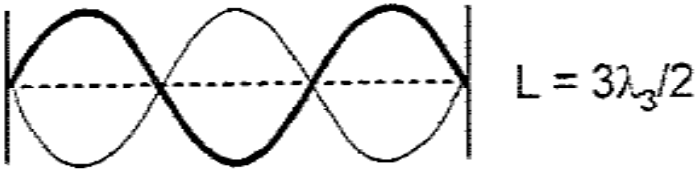
Tensión F



Fundamental or first harmonic



First overtone or second harmonic



Second overtone or third harmonic

$$f_{Fund} = v_S / 2L$$

$$v_S = \sqrt{F/\mu}$$

$$v_S = \sqrt{F/\left(\pi r^2 \rho\right)} =$$

$$= \sqrt{F/\left(\pi r^2\right)\rho} =$$

$$= \sqrt{\sigma/\rho}$$

$$f_{Fund} = \frac{1}{2L}\sqrt{\frac{\sigma}{\rho}}$$

Fig. 10.4. Lowest three modes on a string of length L, each shown at times with maximum and zero excursions. (Based on [471])

La cuerda vibrante como modelo de las cuerdas vocales

TUBOS ABIERTOS Y CERRADOS Y SUS MODOS RESONANTES I

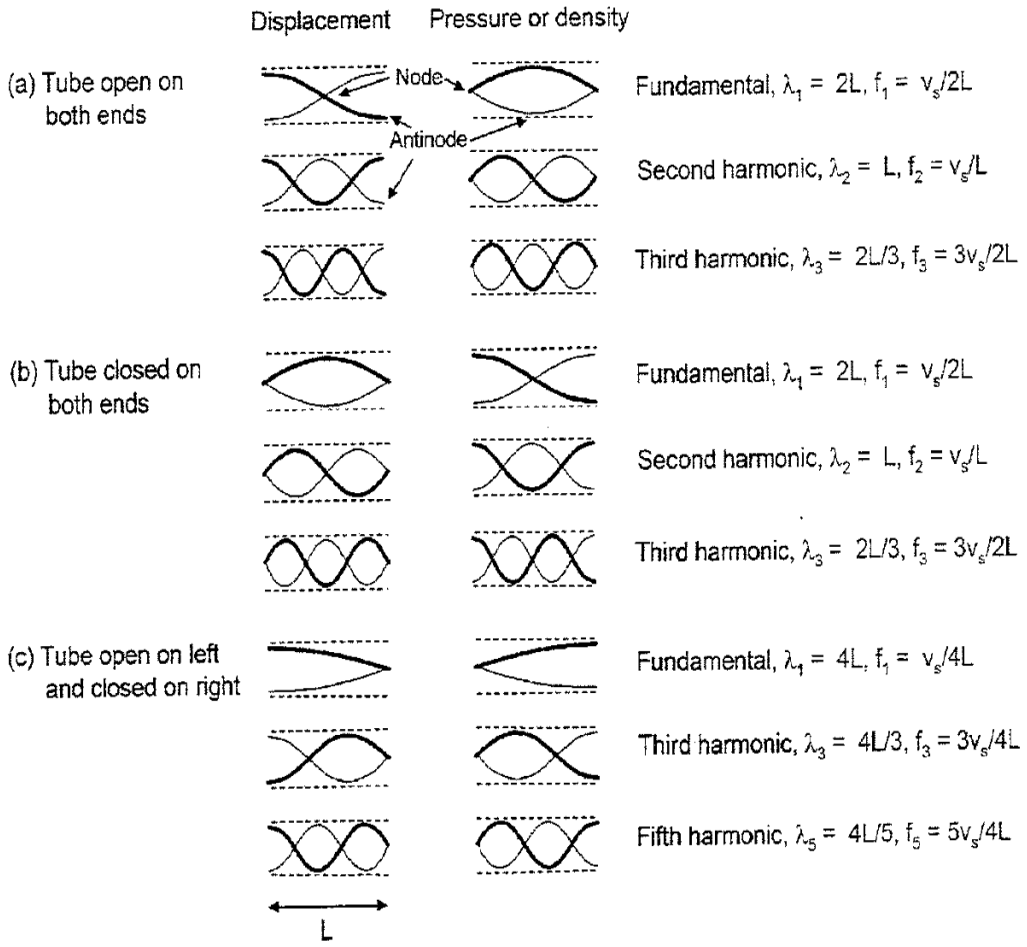
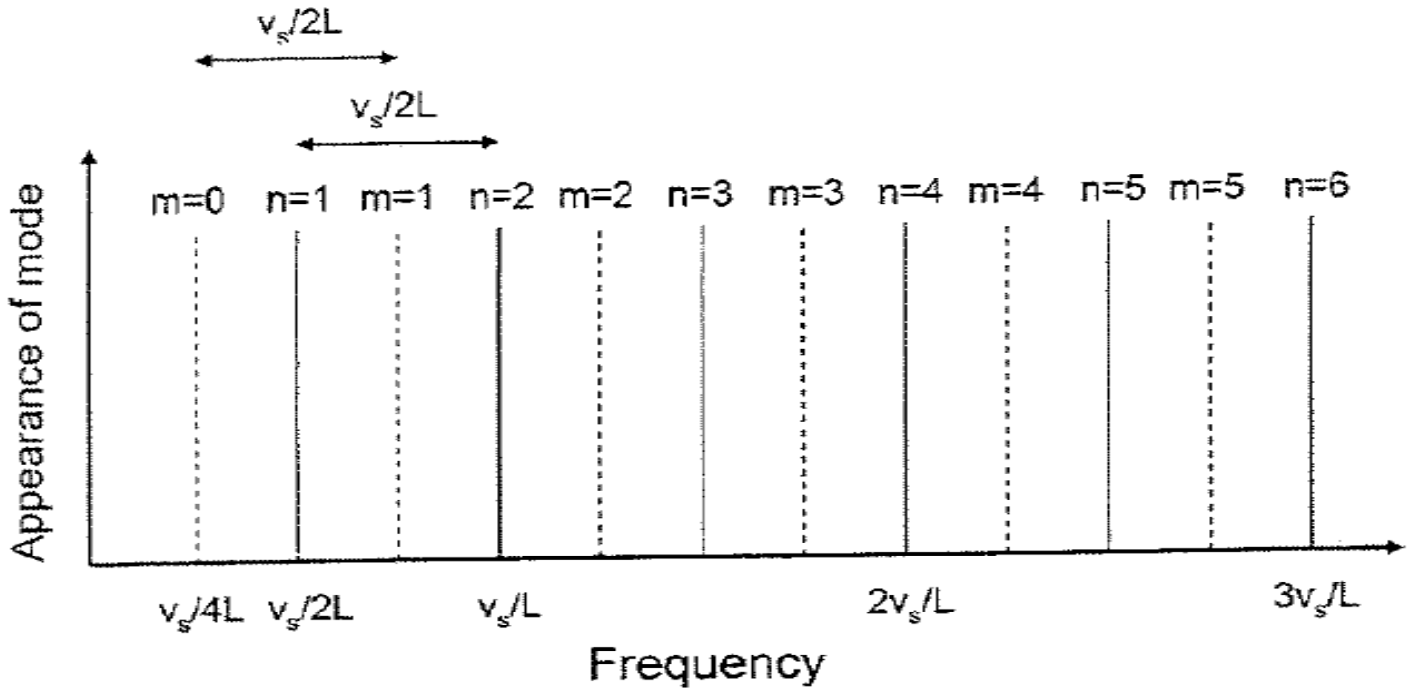


Fig. 10.5. Wave modes in a tube, for tubes (**a**) open on both ends, (**b**) closed on both ends, and (**c**) open on the left side and closed on the right side. The mode displacements of air are shown on the left for the first overtone or fundamental mode and for the next two overtones, and the corresponding changes in pressure and density for these modes are shown on the right. (Based on [471])

TUBOS ABIERTOS Y CERRADOS Y SUS MODOS RESONANTES II



$f_n = n(v_s/2L)$	$n = 1, 2, 3, \ldots$	Both tube ends are closed or open
$f_m = (m + ½)(v_s/2L)$	$m = 0, 1, 2, \ldots$	One tube end is closed, one is open

Fig. 10.6. Mode frequencies for a tube closed on both ends, open on both ends, or closed on one end and open on the other

Los tubos como modelos del sistema resonador humano

FACTOR Q DE UN TUBO RESONADOR

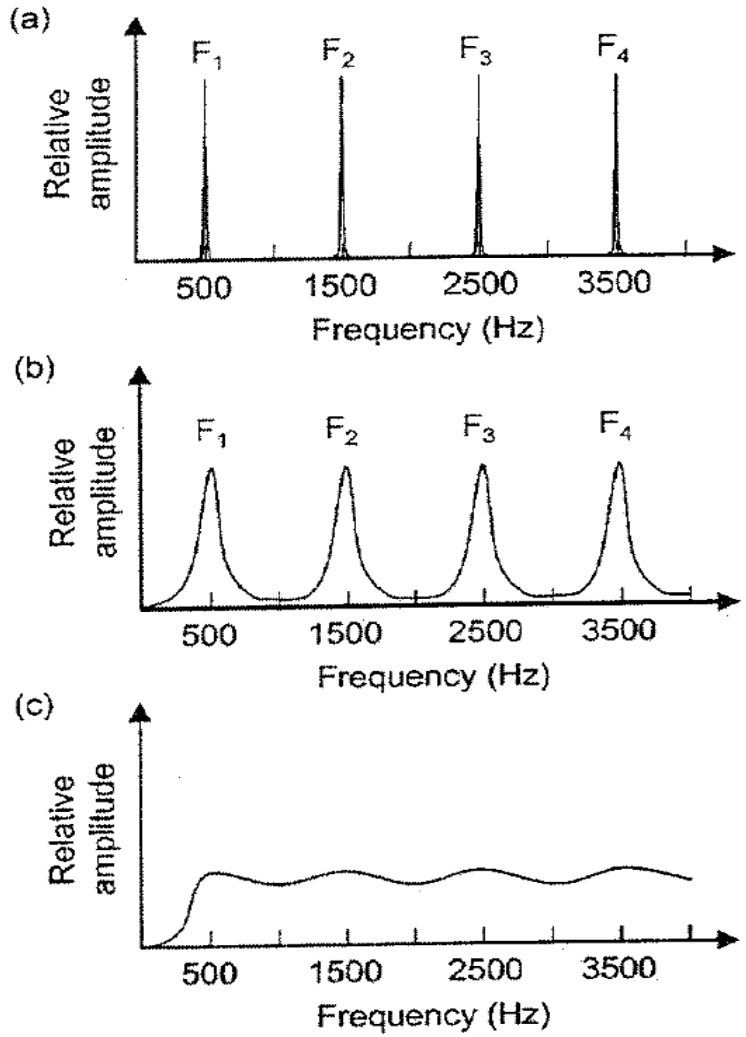
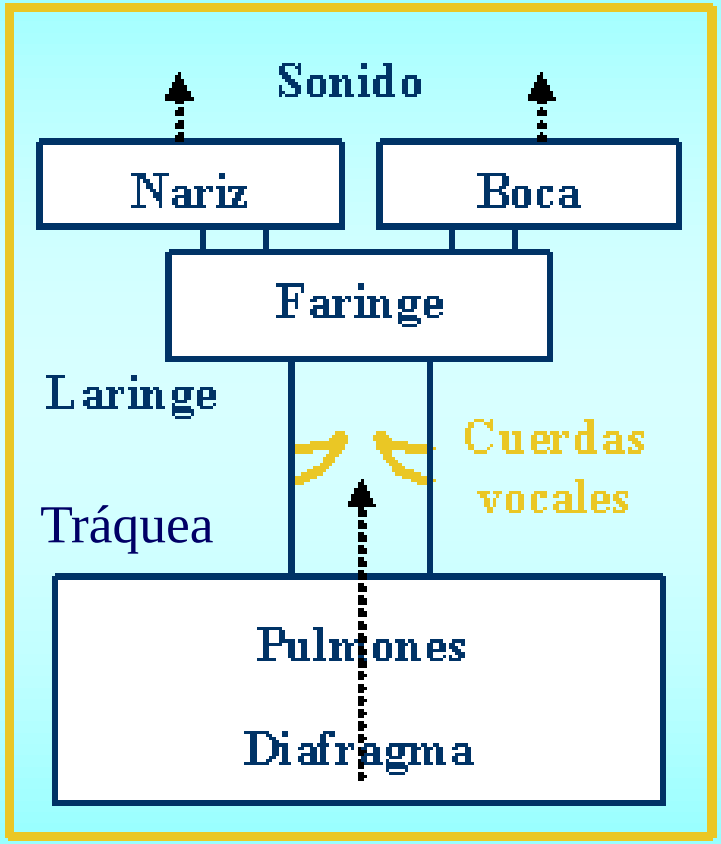


Fig. 10.7. (**a**) Loss-free (infinite Q), (**b**) moderate loss (moderate Q), and (**c**) very lossy (very low Q) transmission resonances for a tube. (Based on [504])

SISTEMA NEUROMUSCULAR DEL HABLA HUMANA I

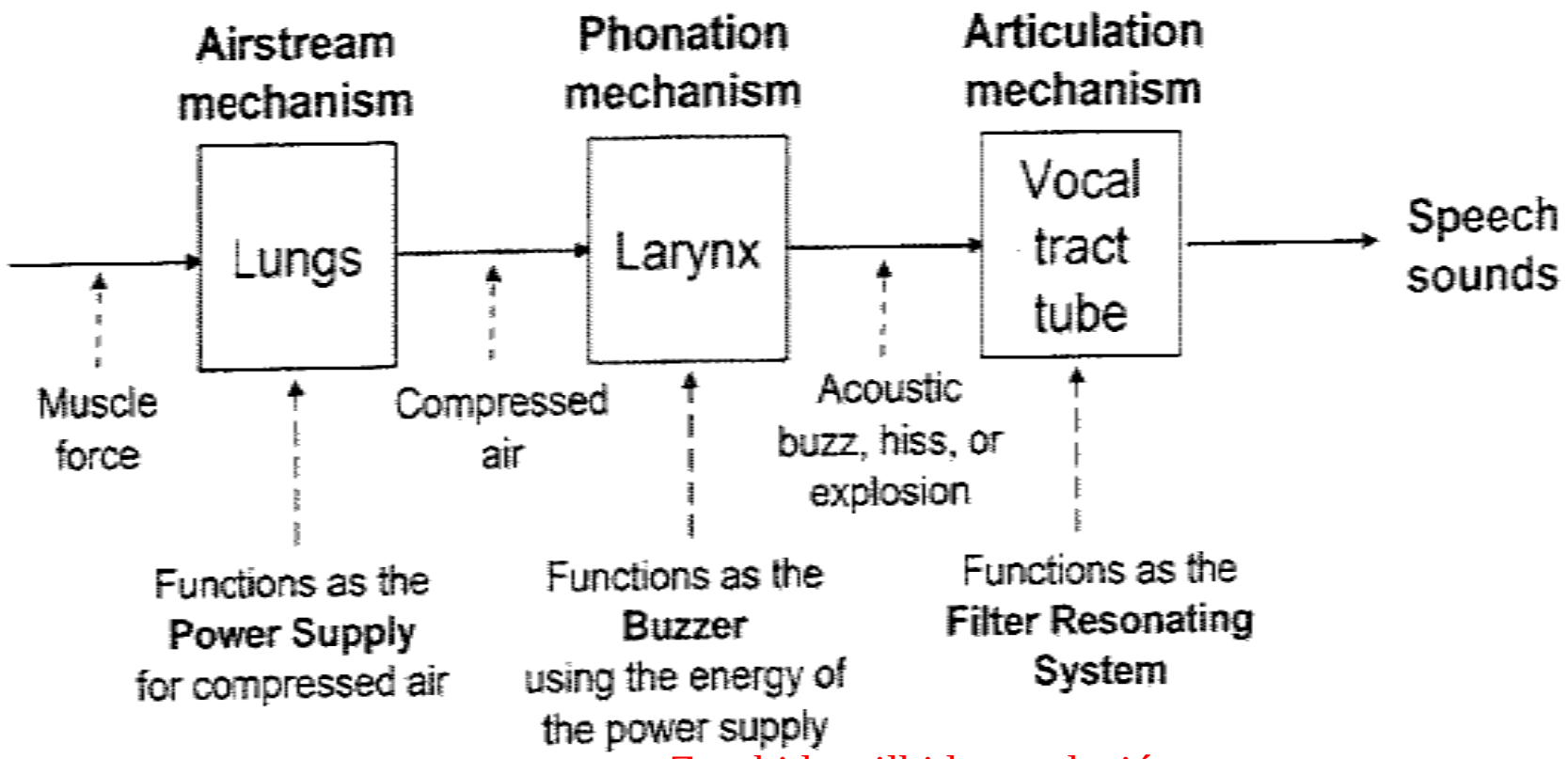


El sistema vocal humano puede dividirse en tres partes:

- **Aparato respiratorio:** donde se almacena y circula el aire. Nariz, traquea, pulmones y diafragma.
- **Aparato de fonación:** donde el aire se convierta en sonido. Laringe y cuerdas vocales.
- **Aparato resonador:** donde el sonido adquiere sus cualidades de timbre que caracterizan cada voz. Cavidad bucal, faringe, paladar óseo, senos maxilares y frontales.

Mujer adulta: $L_{Faringe} + L_{Boca}$ = 6,3 cm + 7,8 cm = 14,1 cm.
Hombre adulto: $L_{Faringe} + L_{Boca}$ = 8,9 cm + 8,1 cm = 17,0 cm.

SISTEMA NEUROMUSCULAR DEL HABLA HUMANA II

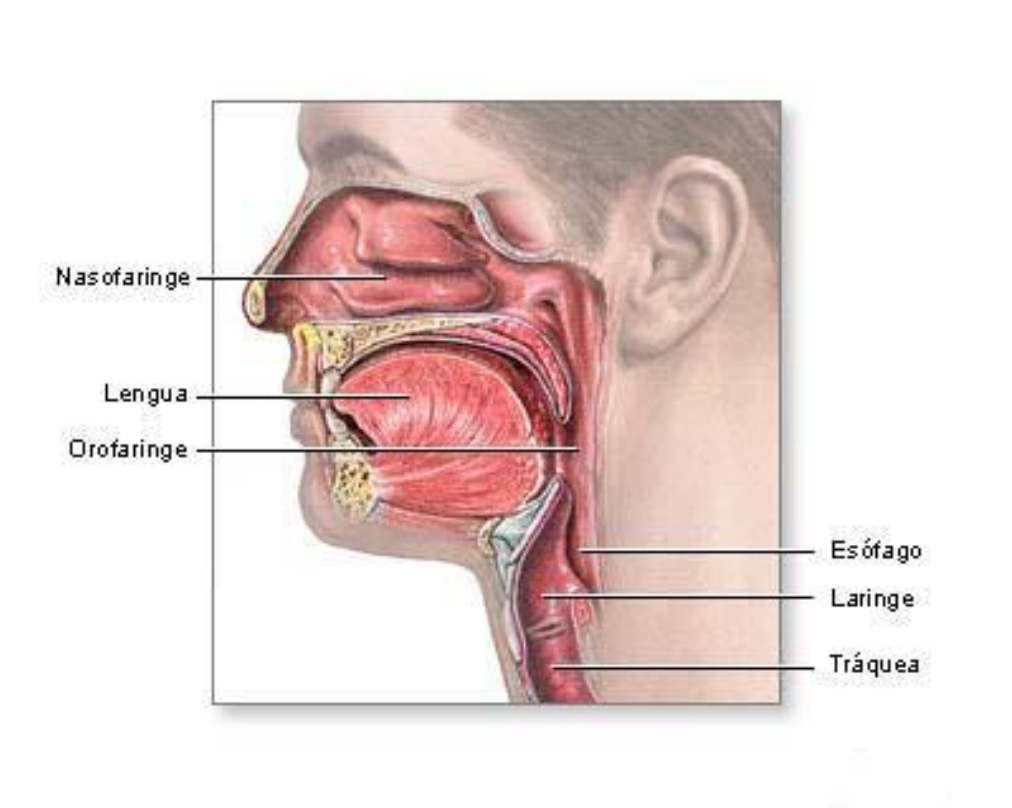


Zumbido, silbido, explosión

Fig. 10.10. The three neuromuscular systems in voice production. (Based on [460])

SISTEMA NEUROMUSCULAR DEL HABLA HUMANA III

- La laringe está situada sobre la tráquea
- Formada por cartílagos unidos por membranas y ligamentos
- Cubierta por músculos y mucosa

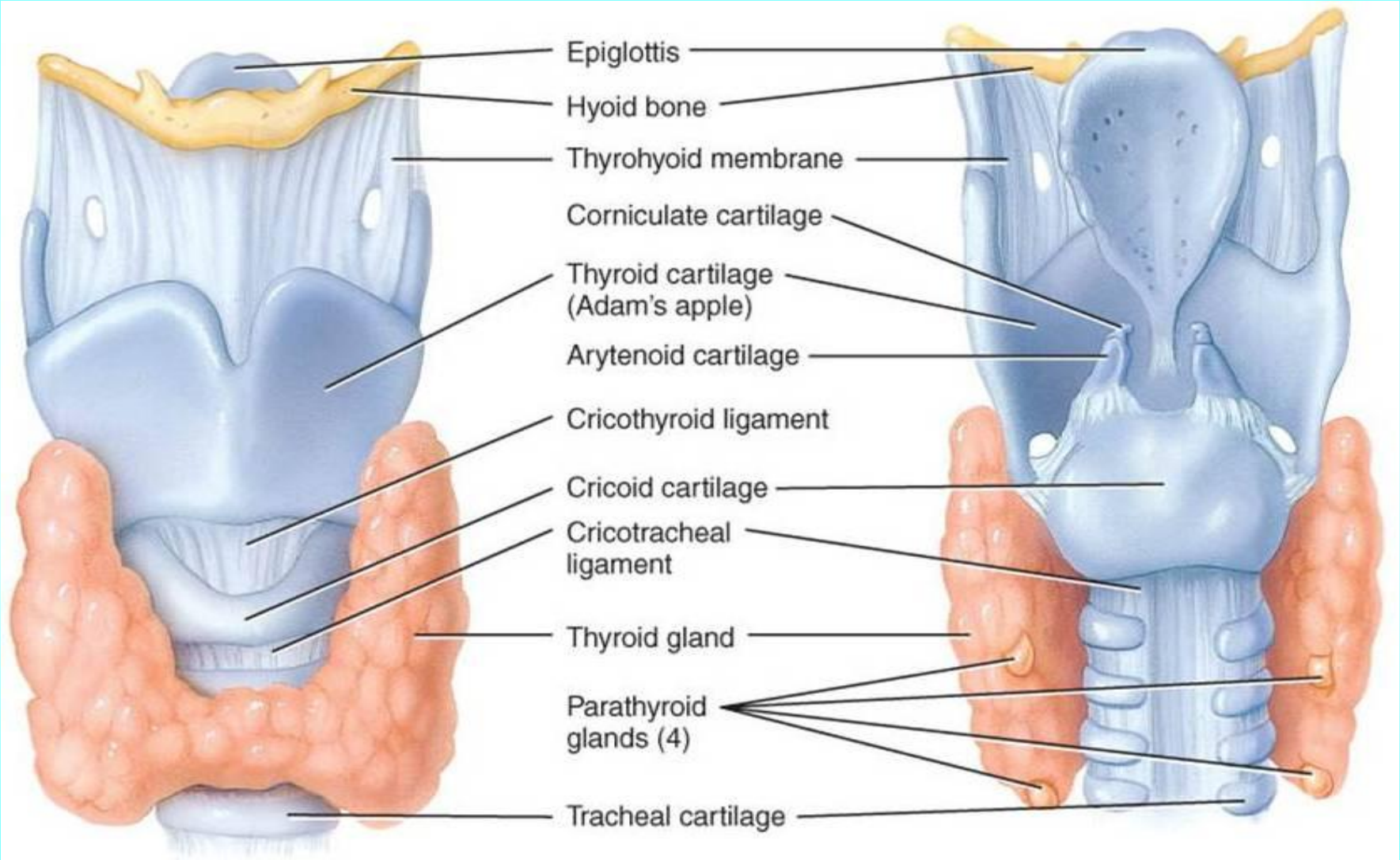


- Las cuerdas vocales son dos pliegues elásticos de la membrana mucosa que reviste la laringe
- Regulan el paso de aire, abriendo o cerrando la glotis

CARTILAGOS DE LA LARINGE I

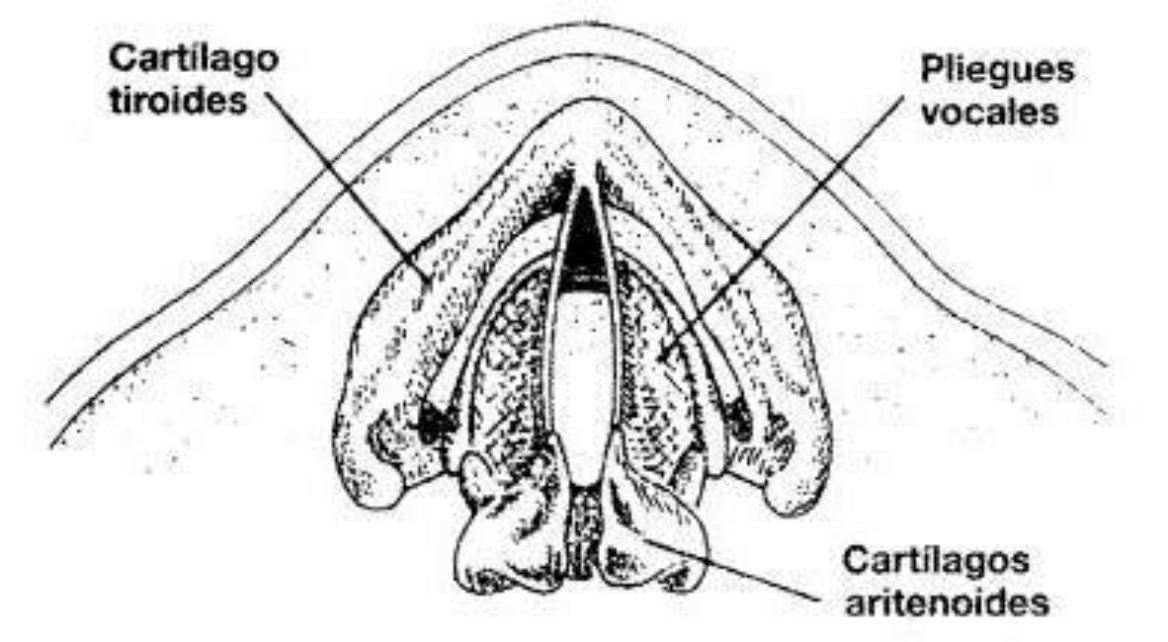
- CRICOIDES: se apoya sobre la tráquea y tiene forma de un anillo. En su parte plana (situada por detrás) tiene dos facetas para la articulación con los aritenoides y dos para el tiroides.
- TIROIDES: formado por dos láminas cuadrangulares que convergen hacia atrás alrededor de los lados del cricoides. Se visualiza como la Nuez de Adán.
- ARITENOIDES: tiene forma de pirámide y se asientan en el cricoides.

CARTILAGOS DE LA LARINGE II



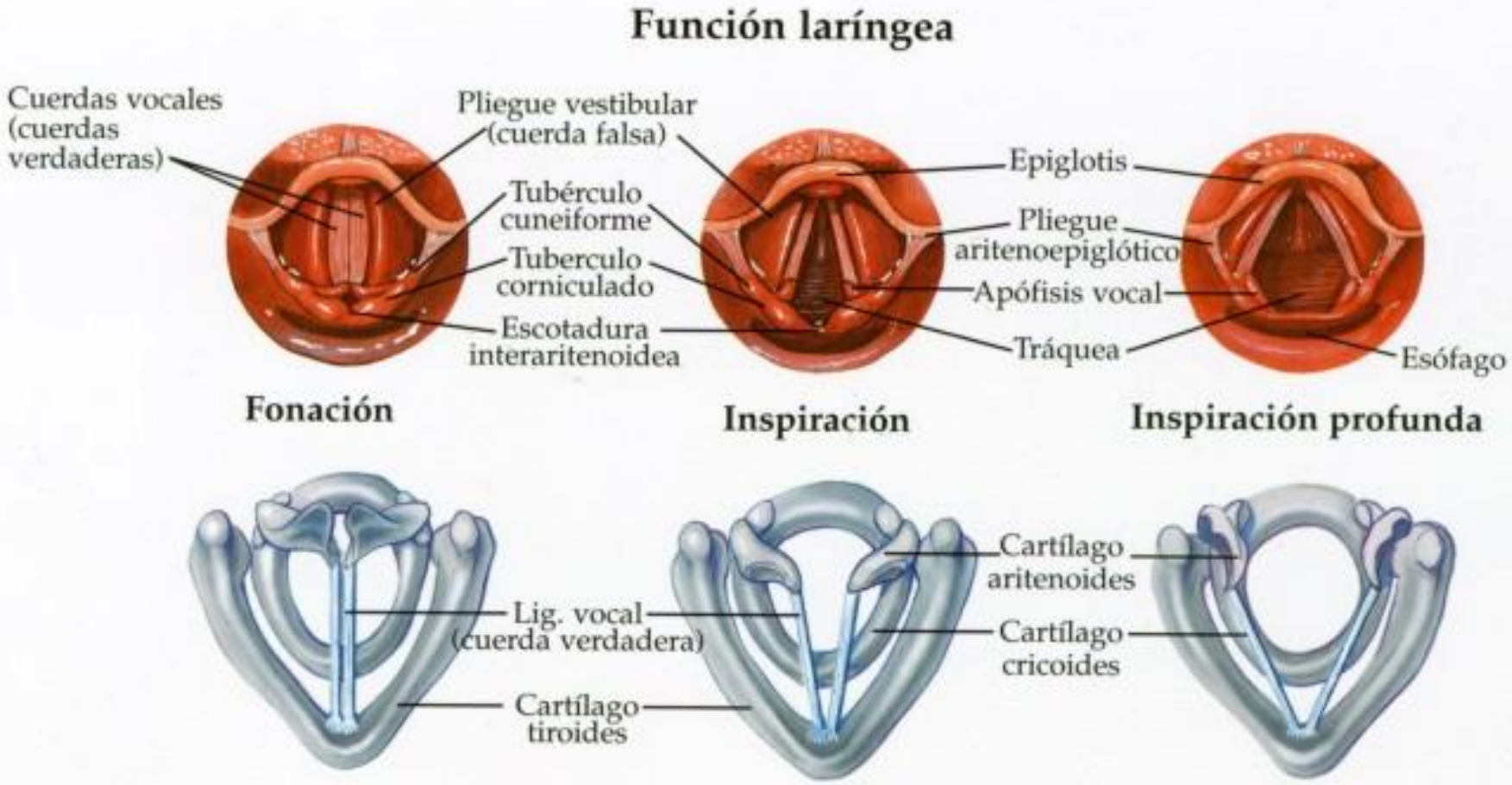
CUERDAS VOCALES I

- Se insertan, por un extremo, en el ángulo inferior del tiroides y, por el otro, en las apófisis vocales de los aritenoides.



- Al rotar los aritenoides hacia adentro, los pliegues vocales se juntan y al hacerlo hacia fuera se separan con el consiguiente cierre y apertura de la glotis.

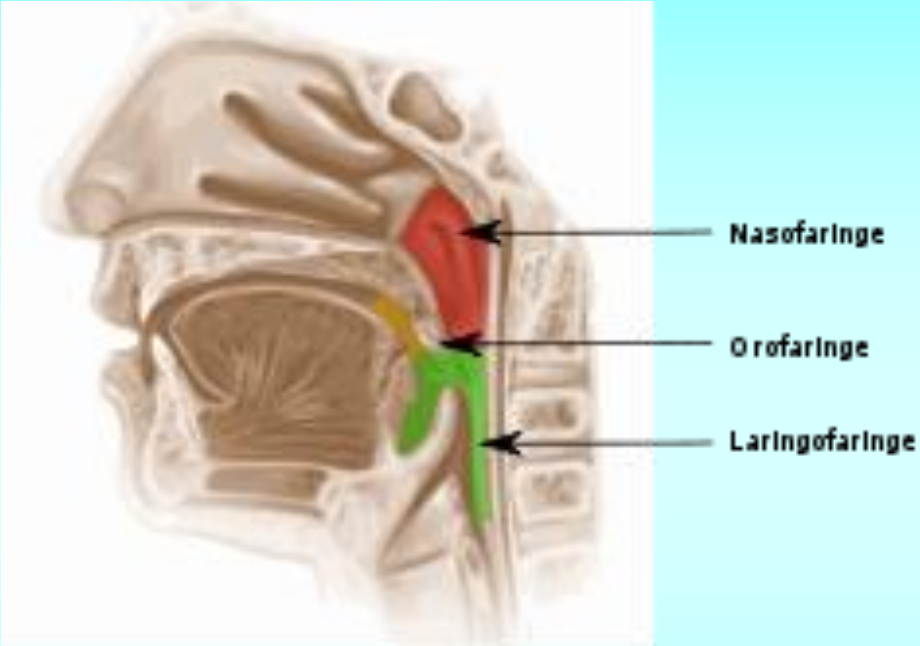
CUERDAS VOCALES II



FARINGE Y VELO

FARINGE

- Conducto mixto
- Tres porciones
- Tamaño y tensión de las paredes varían las características resonantes



VELO

- Porción membranosa del paladar
- Regula la comunicación entre la cavidad oral y nasal (sonido oral o nasal)

CAVIDAD ORAL

LABIOS: determinan el tamaño y forma de la abertura anterior, y modifican el largo de la cavidad oral.

PALADAR Y DIENTES: constituyen estructuras rígidas contra las que los labios y la lengua se mueven para producir sonidos

CAVIDAD NASAL

- Ninguna parte esta sujeta a movimientos musculares, su forma es fija

- Debido a la variabilidad en el ancho de los pasajes y a la cantidad de mucus, los sonidos articulados con resonancia nasal difieren

LOS SONIDOS DEL HABLA

- SONIDOS VOCALICOS: emitidos por la vibración de las cuerdas vocales sin ningún obstáculo

- SONIDOS CONSONANTICOS: emitidos con el cierre total o parcial del tracto por el cual pasa la corriente de aire

PUNTOS DE ARTICULACION EN LA CAVIDAD BUCAL

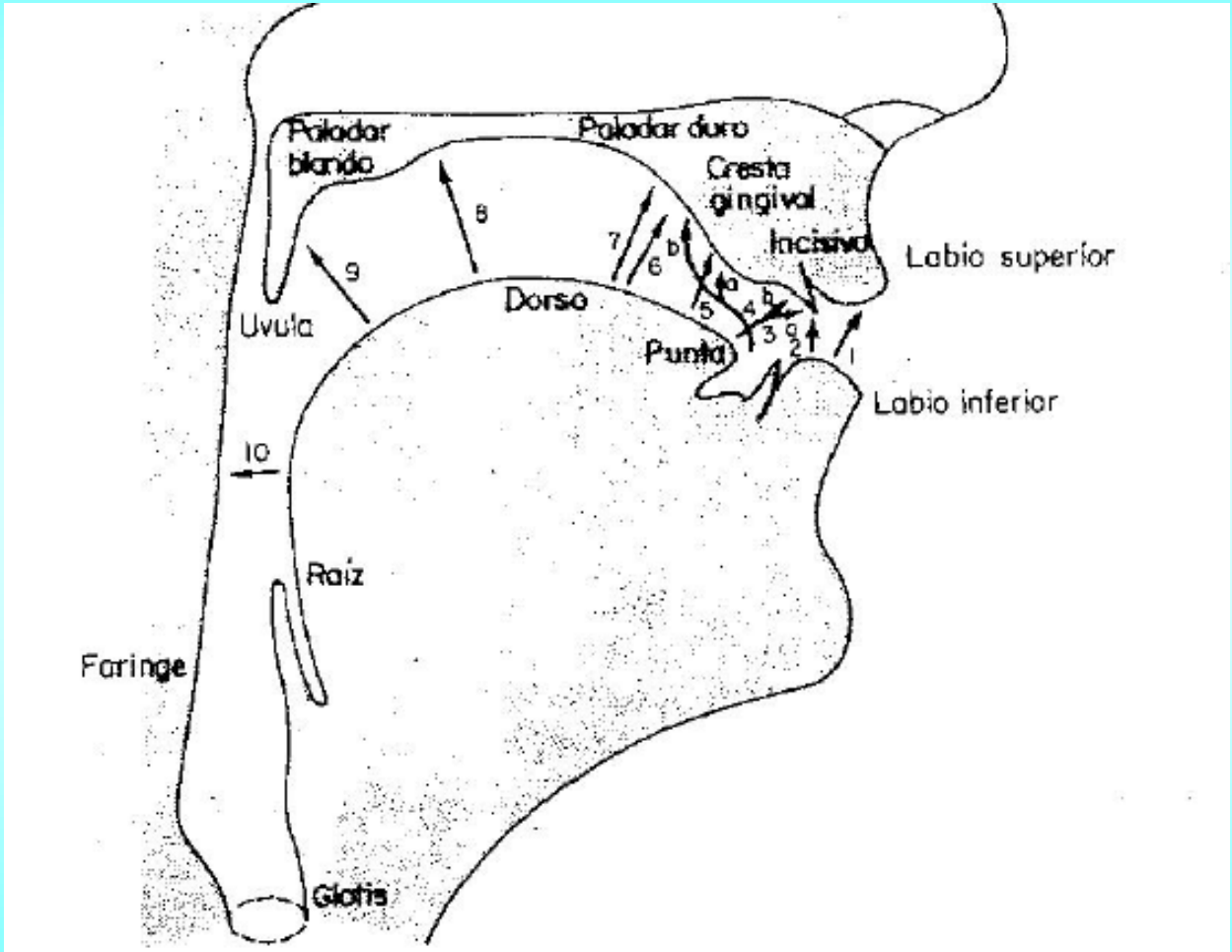
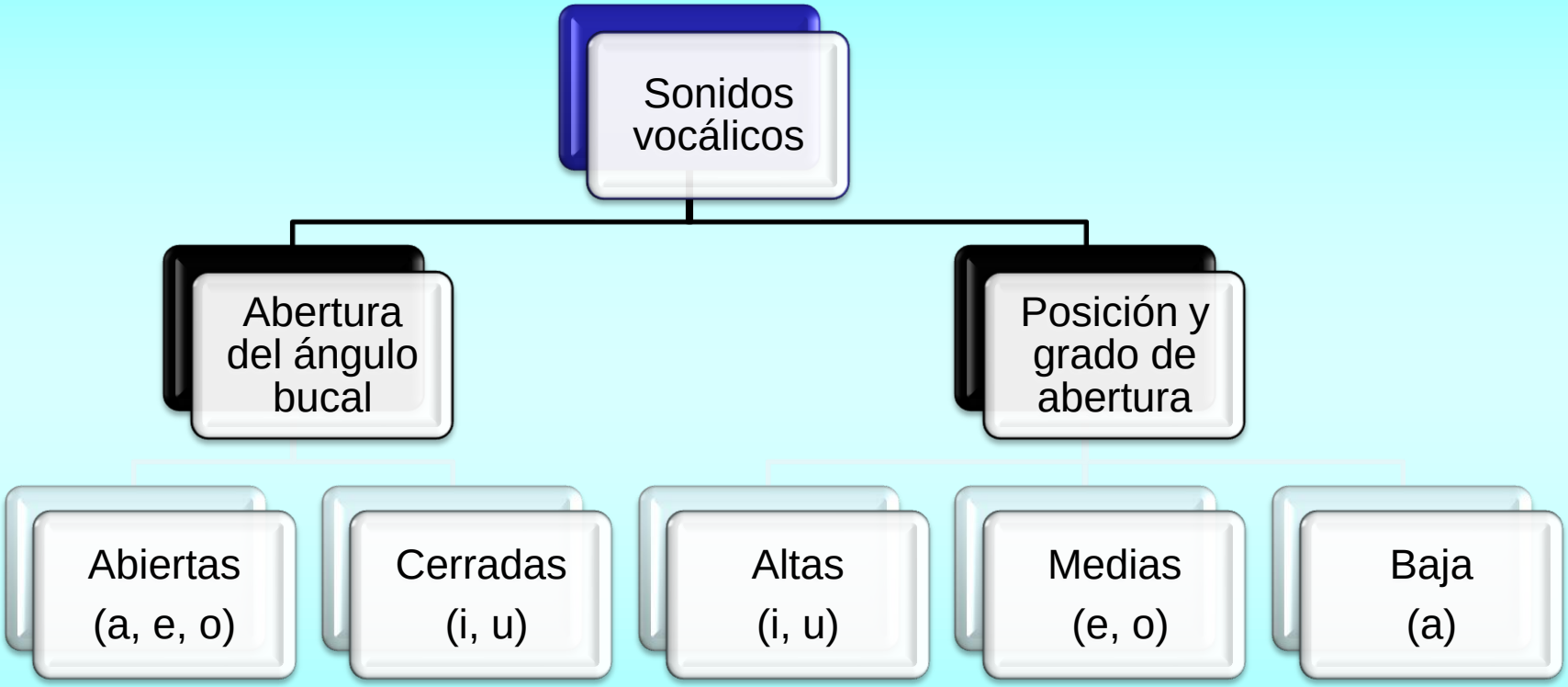
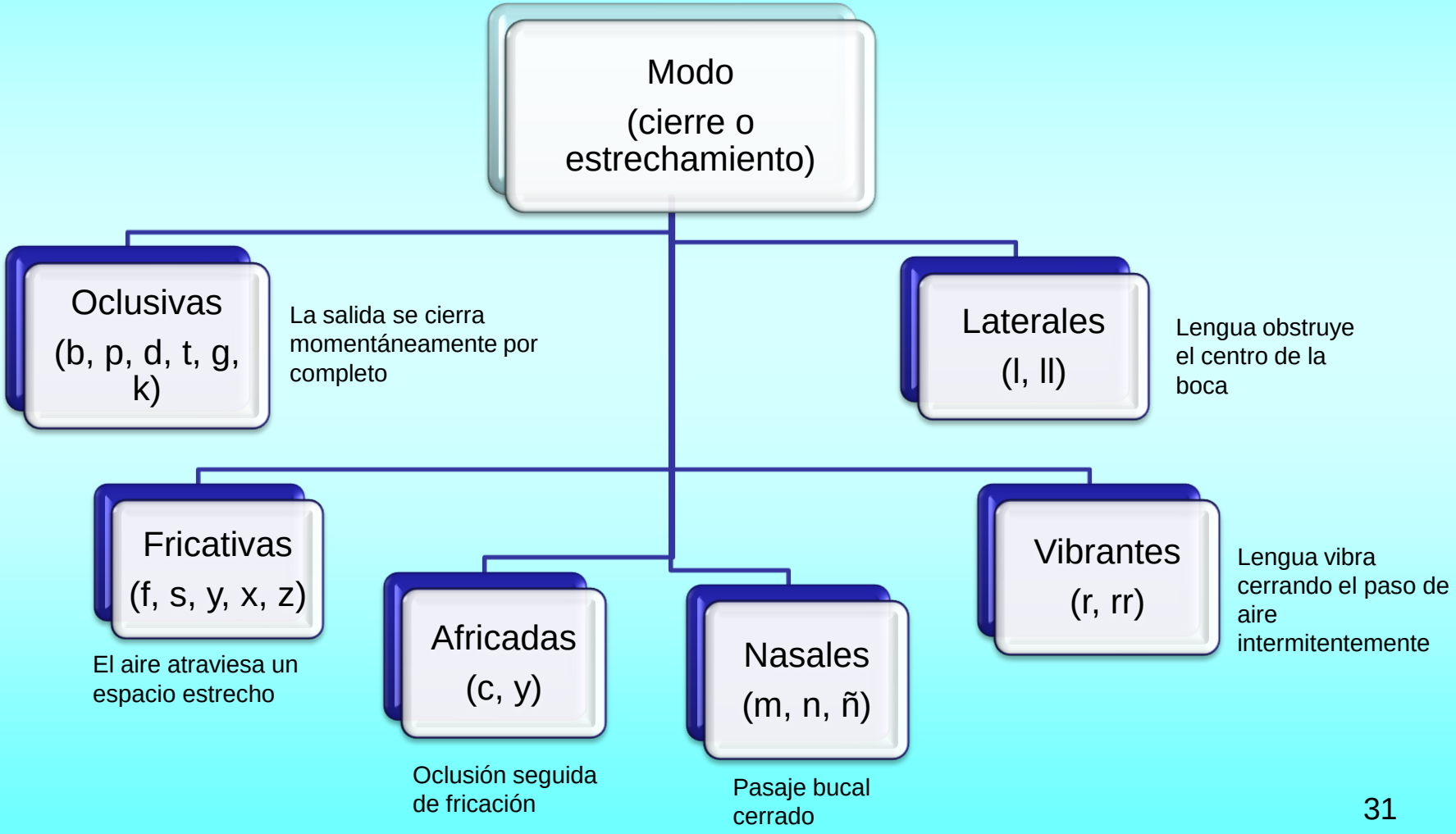


Fig. 12: *Cavidad oral: labios, dientes, lengua y paladar. Las flechas indican los puntos de articulaci´n: (1) bilabial; (2) labiodental; (3a) ápicointerdental; (3b) ápicodental; (4a) ápicogingival; (4b) ápicopalatal; (5) dorsogingival; (6) dorsoprepalatal; (7) dorsopalatal; (8) dorsovelar; (9) dorsouvular; (10) faríngeo.*

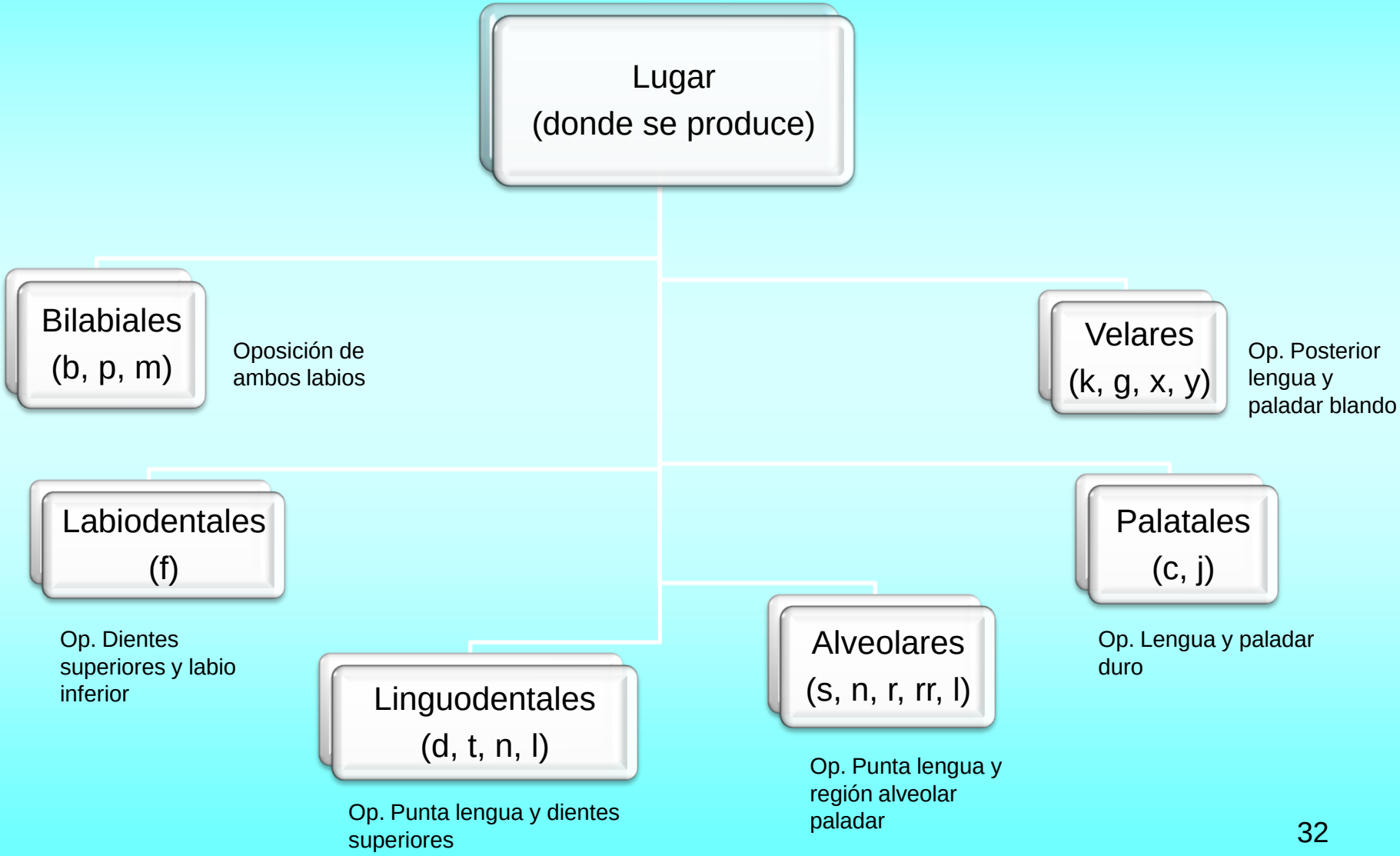
SONIDOS VOCALICOS



SONIDOS CONSONANTICOS



LUGAR DE PRODUCCION



CUERDAS VOCALES EN ACCION I

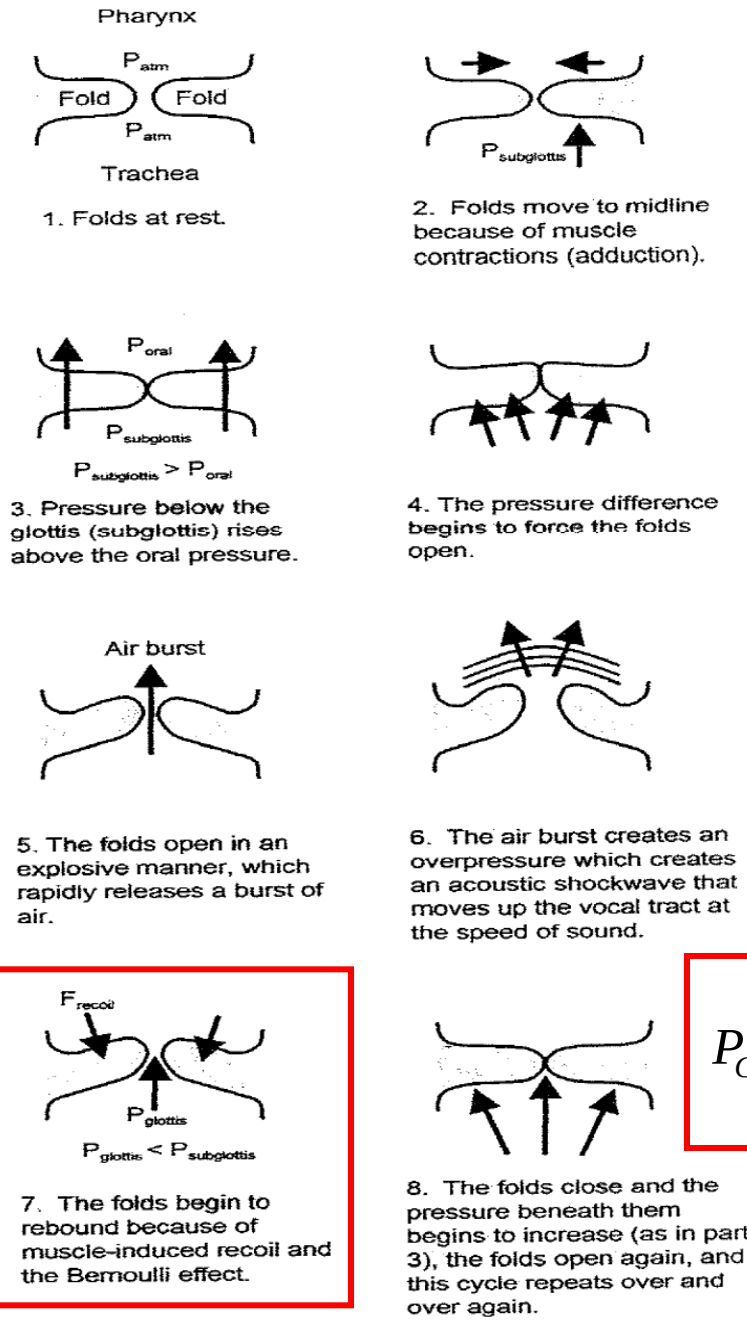
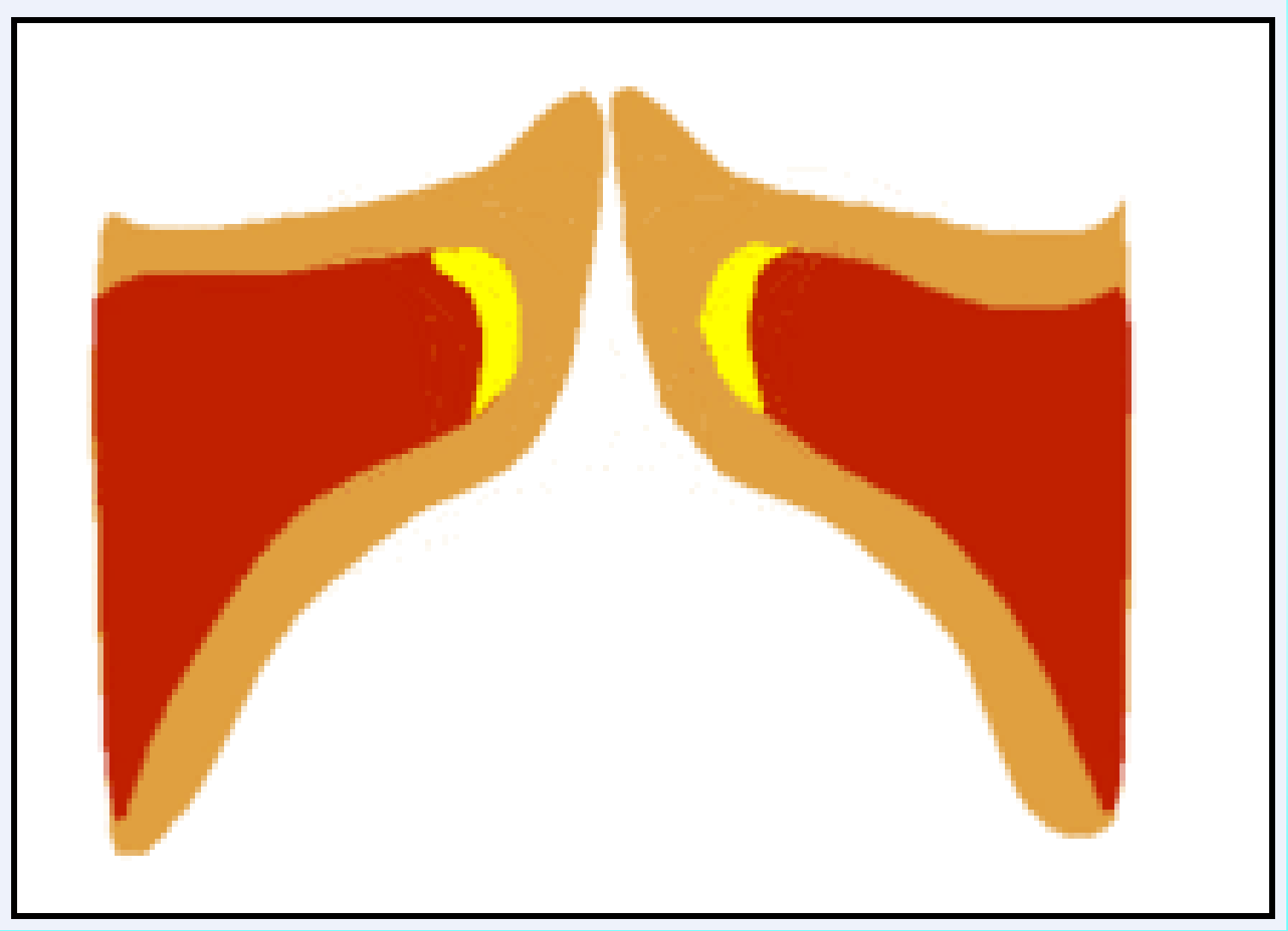


Fig. 10.12. The sequential stages of glottal vibration. (Based on [460])

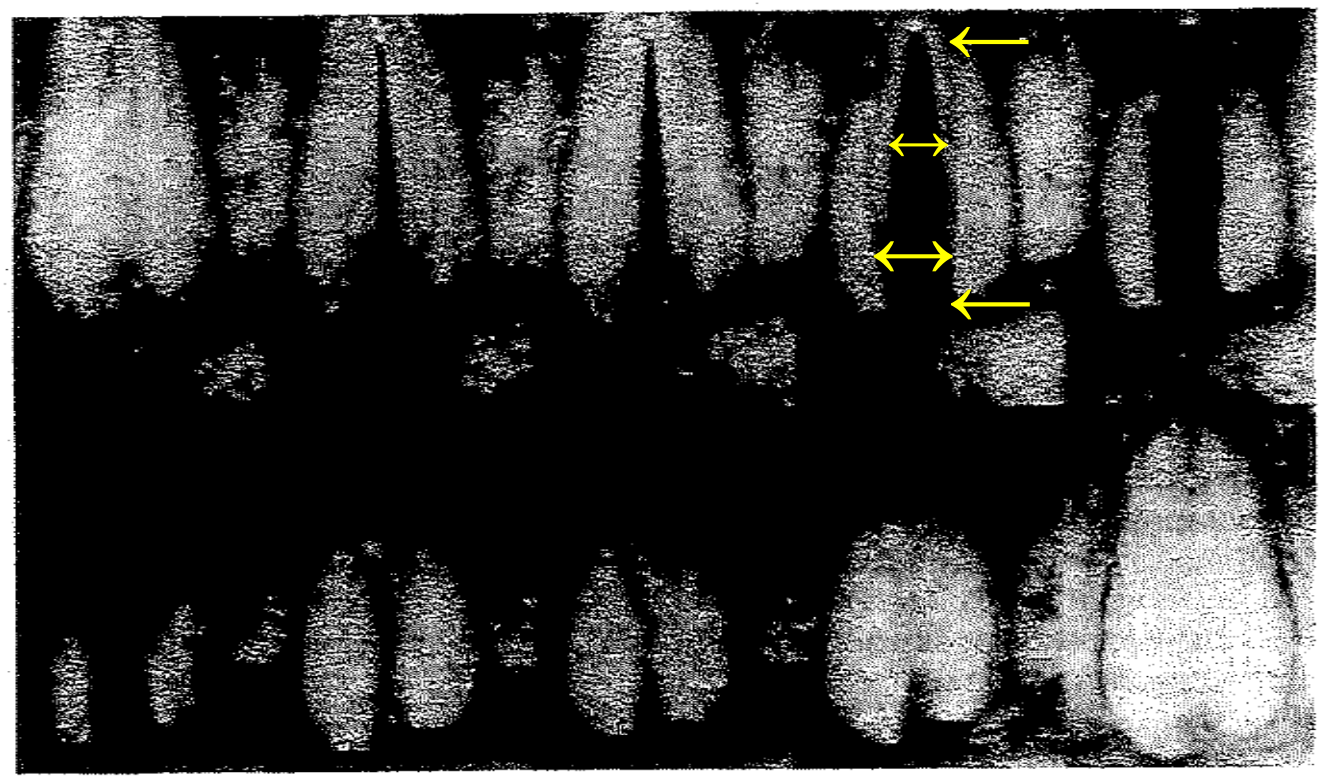
Aplicación del Teorema de Bernoulli según el Modo de Venturi

$$P_{Glotis} - P_{Subglotis} = \frac{1}{2}\rho v_{Subglotis}^2 \left[1 - \left(\frac{A_{Subglotis}}{A_{Glotis}}\right)^2\right] \langle 0$$

CUERDAS VOCALES EN ACCION II



CUERDAS VOCALES EN ACCION III

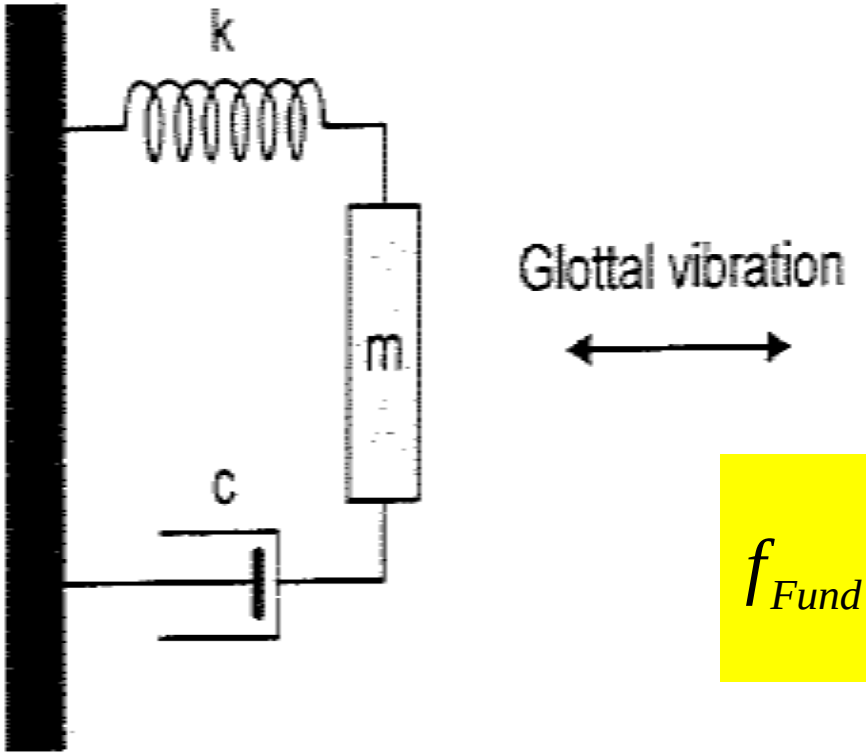


L_H=16 mm
L_M=10 mm

Fig. 10.11. A series of video frames of vocal-fold movement during a normal glottal cycle. Note that the opening is asymmetric, with the glottis more widely open at the bottom than at the top. During whispering, the glottis is even more open than during normal speaking (rightmost in top row), and it is even more open during forced inhalation. (From [504], photo by Debra K. Klein. The University of Iowa Hospitals and Clinics. Used with permission)

Murmullo, susurro

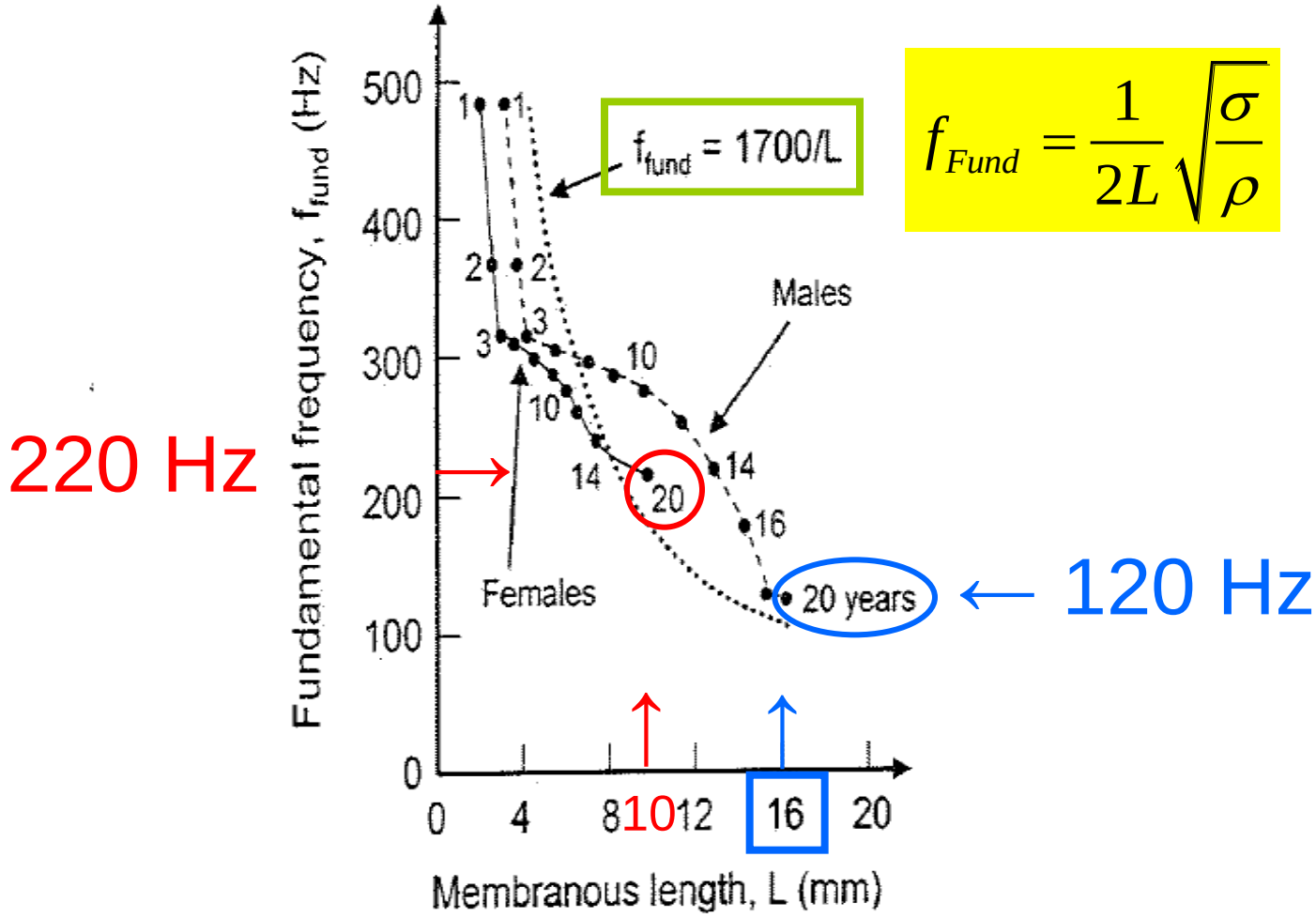
MODELO FISICO DE LAS CUERDAS



$$f_{Fund} = \frac{1}{2L}\sqrt{\frac{\sigma}{\rho}}$$

Fig. 10.13. A one-mass mechanical model of glottal vibration, with pressure against the tissue wall. (Based on [504])

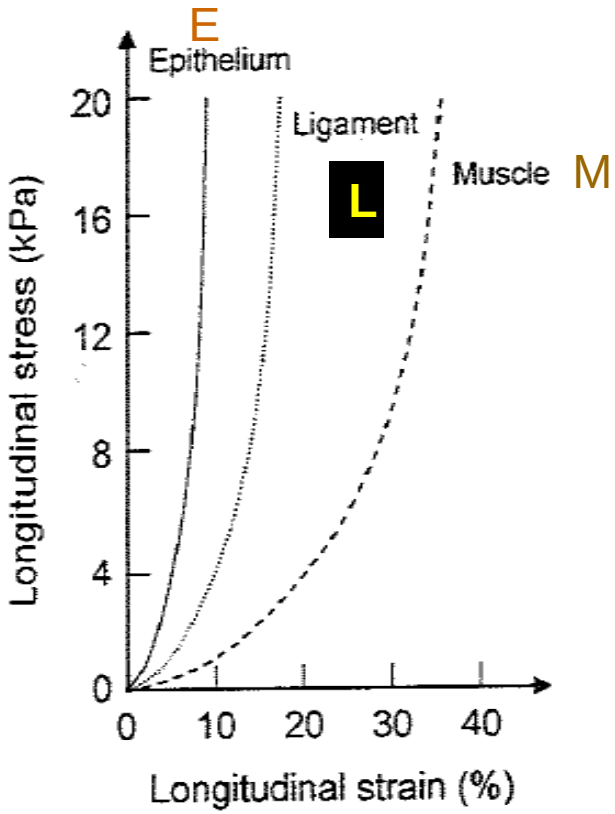
VOCES DE LAS CUERDAS VOCALES



$$f_{Fund} = \frac{1}{2L}\sqrt{\frac{\sigma}{\rho}}$$

Fig. 10.14. Vocal-fold frequency as a function of length, with age as an implicit variable. (Based on [504])

CARACTERISTICAS MECANICAS DE LAS CUERDAS VOCALES



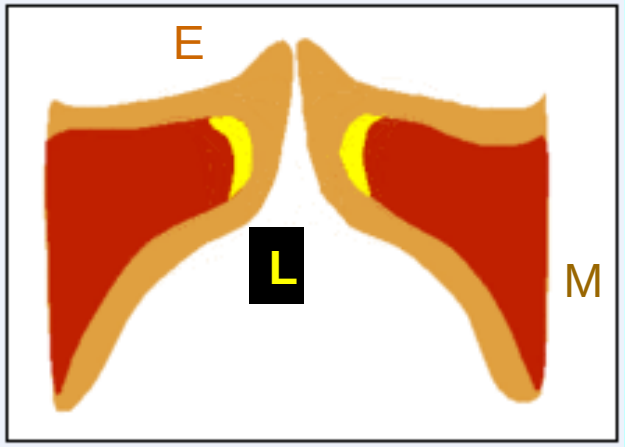


Fig. 10.15. Hypothetical stress–strain curves for tissues in human vocal folds. (Based on [504])

REPRESENTACIONES TEMPORALES Y FRECUENCIALES DE UNA SEÑAL II

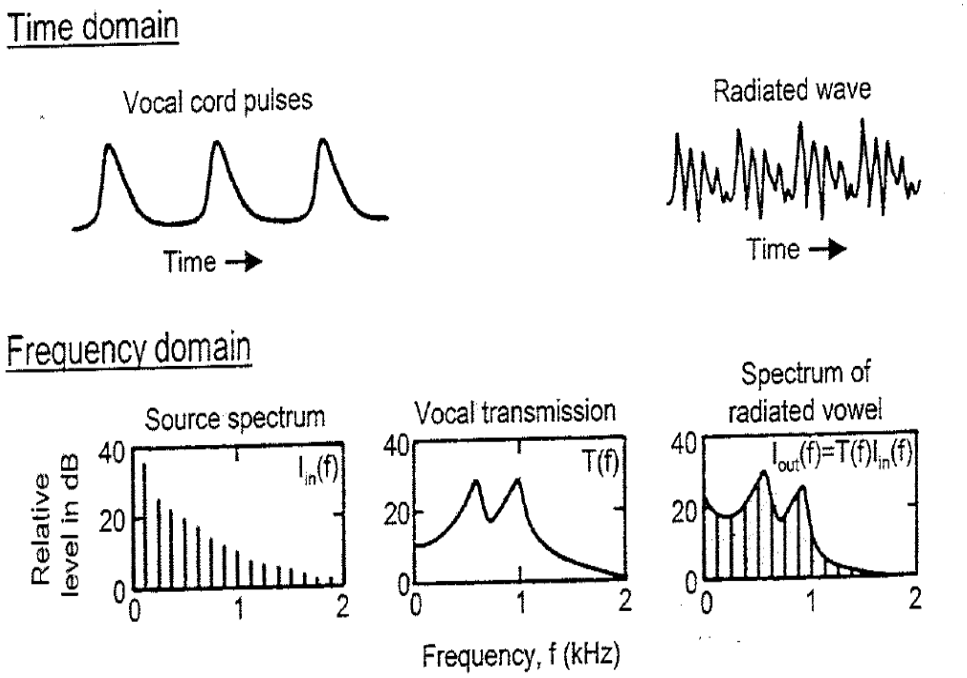


Fig. 10.16. Modification of the glottal wave by the vocal tract in the voice-filtering theory of speaking. The signals plotted vs. time (in the time domain) are in the upper row, while those plotted vs. frequency (in the frequency domain) are in the lower row. The source spectrum from the larynx (shown as vocal-fold pulses in the time domain) is $I_{in}(f)$, where f is frequency. The formation of the first two formants is seen in the vocal transmission ($T(f)$) and the radiated vowel ($I_{out}(f)$). The radiated vowel is shown as a radiated wave in the time domain. It is precisely our inability to conjure up a time-domain analog of the frequency-domain vocal transmission box that makes this type of frequency analysis so important. (Adapted from [464]. Used with permission)

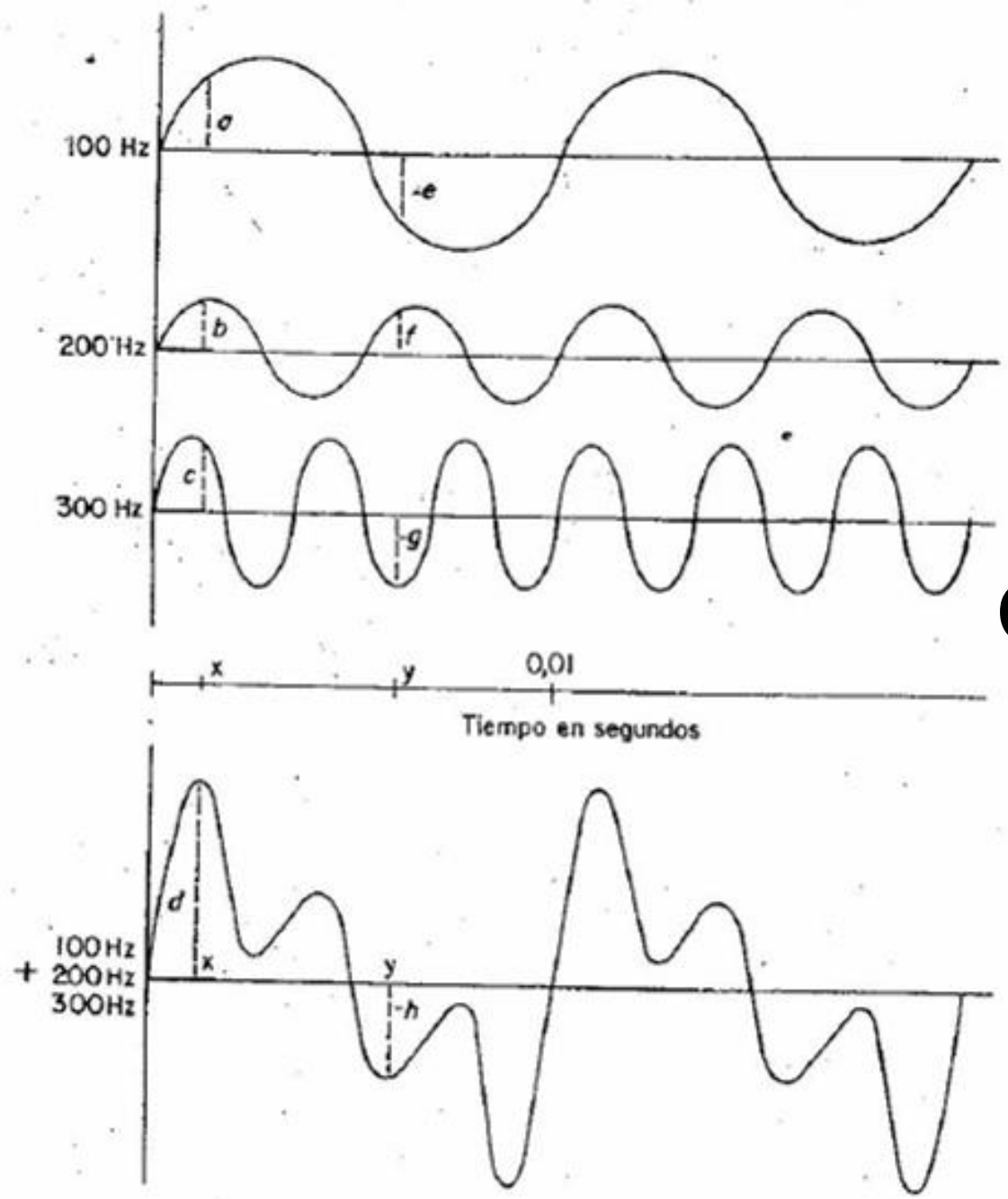


Fig. 8: *Ondas simples de 100, 200 y 300 Hz y onda compleja resultante de la combinación de las tres ondas simples.*

SUMA DE ONDAS SIMPLES Y RESULTANTE COMPLEJA I

SUMA DE ONDAS SIMPLES Y RESULTANTE COMPLEJA II

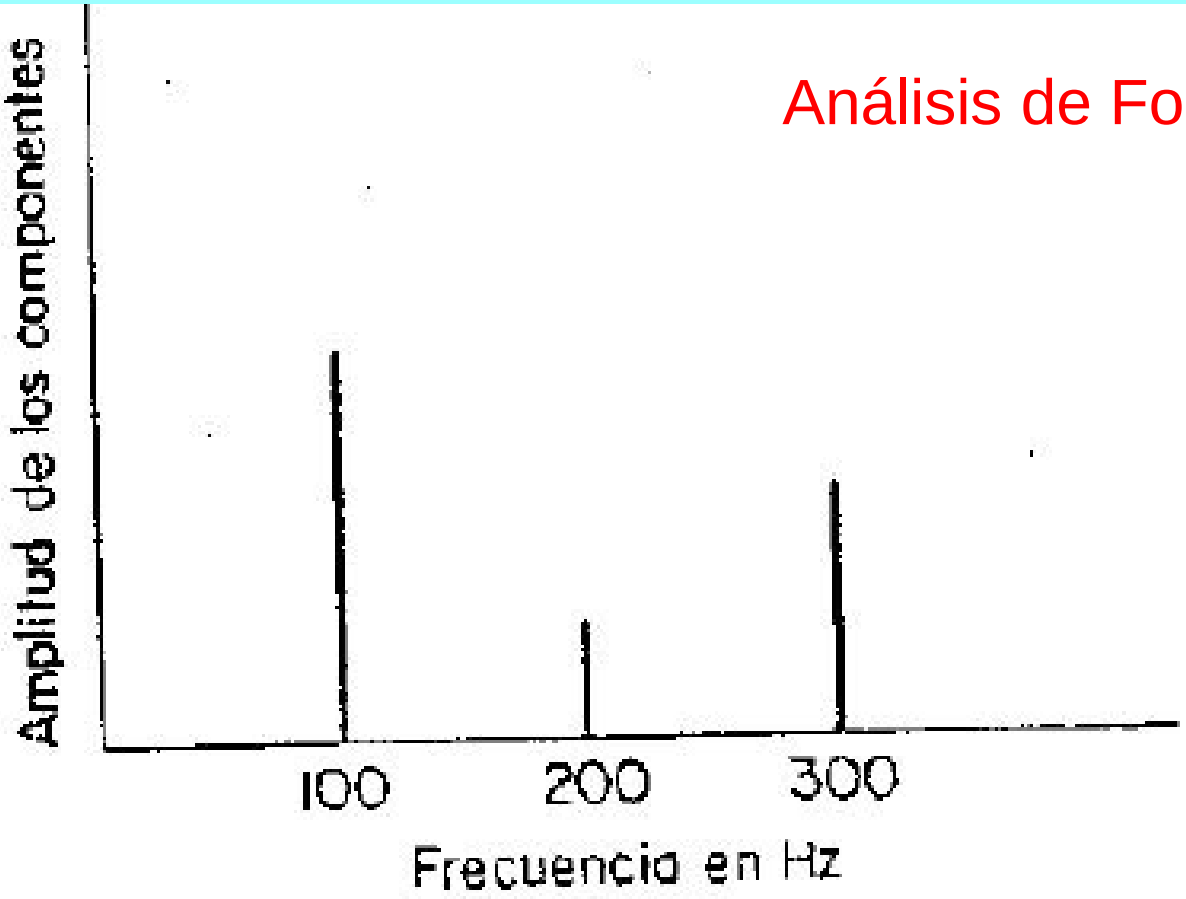


Fig. 9: *Espectro de la onda compleja graficada en la figura 8.*

REPRESENTACIONES TEMPORALES Y FRECUENCIALES DE UNA SEÑAL I

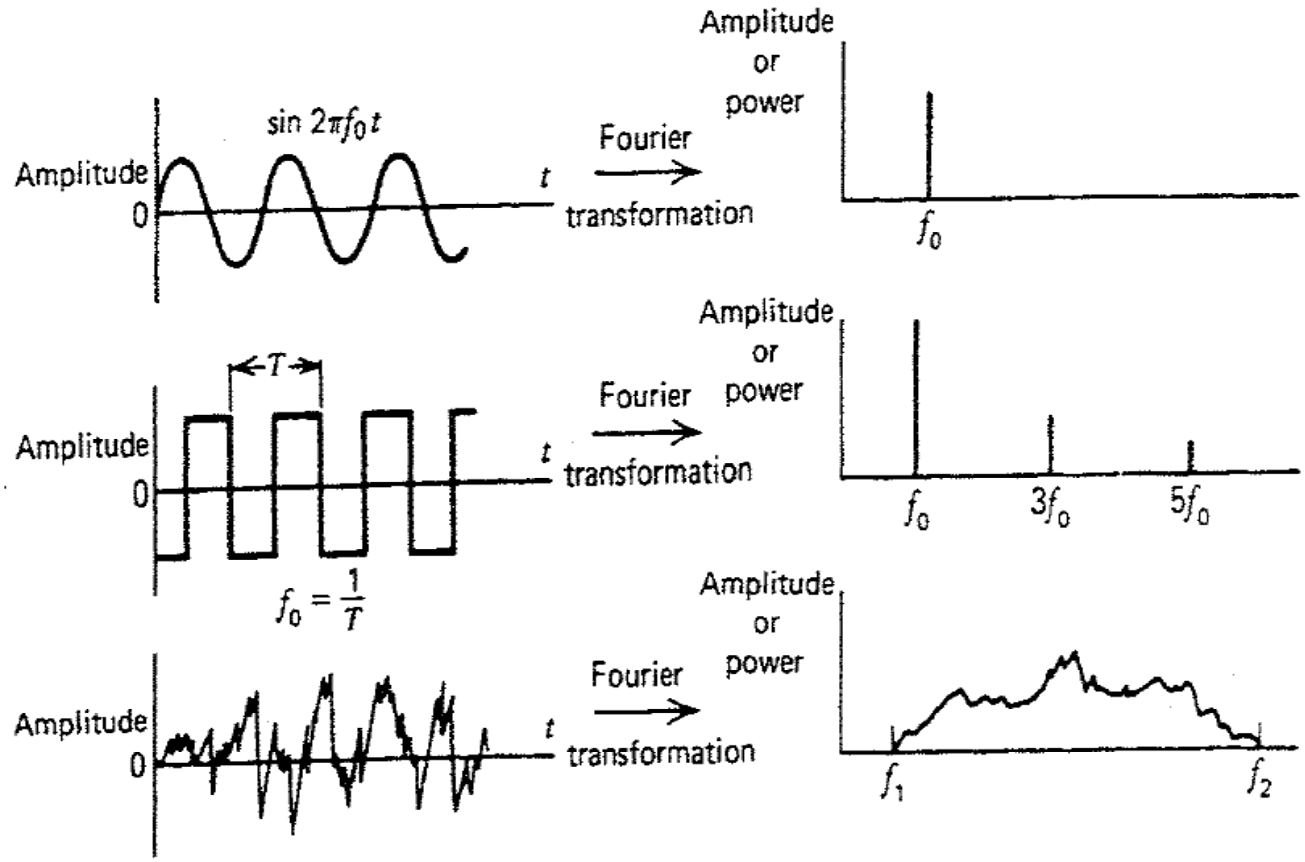


Fig. 10.17. Three waveforms on the left with their variations with time (the time domain), a sine (or cosine) wave, a square wave, and a more random pattern, with their respective frequency components (as Fourier analyzed and in the frequency domain). (From [507]. Reprinted with permission of Wiley)

ESPECTROS TEMPORAL Y FRECUENCIAL DEL SONIDO

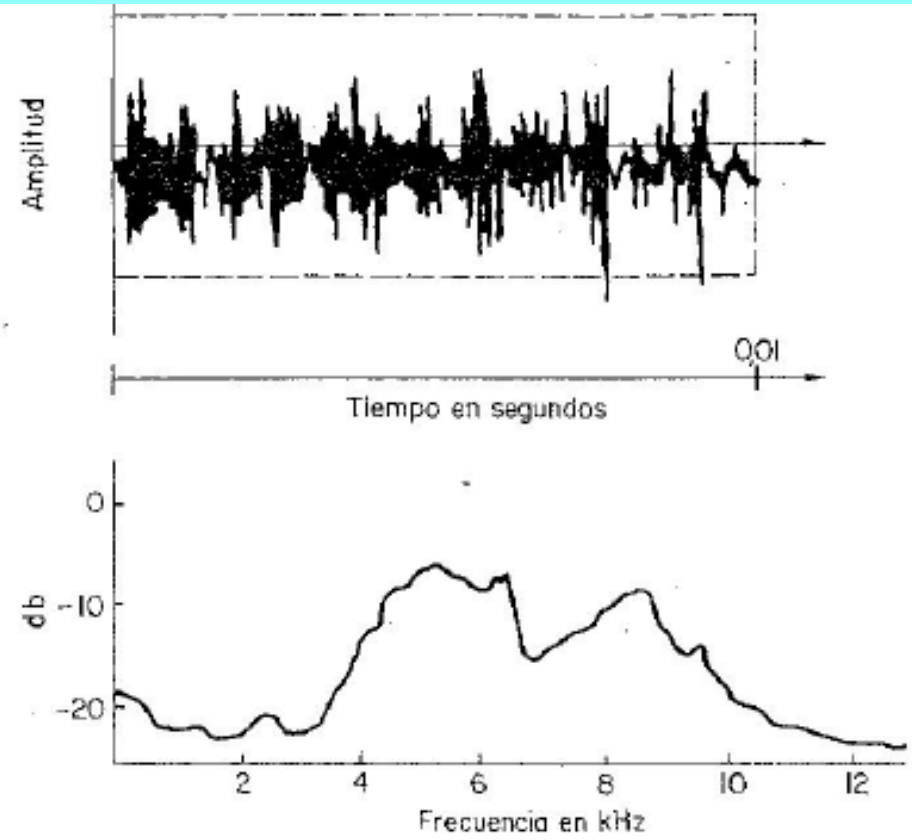
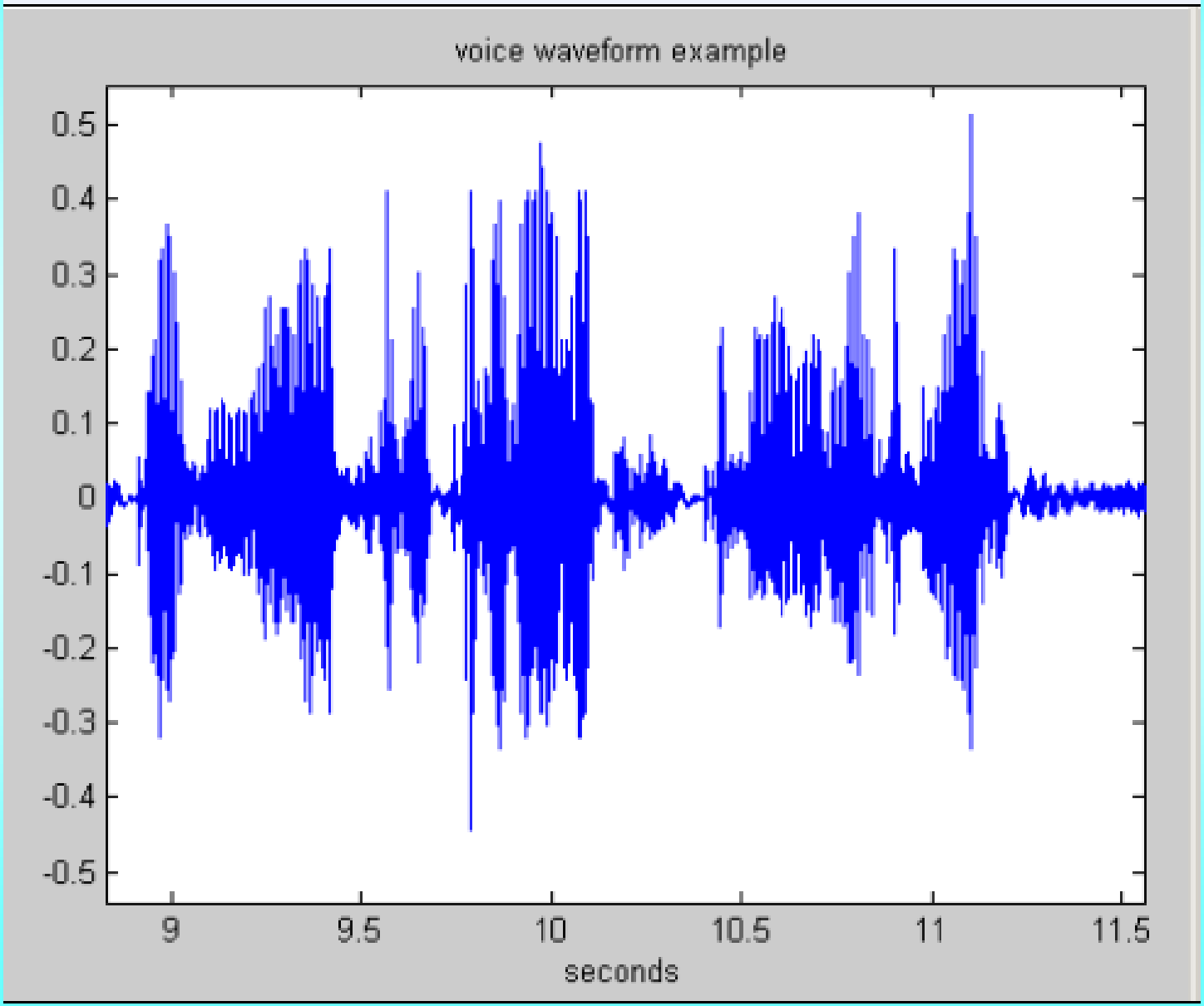


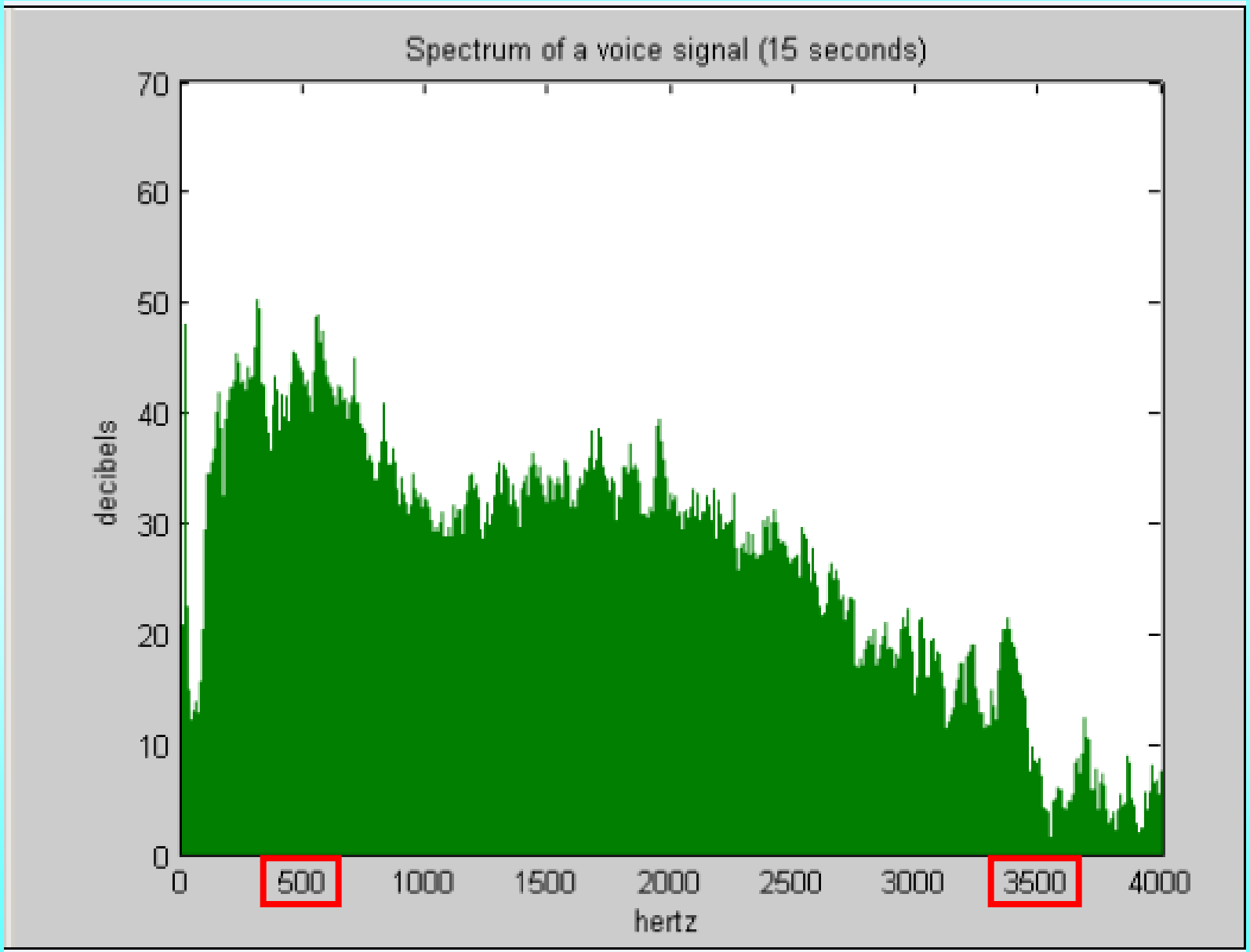
Fig. 12: *Forma de onda y espectro del sonido [s].*

Cuando la amplitud de una onda compleja, tanto periódica como aperiódica, aumenta o disminuye, las amplitudes de todos sus componentes varían en la misma proporción.

ANALISIS TEMPORAL DE LA VOZ



CONTENIDO ESPECTRAL DE LA VOZ



PARAMETROS DE LA VOZ HUMANA I

FISICOS	PERCEPTIVOS
• FRECUENCIA FUNDAMENTAL Baja Alta	ALTURA Grave Agudo
• INTENSIDAD DE FONACION Presión (Pa) o Intensidad (W/m^2)	SONORIDAD Ley de Stevens: $P = K(S - S_0)^n$ P es la percepción del estímulo S por sobre el umbral S_0. K y n son constantes apropiadas. n = 0,54 para audición monoaural y 0,60 para la biaural.
• COMPOSICION DE ARMONICOS	TIMBRE O CALIDAD

PARAMETROS DE LA VOZ HUMANA II

Características de la voz humana

Espectro:

El timbre de la voz humana es muy rico en armónicos, habiéndose observado espectros conteniendo hasta 35 armónicos diferentes.

Duración:

Duración variable, con duración máxima fija (tiempo que una persona puede espirar aire sin inspiración). La duración de las vocales es relativamente grande. La duración promedio de una vocal es de 0,2 s a 1 s.

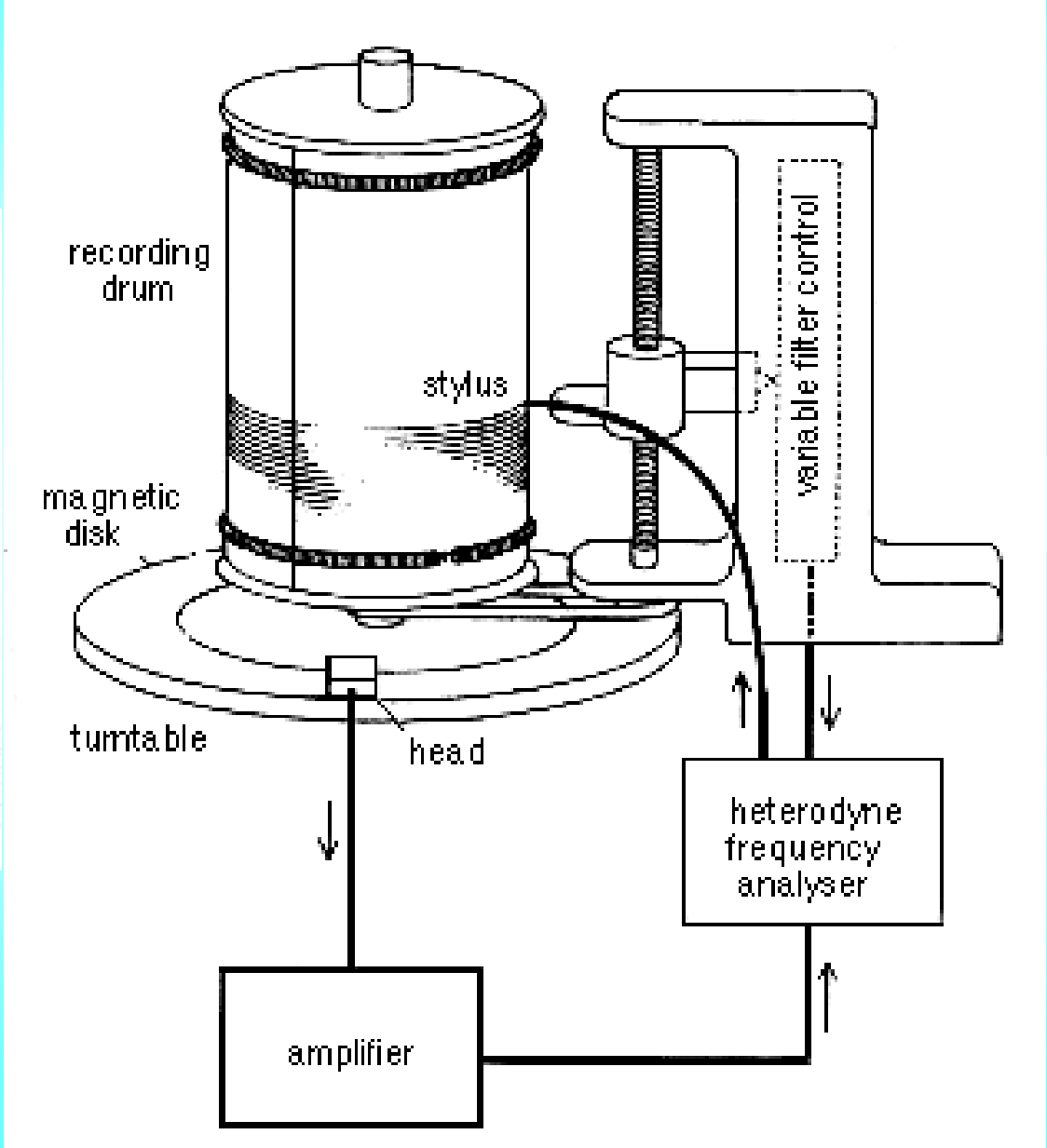
Envolvente:

En la producción de una vocal se siguen los periodos de ataque,extinción y estado estacionario. Durante los tres, hay un cambio considerable en el espectro acústico.

El estado estacionario muestra el menor cambio en las componentes en frecuencia. El ataque y la extinción son relativamente largos, aunque pueden variar sobre un amplio rango. Esto es debido a la naturaleza altamente resonante de la cavidad bucal.

AUDIOESPECTROGRAFO

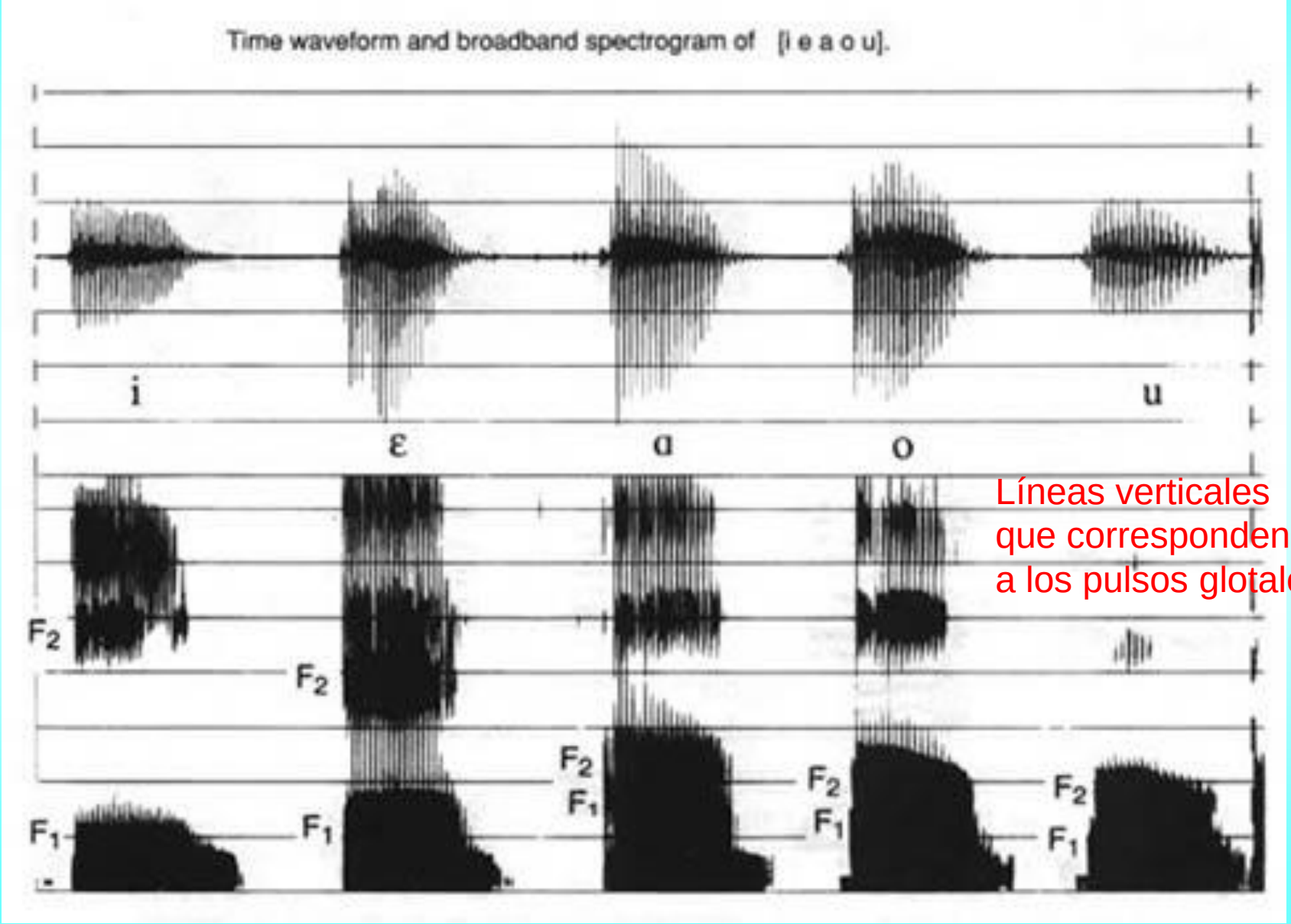
Fig. 1.—The apparatus used for speech analysis. Sounds recorded by the machine on the right are transferred to the magnetic disc of the centre unit. The portrayal is made by a stylus on the electrically sensitive paper attached to the drum which rotates with the disc.



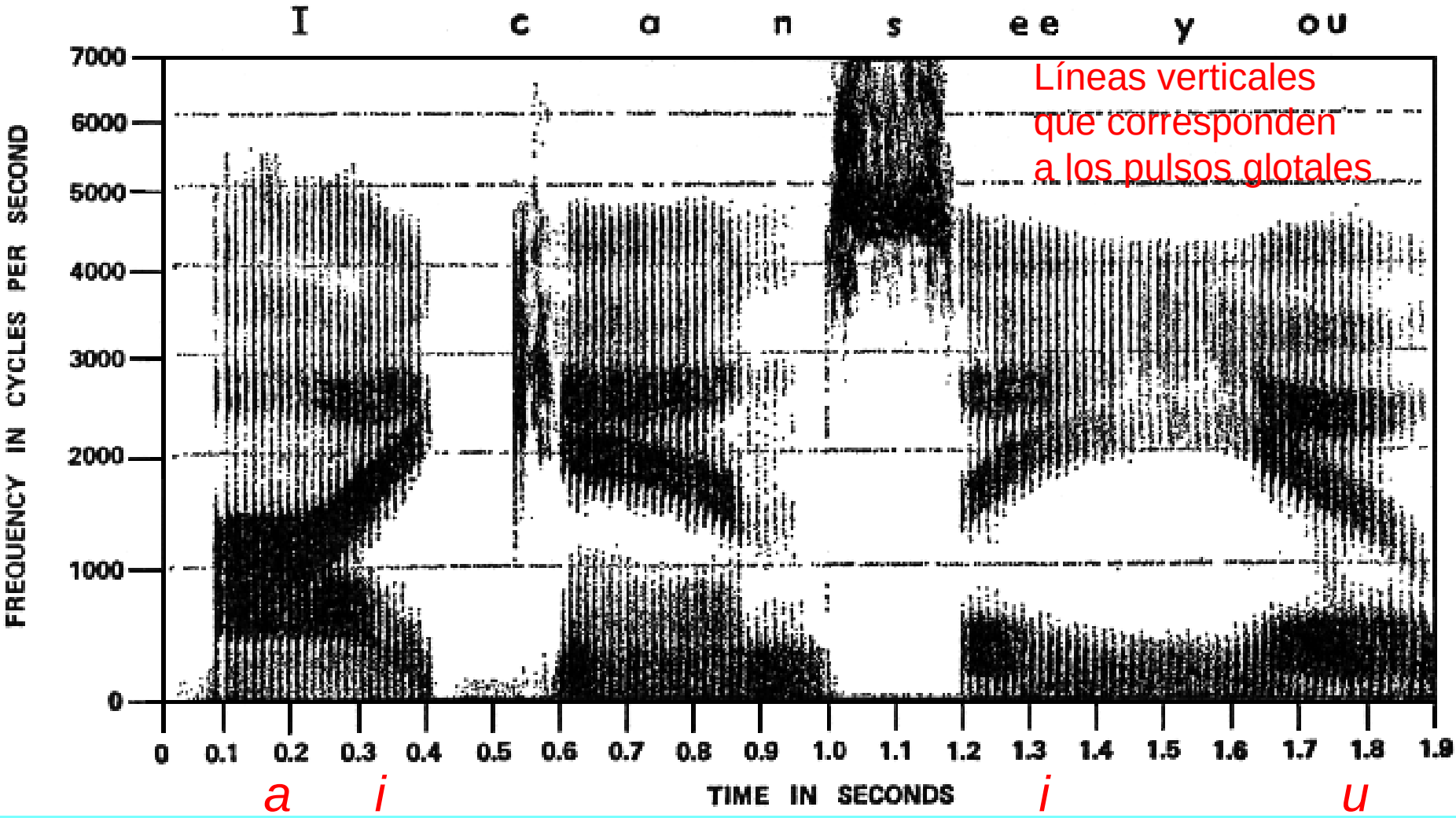
AUDIOESPECTROGRAMAS INGLESES I

Forma de onda

Audiograma y Formantes



AUDIOESPECTROGRAMAS INGLESES II

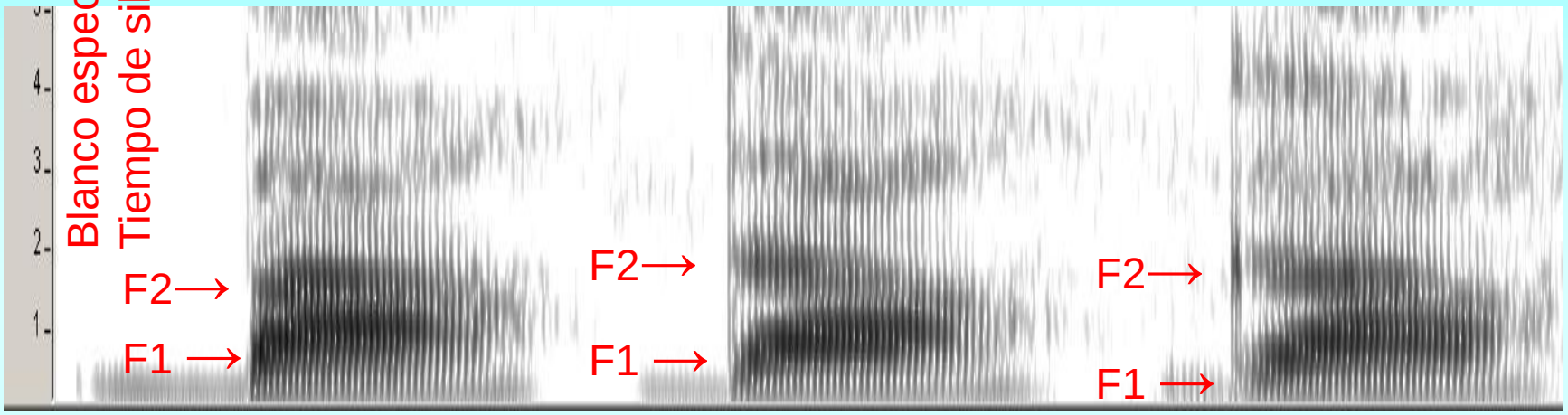


AUDIOESPECTROGRAMAS CASTELLANOS
LOS FORMANTES: F1 Y F2

Blanco espectrográfico
Tiempo de silencio

Sílabas

ba ***da*** ***ga***



↑ 12 ms ↑ Comienzo de la Explosión

↑ ↑ 7 ms Vibración laríngea

↑ ↑ 5 ms

Líneas verticales que corresponden a los pulsos glotales

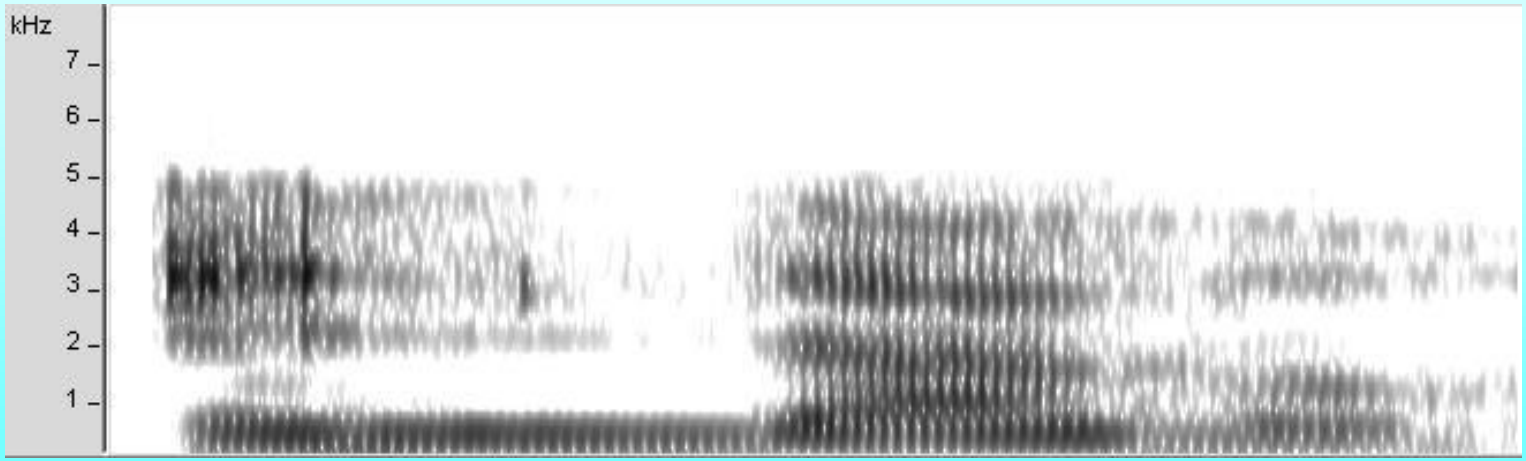
Oclusión y modulación:

Bilabial ***Apicodental*** ***Dorsovelar***

AUDIOESPECTROGRAMAS CASTELLANOS

Un bebé

El dado



FORMANTES F1 Y F2, Y REGION PRINCIPAL FORMANTICA

Centro formántico de las vocales		
Vocal	Formante F1	Formante F2
u	320 Hz	800 Hz
o	500 Hz	1000 Hz
å	700 Hz	1150 Hz
a	1000 Hz	1400 Hz
ö	500 Hz	1500 Hz
ü	320 Hz	1650 Hz
ä	700 Hz	1800 Hz
e	500 Hz	2300 Hz
i	320 Hz	3200 Hz

Formantes vocálicos	
Vocal	Región principal formántica
/u/	200 a 400 Hz
/o/	400 a 600 Hz
/a/	800 a 1200 Hz
/e/	400 a 600 y 2200 a 2600 Hz
/i/	200 a 400 y 3000 a 3500 Hz

F1 Y F2 DEL INGLES ESTADOUNIDENSE

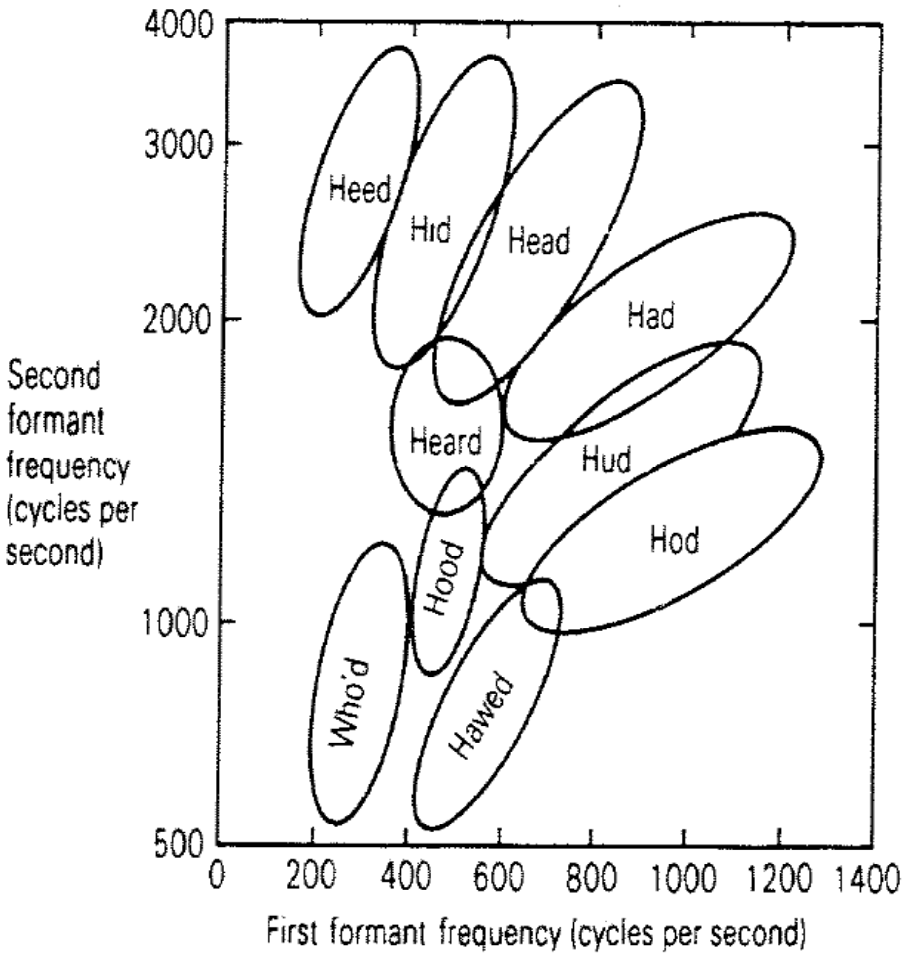
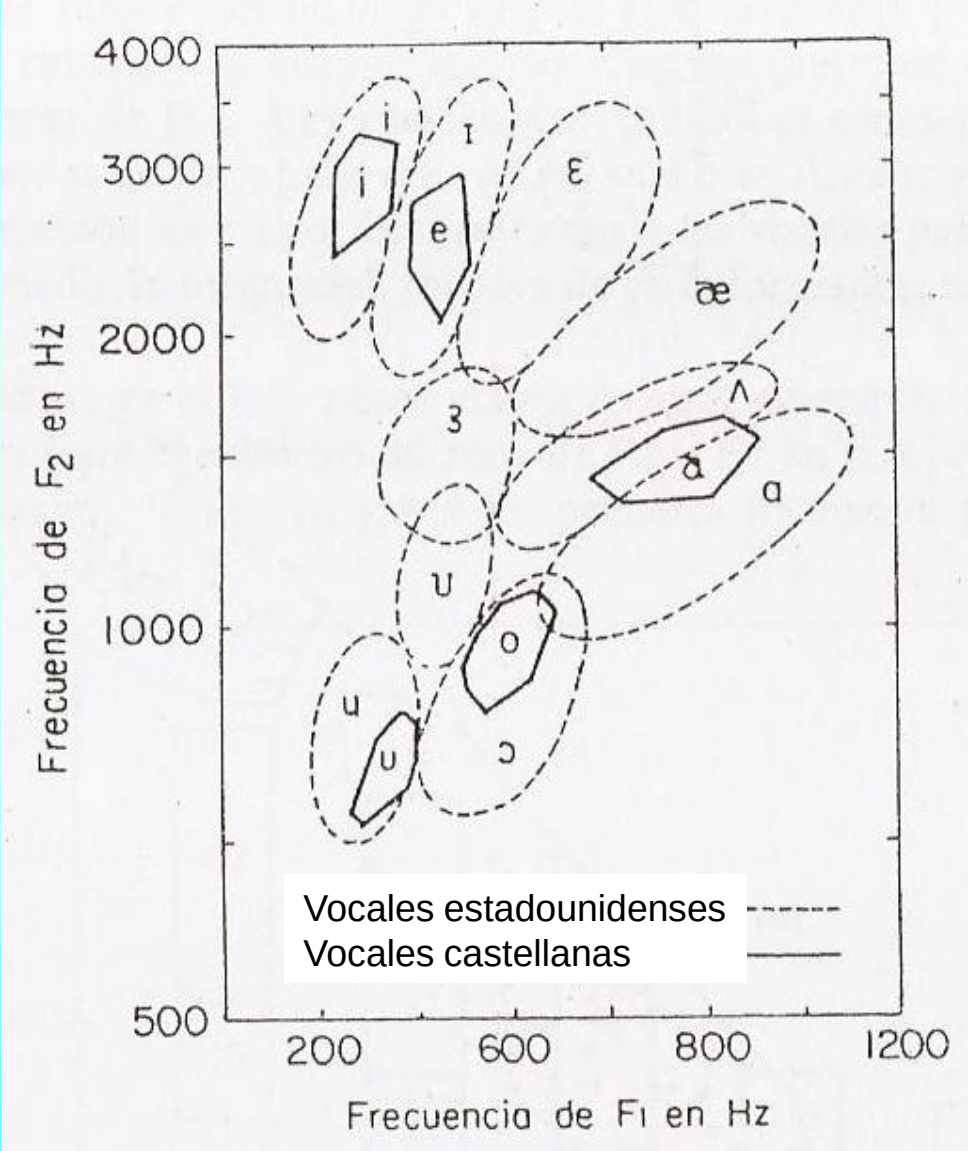


Fig. 10.19. Second-formant frequencies vs. first-formant frequencies for 10 American English vowels, as spoken by a wide range of 76 people: men, women, and children. The enclosures include 90% of the sounds spoken. (From [447] as adapted from [493], and used with permission)

F1 Y F2 DEL CASTELLANO ARGENTINO Y DEL INGLES ESTADOUNIDENSE



PRIMER FORMANTE F1 Y SEGUNDO FORMANTE F2

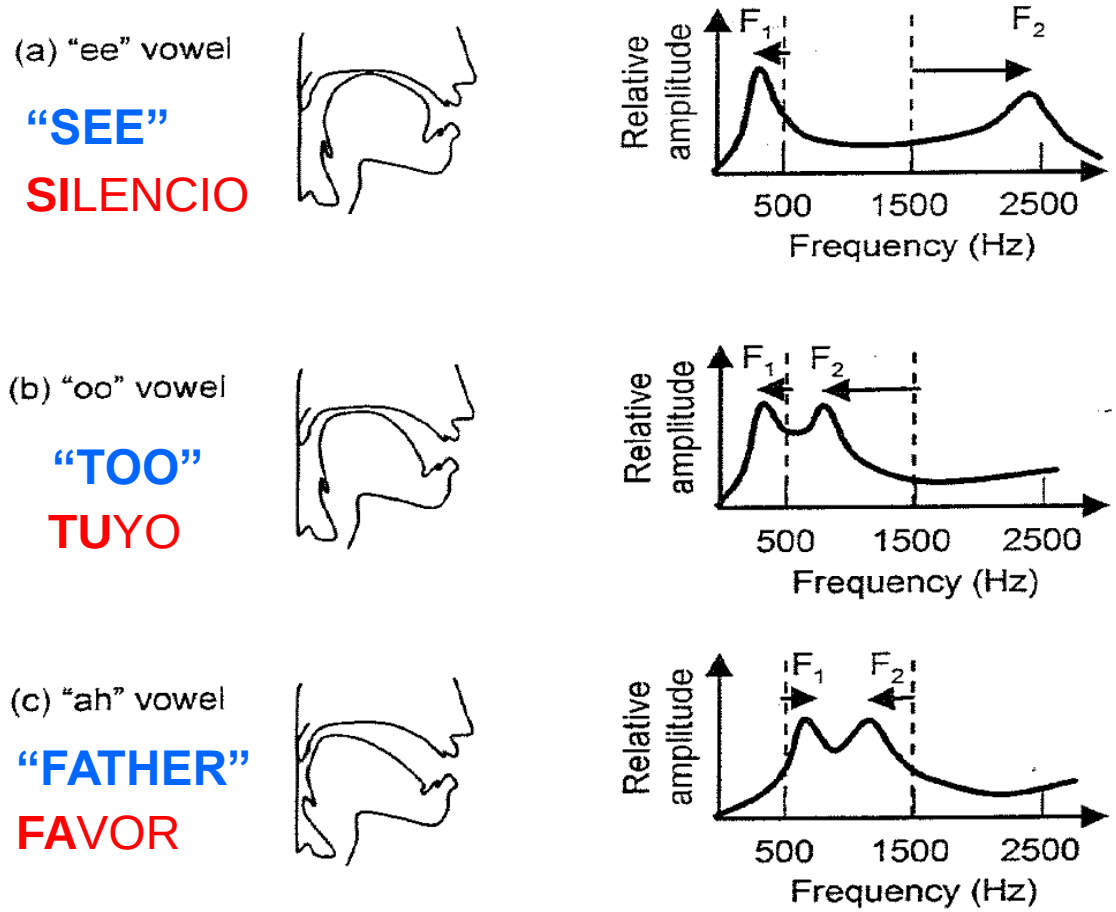


Fig. 10.24. Vocal tract shapes and spectra for three vowels: (**a**) "ee" as in "see," (**b**) "oo" as in "too," and (**c**) "ah" as in "father" and "pot." The difference of the first two formants are shown here relative to those for a tube with constant cross-section. These are similar to Fig. 10.18a–c, except for the more realistic vocal tract depicted here and the mouth is on the right of the larynx here. (Based on [504])

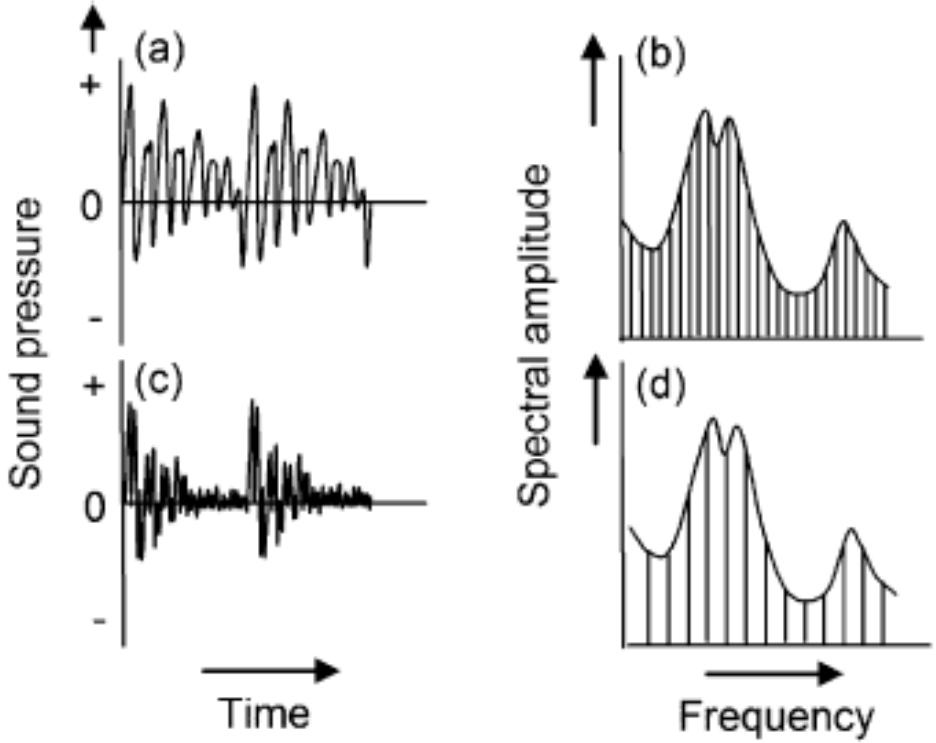


Fig. 10.21. Wave shapes (**a**,**c**) and corresponding spectra (**b**,**d**) for the same vowel "aw" as in "bought" and "awe," but with two different vocal fold frequencies of (a,b) 90 Hz and (c,d) 150 Hz. (Based on [461])

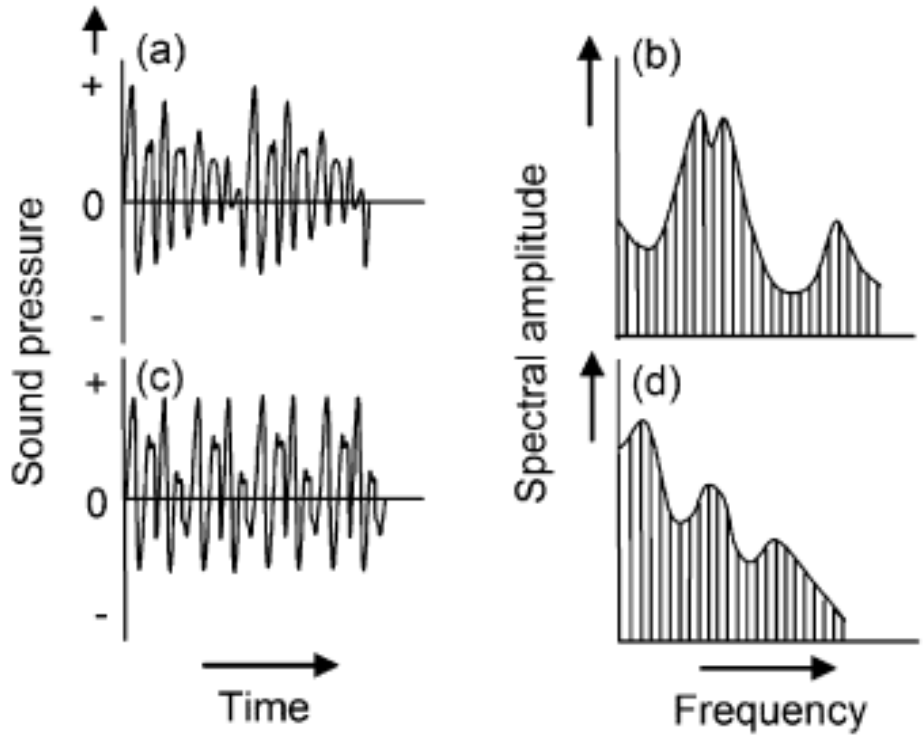


Fig. 10.22. Wave shapes (**a**,**c**) and corresponding spectra (**b**,**d**) for different vowels (a,b) "aw" as in "bought" and "awe" and (c,d) "uh" as in "but" and "about," but with the same vocal fold fundamental frequency of 90 Hz. (Based on [461])

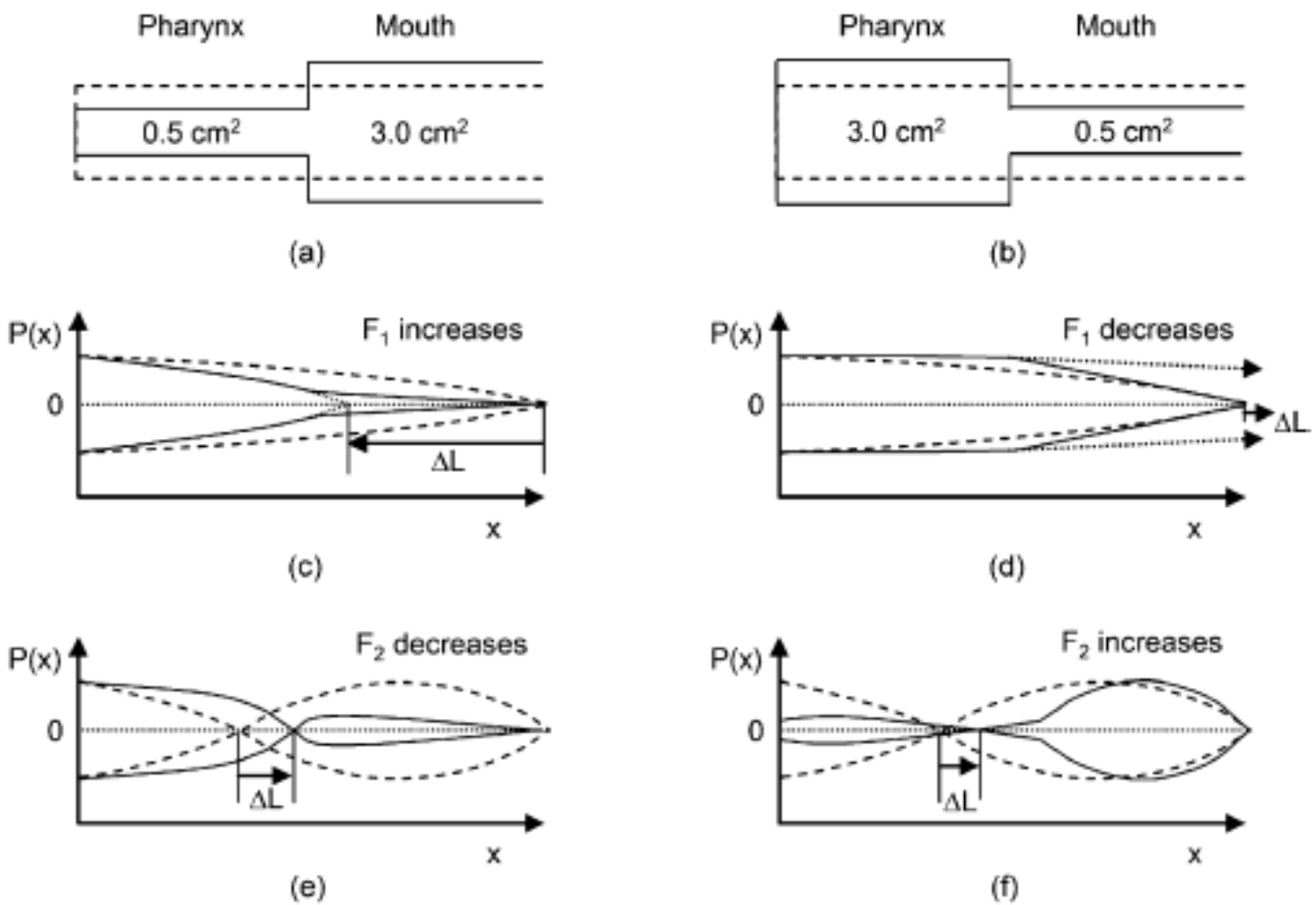


Fig. 10.25. Two-tube models of (left side; **a**,**c**,**e**) "ah" as in "father" and "pot," and (right side; **b**,**d**,**f**) "ee" as in "see," each showing the two-tube model with noted cross-sectional area in the equal length tubes in (a,b), modification of the mode for the one-tube model (*dashed lines*) to the mode in the two-tube model (*solid lines*, with changes in effective length denoted by the *dotted lines*) for the first (c,d) and second (e,f) formants. (Based on [504])

VOCES Y CARACERISTICAS DEL TRACTO VOCAL: LOS FORMANTES

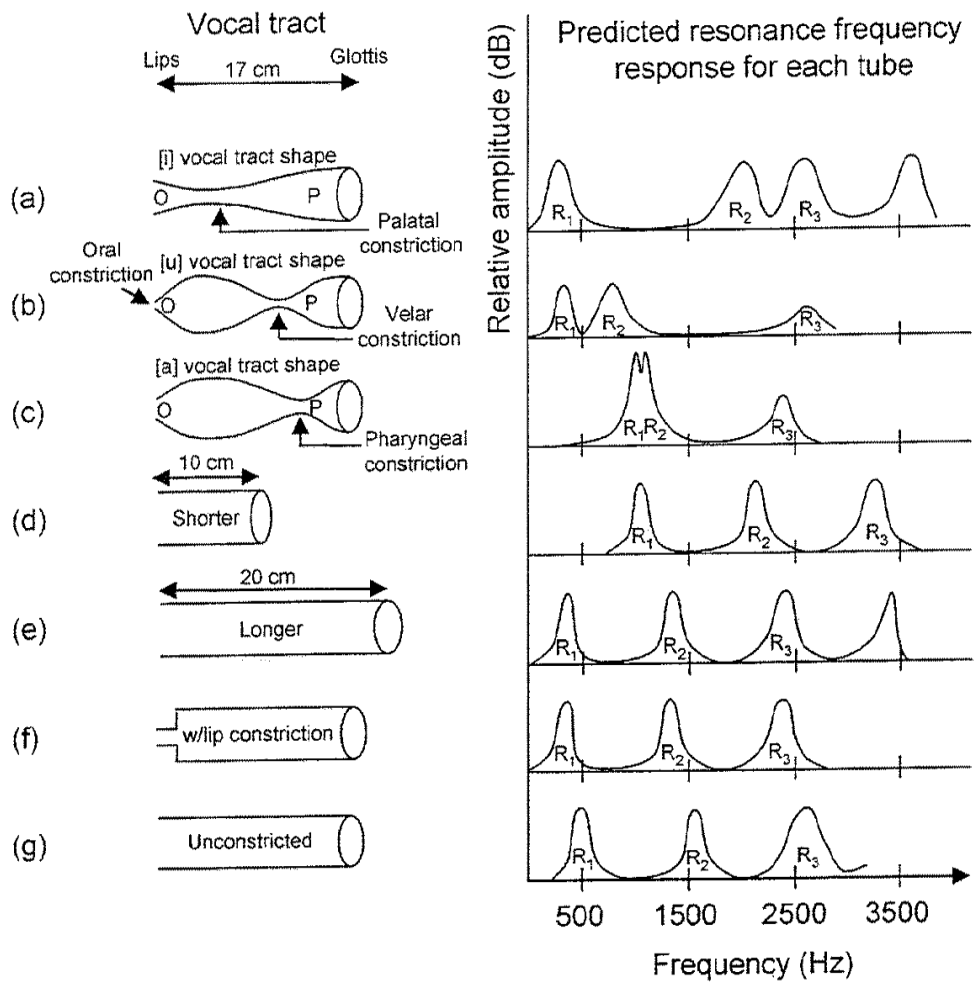


Fig. 10.18. Resonance frequencies for vocal tracts with different lengths and constrictions, relative to the unconstricted vocal track in (g). The vowels are (**a**) [i] as in "sit," (**b**) [u] as in "put," and (**c**) [a] (or "ah") as in "father" and "pot." (Based on [460])

ARMONICOS Y ENERGIA DE LA VOZ

- La inteligibilidad oral se debe a las altas frecuencias.
- Para que el habla sea comprensible, es indispensable la presencia de armónicos cuyas frecuencias se halla entre 500 y 3500 Hz.
- La energía de la voz está contenida en su mayor parte en las bajas frecuencias y su supresión resta potencia a la voz que suena delgada y con poca energía.

PARAMETROS DE LA VOZ HUMANA III

Gama de niveles de intensidad

Emisión	Intensidad (w/m^2)	Nivel sonoro (dB)
Nivel mínimo de la voz humana	10^{-10}	20
Mujer conversando en voz baja	$3.16x10^{-10}$	25
Hombre conversando en voz baja	10^{-9}	30
Mujer conversando en voz normal	10^{-7}	50
Hombre conversando en voz normal	$3.16x10^{-7}$	55
Mujer hablando en público	10^{-6}	60
Hombre hablando en público	$3.16x10^{-6}$	65
Mujer hablando esforzándose	10^{-5}	70
Hombre hablando esforzándose	$3.16x10^{-5}$	75
Mujer cantando	10^{-4}	80
Hombre cantando	$3.16x10^{-4}$	85
Nivel máximo de la voz humana	10^{-3}	90

Gama de frecuencias fundamentales

Voz	Extensión (Hz)	Tesitura
Soprano	247-1056	SI_3-DO_6
Mezzosoprano	220-900	LA_3-SIb_5
Contralto	176-840	FA_3-LAb_5
Tenor	132-528	DO_3-DO_5
Barítono	110-440	LA_2-LA_4
Bajo	82-396	MI_2-SOL_4

AUDIOESPECTROGRAMAS DE VOCES DE CANTANTES

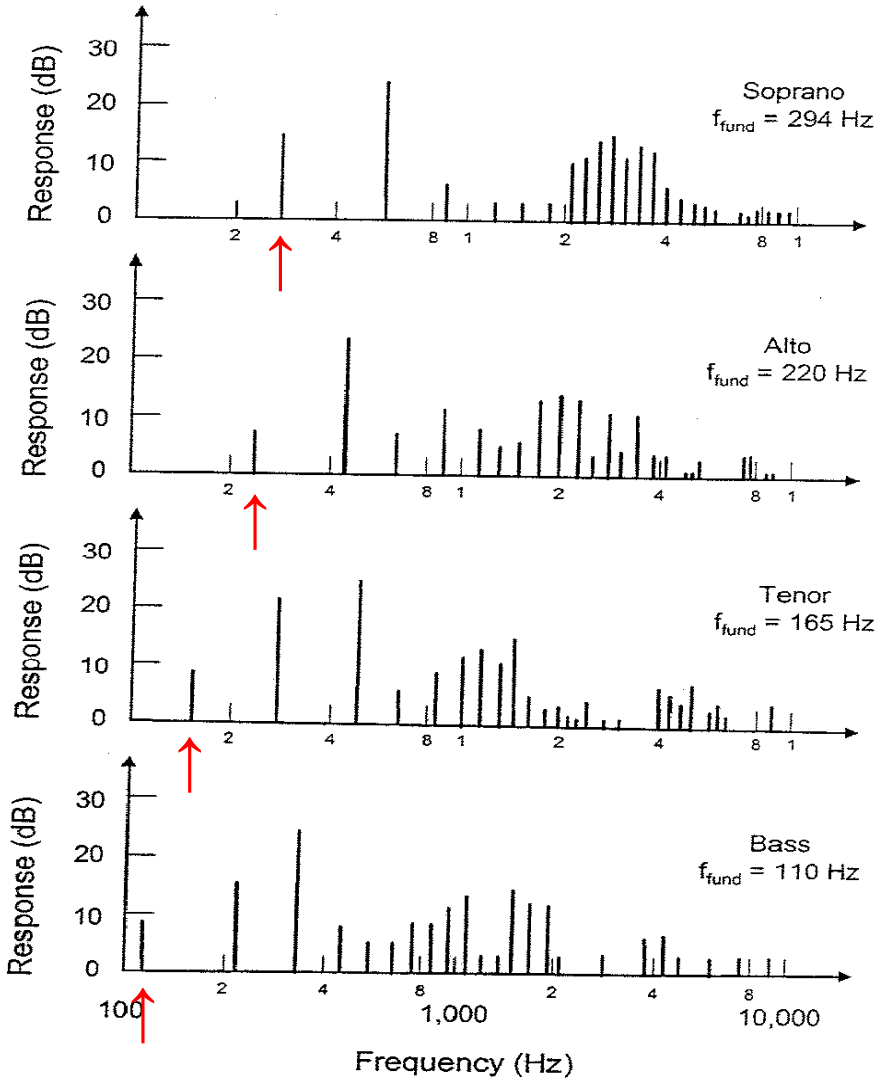
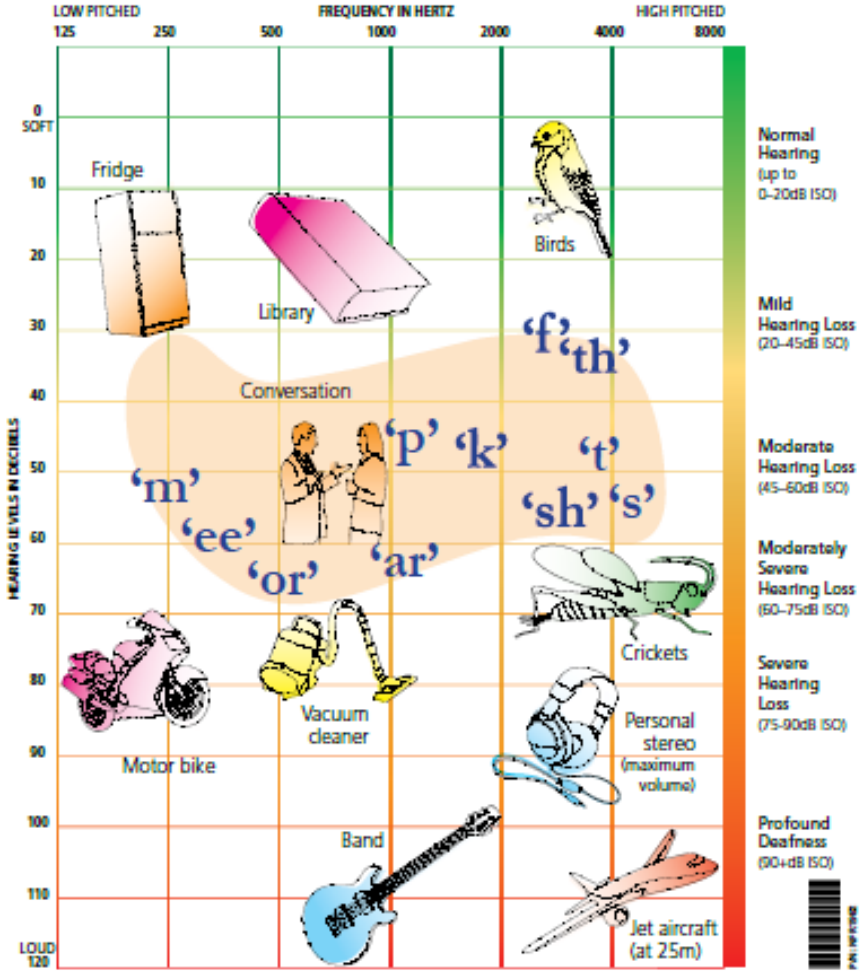


Fig. 10.20. The acoustic spectra for four voices, with the given fundamental frequencies, producing the vowel "ah" as in "father" and "pot." (Based on [492])

Frequency and intensity of familiar sounds

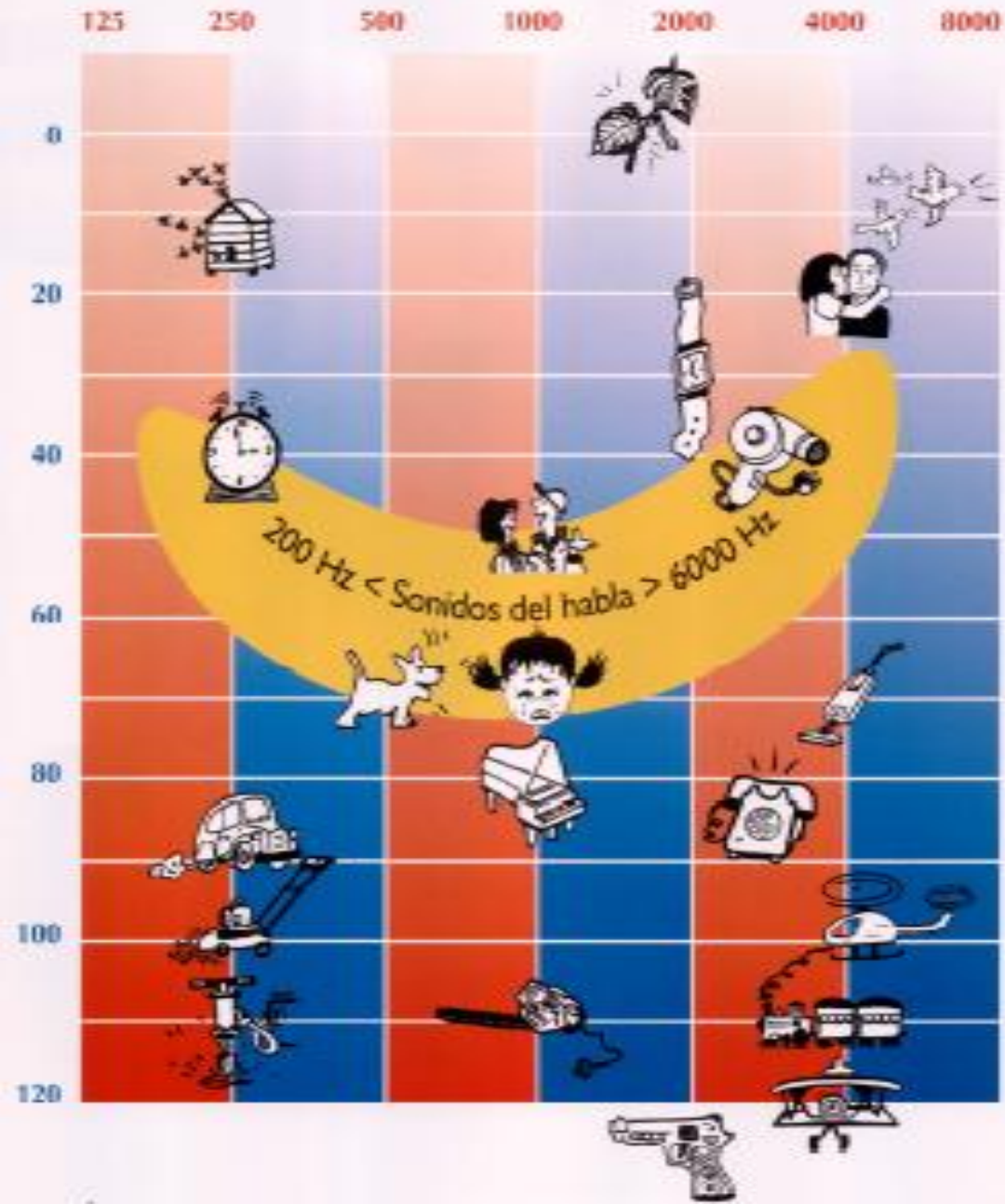
THE SPEECH INFORMATION ON THIS CHART IS BASED ON MEASUREMENTS MADE BY NATIONAL ACOUSTIC LABORATORIES, THE RESEARCH DIVISION OF AUSTRALIAN HEARING. EVERYDAY SOUNDS COVER A RANGE OF FREQUENCIES AND INTENSITIES. THIS CHART IS A GUIDE ONLY.



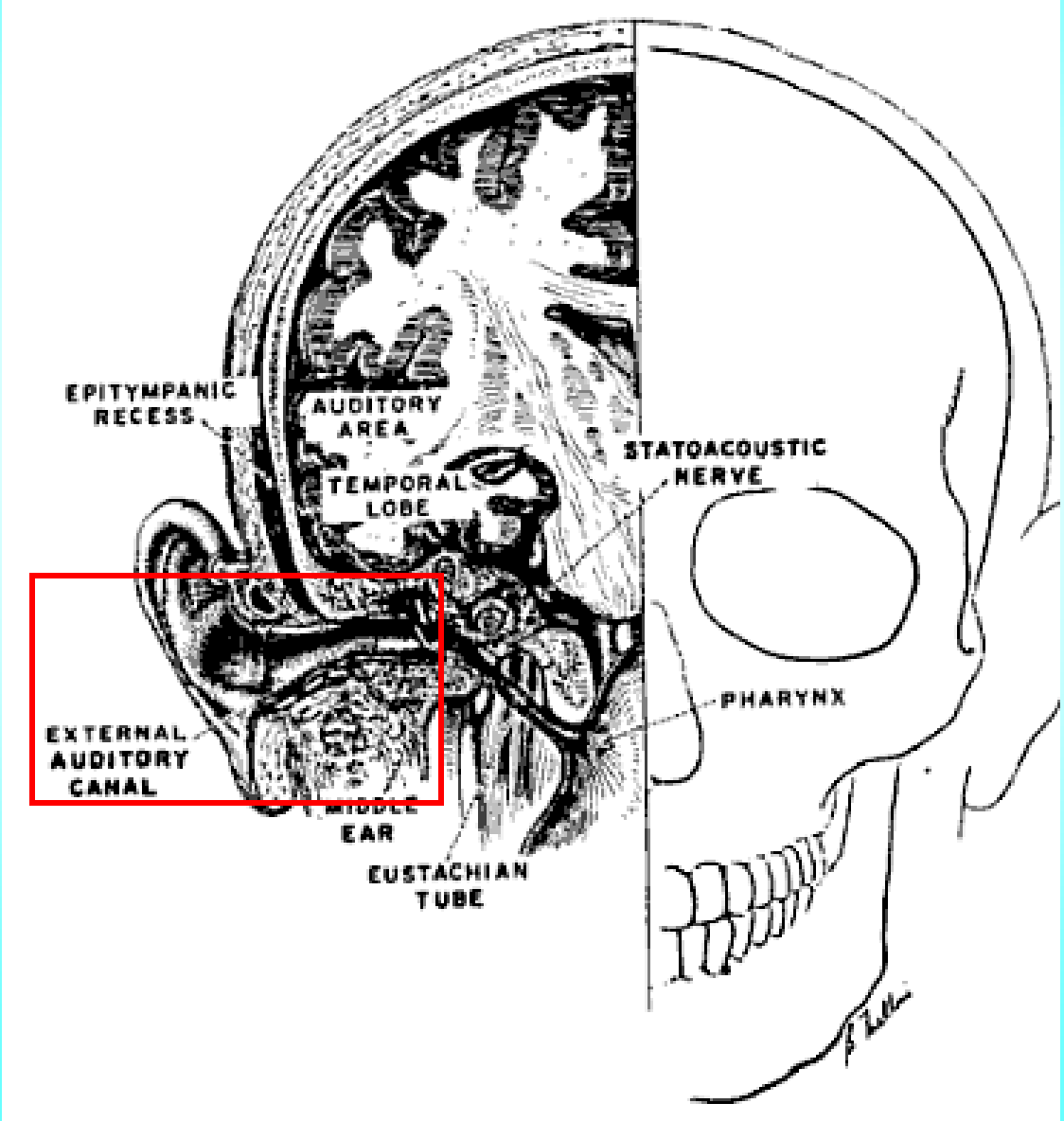
FREQUENCY AND INTENSITY OF FAMILIAR SOUNDS

Australian Hearing | 131 797 www.hearing.com.au

AUDIOGRAMA


125
250
500
1000
2000
4000
8000
0
20
40
60
80
100
120
200 Hz < Sonidos del habla > 6000 Hz

EL SISTEMA AUDITIVO EN RELACION CON EL CRANEO Y EL CEREBRO



TUBOS ABIERTOS Y CERRADOS Y SUS MODOS RESONANTES I

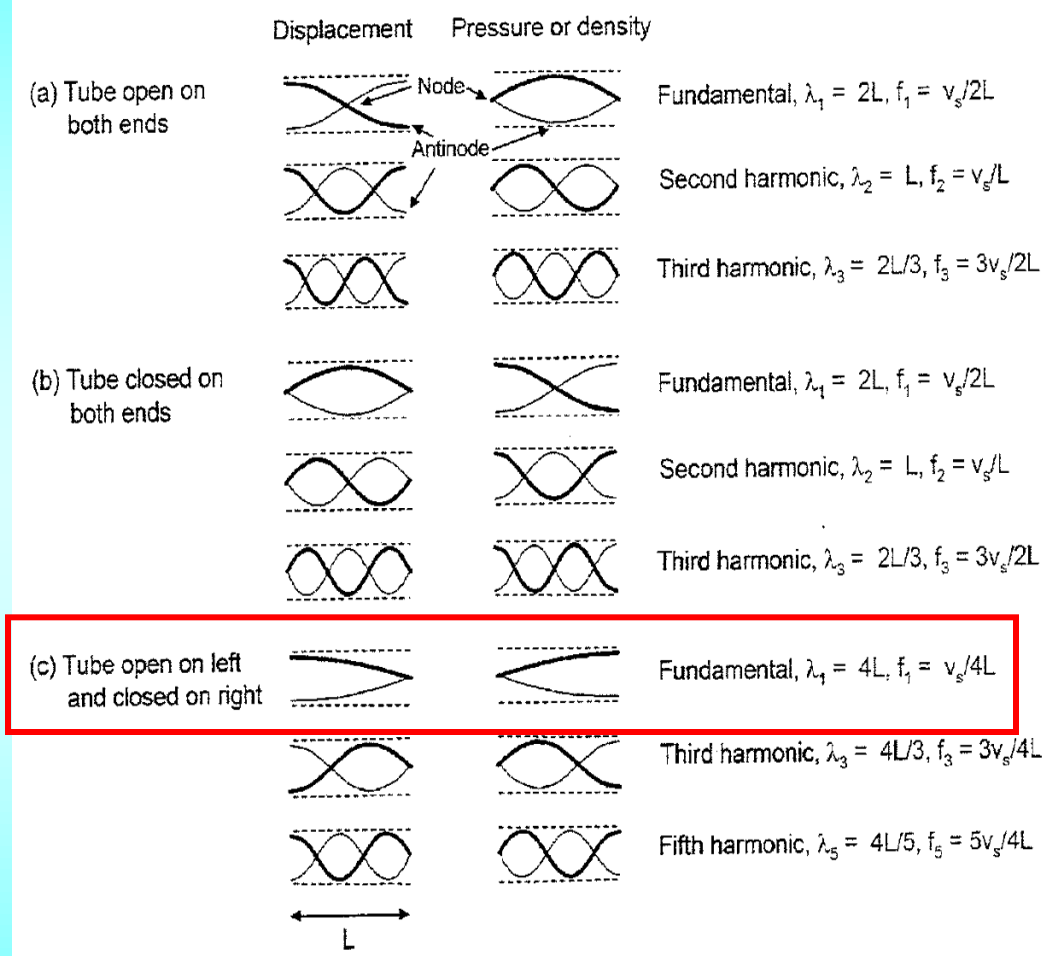
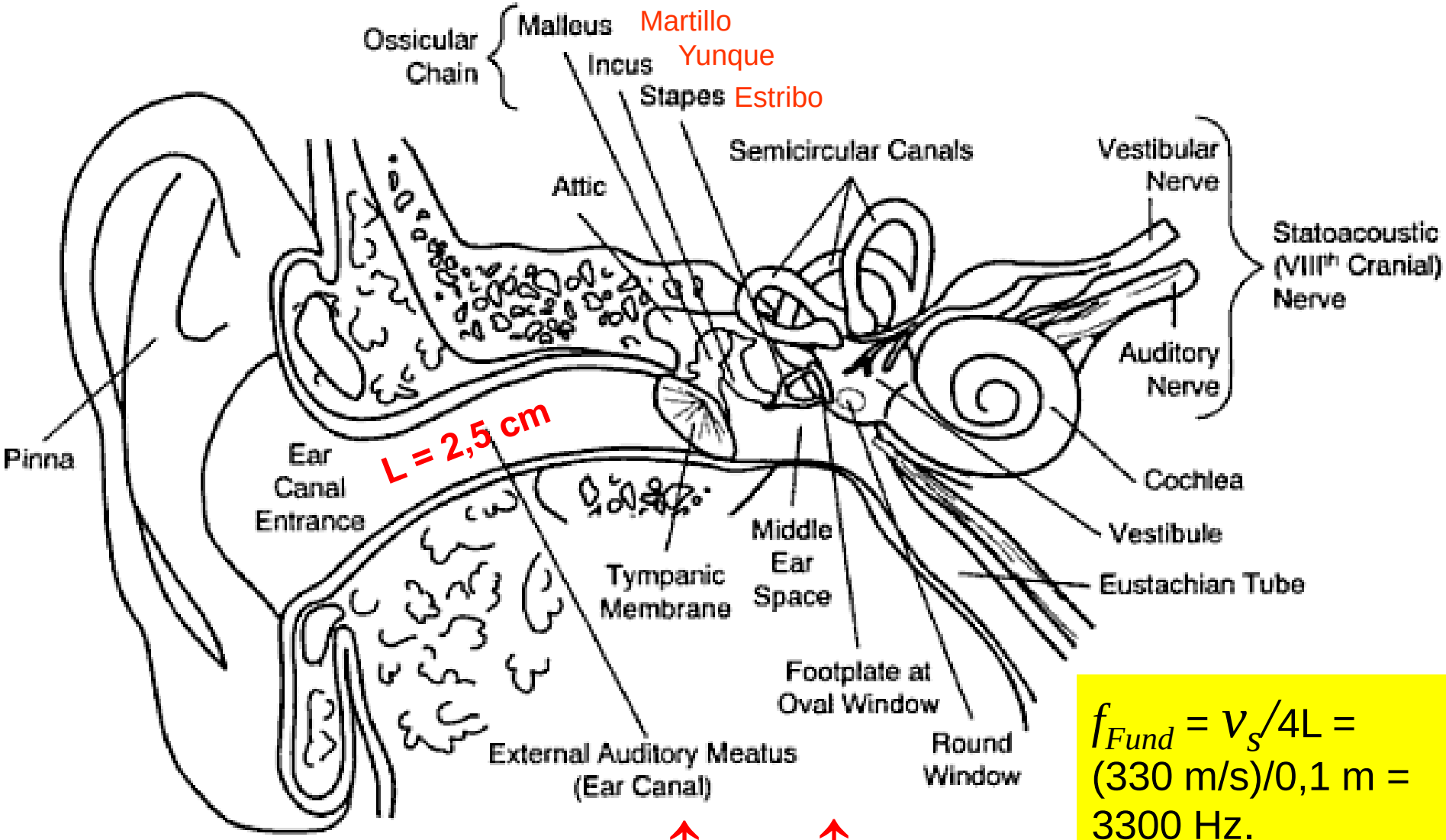


Fig. 10.5. Wave modes in a tube, for tubes (**a**) open on both ends, (**b**) closed on both ends, and (**c**) open on the left side and closed on the right side. The mode displacements of air are shown on the left for the first overtone or fundamental mode and for the next two overtones, and the corresponding changes in pressure and density for these modes are shown on the right. (Based on [471])

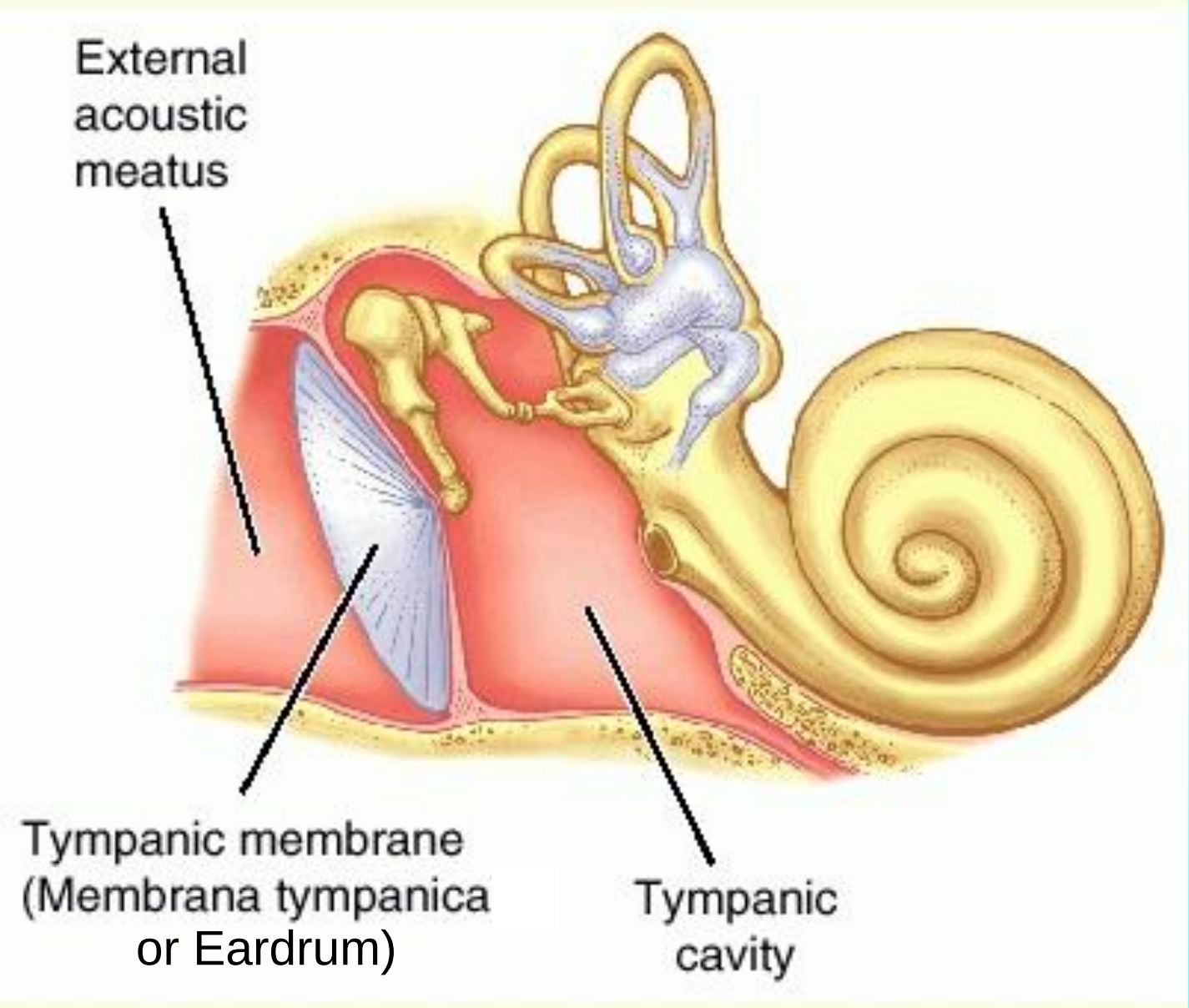
OIDO Y CANALES SEMICIRCULARES



$f_{Fund} = v_s/4L =$ (330 m/s)/0,1 m = 3300 Hz.

Oido externo ↑ Oido medio ↑ Oido interno

CORTE DEL OIDO MEDIO



OIDO MEDIO Y DETALLE DE LA COCLEA

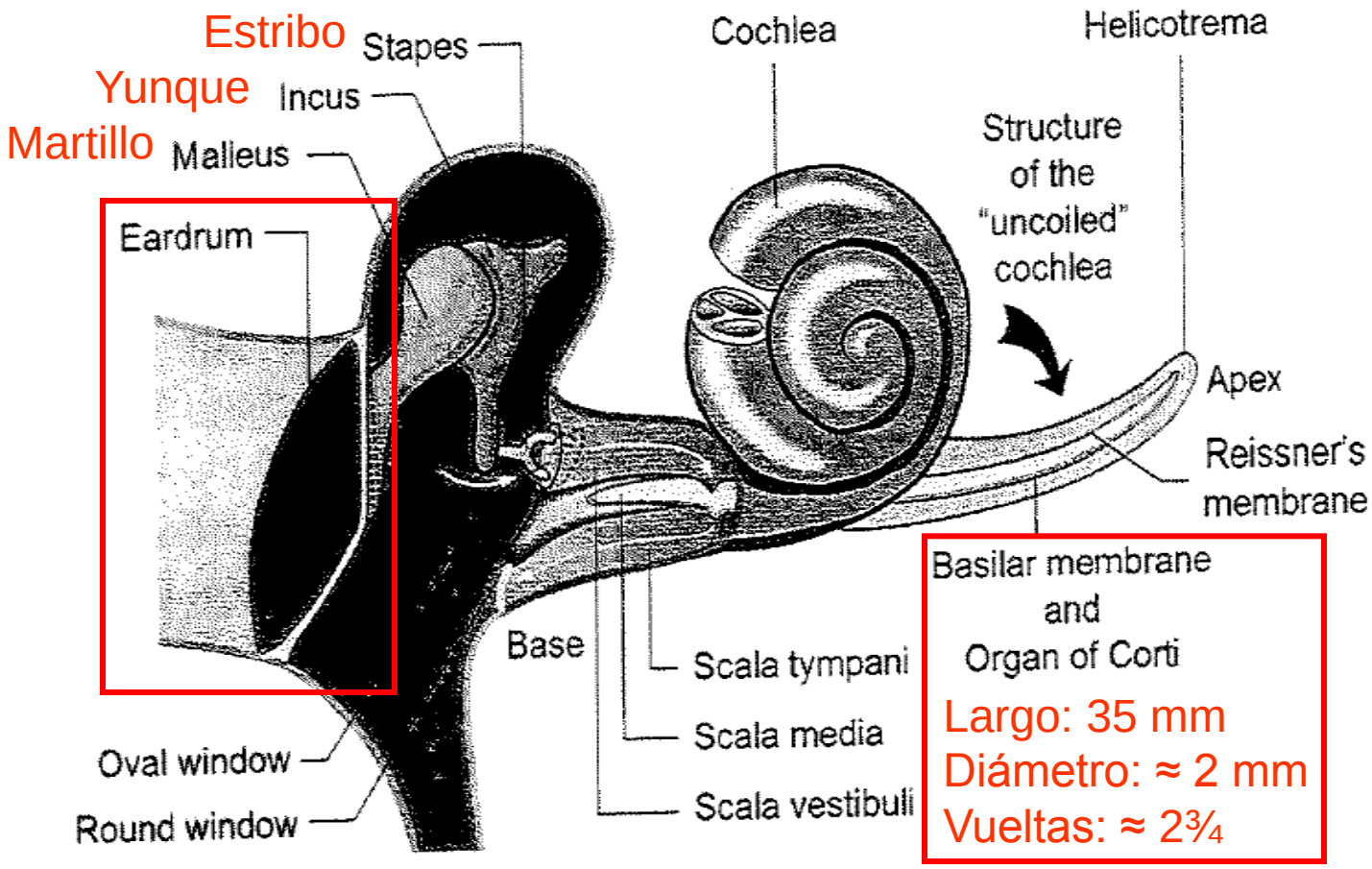
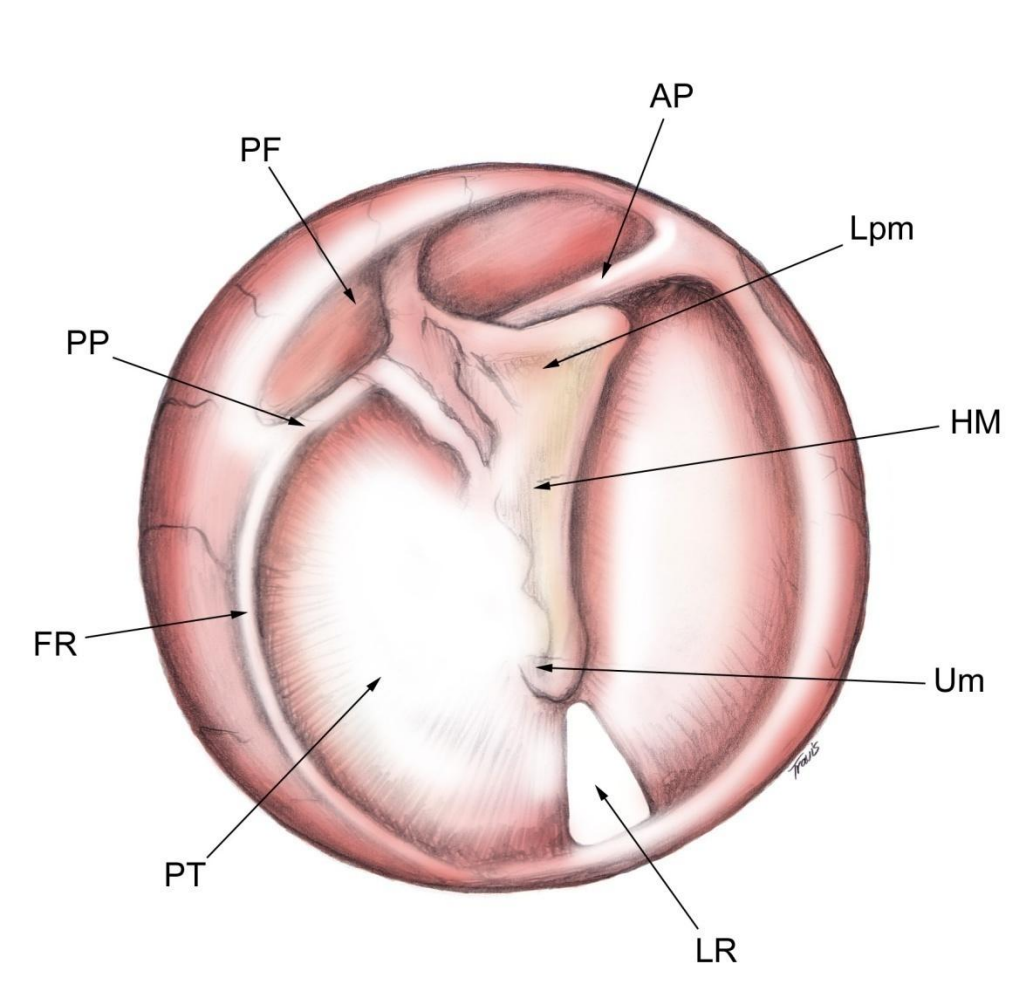


Fig. 10.27. Middle ear in detail and visualization of partial and total uncoiling of the cochlea. The cut in the partially uncoiled cochlea shows the cross-section of the tubes, which is seen in more detail in Fig. 10.32. (From [497])

OTOSCOPIA DEL TIMPANO I



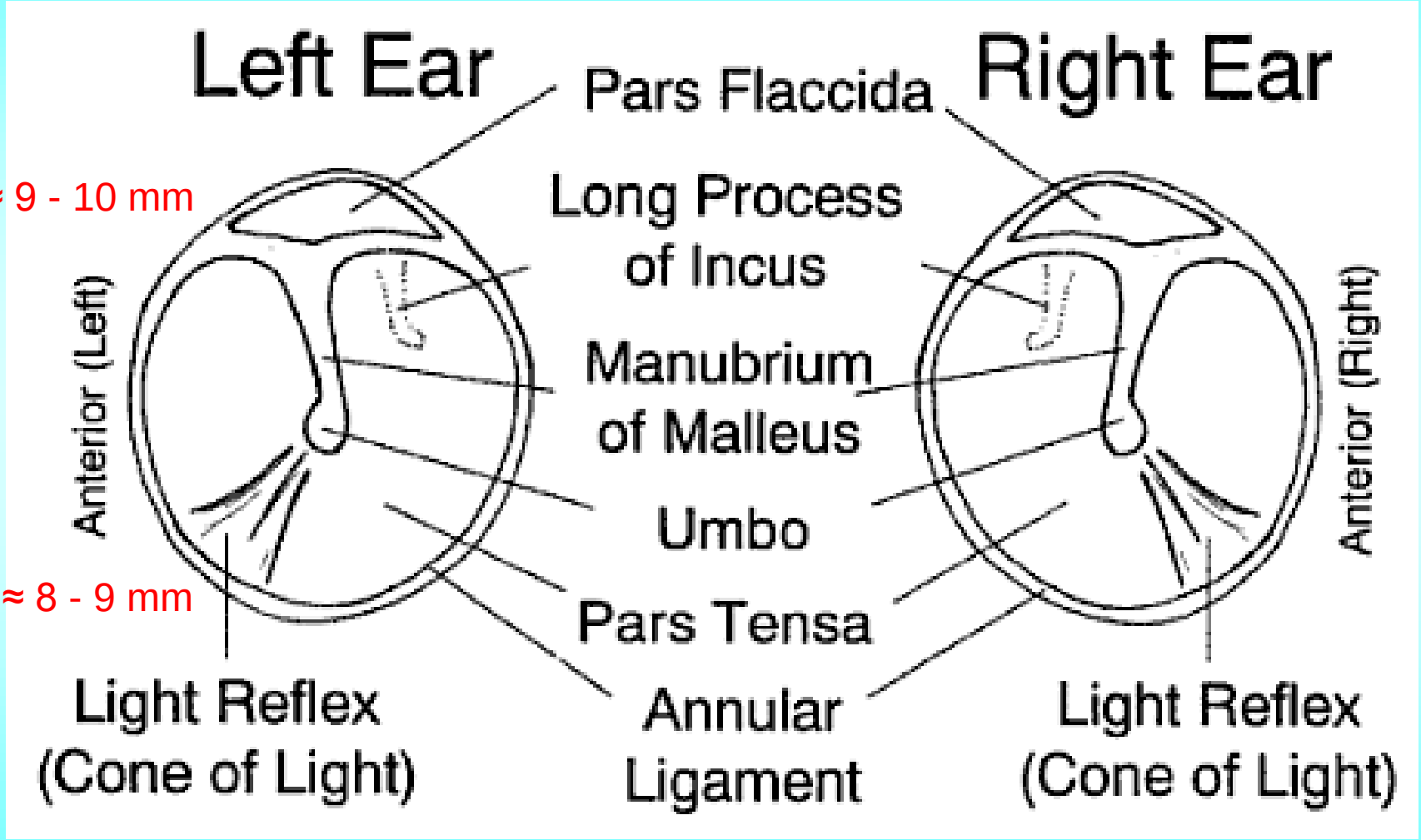
Normal tympanic membrane. Pars tensa (PT), pars flaccida (PF), light reflex (LR), fibrous ring (FR), umbo (Um), handle of malleus (HM), lateral process of malleus (Lpm), anterior plica (AP), posterior plica (PP).

LR or cone of light: the triangular reflection portion on the tympanic membrane.

OTOSCOPIA DEL TIMPANO II

$D_{\perp} \approx 9 - 10$ mm

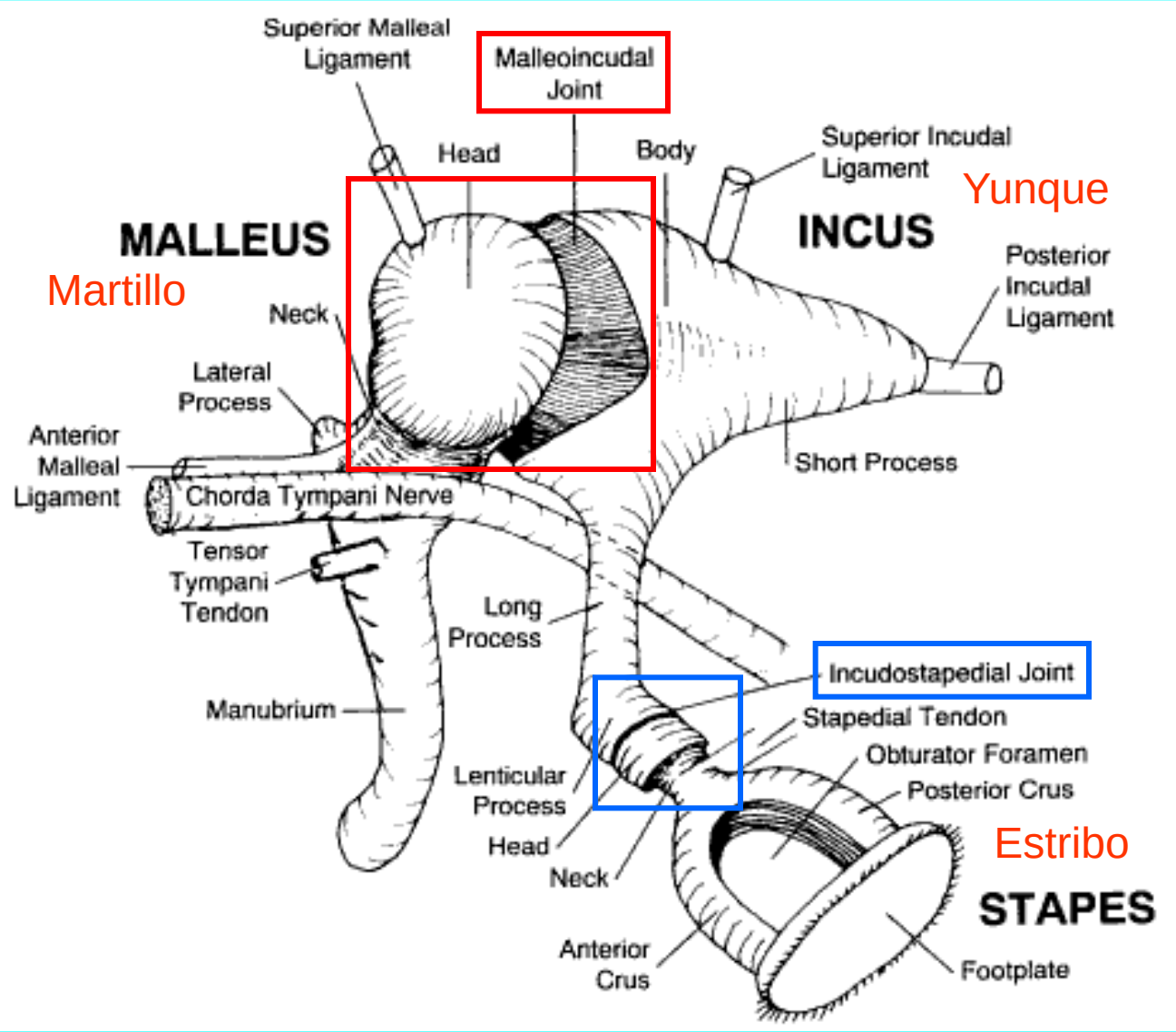
$D_{=} \approx 8 - 9$ mm

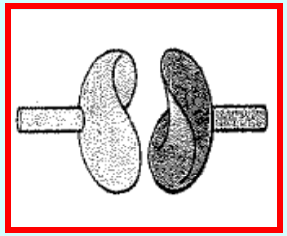


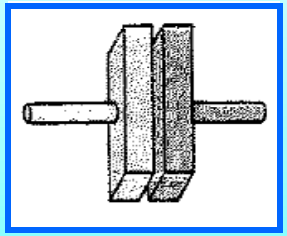
Area total ≈ 85 mm^2

Area efectiva ≈ 55 mm^2

ARTICULACIONES MARTILLO–YUNQUE–ESTRIBO



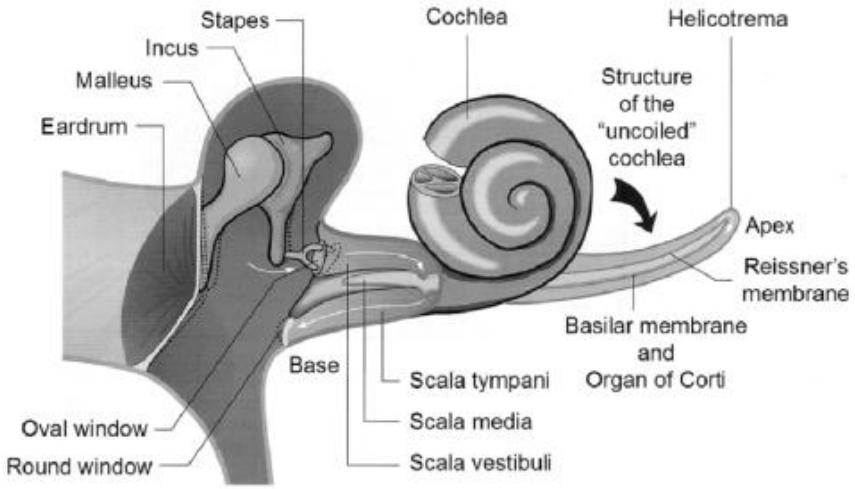




SISTEMA DE TRANSMISION

$$T_{Trans} = \frac{4Z_2 / Z_1}{(1 + Z_2 / Z_1)^2}$$

$$T = 0.13$$



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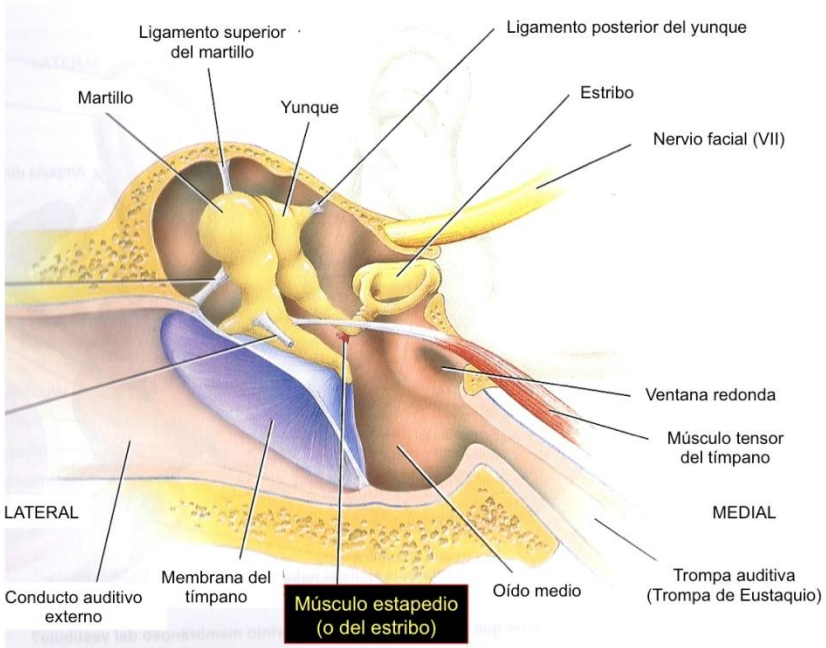
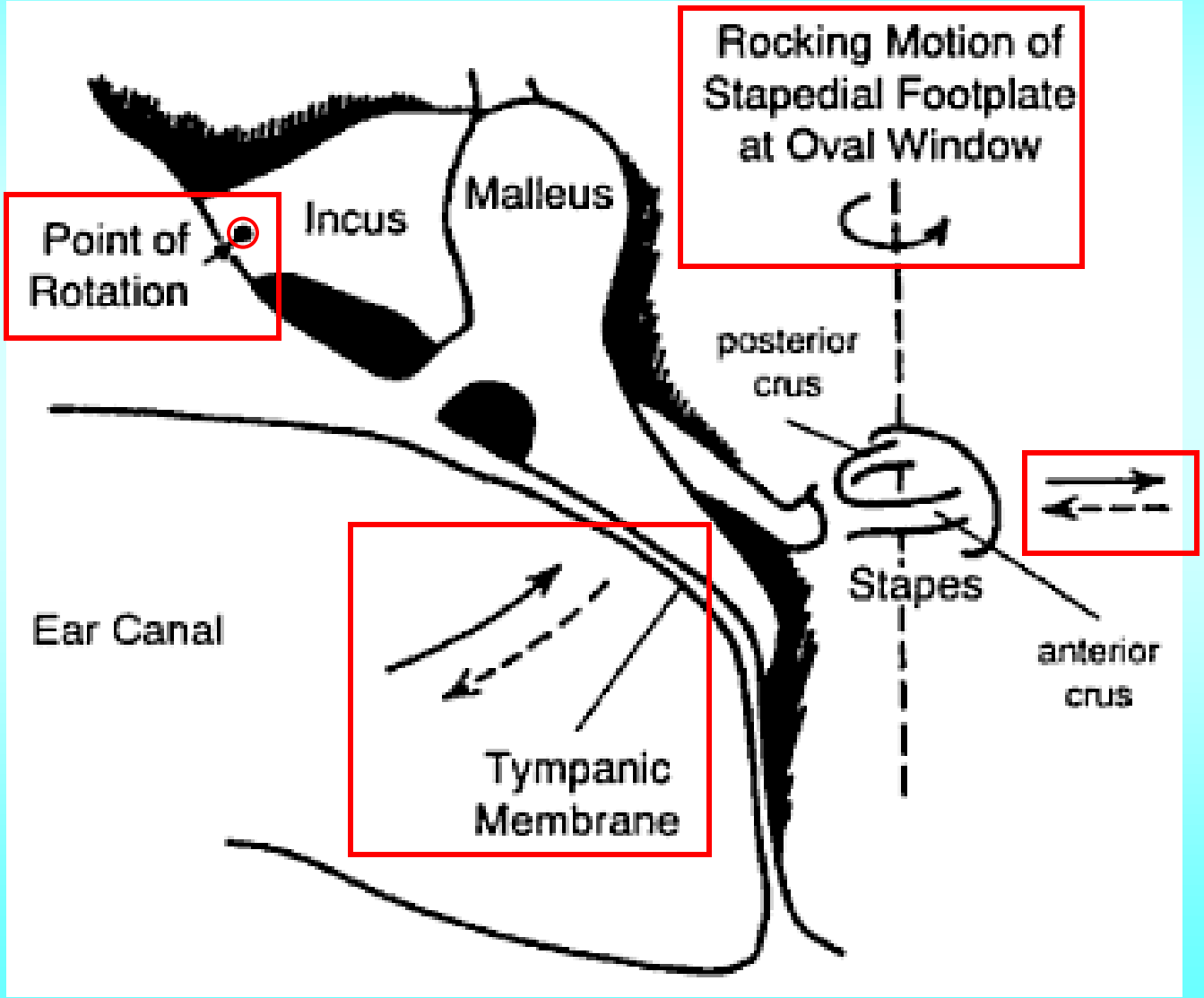
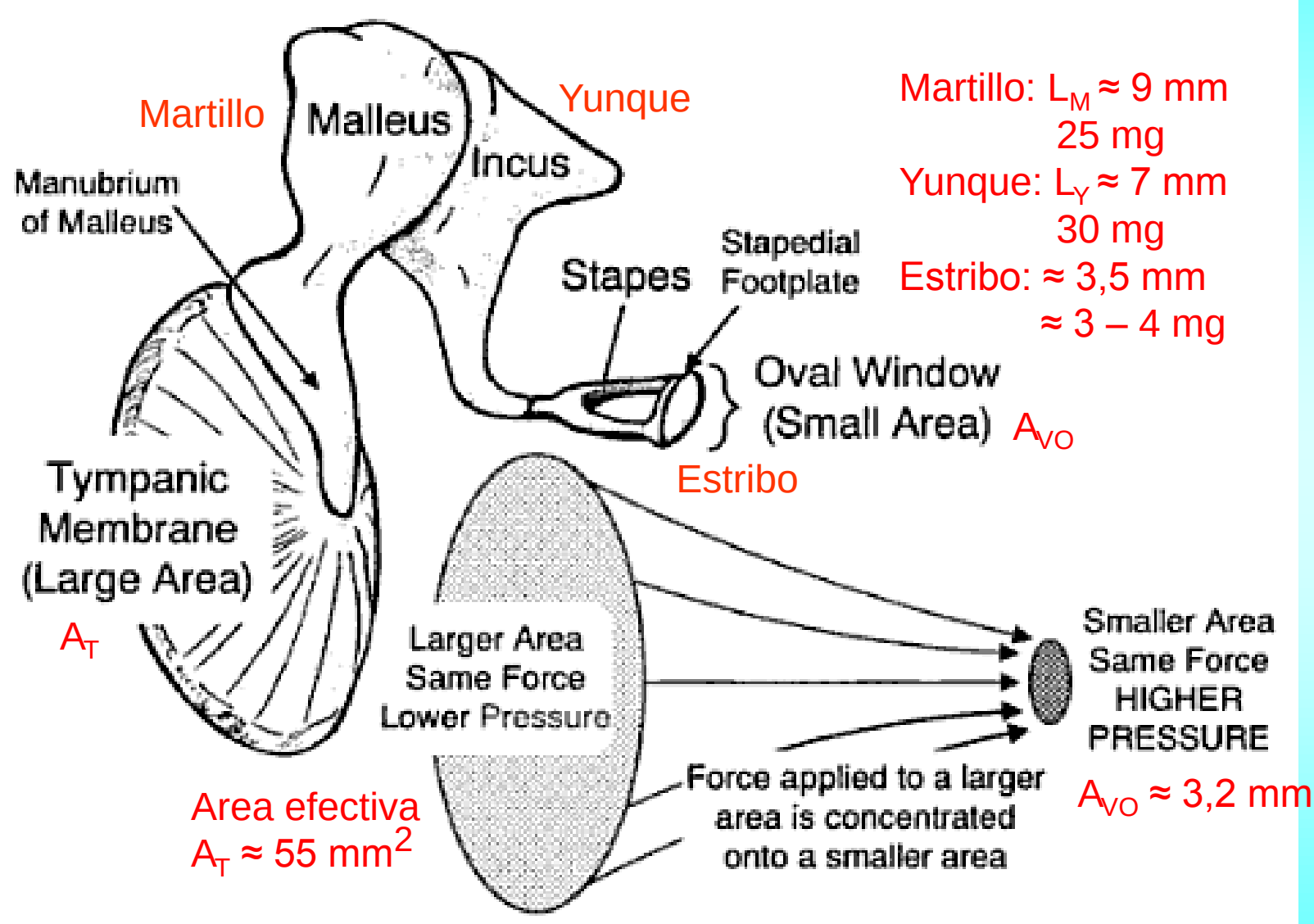


SISTEMA DE TRANSMISION



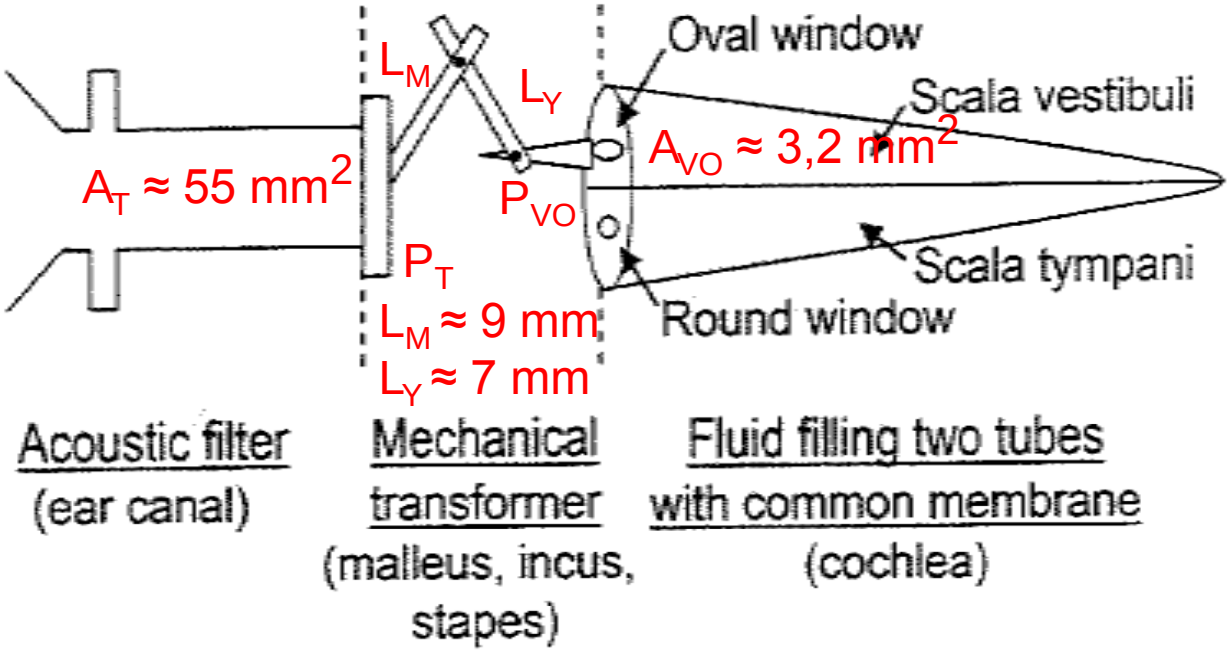
AMPLIFICACION EN EL OIDO MEDIO I



Martillo: $L_M \approx 9$ mm
25 mg
Yunque: $L_Y \approx 7$ mm
30 mg
Estribo: ≈ 3,5 mm
≈ 3 – 4 mg

ANALOGIA MECANICA APROXIMADA DE LA FUNCION DEL OIDO MEDIO

$$P_{VO} = \frac{A_T}{A_{VO}} \frac{L_T}{L_{VO}} P_T = (17).(1,3) P_T = 22,1.P_T$$



(Martillo, yunque y estribo)

Fig. 10.28. Mechanical analogs of the outer, middle, and inner ear. (Based on [473])

$$20\log_{10}\frac{P_{VO}}{P_T} = 20\log_{10} 22,1 \approx 27dB$$

EFECTO DEL MANUBRIO SOBRE EL TIMPANO

Se supone que:

$$22{,}1 \rightarrow 44$$

$$20\log_{10} 44 \approx 33dB$$

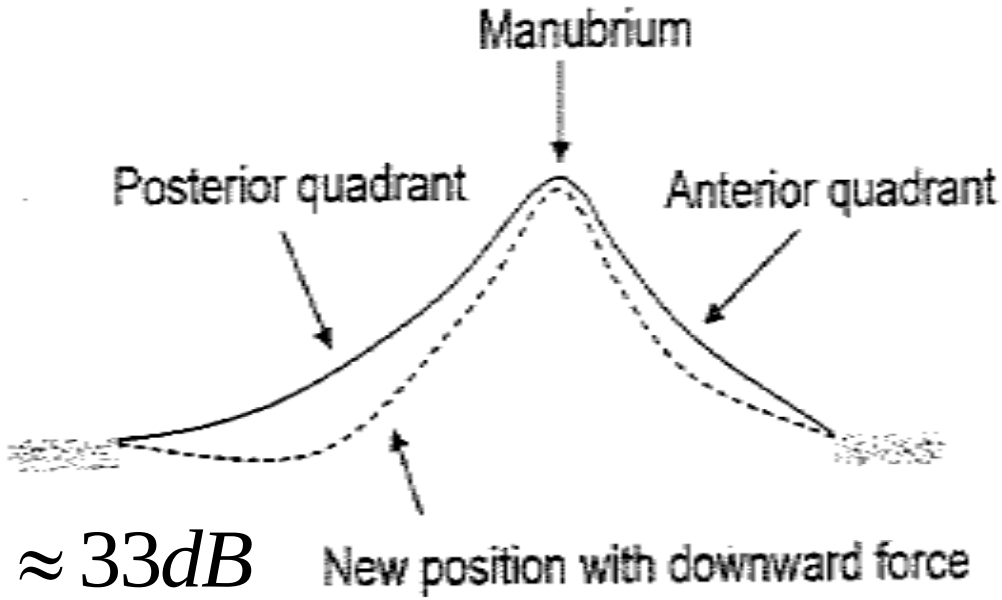
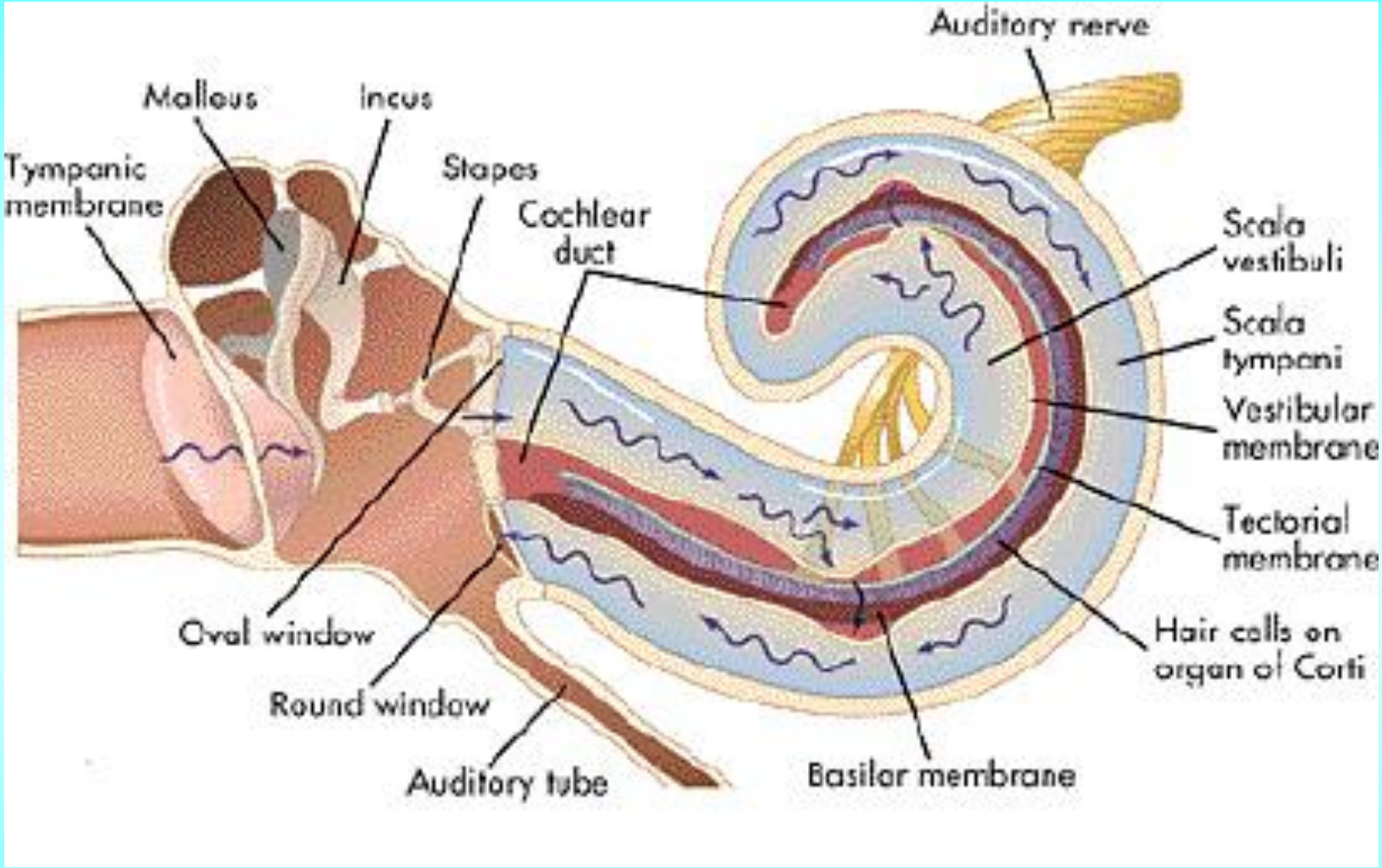


Fig. 10.31. Curved membrane buckling principle for the eardrum, with the position of the manubrium of the malleus shown. The membrane is shown without a force (*unbroken lines*) and with a (downward) force (*dashed lines*). (Based on [470, 505])

PASOS DEL PROCESO AUDITIVO



1- Las ondas sonoras entran por el canal timpánico.
2- El movimiento del tímpano es transferido por los osículos a la ventana oval.
3- El movimiento de la ventana oval produce ondas de presión en el fluido de la coclea.
4- Estas ondas hacen vibrar la membrana basilar y las cilias de las células ciliadas.

FUNCION DE TRANSFERENCIA: NIVEL SONORO A LA ENTRADA Y NIVEL DE SENSACION AUDITIVA A LA SALIDA

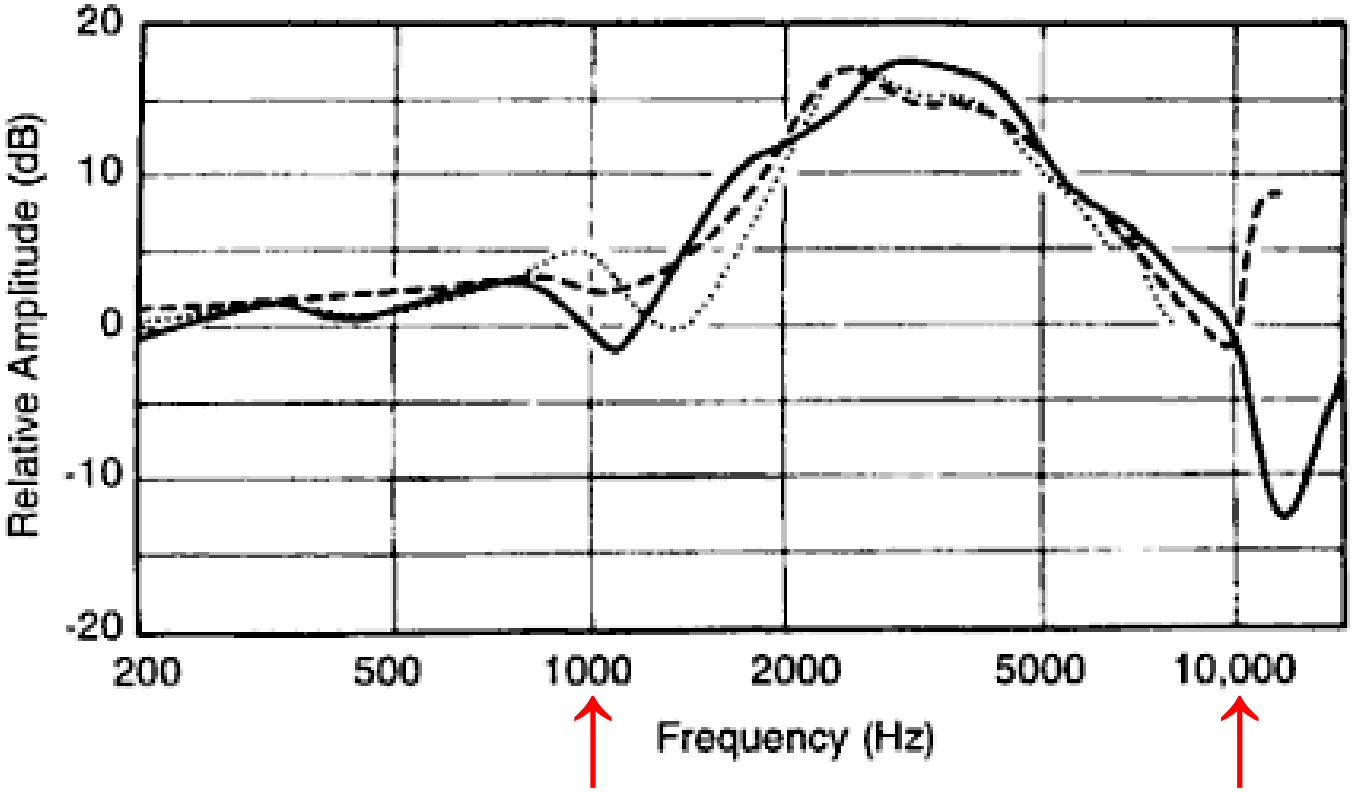
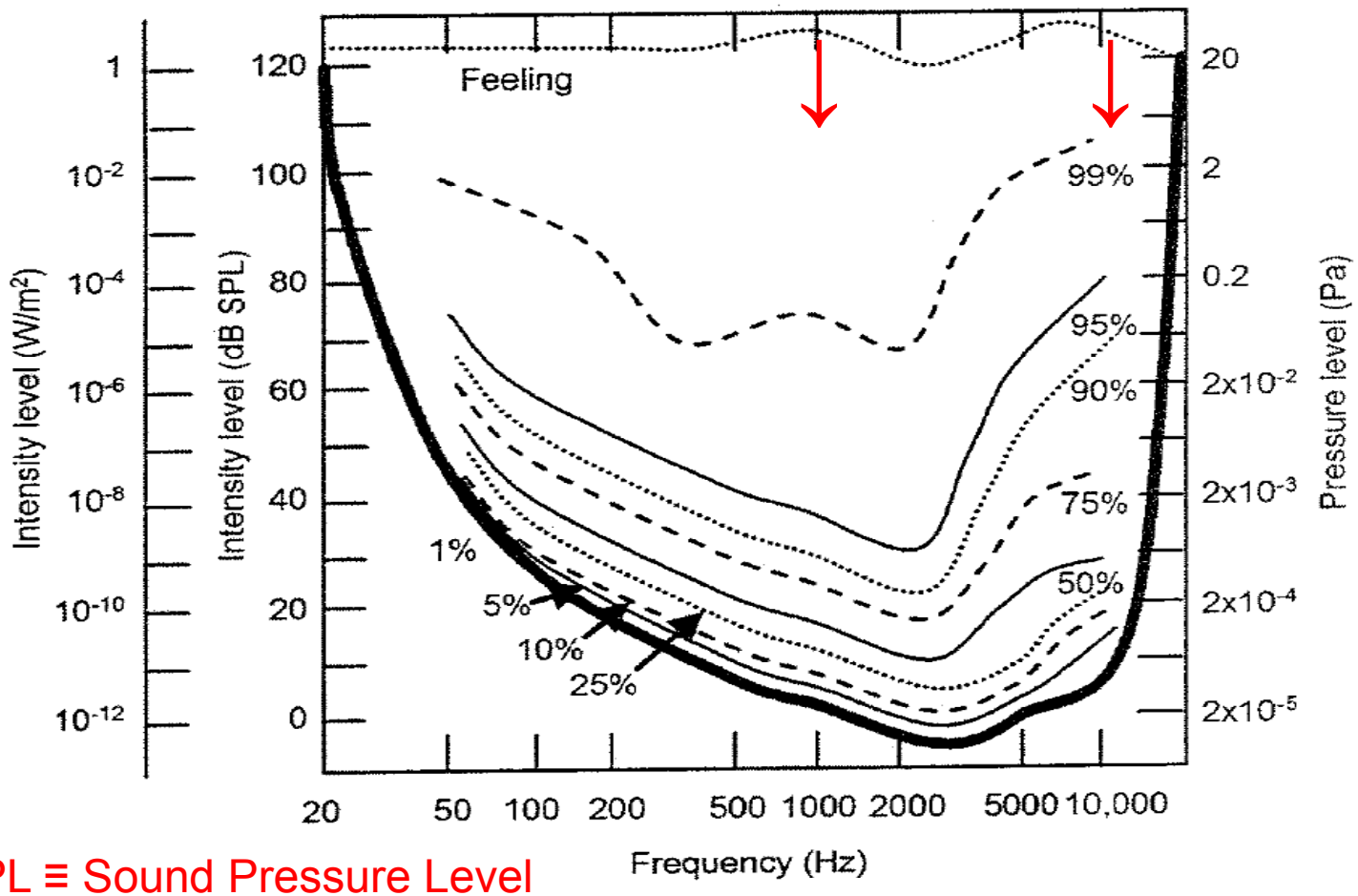


Fig. 2.15 Average head-related transfer functions (sound level at the eardrum compared with outside of the ear) for sounds presented from a loudspeaker directly in front of the subjects. *Dotted line*, Wiener & Ross (1946); *dashed line*, Shaw (1974); *solid line*, Mehrgardt & Mellert (1977). (Reprinted with permission from Mehrgardt, S., & Mellert, V. (1977). Transformation characteristics of the external human ear. *Journal of the Acoustical Society of America*, *61*, 1567–1576. Copyright 1977, American Institute of Physics.)

UMBRAL AUDITIVO ABSOLUTO
(Para residentes típicos estadounidenses)



SPL ≡ Sound Pressure Level

Fig. 10.29. Absolute auditory threshold for typical US residents. The curves show the percentage of people who could hear sounds below the level of the curve; the top curve shows the threshold for "feeling" in the ear. (Based on [461])

LIMITES DE SENSIBILIDAD

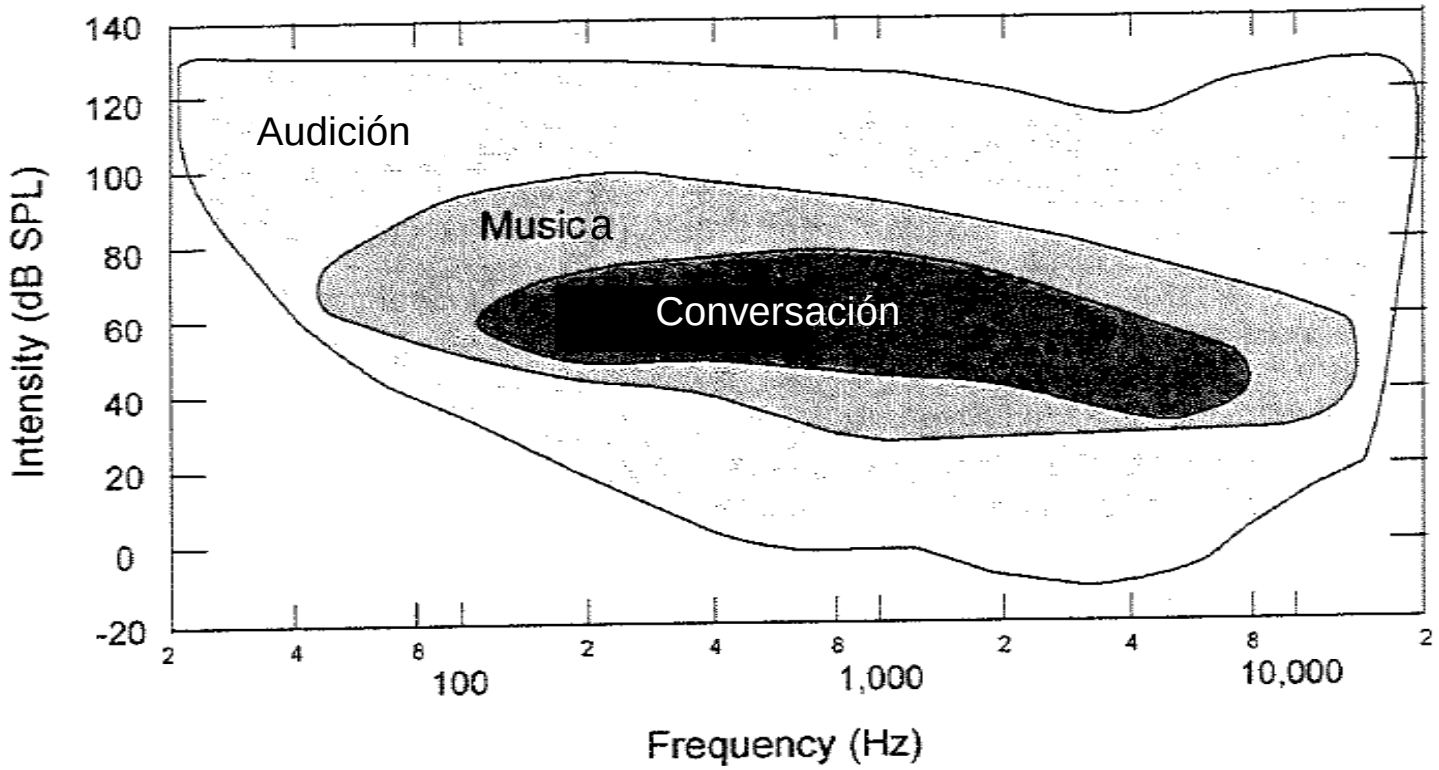


Fig. 10.30. The boundaries for normal hearing, in terms of limits of acoustic intensity and frequency, compared to the frequency and volume ranges of speech and orchestral music. (Based on [454, 491])

CORTE DE LA COCLEA

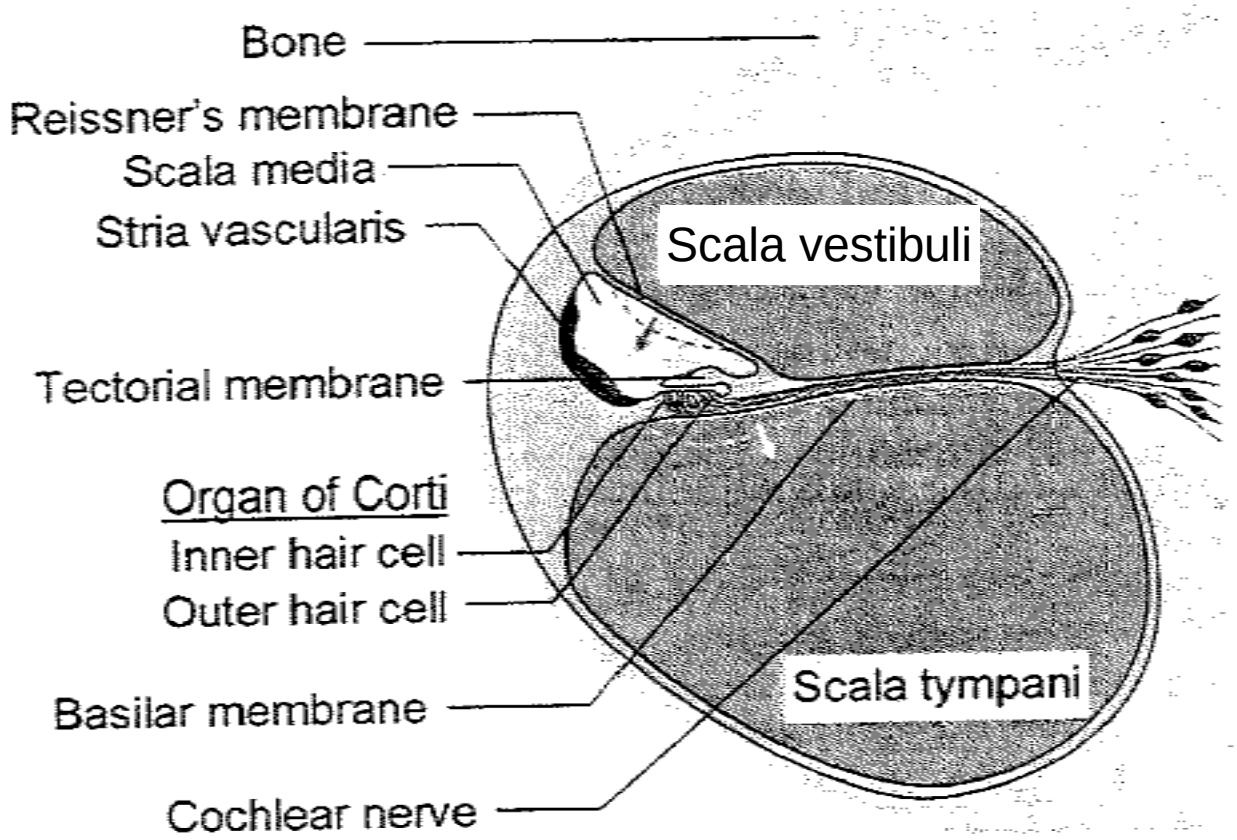


Fig. 10.32. Cochlea cross-section. (The cochlear nerve combines with nerves from the semicircular canals to form the auditory nerve.) (From [497])

ORGANO DE CORTI

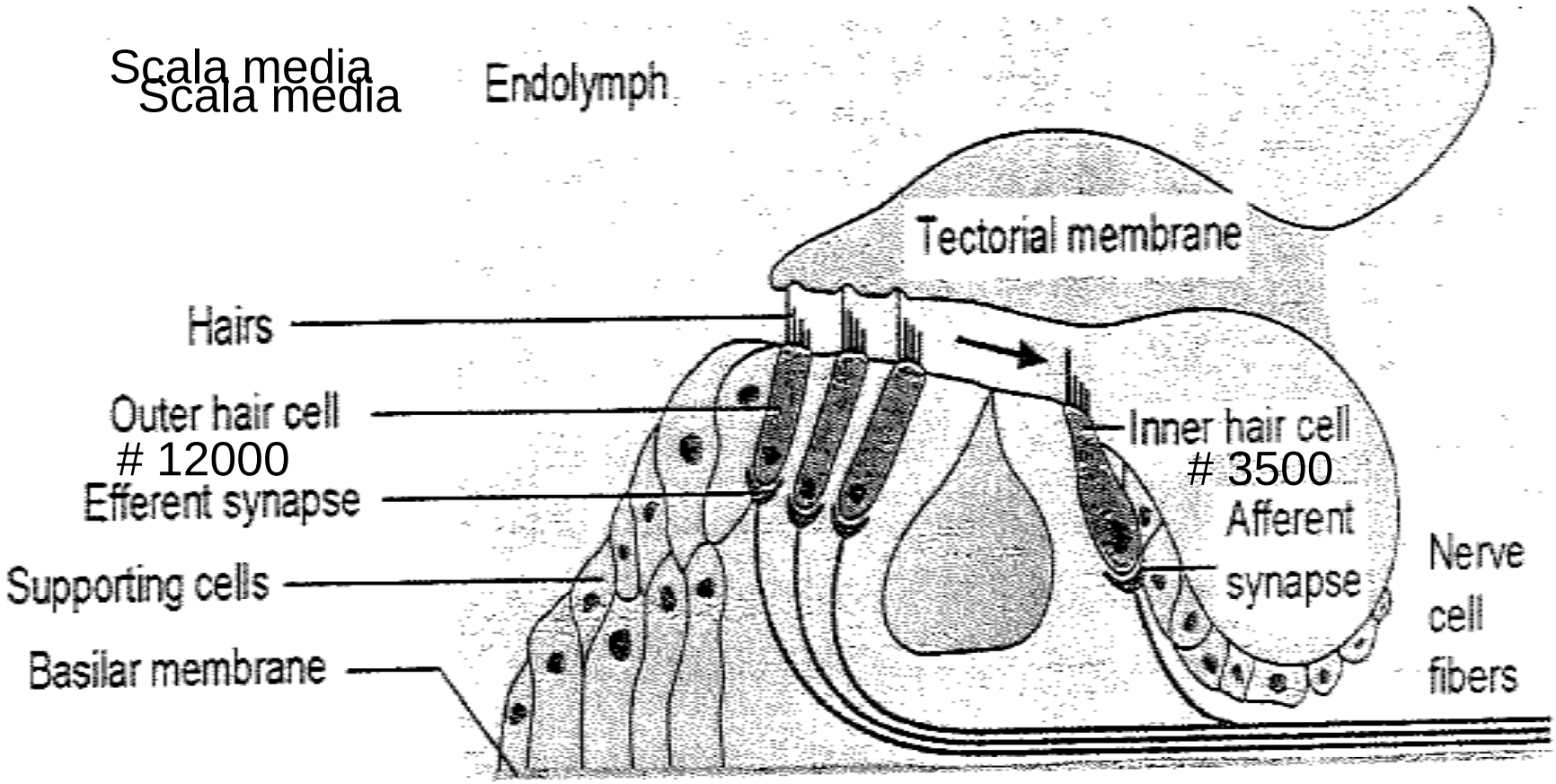


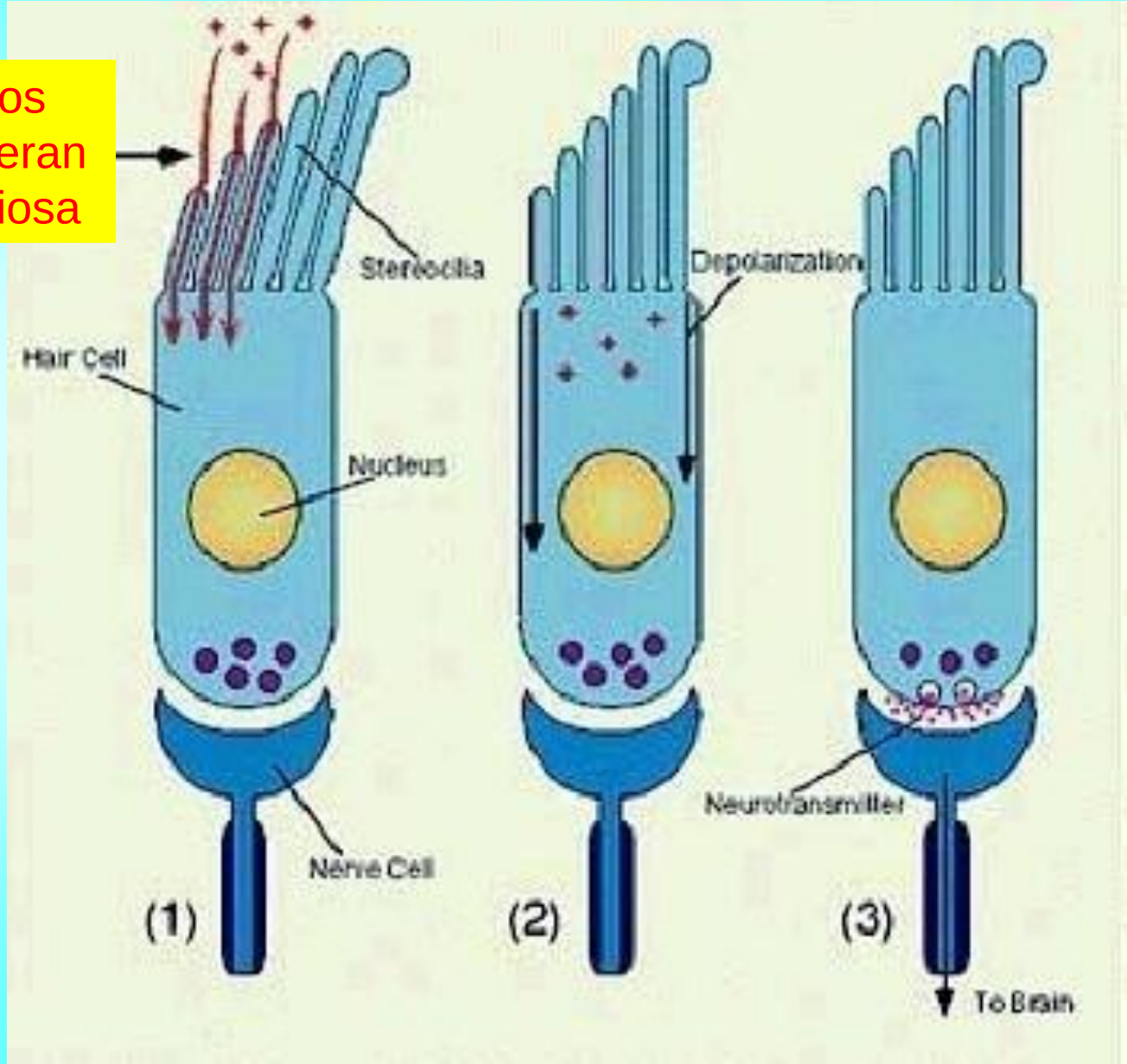
Fig. 10.34. Inner and outer hair cells in Organ of Corti. (From [497])

CELULA ESTEREOCILIADA

Micrografía electrónica de una célula ciliada.

ACCION DE LAS CELULAS CILIADAS

Desplazamientos de 10^{-10} m generan respuesta nerviosa



LA COCLEA SE ADELGAZA MIENTRAS LA MEMBRANA BASILAR SE ENSANCHA

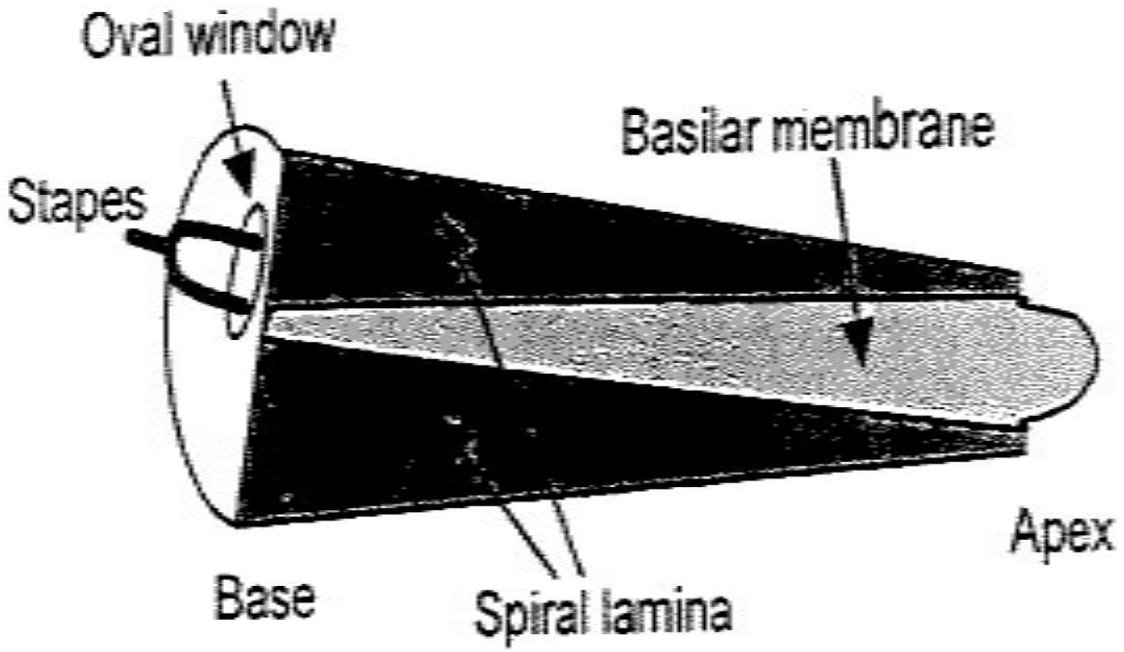


Fig. 10.35. The uncoiled cochlea gets narrower from the base at the stapes to the apex, as the basilar membrane gets wider. (Based on [472, 498])

MODOS RESONANTES MECANICOS DE LA COCLEA I

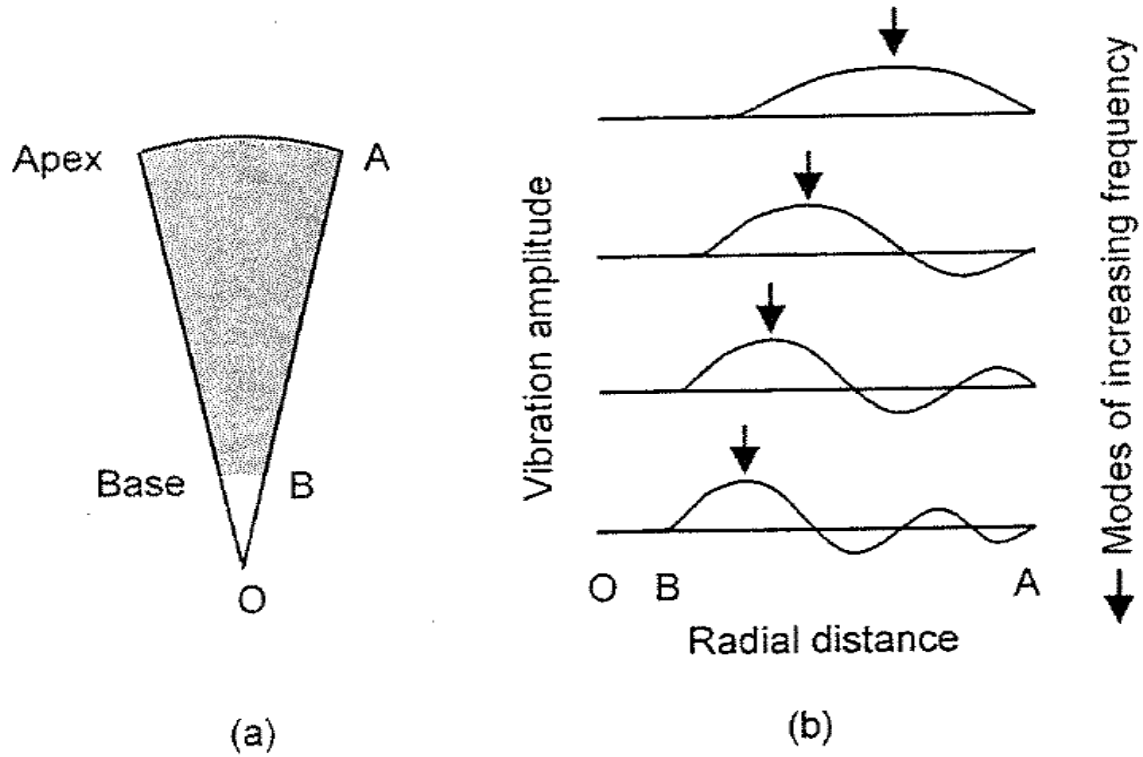


Fig. 10.38. Mechanical vibration model of the uncoiled cochlea in Fig. 10.35 modeled as a tapered membrane with uniform stiffness in (**a**), with predictions of the first few modes in (**b**). The principal maxima (at the positions of the arrows) of the modes move to the base with increasing frequency, which agrees with the trend in Fig. 10.36. For an untapered membrane, the modes would look the same except each antinode (maximum and minimum) in the mode would have the same magnitude. (Based on [466])

MODOS RESONANTES MECANICOS DE LA COCLEA II

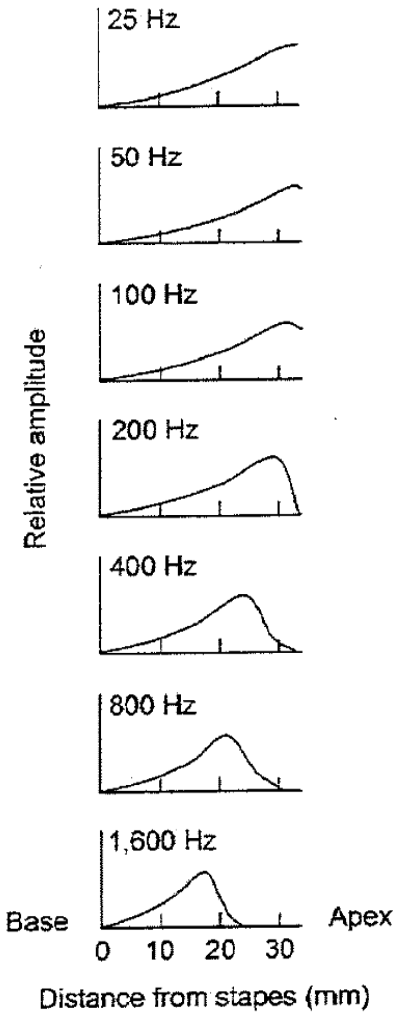


Fig. 10.36. Envelope of basilar membrane vibration vs. frequency. (Based on [453, 472])

MODOS RESONANTES MECANICOS DE LA COCLEA III

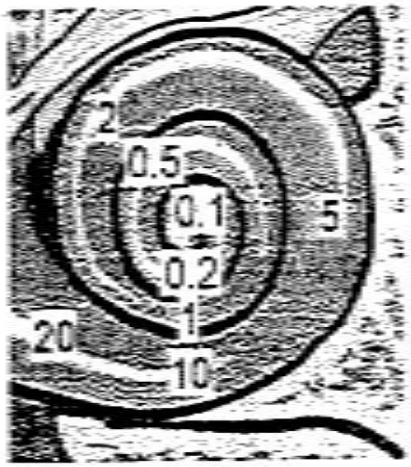
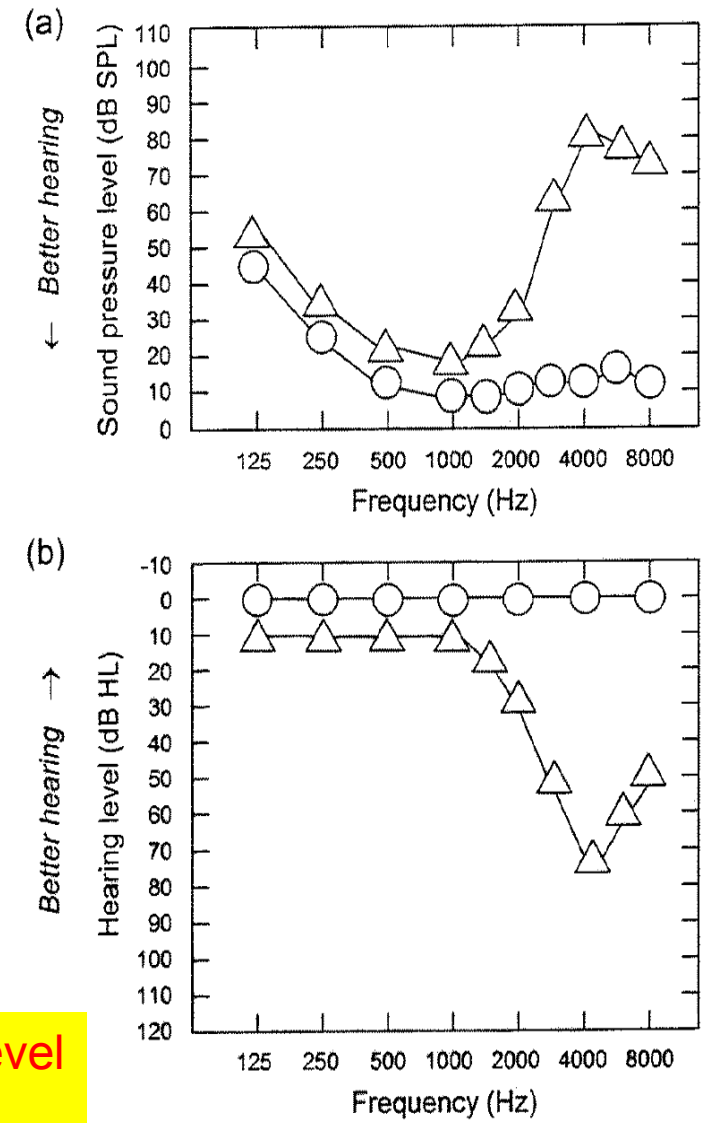


Fig. 10.37. Tonotopic map of cochlear sensitivity to audio frequencies (shown in kHz). (From [497], and based on [457, 465, 472])

AUDIOGRAMAS I



SPL ≡ Sound Pressure Level
HL ≡ Hearing level

Fig. 10.42. Audiograms in (**a**) dB SPL and (**b**) dB HL units for a normal person (*circles*) and one with high-frequency hearing loss (*triangles*). (Based on [469, 470])

AUDIOGRAMAS II

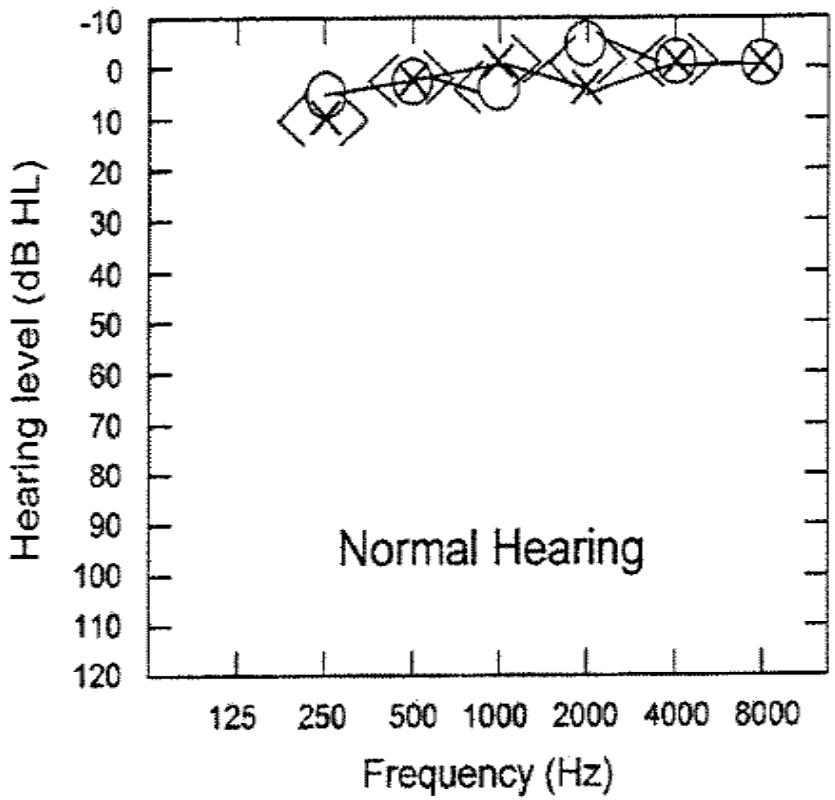


Fig. 10.43. Example of a real audiogram for a person with normal hearing. Audiogram key: right air-conduction (*open circles*), left air-conduction (*cross symbols*), right bone-conduction (*left angular brackets*), and left bone-conduction (*right angular brackets*), all unmasked. (Based on [470])

AUDIOGRAMAS III

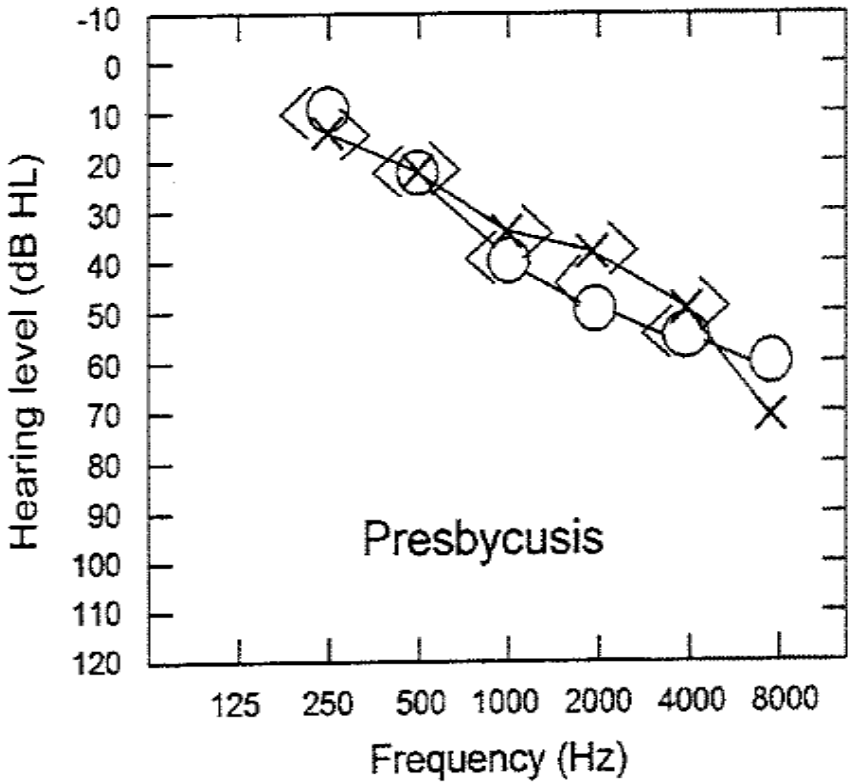


Fig. 10.45. Audiogram of a patient with bilateral hearing loss (i.e., loss in both ears) from (essentially symmetrical bilateral sloping) sensorineural hearing loss associated with presbycusis. Audiogram key: right air-conduction (*open circles*), left air-conduction (*cross symbols*), right bone-conduction (*left angular brackets*), and left bone-conduction (*right angular brackets*), all unmasked. (Based on [470])

AUDIOGRAMAS IV

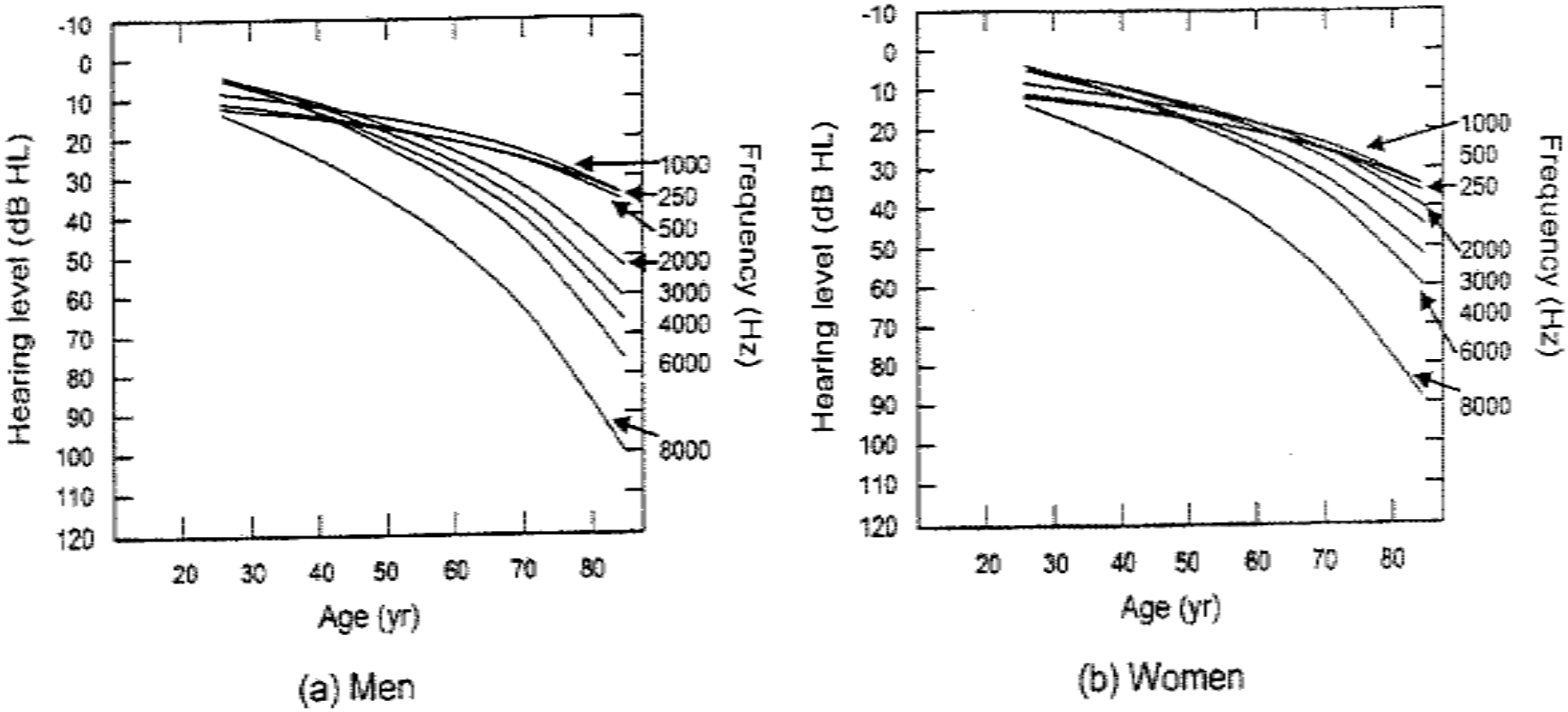


Fig. 10.44. Hearing levels vs. age for (**a**) males and (**b**) females. (Based on [470, 483, 500]. Also see [495] for more data)

VIBRACIONES CRANEALES

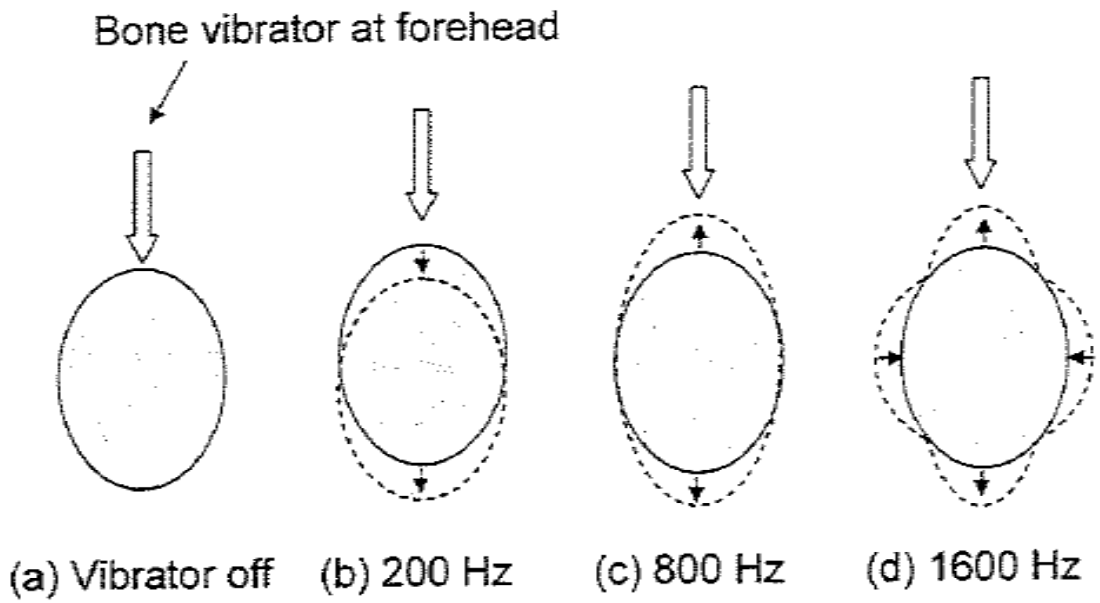


Fig. 10.46. Skull vibration patterns induced by (**a**) a bone vibrator positioned on the forehead, vibrating at different applied frequencies (**b**) 200 Hz, (**c**) 800 Hz, (**d**) 1,600 Hz. In (b)–(d) the vibrating skull (*dashed lines*) is shown relative to the still skull (*unbroken lines*) for a particular phase in the vibration. The small arrows depict the displacement, a displacement that is greatly exaggerated to illustrate it. In the opposing phase, the motion is reversed, with all arrows reversed (just as for a sine wave). (Based on [452, 470])

CARACTERIZACION DE FUENTES DE SONIDOS EN NUESTRO CUERPO

Table 10.6. Estimated acoustic parameters from sources in the body. (From [467])

source	maximum pressure change (atm.)	typical frequency (Hz)
shouting	0.05	1,000
talking	0.005	1,000
whispering	0.0005	1,000
running	2.0	4
walking	0.4	1
clapping hands, vigorously	0.2	2
chewing crunchy food	0.0001	1,000
respiratory airflow turbulence	0.00004	1,000
arterial pulse	0.02	1

ACCION DE VIBRACIONES EN NUESTRO CUERPO

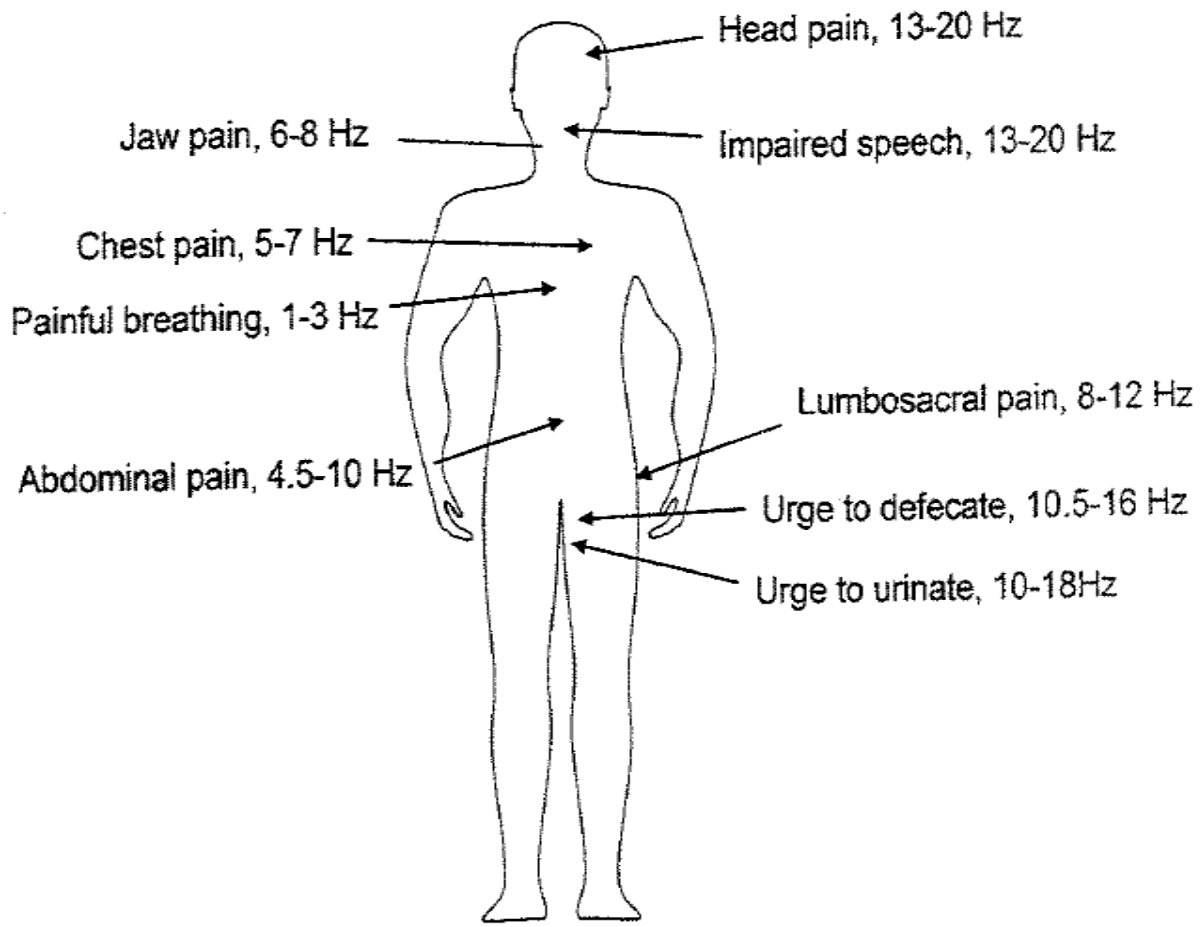


Fig. 10.54. Pain symptoms from vibrations from 1 to 20 Hz. (Based on [455, 487])

FONOCARDIOGRAMAS

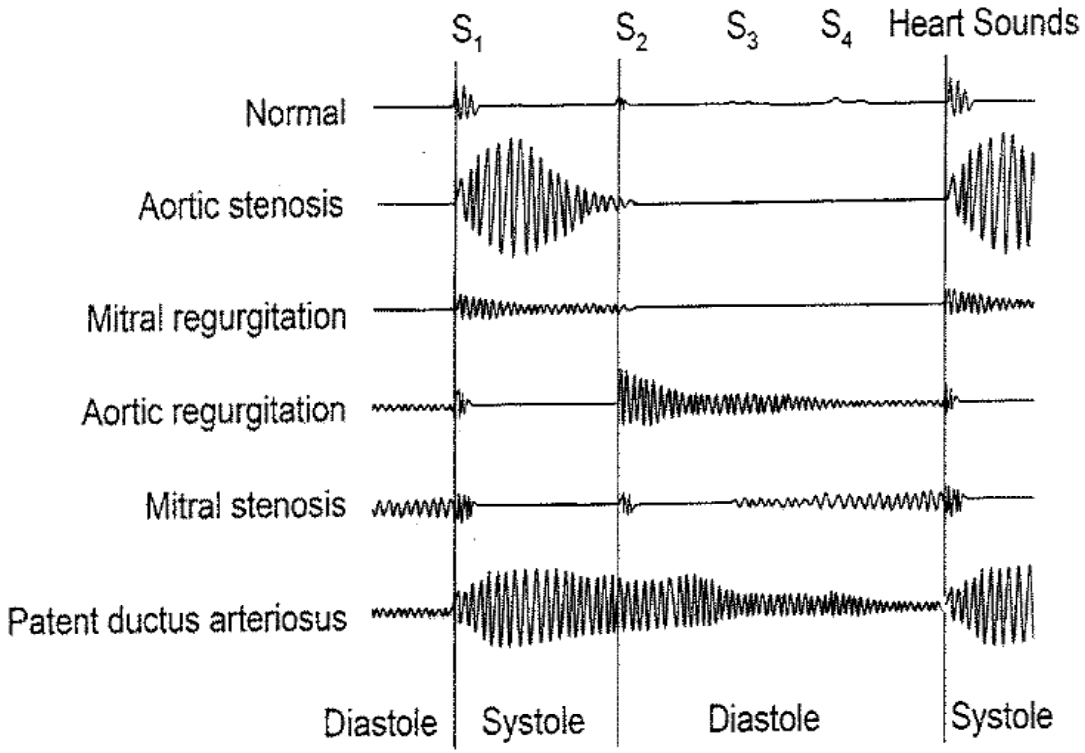


Fig. 10.55. Idealized phonocardiograms (sound traces) for normal and abnormal hearts, with left heart valve stenosis (partial blockage) or regurgitation (backflow) or with *patent ductus arteriosus*. (Patent ductus arteriosus is the condition when the ductus arteriosus (arterial shunt of pulmonary arterial blood flow from pulmonary artery to the aorta in a fetus) does not close after birth.) The times of the first (S_1), second (S_2), third (S_3), and fourth or atrial (S_4) heart sounds are shown. Also see the phonocardiogram in Fig. 8.5. (Based on [476])

MEDICION DE LA VELOCIDAD DEL FLUJO SANGUINEO POR ECO DOPPLER

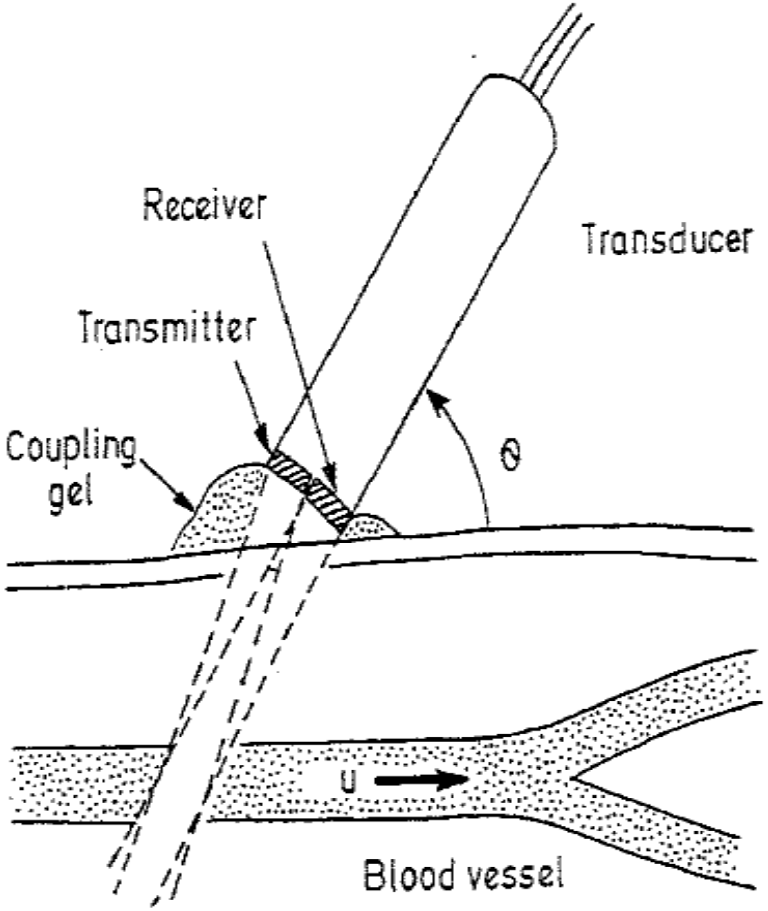


Fig. 10.56. Doppler examination of blood flow in a vessel at a speed u, with scanning shown. (Reprinted from [489]. Used with permission of Elsevier)