與助聽器選配相關的耳朵構造和生理

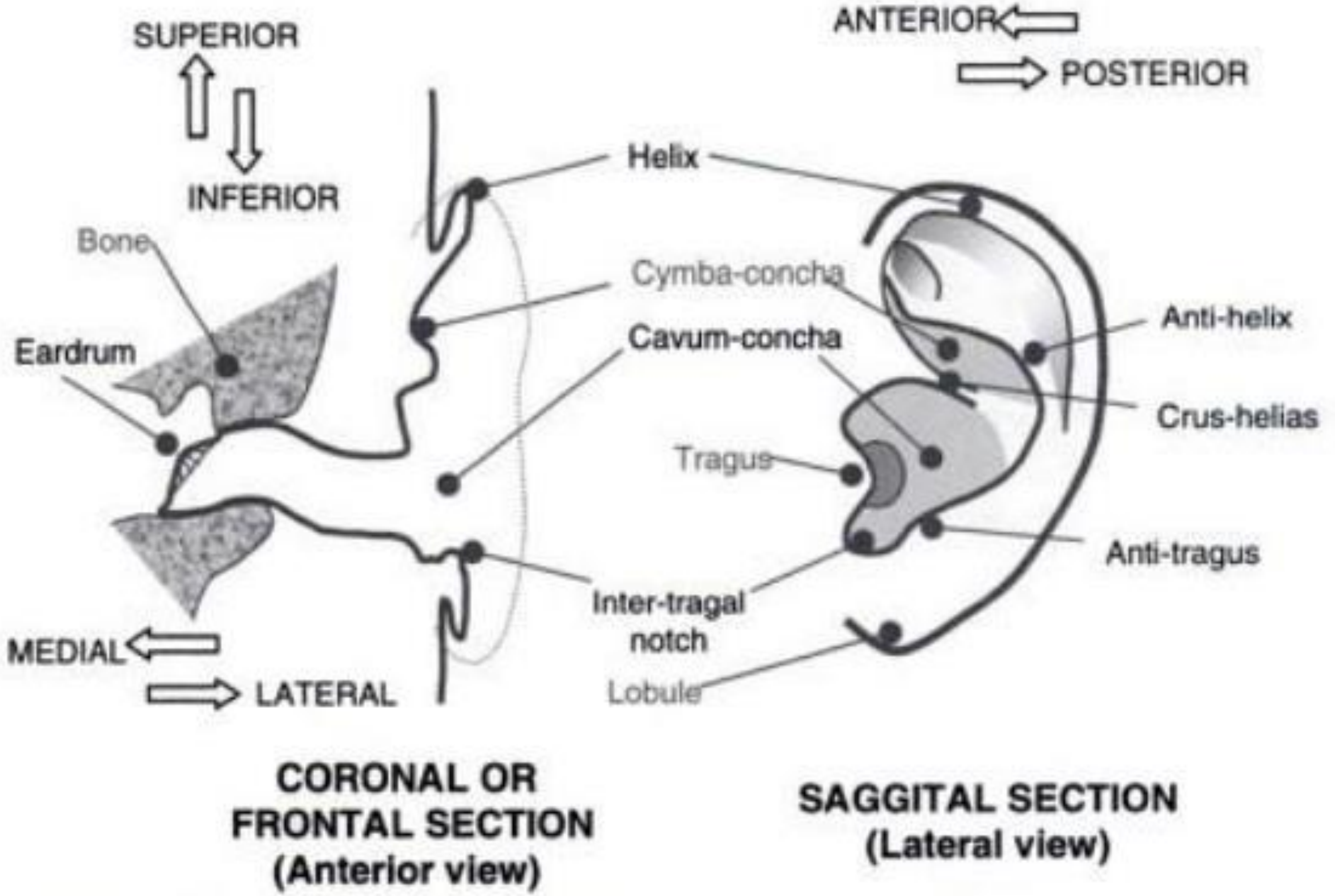
江源泉 Ph. D., CCC-A

8/10/2013

(1) 外耳

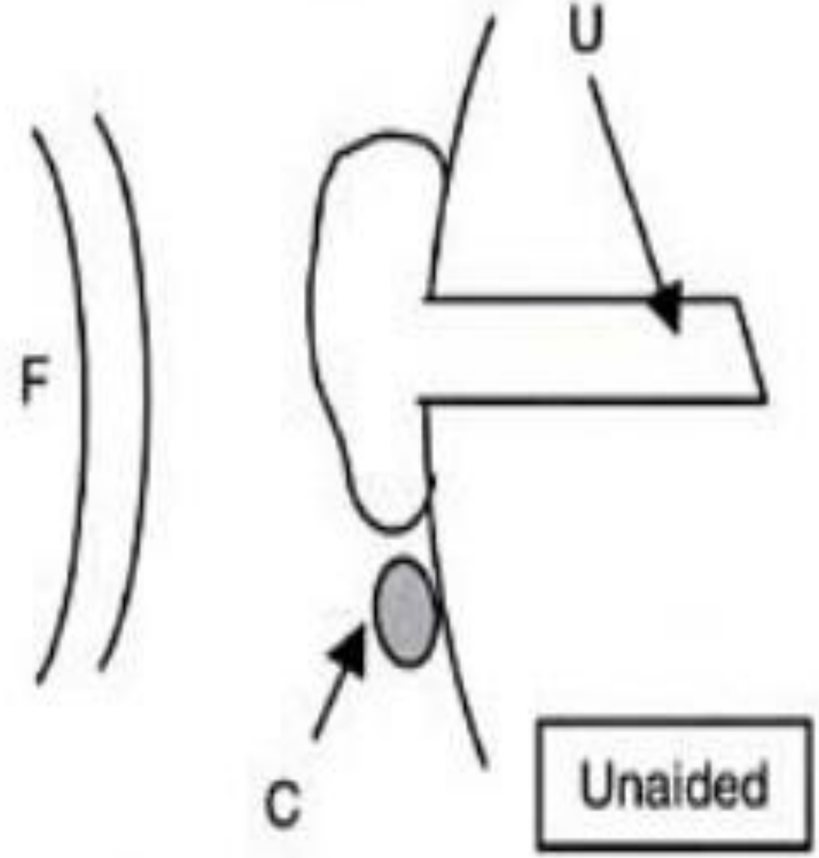
1. 助聽器/耳模阻塞耳道後產生的閉塞效應 (the occlusion effect)
2. 耳道內的共鳴聲音進入耳道內遇到耳膜產生的駐波(standing wave) 和1/4波長的共鳴 (quarter wavelength resonance)

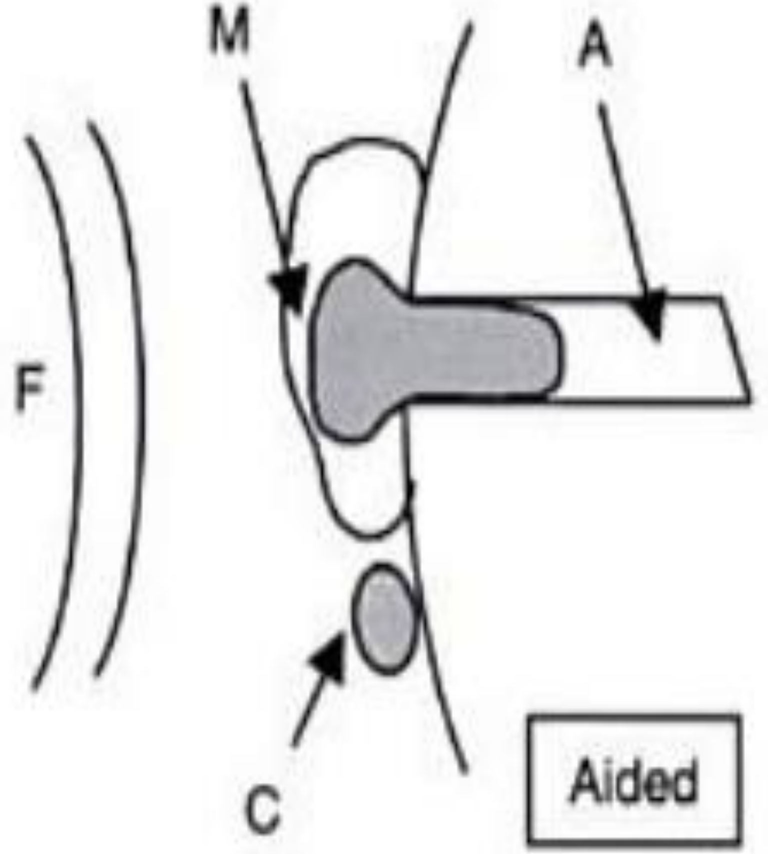
外耳的剖面和側面


SUPERIOR
INFERIOR
Bone
Eardrum
MEDIAL
LATERAL
ANTERIOR
POSTERIOR
Helix
Cymba-concha
Cavum-concha
Tragus
Inter-tragal notch
Lobule
Anti-helix
Crus-helias
Anti-tragus
CORONAL OR FRONTAL SECTION (Anterior view)
SAGGITAL SECTION (Lateral view)

1. 閉塞效應 (the occlusion effect)

開放 vs. 閉塞





閉塞效應實驗

- 說 /ㄚ/ , /ㄧ/, /ㄨ/
- 壓住tragus把耳道蓋住
- 再說 /ㄚ/ , /ㄧ/, /ㄨ/

A: 外耳道的剩餘空間

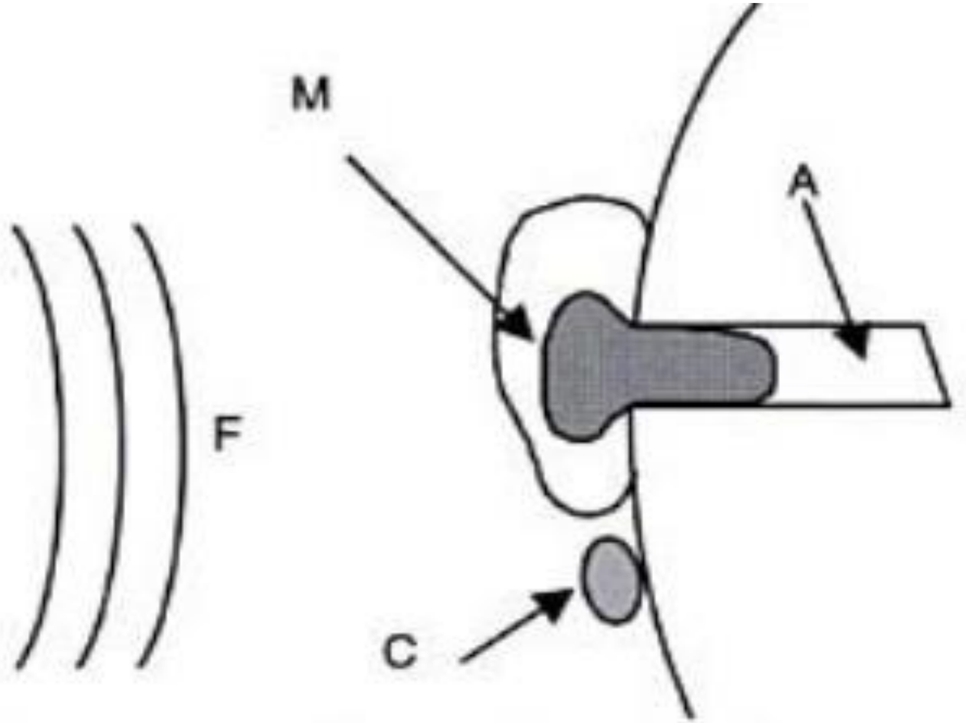


Figure 4.9 Location of SPLs involved in the measurement of real-ear aided gain. *F* is located in the undisturbed sound field (e.g. with the head absent), *C* is at the control microphone location on the surface of the head, *M* is at the hearing aid microphone port, and *A* is within the residual ear canal close to the eardrum.

閉塞效應的生理

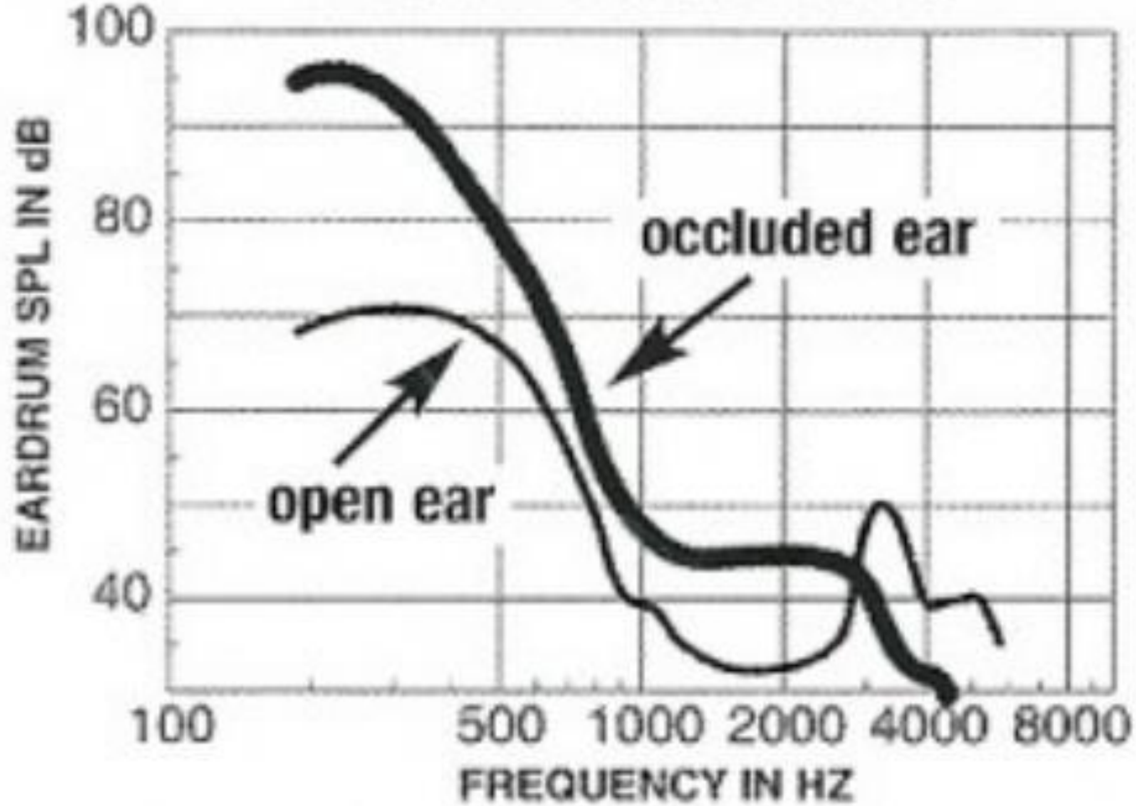
- 外耳道的剩餘空間四周: 耳膜、耳模內端、耳道內壁的軟、硬骨部分
- 振動的來源: 開口說話時，聲帶的振動透過骨導經下顎，傳到耳道
- 骨導的聲音造成外耳道的軟骨部分振動，在耳道內產生低頻的氣導聲音

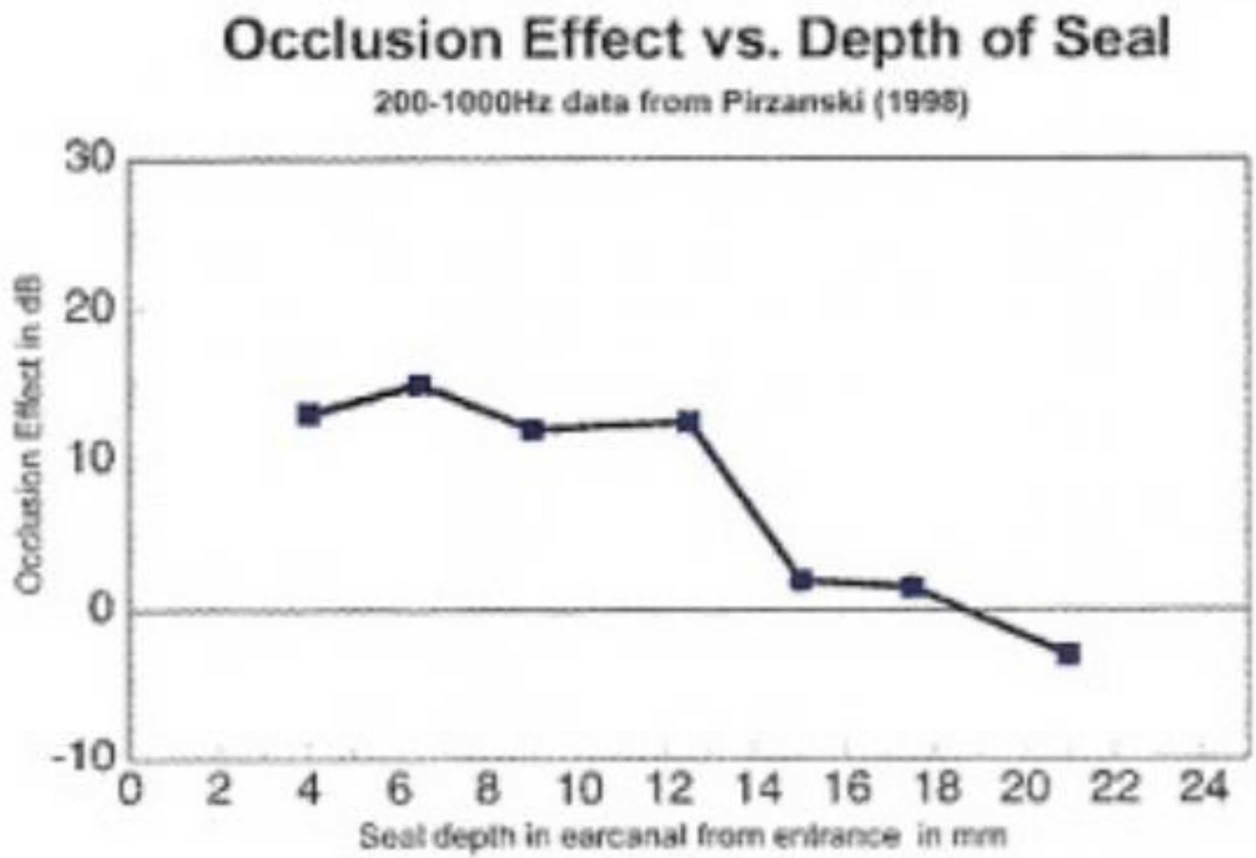
閉塞效應

- 封閉的耳道中, 低頻音的增加, 主要低於500Hz
- 最大效應頻率是300 Hz附近(Killion et al., 1988)
- 成因: 頭顱內硬骨導帶動耳道軟骨的振動
- 來源: HA使用者自己的聲音或吹管樂器
- 不會發生在開敞的耳朵
- 對低頻250-500 Hz聽損40 dB以上者, 通常不會造成問題

Earcanal SPLs measured behind sealed shallow earmold while female vocalized "ee"

Killion, Wilber and Gudmundsen (1988)





耳模的深度與閉塞效應的關係

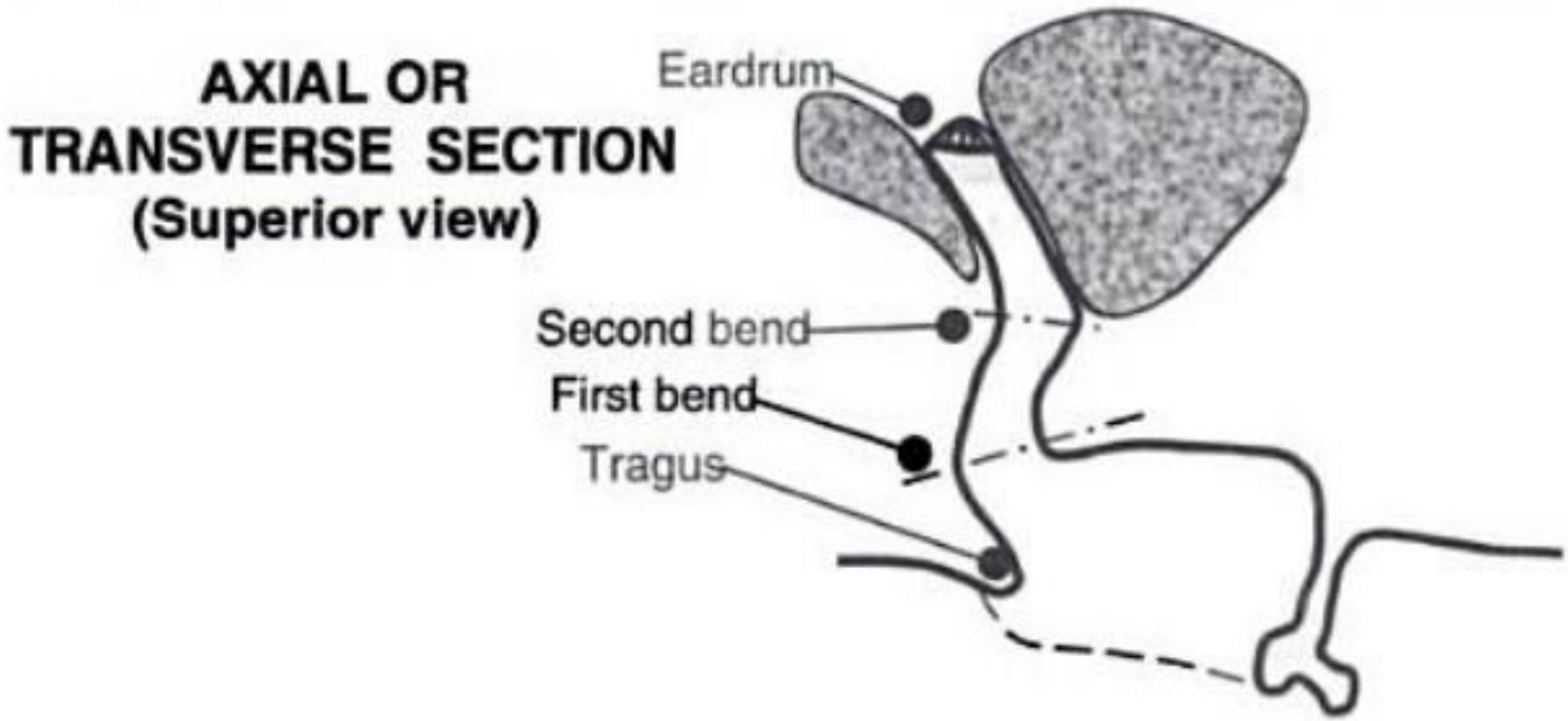
解決occlusion effect的方法

1. 增加耳模/shell 在耳道內的深度，超過第二折點(2nd bend), 以避免軟骨振動
2. Venting (> 2mm)

- 增加 vent 直徑, 或縮短vent 的長度
- 非閉塞頻率高低都一致，越高, vent要越大
- 3mm 可解決所有狀況.

(改變助聽器程式,如減少低頻, 無法改善!)

外耳 (視線穿越頭顱)

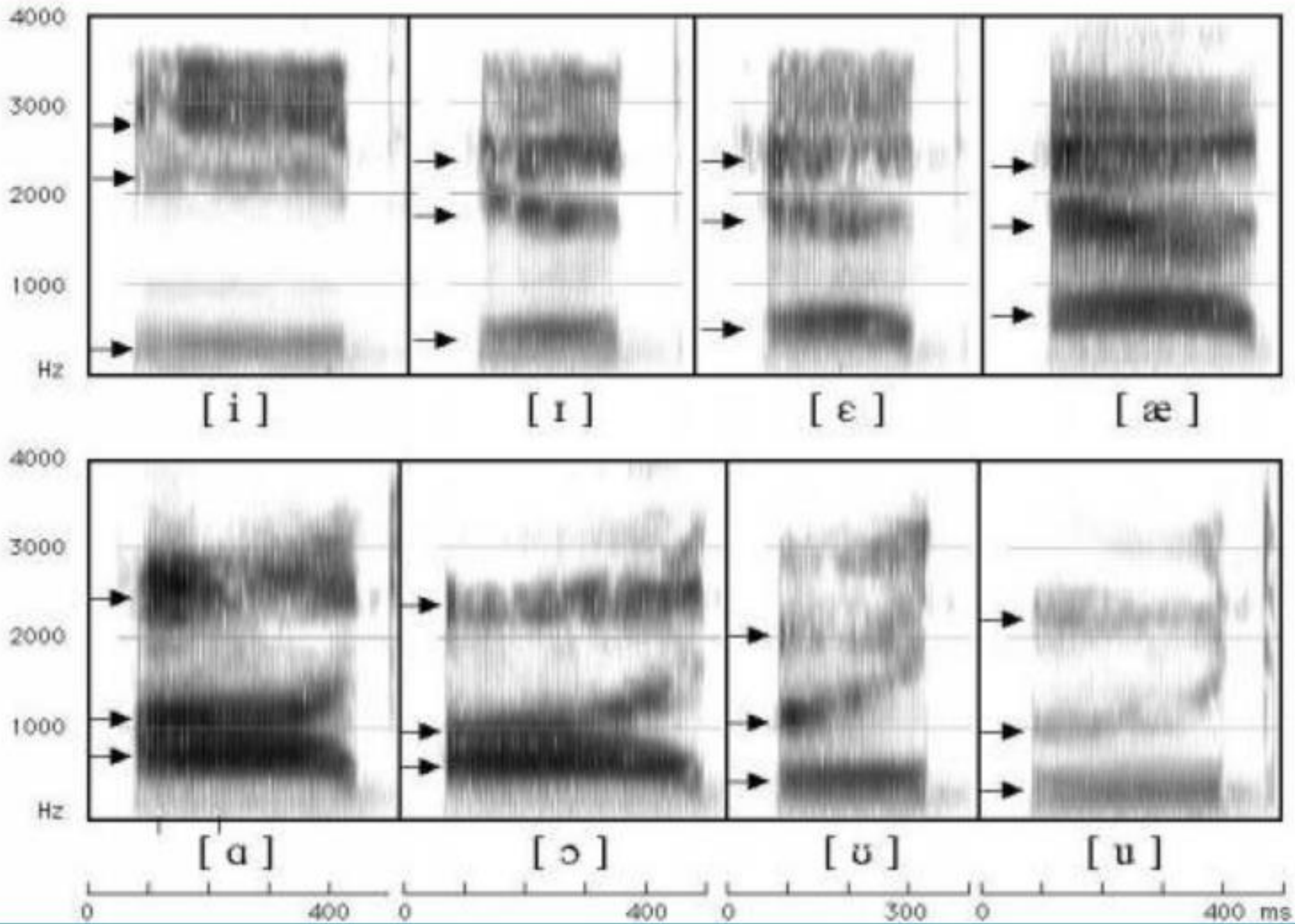

AXIAL OR
TRANSVERSE SECTION
(Superior view)
Eardrum
Second bend
First bend
Tragus

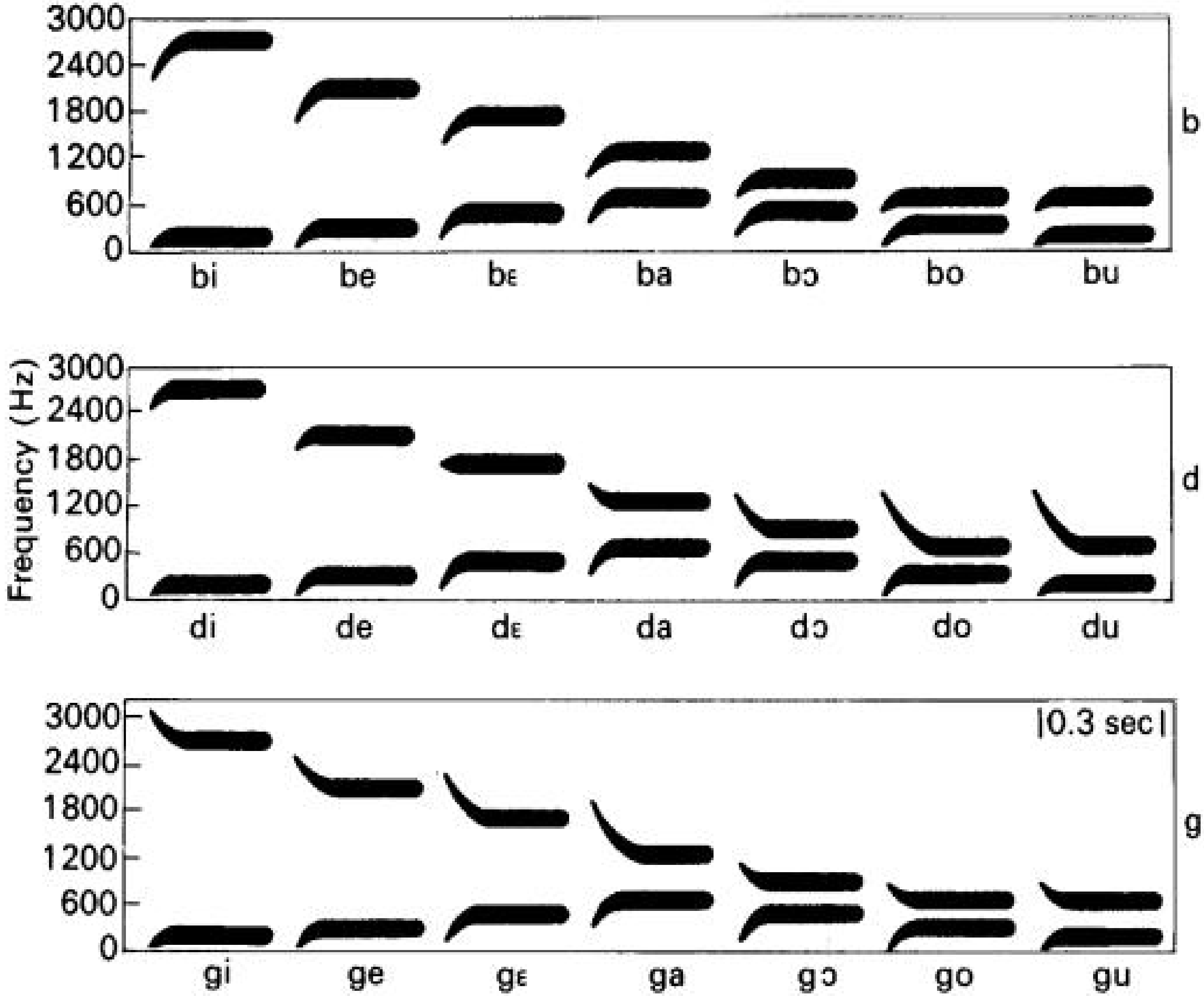
回到/ㄚ/ , /ㄧ/, /ㄨ/

- 說 /ㄚ/ , /ㄧ/, /ㄨ/
- 壓住tragus把耳道蓋住
- 再說 /ㄚ/ , /ㄧ/, /ㄨ/

- 檢測問題是否在於閉塞效應: HA 開 vs. HA 關

英語母音聲譜圖




Frequency (Hz)
3000
2400
1800
1200
600
0
bi
be
bɛ
ba
bɔ
bo
bu
b
di
de
dɛ
da
dɔ
do
du
d
|0.3 sec|
gi
ge
gɛ
ga
gɔ
go
gu
g

2. 耳道內的共振 (resonances)

駐波(Standing wave)

- 由入射波 + 反射波 因相位差形成

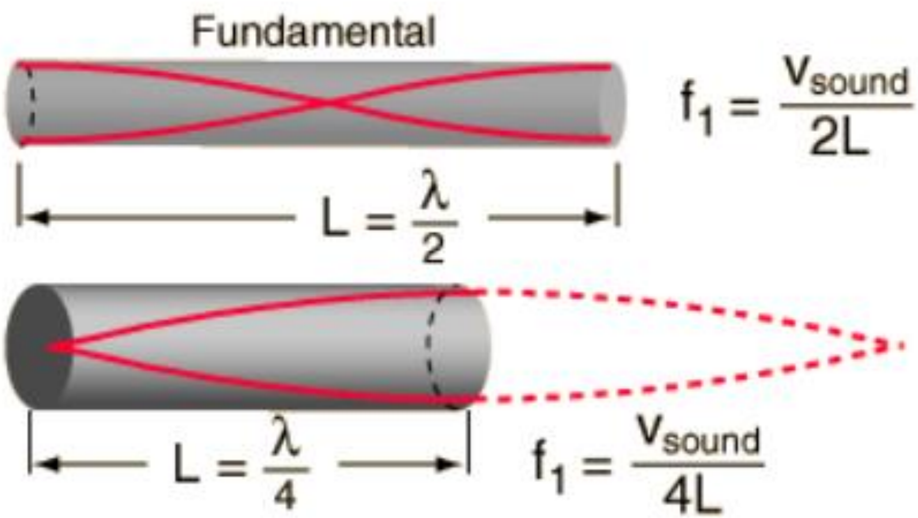
http://www.youtube.com/watch?v=yCZ1zFPvrIc

- 節點 (node) 和 波腹(antinode)

http://www.youtube.com/watch?v=-n1d1rycvj4

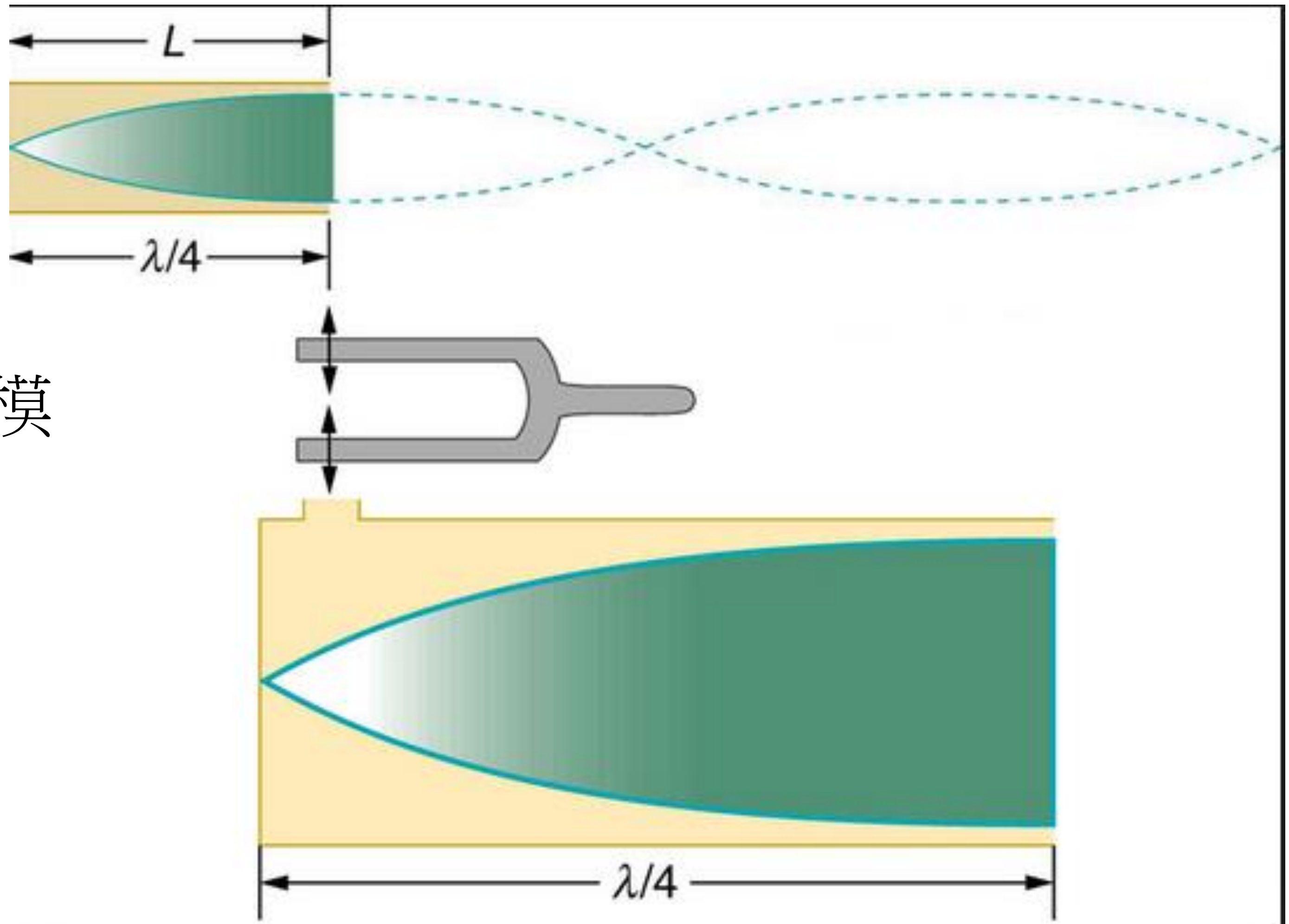
- 頻率越高, 節點越多. 節點的振幅= 0; 波腹的振幅最大

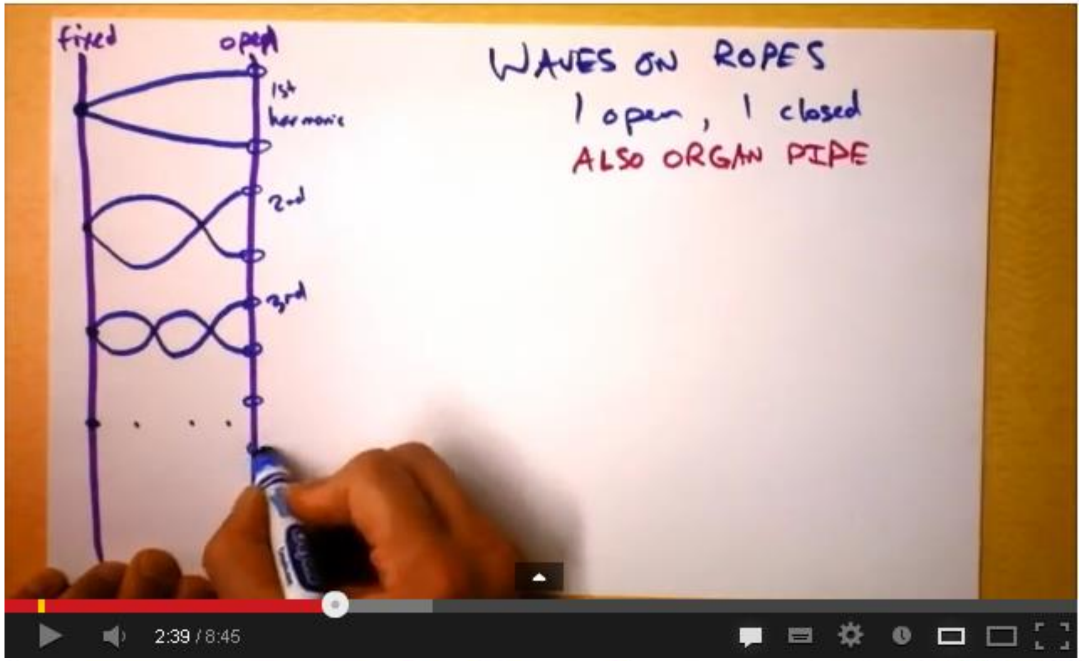
L = 管長; Vsound = f x 波長(λ)

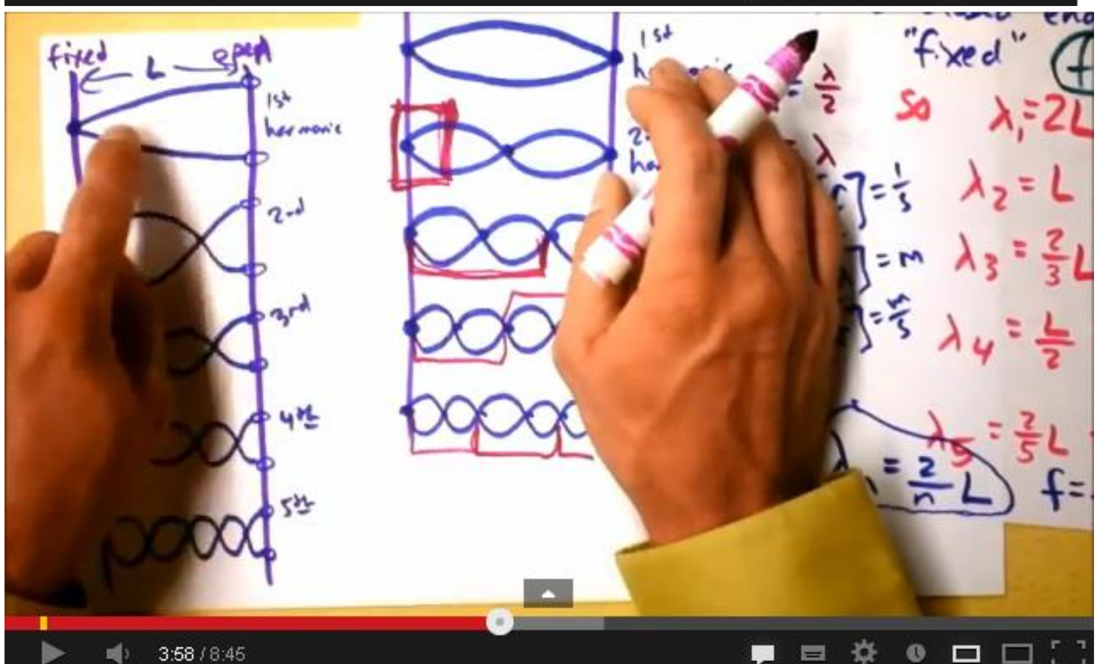


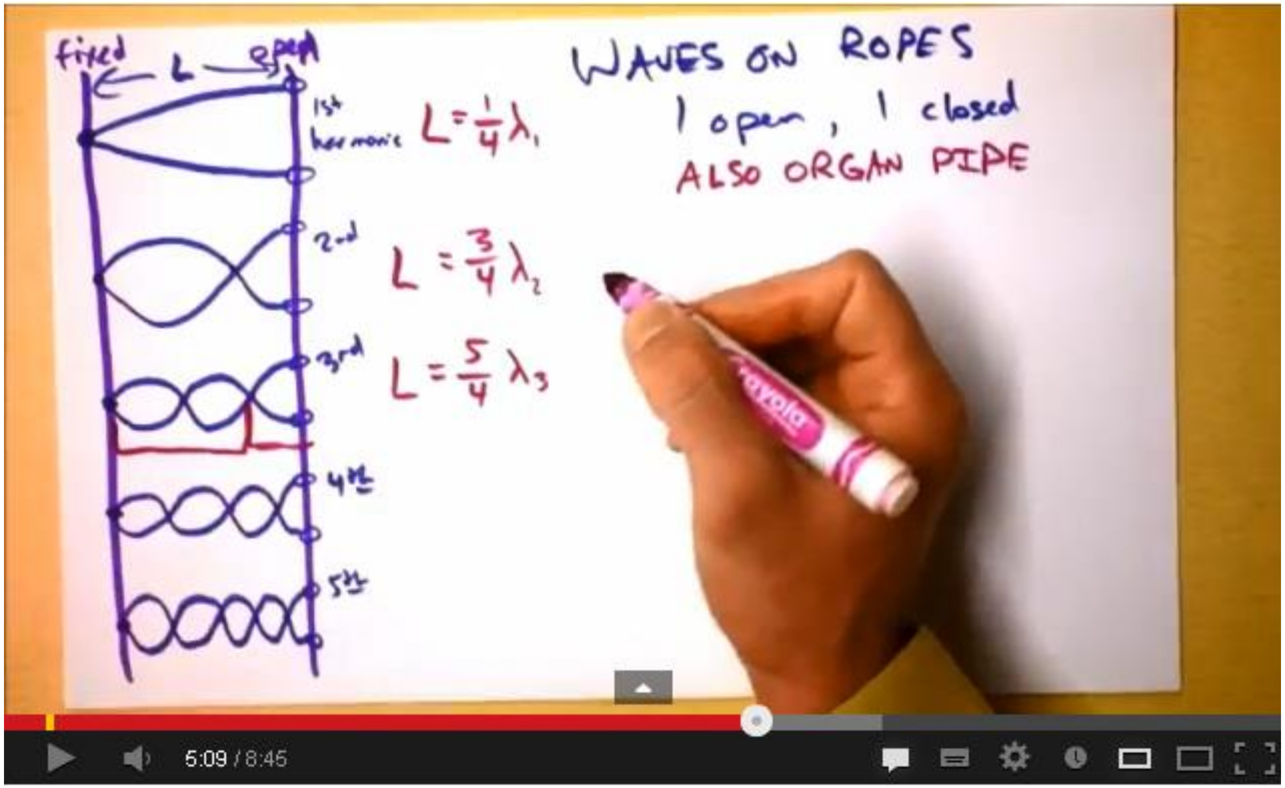
外耳道= 一端封閉的管子

- 耳模



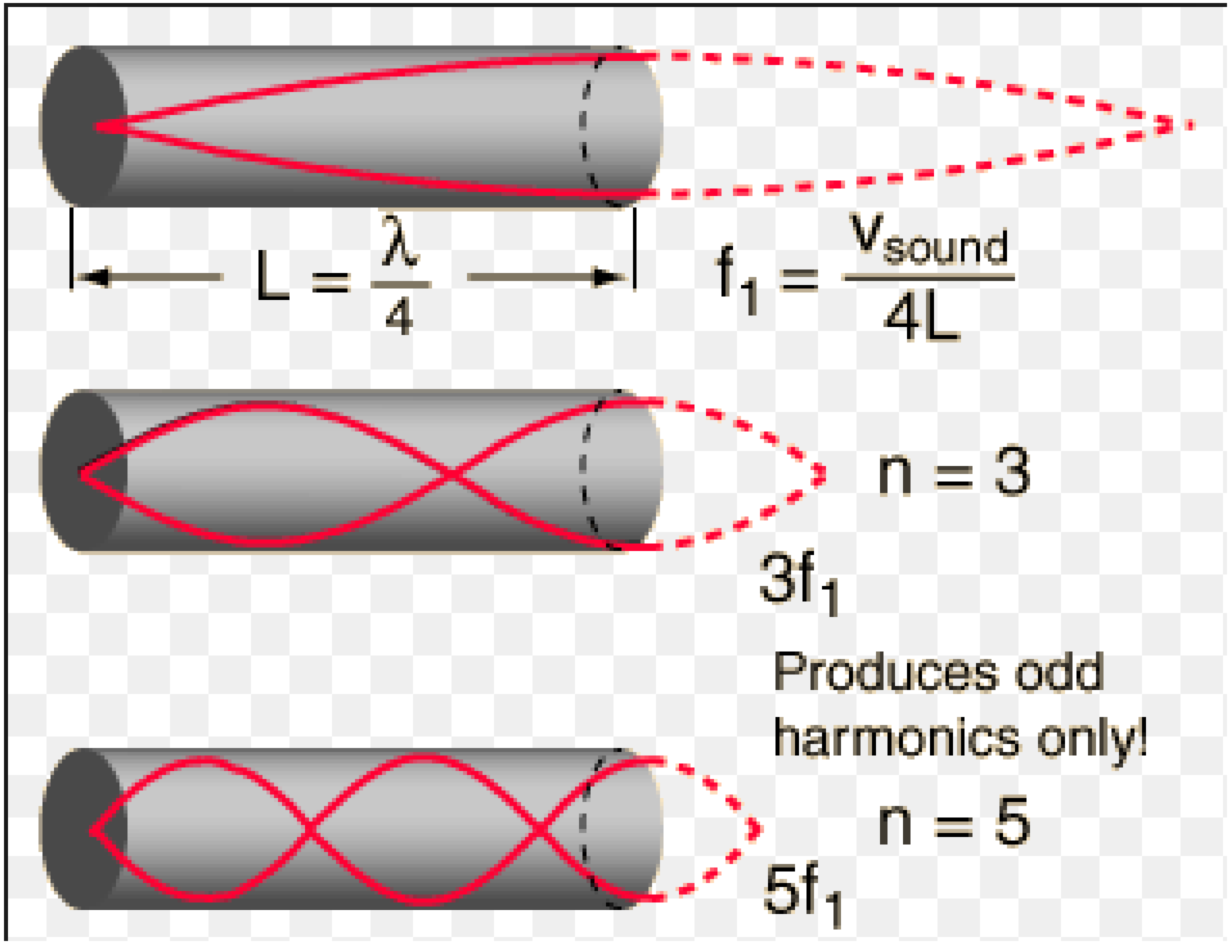

fixed
open
1st harmonic
2nd
3rd
WAVES ON ROPES
1 open, 1 closed
ALSO ORGAN PIPE
2:39 / 8:45

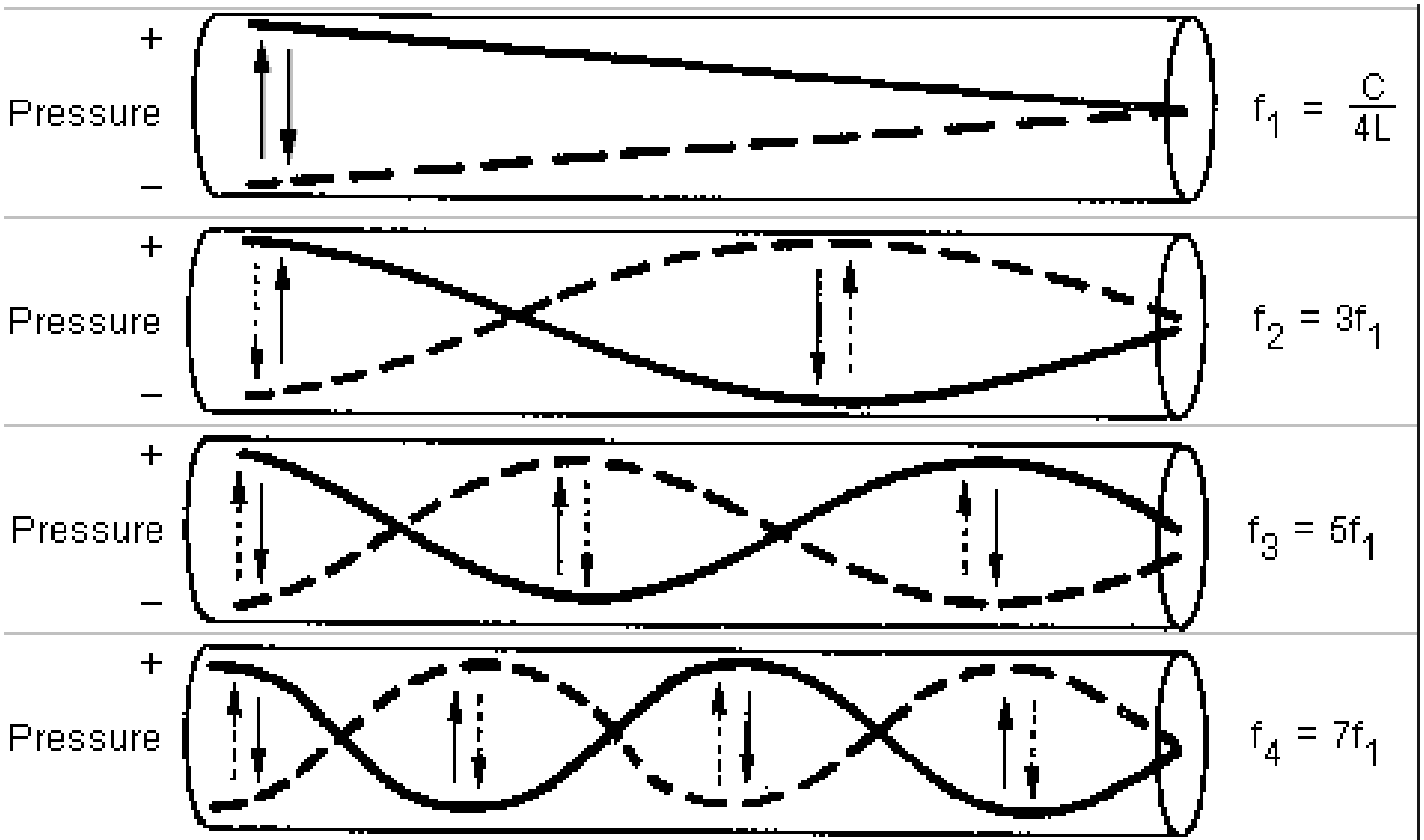

fixed
L
open
1st harmonic
2nd
3rd
4th
5th
"fixed"
So
$\lambda_1 = 2L$
$\lambda_2 = L$
$\lambda_3 = \frac{2}{3}L$
$\lambda_4 = \frac{L}{2}$
$\lambda_5 = \frac{2}{5}L$
$= \frac{2}{n}L$
3:58 / 8:45



WAVES ON ROPES
1 open, 1 closed
ALSO ORGAN PIPE
fixed
L
open
1st harmonic
$L = \frac{1}{4}\lambda_1$
2nd
$L = \frac{3}{4}\lambda_2$
3rd
$L = \frac{5}{4}\lambda_3$
4th
5th
5:09 / 8:45

¼ 波長的駐波+ 諧音

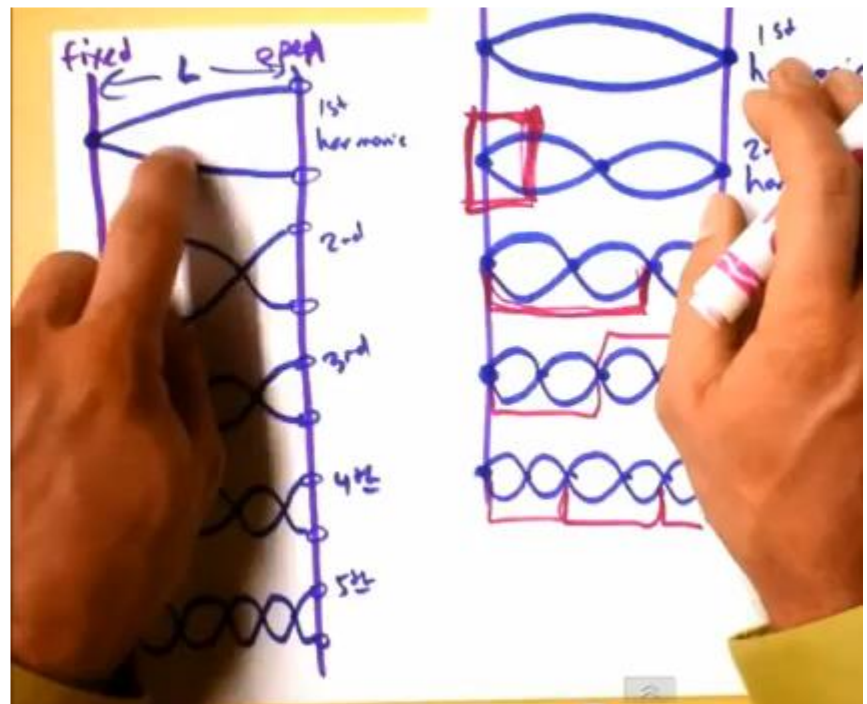



+
Pressure
–
$f_1 = \frac{C}{4L}$
+
Pressure
–
$f_2 = 3f_1$
+
Pressure
–
$f_3 = 5f_1$
+
Pressure
$f_4 = 7f_1$

外耳道= 一端封閉的管子(1)

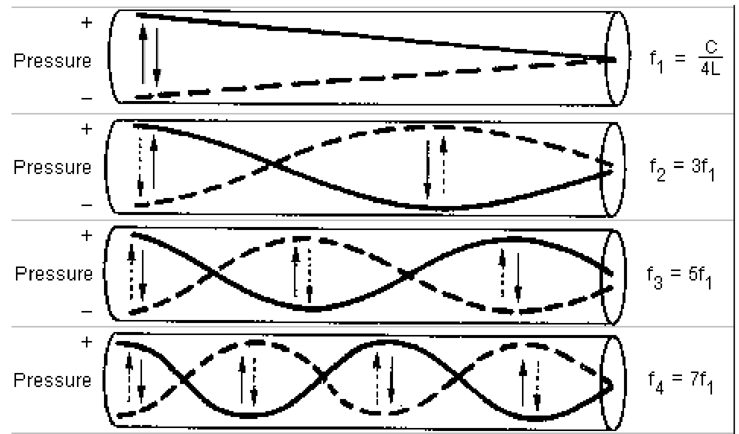
- 聲音進入耳道內遇到耳膜產生的駐波 (standing waves)
- 其基頻的波長(λ)
  = 4倍耳道的長度 (L)

  L = 4λ ; λ = ¼ L



外耳道= 一端封閉的管子(2)

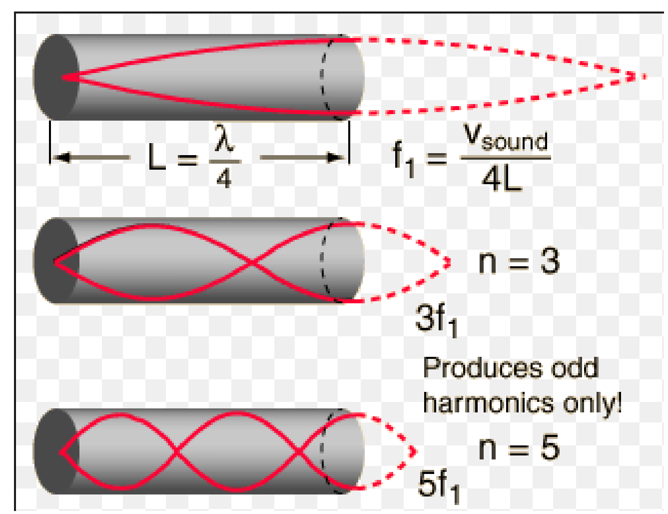
- 除基頻 f 外，其他的共振(resonance)出現在f的1,3,5...奇數基倍頻率



¼ 波長共振

3/4

5/4



計算耳道的<u>最低</u>共振頻率

人耳道L = 約25 mm

音速 C= 340 m/s;

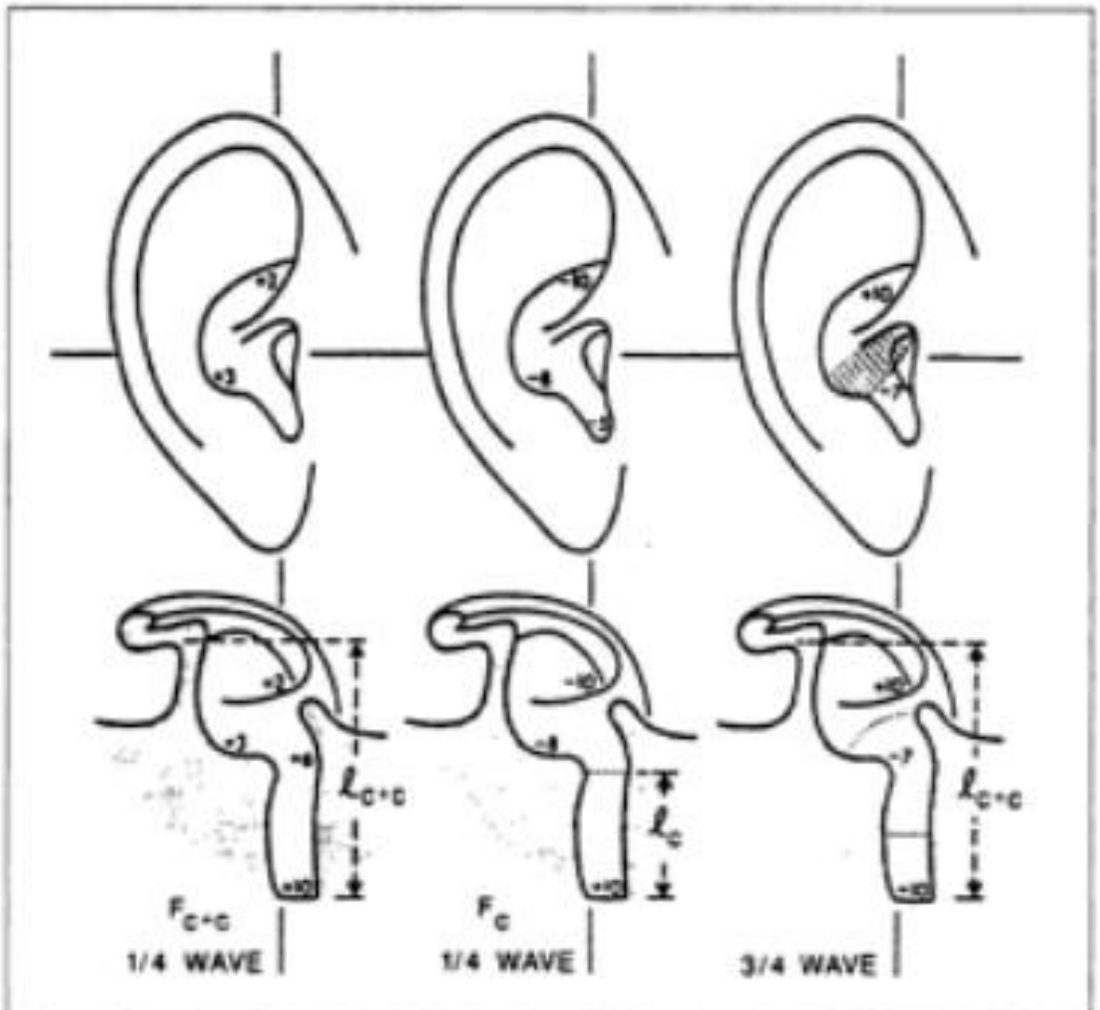
C = 頻率 f x 波長 λ; f = C / λ

λ = 4 L = 4 X 0.025 m = 0.1 m

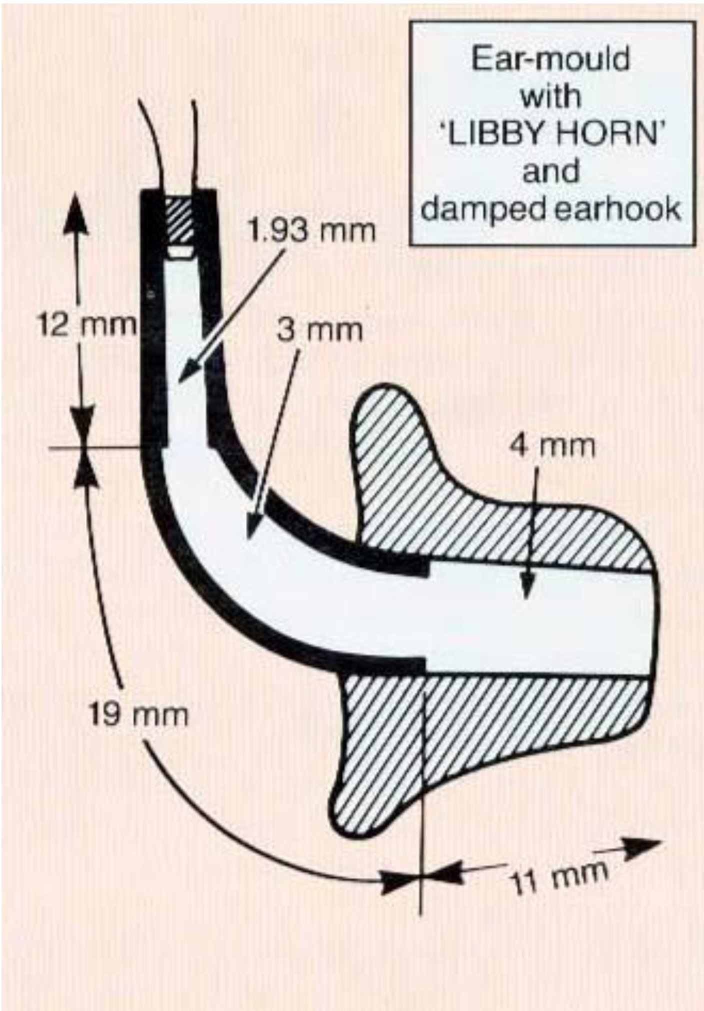
f = C / λ = 340 m/s / 0.1 m

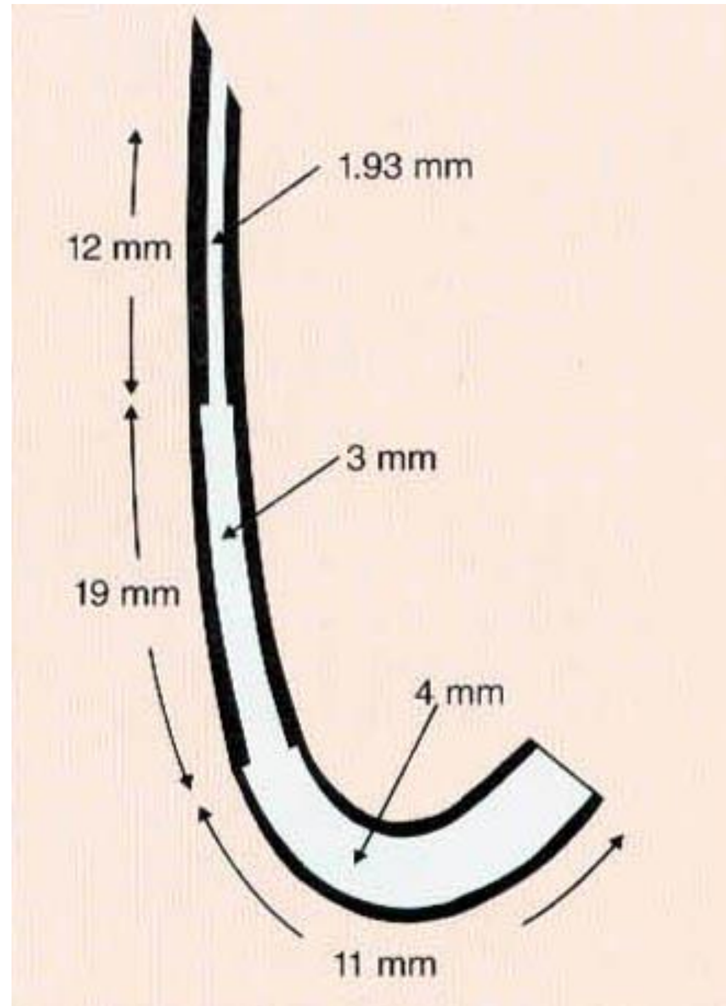
= 3400 Hz

1/4 波長駐波原理的其他應用(1)

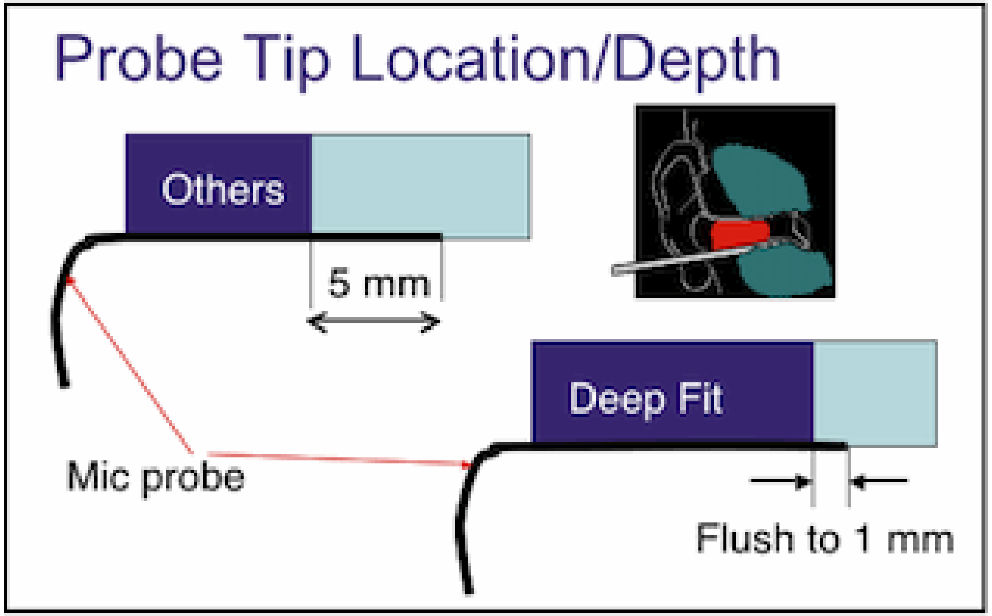


應用 (2)－－Tubing

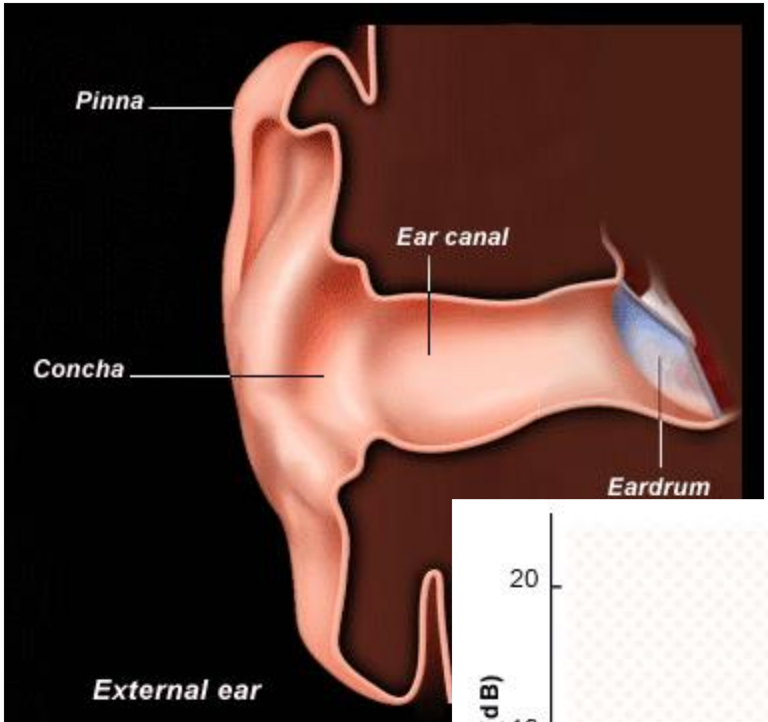

Ear-mould
with
'LIBBY HORN'
and
damped earhook
1.93 mm
12 mm
3 mm
4 mm
19 mm
11 mm

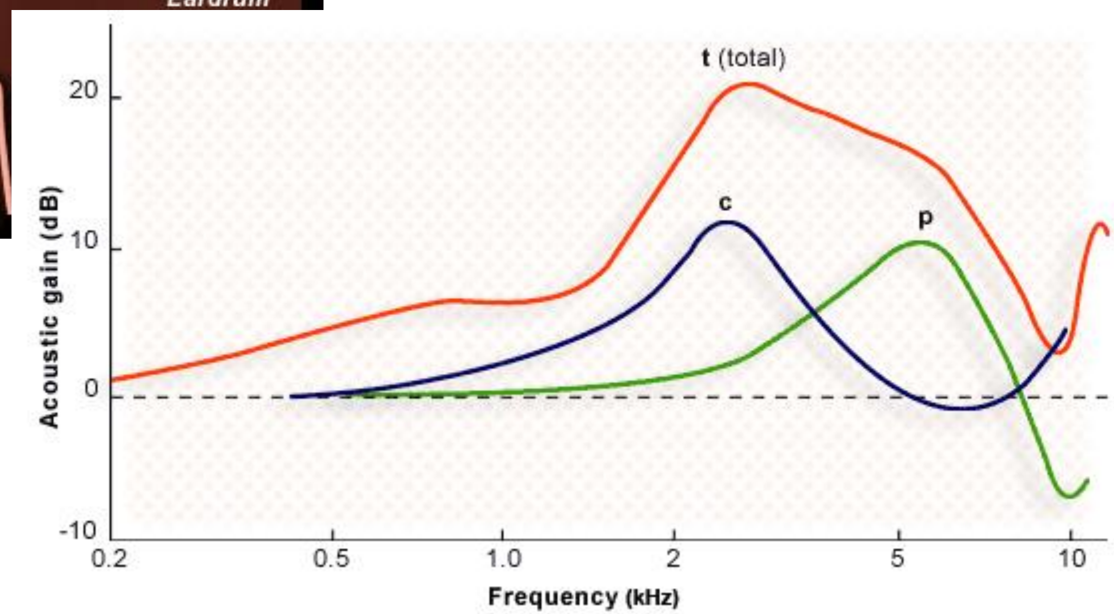

1.93 mm
12 mm
3 mm
19 mm
4 mm
11 mm

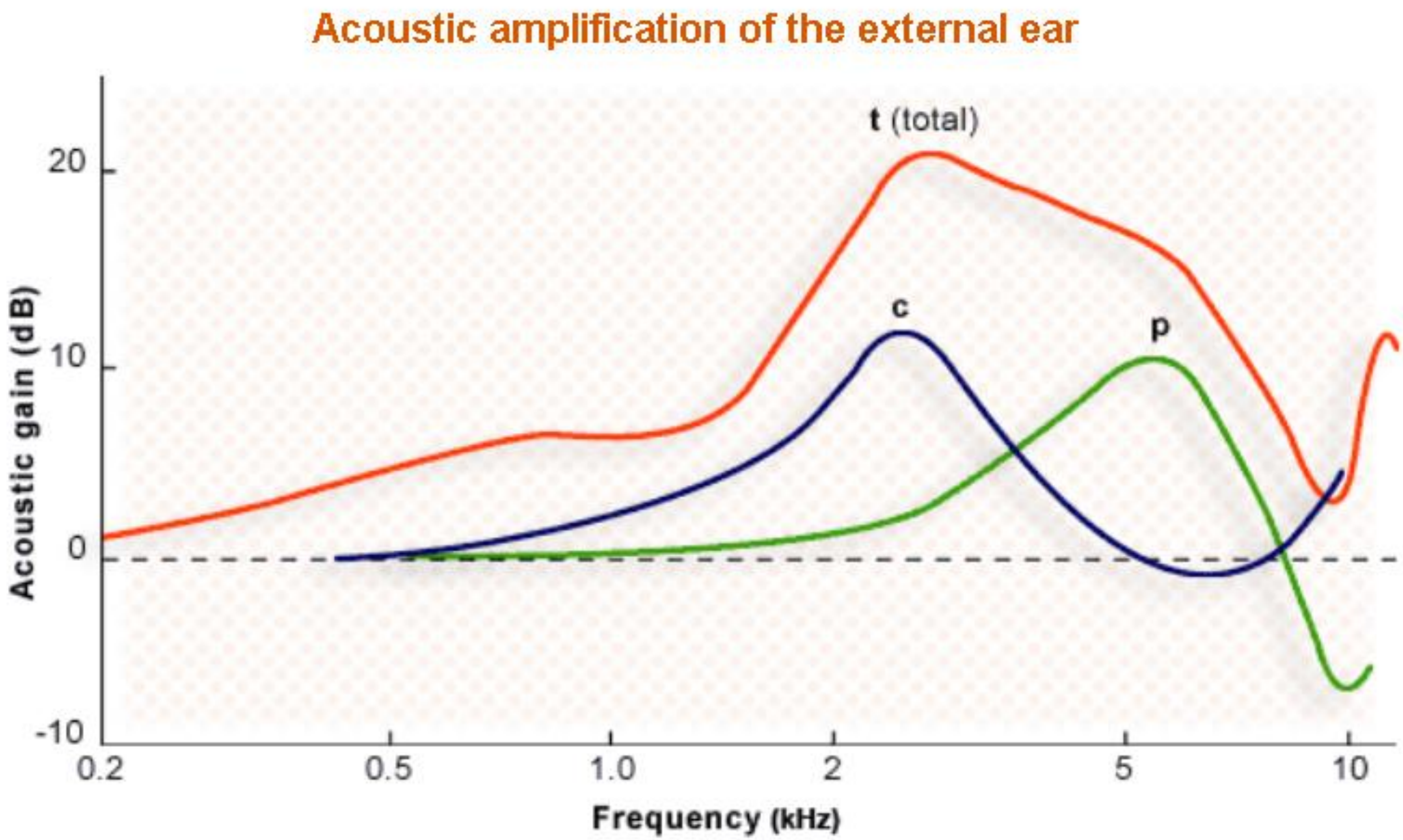
應用(3)—真耳測試Probe tube 的放置



從理論到實務


Pinna
Ear canal
Concha
Eardrum
External ear

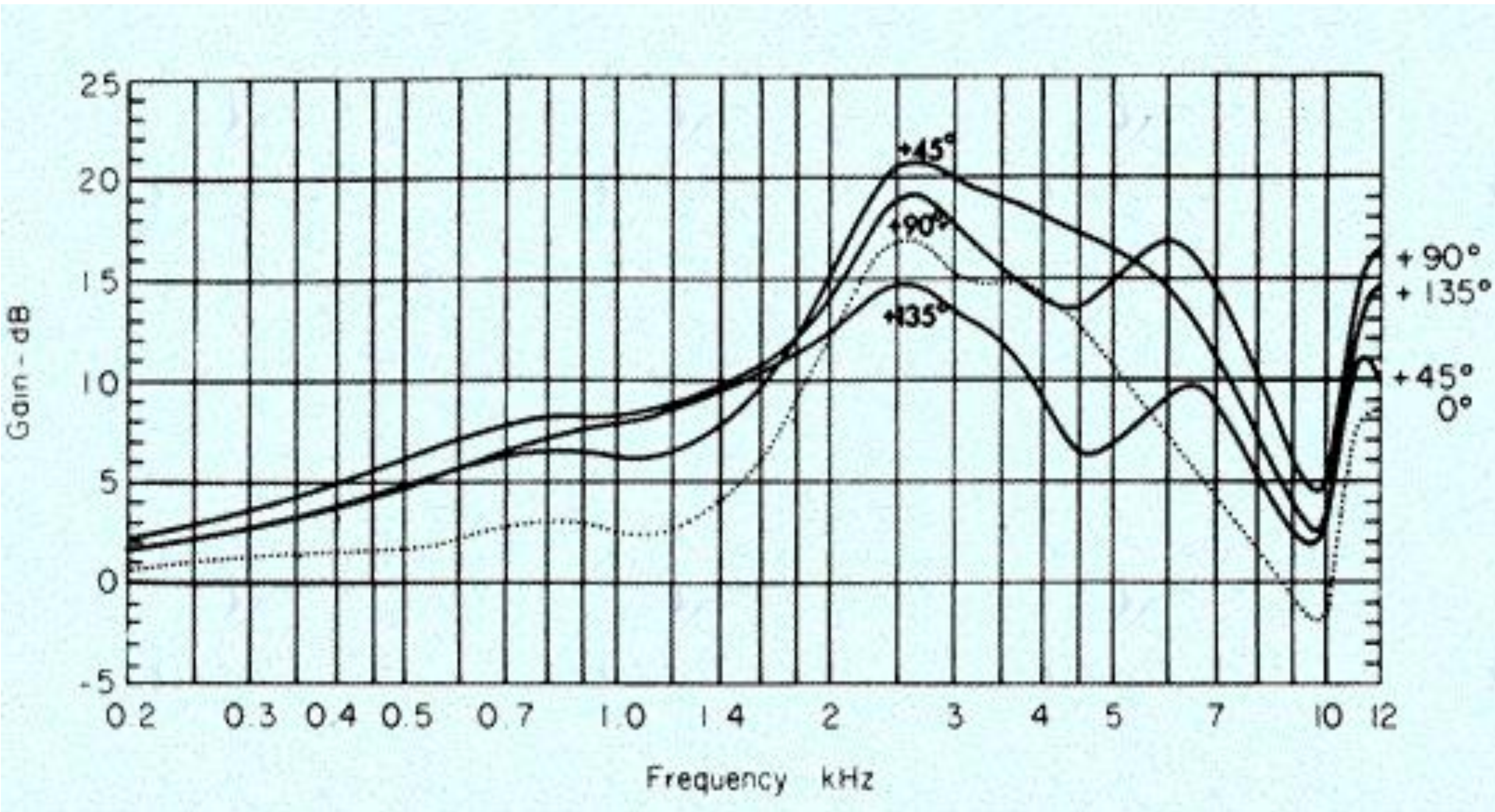

t (total)
c
p
20
10
0
-10
Acoustic gain (dB)
0.2
0.5
1.0
2
5
10
Frequency (kHz)



C : CANAL (耳道)　　P : PINNA (耳廓)

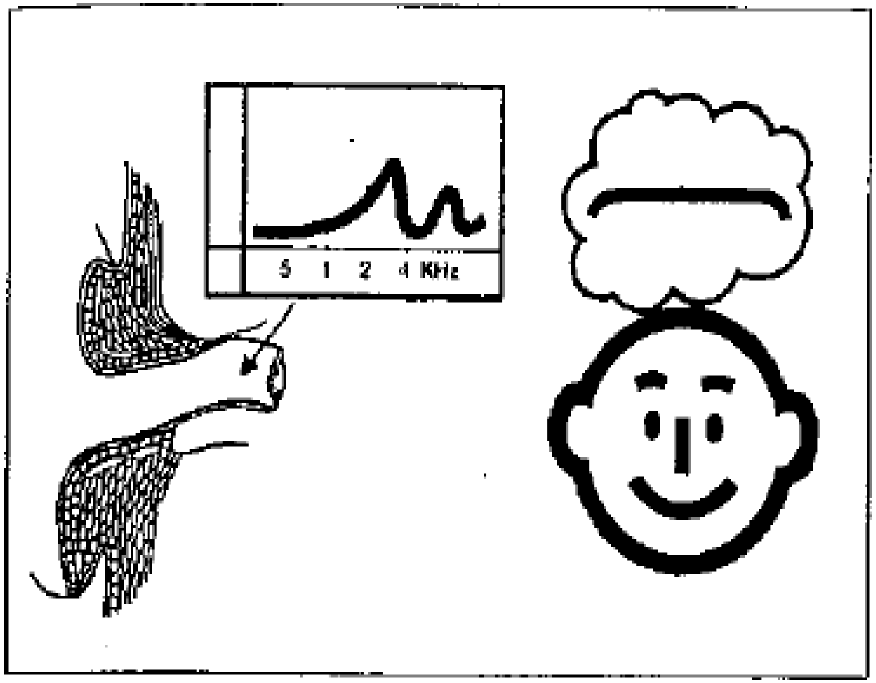
◎ 在 3000 Hz, 最後的gain (t) 是 20 dB (放大10 倍).

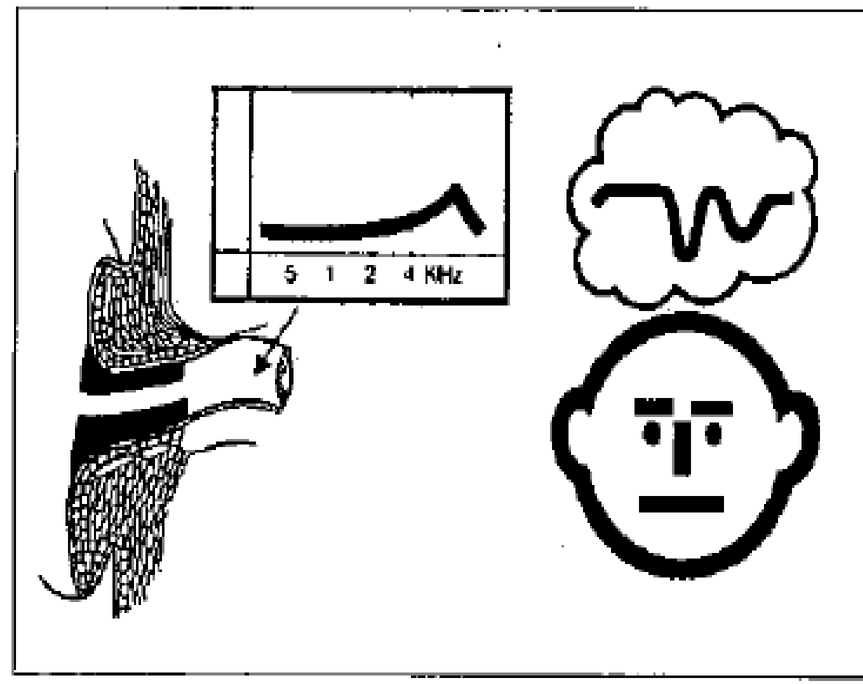
外耳的平均gain



25
20
15
10
5
0
-5
Gain - dB
+45°
+90°
+135°
+90°
+135°
+45°
0°
0.2
0.3
0.4
0.5
0.7
1.0
1.4
2
3
4
5
7
10
12
Frequency kHz

自然放大效應 vs. 耳膜放大效應





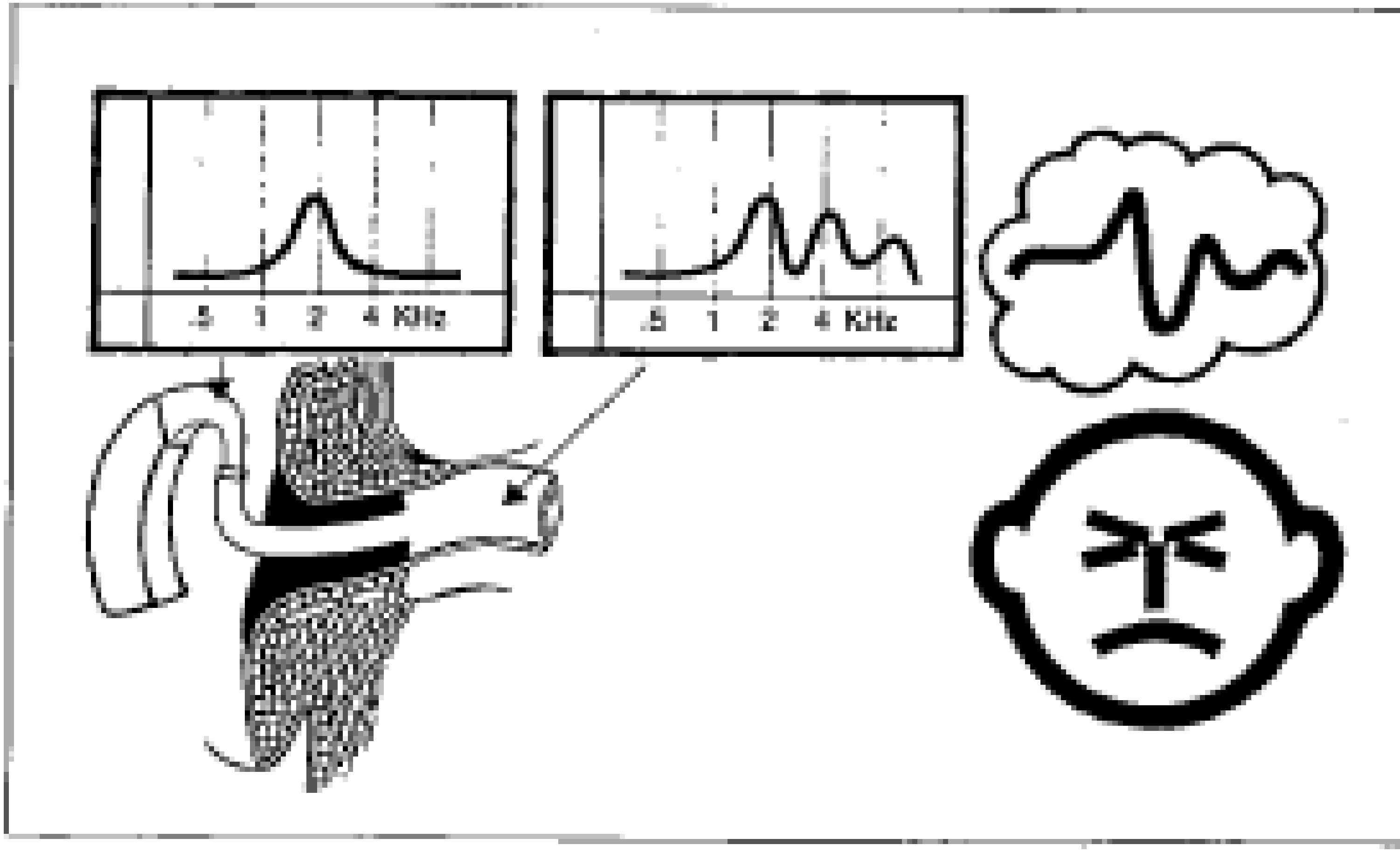
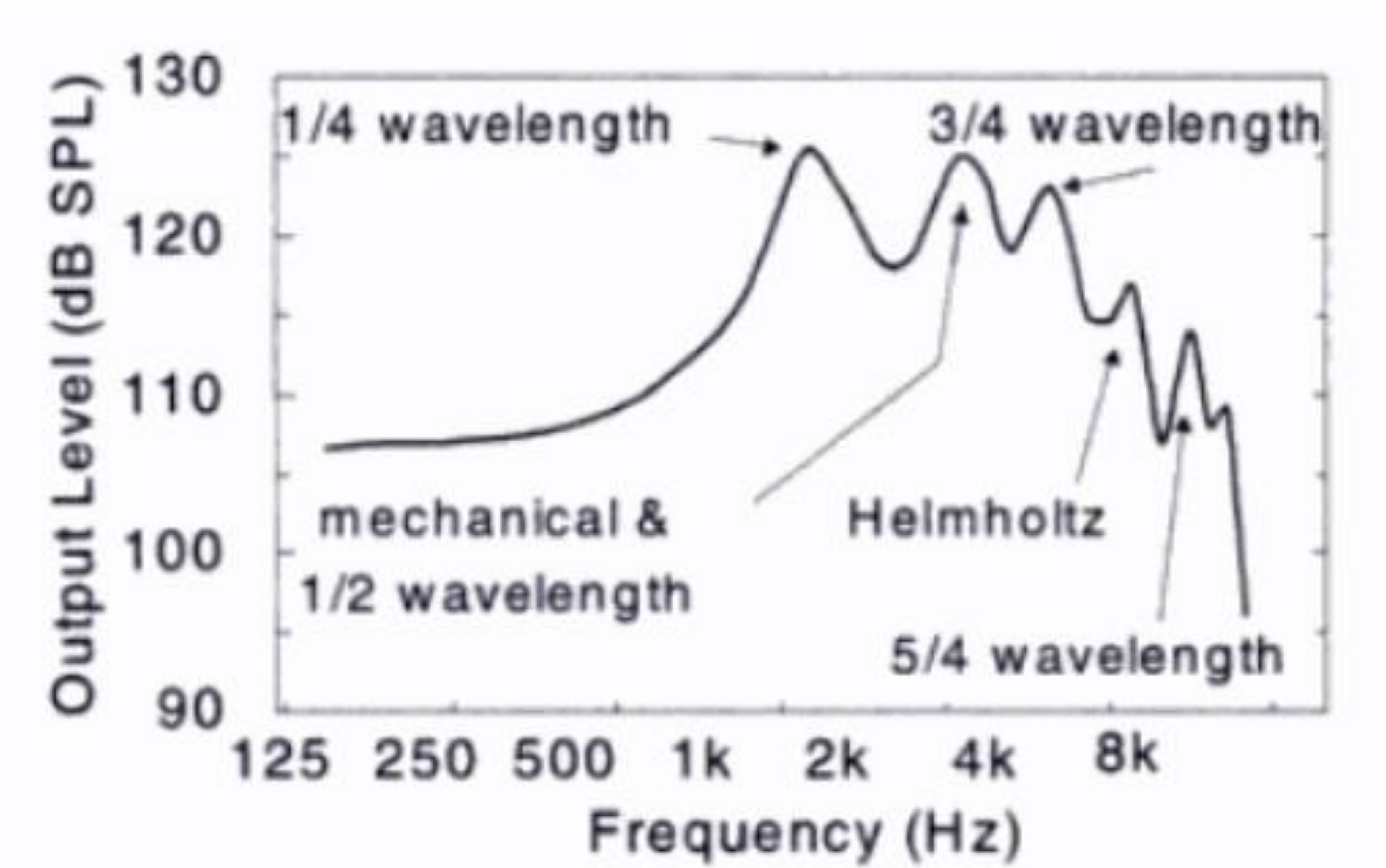


Figure 12–18. Adding a hearing aid system with peaks at frequencies other than the natural ear canal resonances can result in insertion gains with pronounced peaks and valleys.

BTE內Receiver接上tubing的頻率反應(1)



BTE的gain

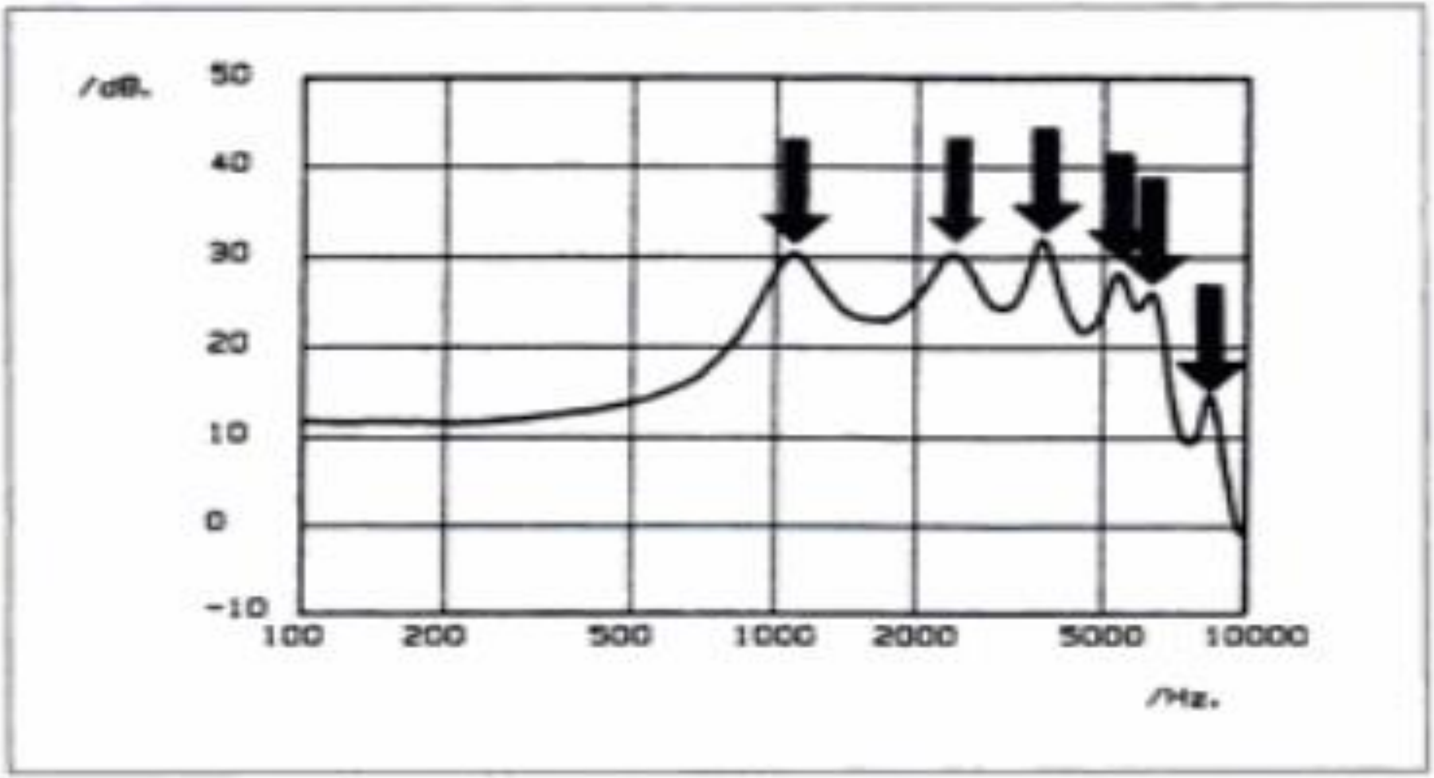
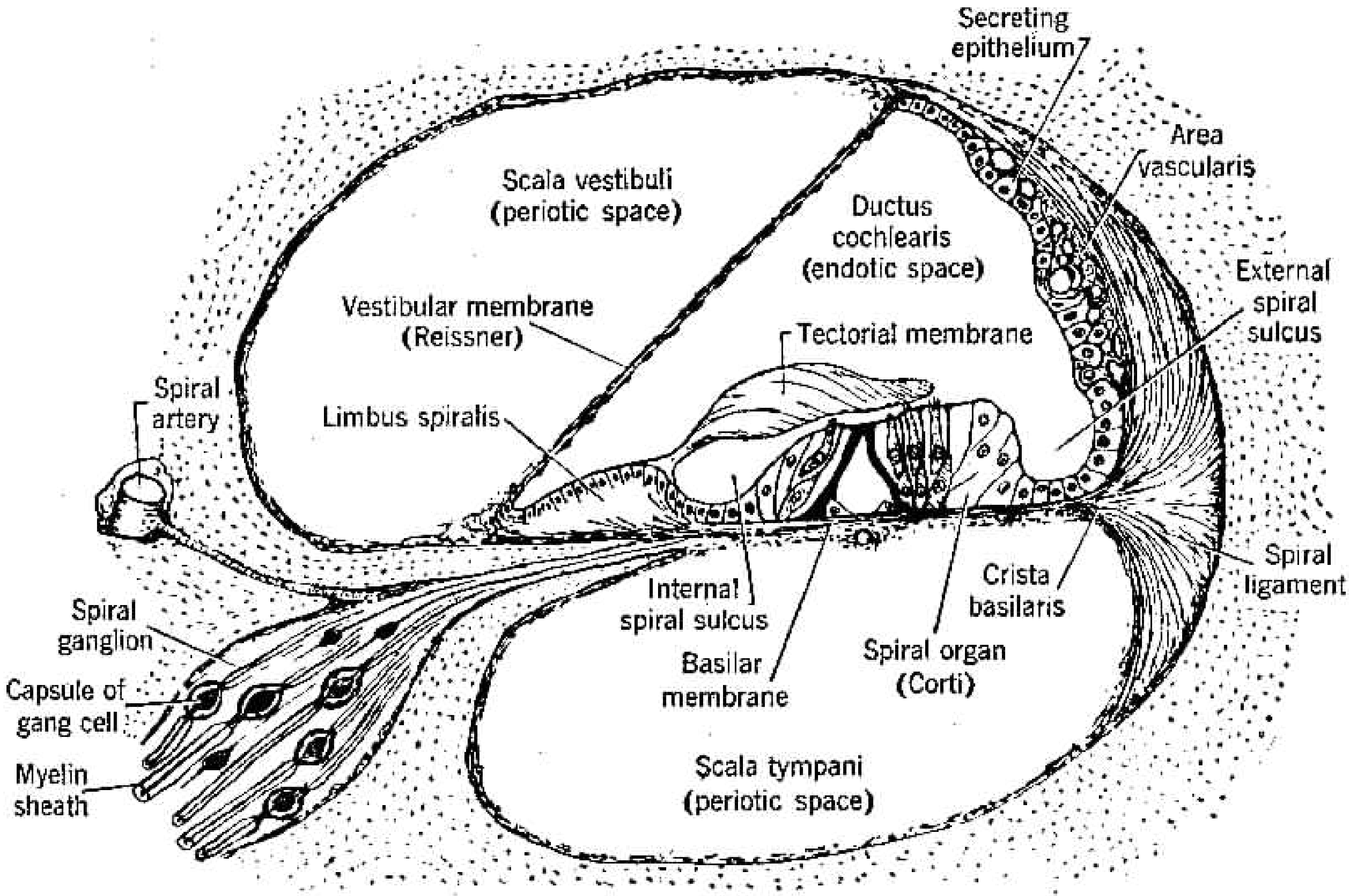


Figure 12–25. Gain response of a BTE aid as measured on an ear simulator. The tubing system consists of a receiver tube (8 mm × 1 mm), a hook (27 mm × 1.5 mm), a tube (25 mm × 2 mm), and an earmold bore (18 mm × 3 mm). All the peaks under the black arrows are standing wave resonances in the various transmission lines. The shaded arrow indicates the receiver resonance.

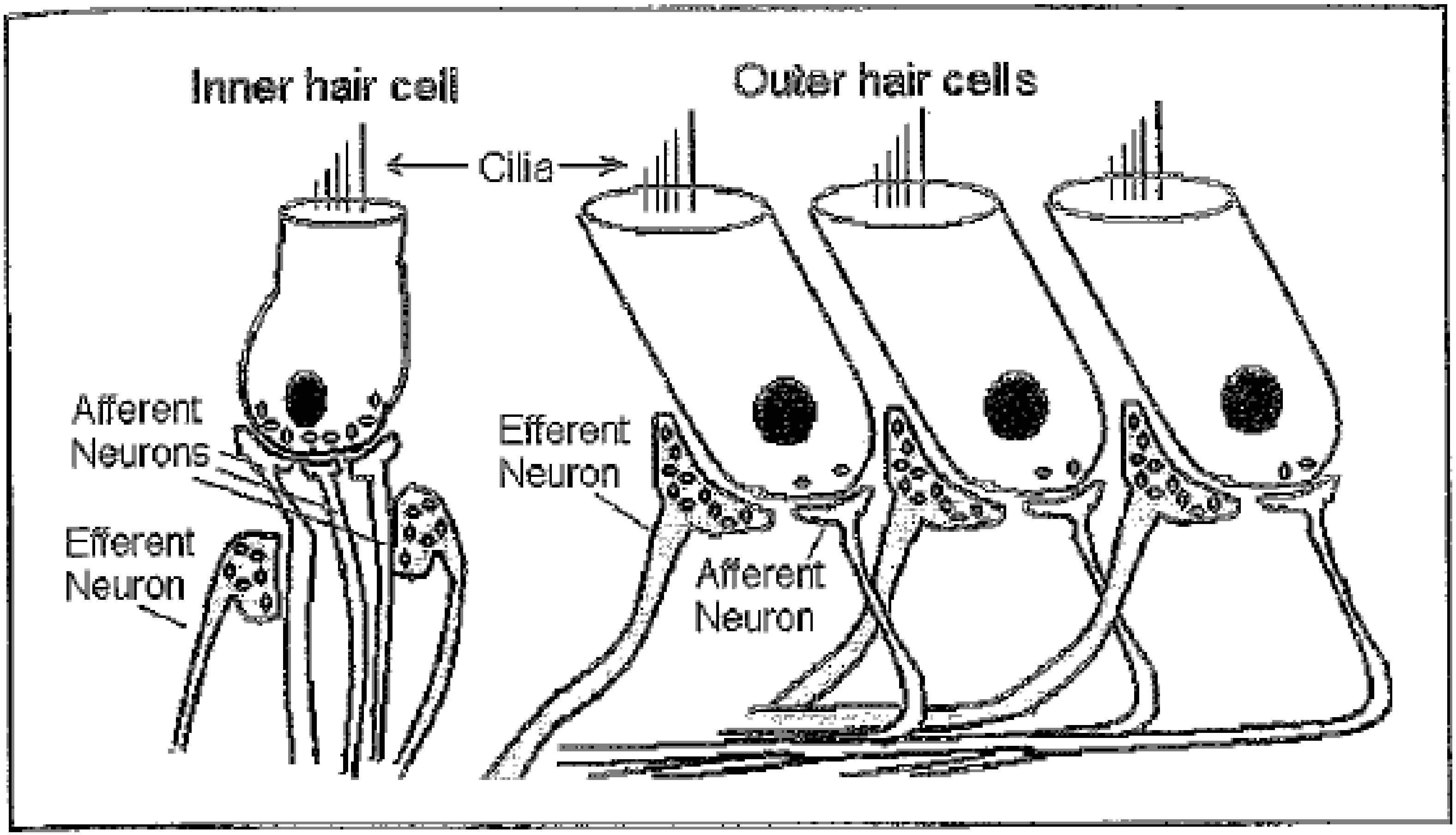
(2) 內耳

耳蝸內的內、外毛細胞的構造和生理

耳蝸的橫切面


Secreting epithelium
Area vascularis
Scala vestibuli (periotic space)
Ductus cochlearis (endotic space)
External spiral sulcus
Vestibular membrane (Reissner)
Tectorial membrane
Spiral artery
Limbus spiralis
Spiral ligament
Crista basilaris
Internal spiral sulcus
Spiral ganglion
Spiral organ (Corti)
Basilar membrane
Capsule of gang cell
Myelin sheath
Scala tympani (periotic space)

聽神經在基底膜下端的分佈



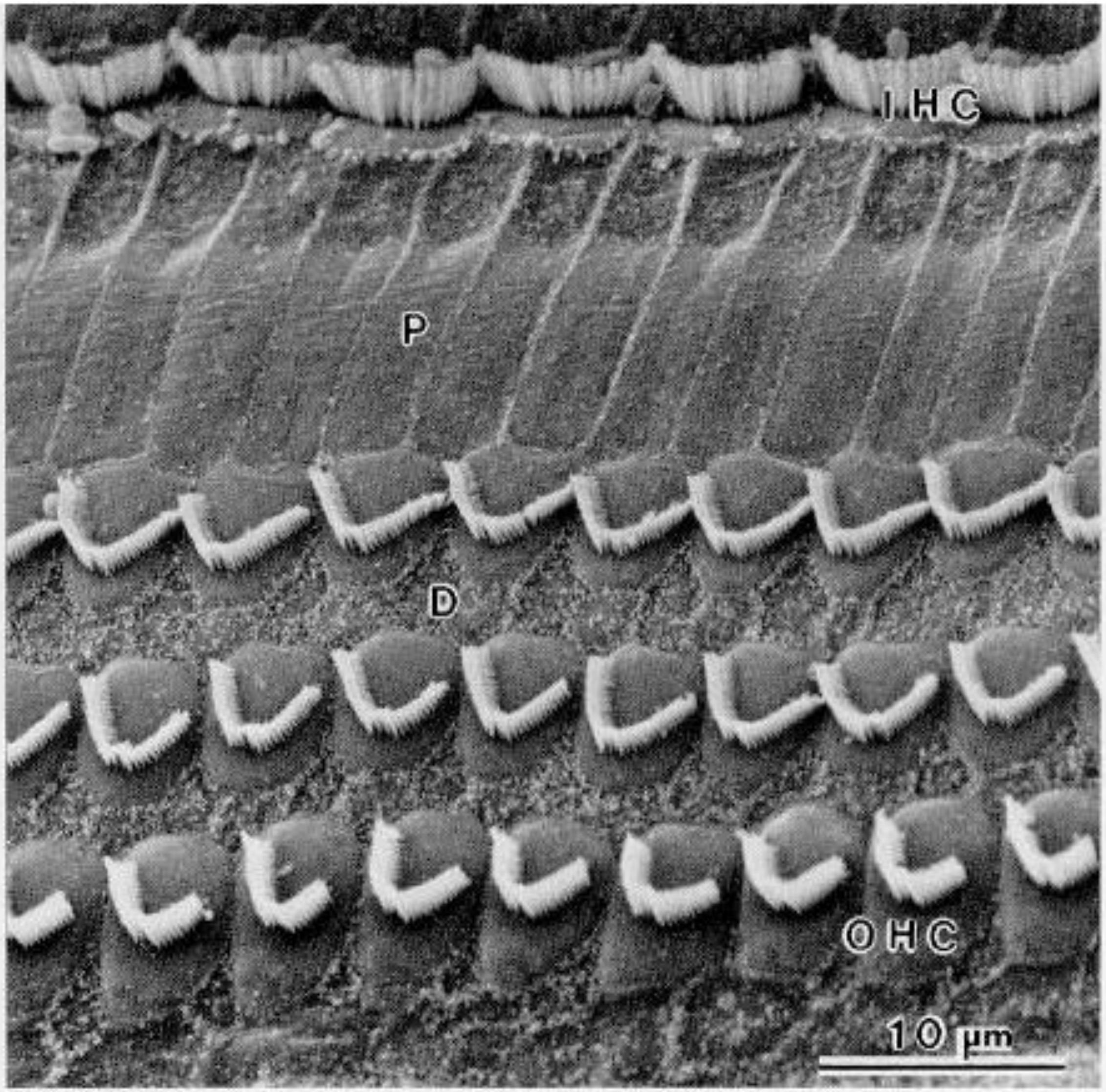
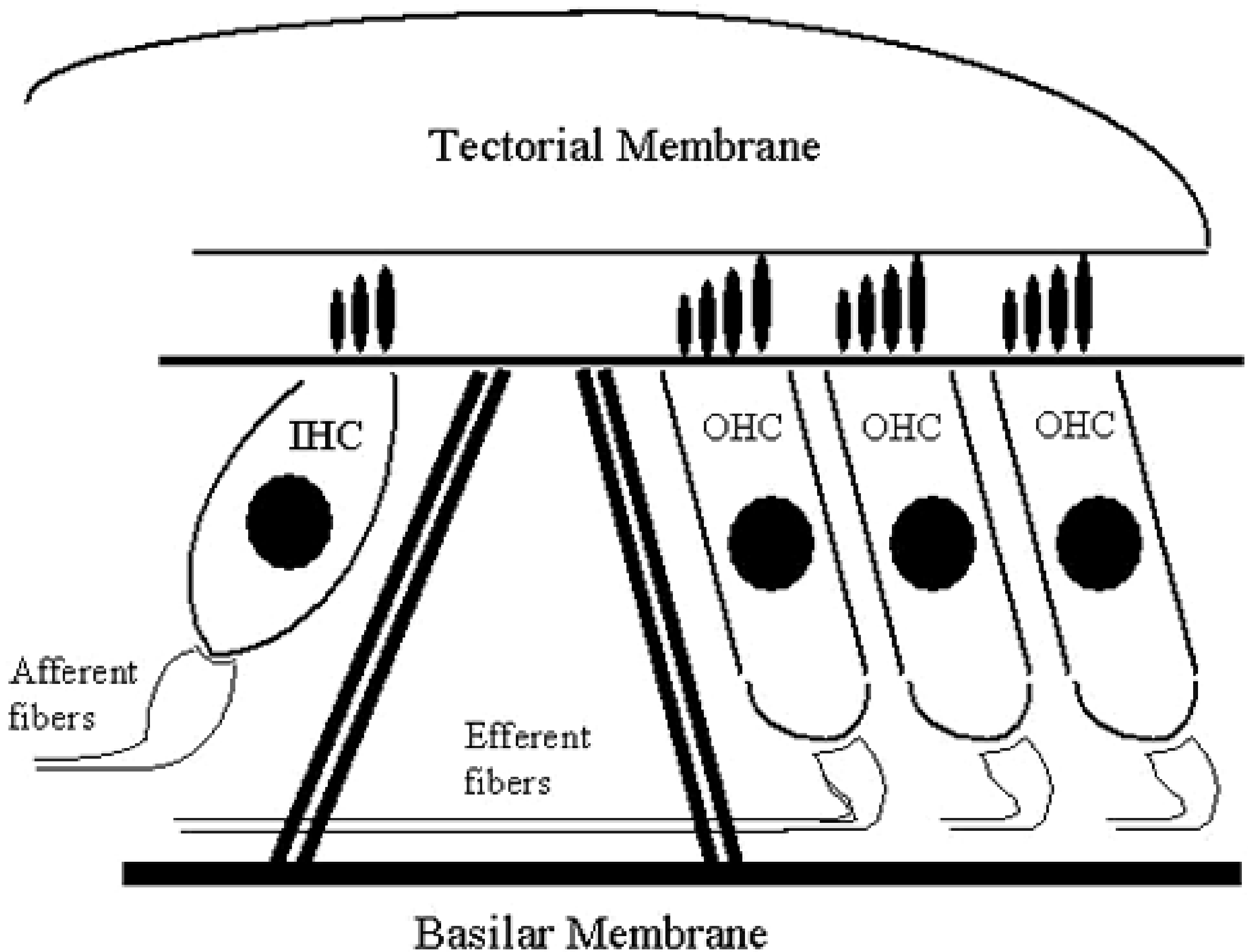
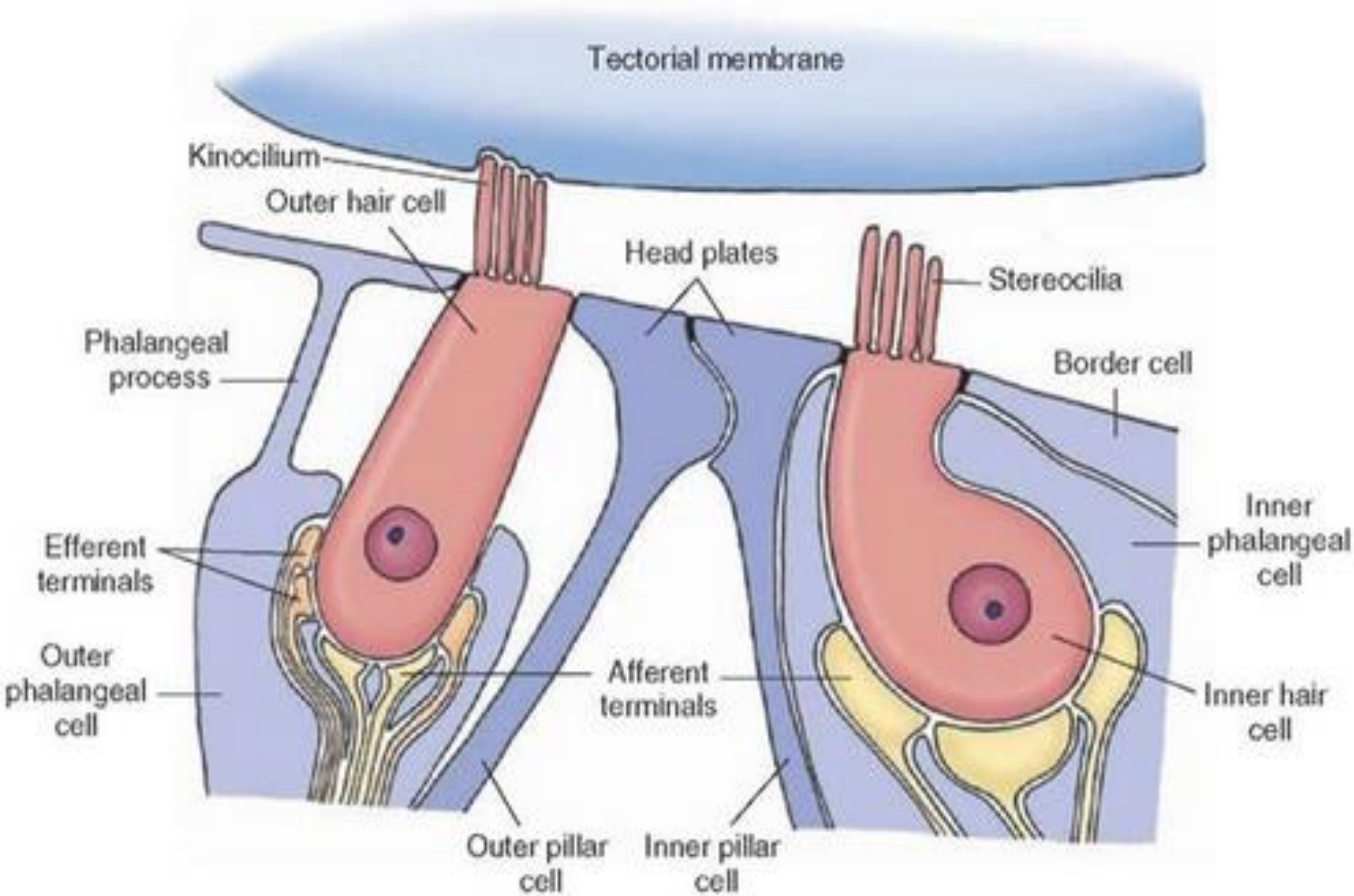


FIG. 6. The sensory epithelium of the organ of Corti—the reticular lamina. D, Deiters' cells; IHC, inner hair cells; OHC, outer hair cells; P, pillar cells.

耳蝸內、外毛細胞的結構示意



OHC, IHC 和 頂膜



Tectorial membrane
Kinocilium
Outer hair cell
Head plates
Stereocilia
Phalangeal process
Border cell
Efferent terminals
Inner phalangeal cell
Outer phalangeal cell
Afferent terminals
Inner hair cell
Outer pillar cell
Inner pillar cell

內毛細胞 (IHC)

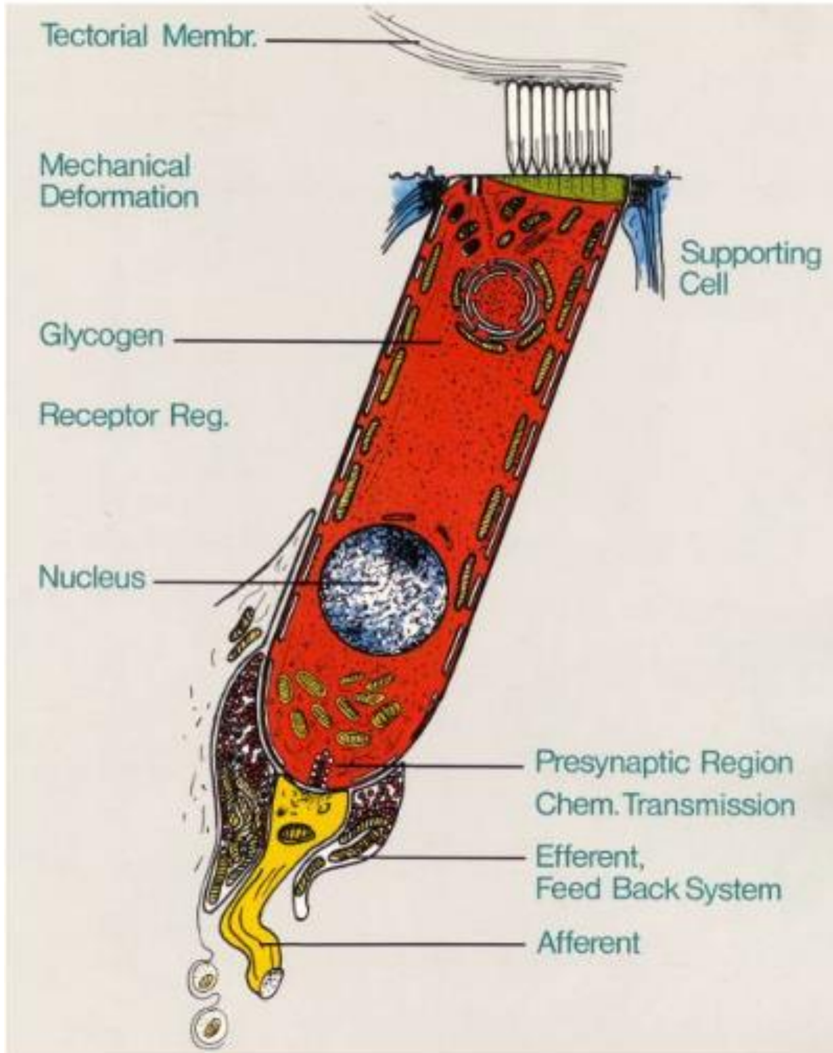
- IHC外型如燒杯(flask)(一排, 3000個)
- IHC頂端不觸及頂膜(tectorial membrane)
- 上傳(afferent,從周邊到中樞) : IHC將訊息經由腦幹神經送往大腦.
- IHC 無法感知比會話音量小的聲音(50-65 dB SPL)
- IHC損壞造成的聽損都在重度 (60 dB)以上 ，或/並有非常差的語詞理解力. (即使音量放大, 仍有扭曲(distortion)的問題.

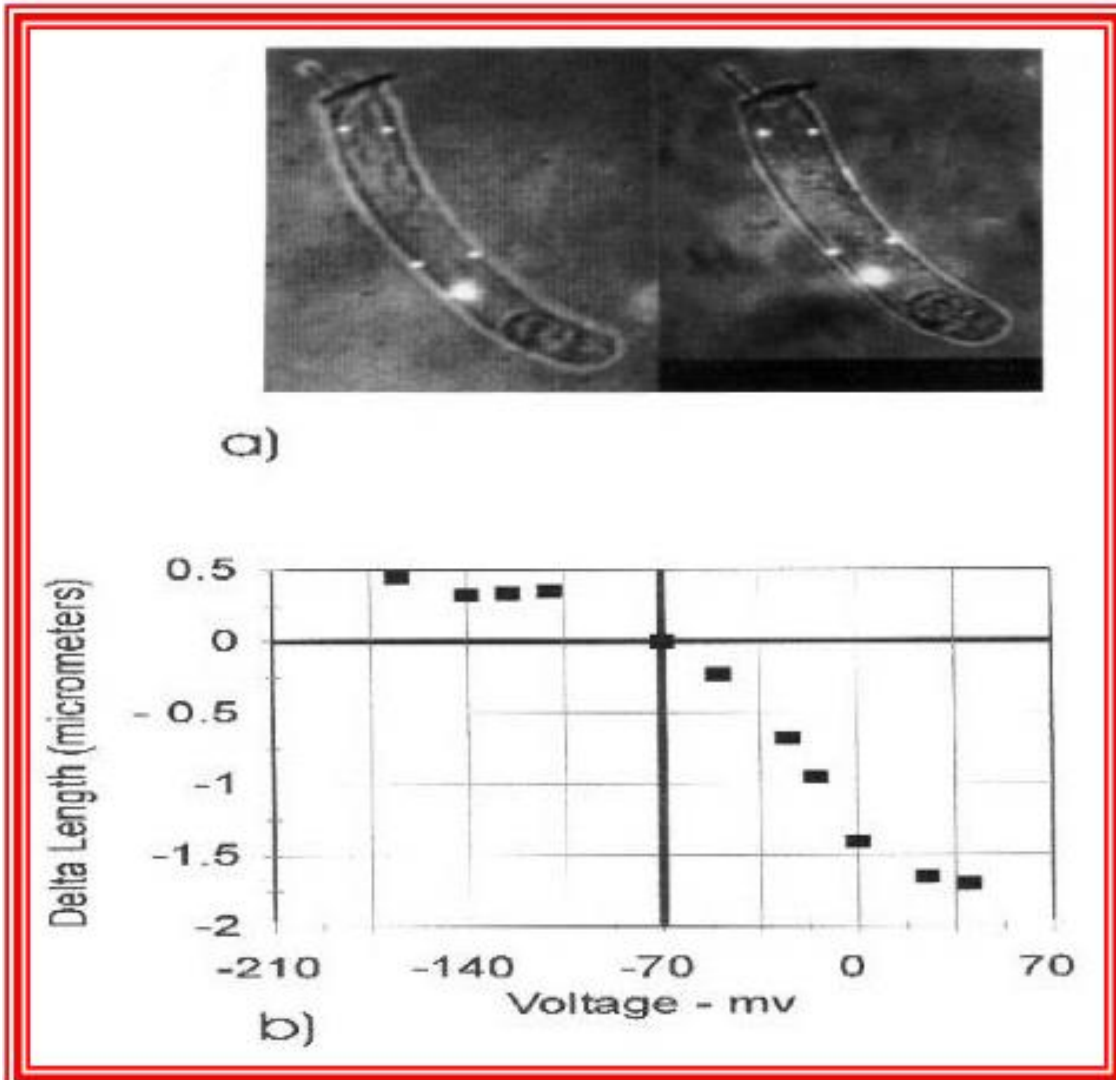
外毛細胞 (OHC)

- OHC外型如試管 (三-五排, 12,000個)
- OHC上方末端纖毛埋在頂膜內
- 下傳(efferent, 從中樞到周邊):OHC接收來自下腦幹聽覺神經的訊息,
- OHC機械性的放大弱小(低頻50-高頻65 dB SPL)聲音. OHC亦被成稱作耳蝸的放大器，是耳蝸內的活動部位,可快速伸縮.
- OHC讓traveling wave的波峰變尖銳
- OHC的損壞造成聽損最高不超過 60 dB(中重度)
- 當弱音進入耳蝸， OHC會縮小，把頂膜下拉，才撥動IHC上方末端纖毛

OHC

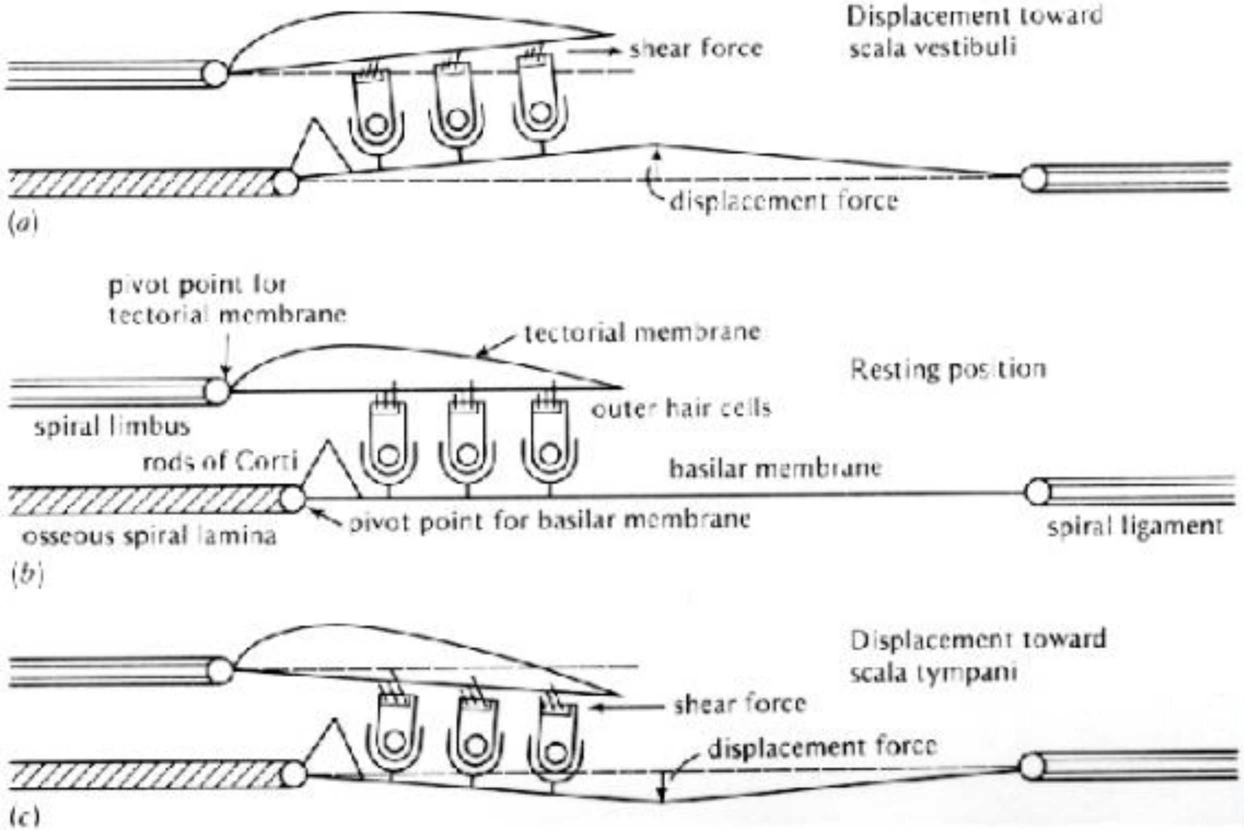
頂膜


Tectorial Membr.
Mechanical
Deformation
Supporting
Cell
Glycogen
Receptor Reg.
Nucleus
Presynaptic Region
Chem. Transmission
Efferent,
Feed Back System
Afferent

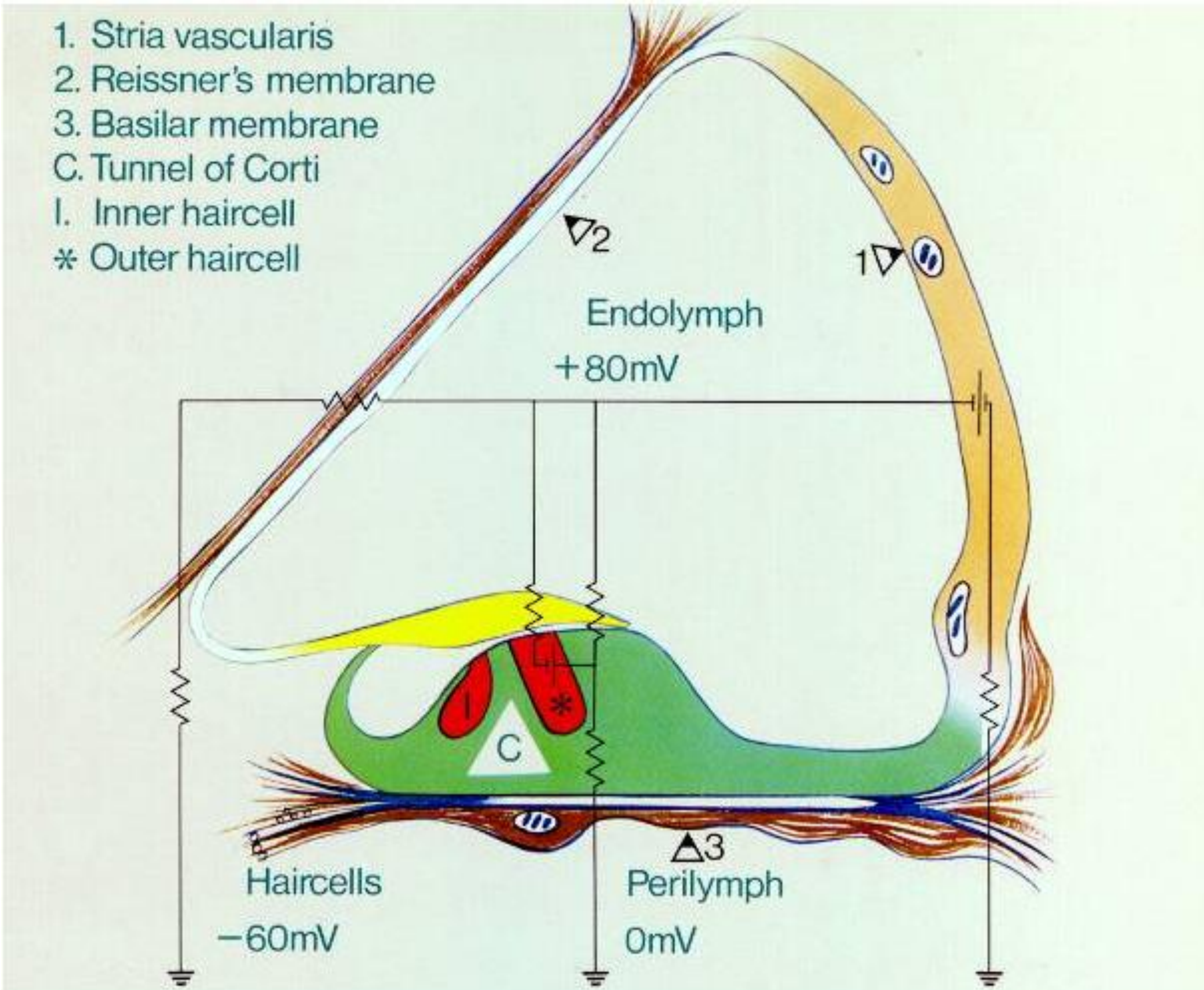


OHC的長度與電壓的改變

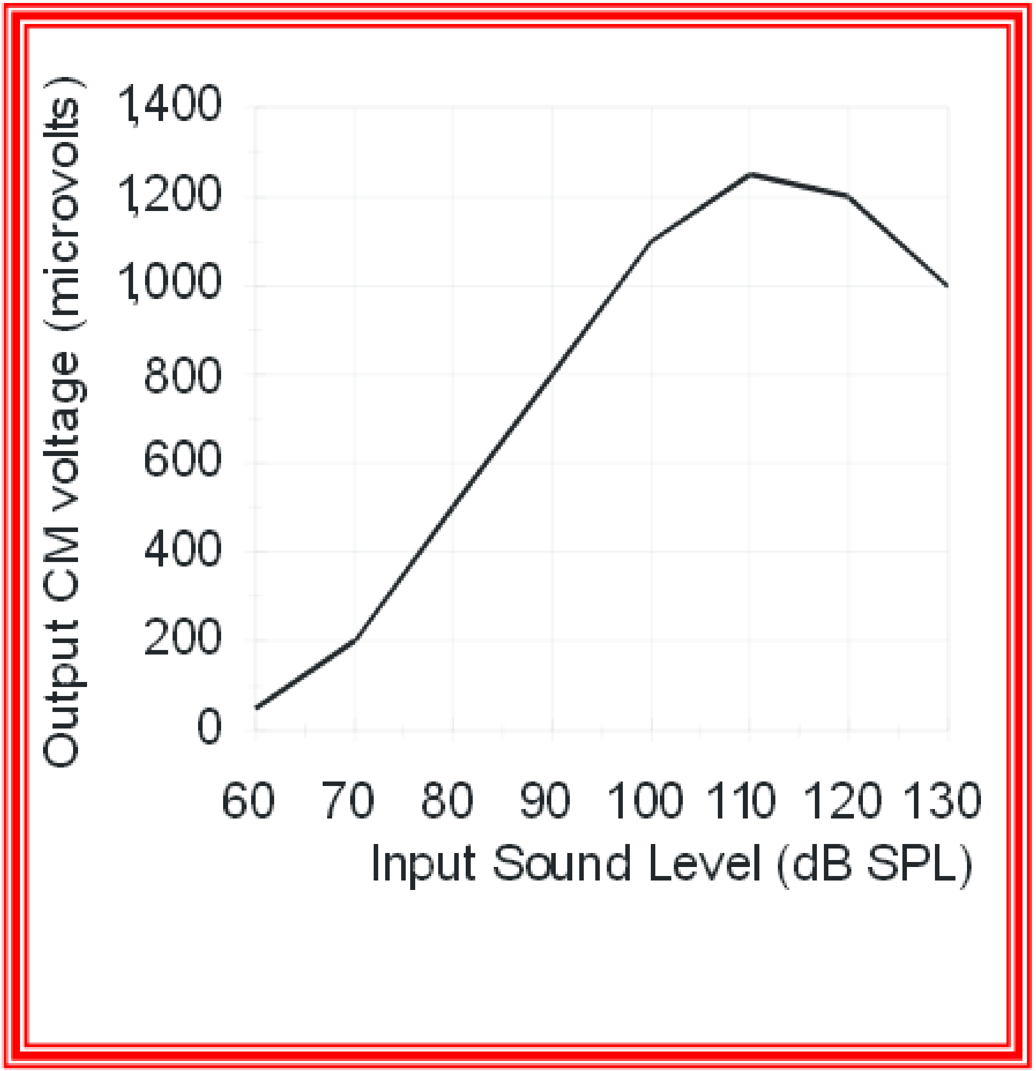
Summary



shear force
Displacement toward
scala vestibuli
displacement force
(a)
pivot point for
tectorial membrane
tectorial membrane
Resting position
outer hair cells
spiral limbus
rods of Corti
basilar membrane
pivot point for basilar membrane
osseous spiral lamina
spiral ligament
(b)
Displacement toward
scala tympani
shear force
displacement force
(c)



1. Stria vascularis
2. Reissner's membrane
3. Basilar membrane
C. Tunnel of Corti
I. Inner haircell
* Outer haircell
2
1
Endolymph
+80mV
I
*
C
3
Haircells
−60mV
Perilymph
0mV



Input-Output function for the cochlear mcrophonic (CM)

IHC、 OHC的傷害和聽損程度的關係

- OHC的傷害造成聽損最高不超過 60 dB:

  OHC : 負責弱小聲,

  低頻- 50 dB 以下,

  高頻 – 65 dB 以下

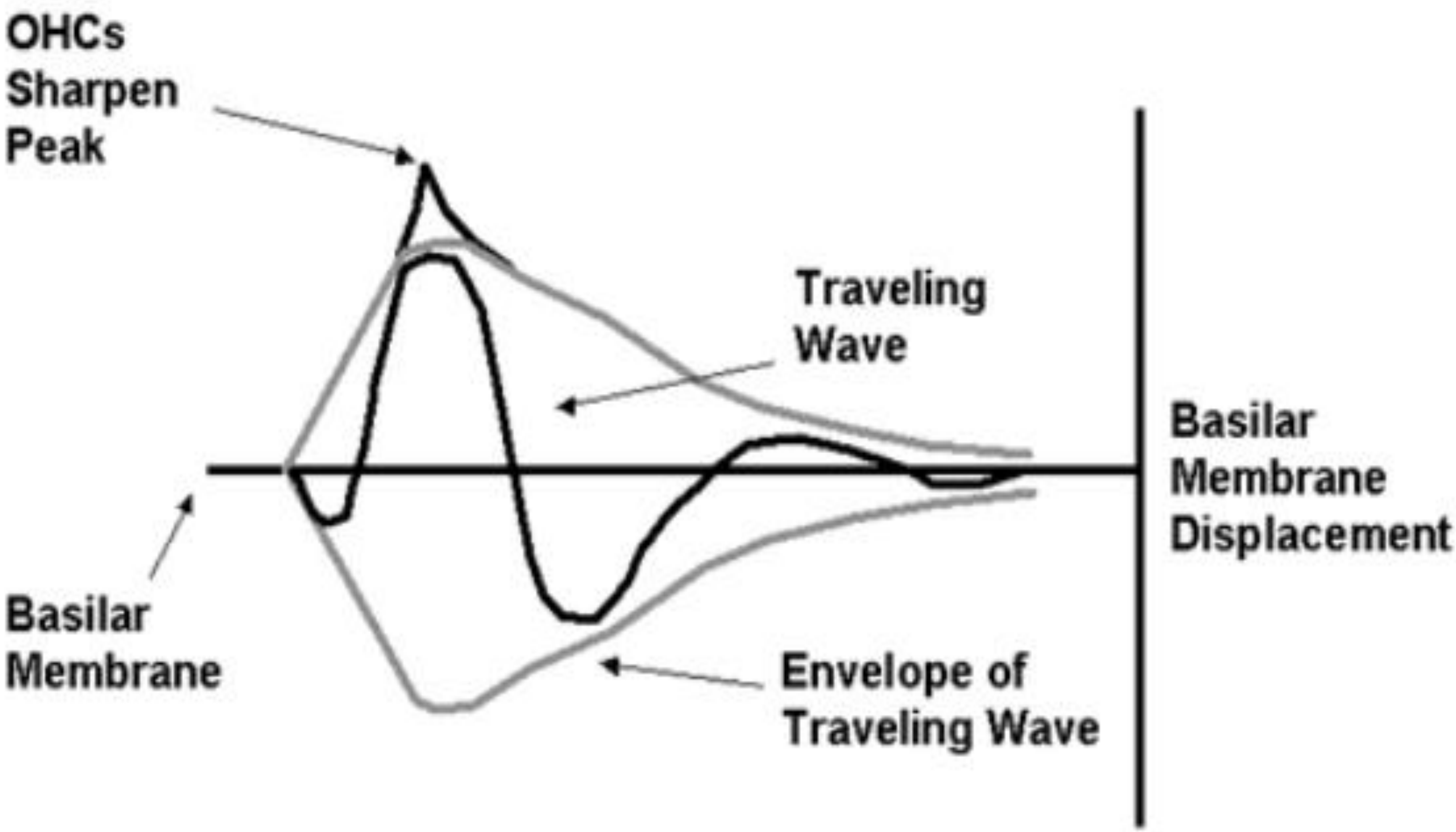
- IHC傷害所造成的聽損都在重度 (60 dB)以上:

  根據B.C. Moore, 若IHC也受傷, 聽損會再加 25-30 dB, 因此

  低頻= 50 + (25-30)dB ＝75 -80 dB； ,

  高頻 = 65 + + (25-30)dB = 90+ dB

- 因此, 重度以上聽障是IHC+ OHC都受傷

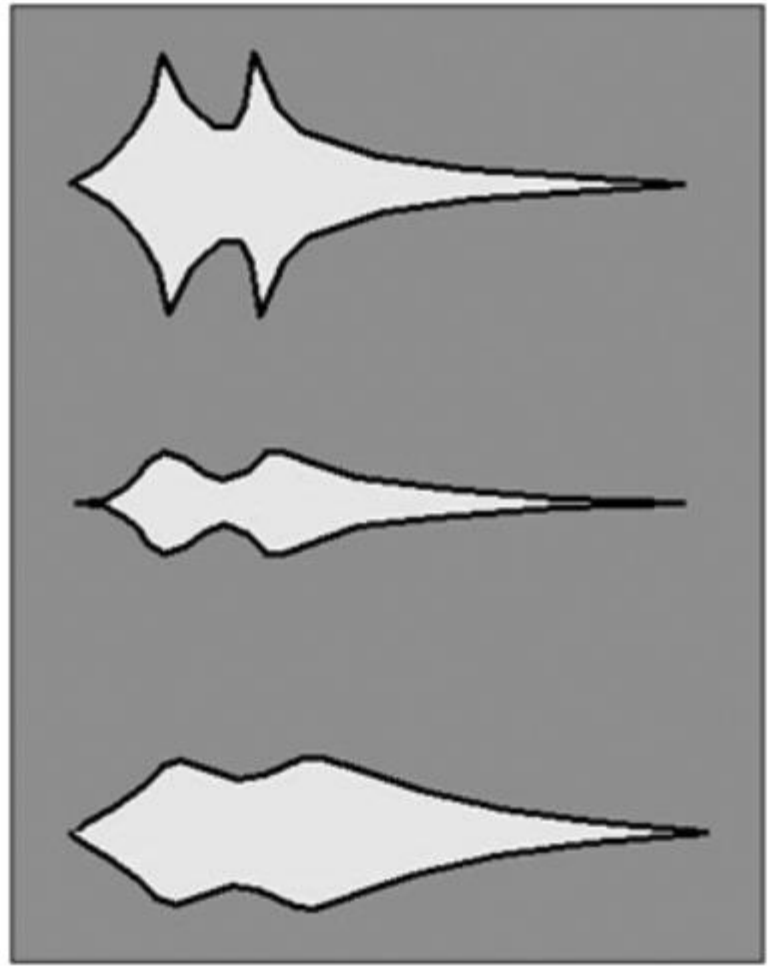


OHC: 1. 將traveling wave放大
2. 將波峰變尖

自然的traveling wave,
兩個頻率相近的音激
起兩個波峰

OHC損壞的感官神經
性聽損，振幅減小，
波峰呈圓形

靠助聽器產生的
traveling wave，振幅
增大，但無法重建波
峰的尖銳



從理論到實務

臨床案例證明

- 最常見耳朵傷害是OHC傷害
- 結果是最常見的中度 感官神經性聽障(SNHL)
- 比一般會話小的音量(50-65 dB HL)聽不到,但…
- 90-100 dB HL聽起來卻和正常聽者一樣大聲

助聽器能替這批人(SNHL)做什麼?

- 對弱小聲, 提供明顯放大, 但…
- 對大的音量, 逐漸減少放大
- 以上兩作法 = Wide Dynamic Range Compression
- WDRC 就是在模仿SNHL患者他們的OHC之前所做的事
- 既然OHC 負責處理的是50-65 dB SPL 以下的聲音, 所以WDRC的knee point 最常是在input到達50 dB處

助聽器<u>不能</u>替這批人(SNHL)做什麼?

- 不能恢復正常的traveling waves
- (一旦失去尖峰, 永遠失去)
- 失去尖峰就失去分開距離相近的波峰, 也就失去分離相近頻率的能力, 包涵分離說話和背景噪音的能力