Chapter 9

The Functions of Sensory Organs

The formation of a sensation :

sense organs 、
neural pathways and
cortical centers

The senses : conscious
unconscious : blood pressure
muscle length
pH, PCO_2 *etc.*

General physiology of

1. General Properties of the sensory receptors

Definitions and *Classifications* :

Sensory receptors,
sense organs

General properties :

adequate stimulus
transduction (sensor, transducer)
encoding
adaptation

1.1 *Definitions* and *Classifications* : Sensory receptors, sense organs

sensory receptors : cutaneous or internal

sense the changes of

external / internal environments

The simplest : free nerve endings : pain

Those with auxiliaries :

spindle, pacinian corpuscle

Special sense organs : structurally and functionally

ultimately differentiated receptor cells

+ auxiliaries

e.g.

the eyes	*: vision*
the ears	*: hearing*
vestibules	*: equilibrium*
olfactory mucous membranes	*: smell*
taste buds	*: taste*

These sensory organs are *special sense organs* ;

all situate on the head, for *evolutional* reasons;

Classifications :

Location :

tele-ceptor : " distance receiver"

intero-ceptor : internal environment

extero-ceptor : external environment near at hand

proprio-ceptor : the position of body in space

Adequate stimulus :

mechanic (stretch) receptors
noci-ceptor,
photo-receptor,
chemo-receptor
temperature receptor,
osmotic receptors *etc.*

1.2 General properties

#1. adequate stimulus

differential sensitivity

electromagnetic wave of λ 370~740 nm is the adequate stimulus of the eyes;

mechanic vibration of 16~20,000 Hz is that of the cochlea

Sensory threshold :

the minimum intensity of *adequate stimulus* used to elicit a response

the necessary intensity (or energy) would be much greater if using in-adequate stimuli to elicit a response ,

e.g. : press an eyeball, a lightness…

Discrimination threshold

#2. Transduction

Sensory receptors functions like transducers or sensors in electronic devices;

Stimuli Energy (various energy forms)

→ Ap in afferent nerves (are converted into electrical signals, *i.e.)*

stimulus →

changes of membrane potential :

if on cell body : receptor potential

if at its endings : generator potential

Mechanisms :

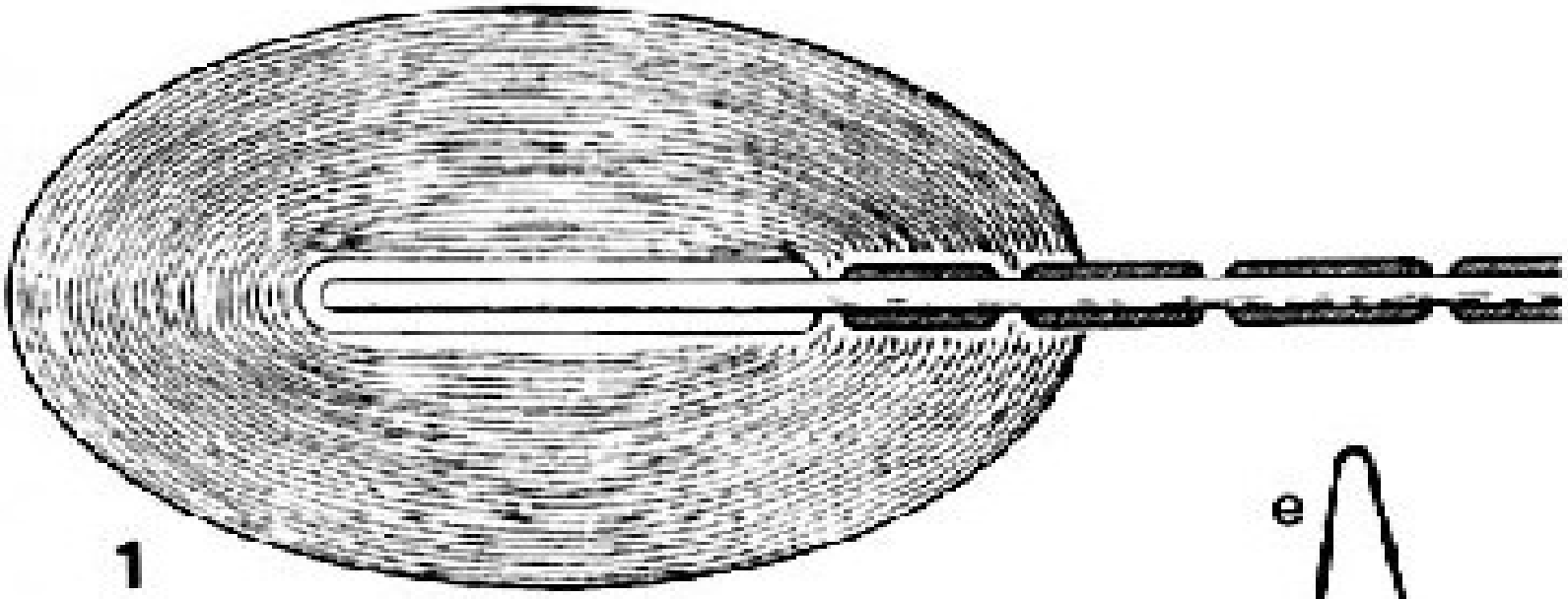
transmembrane signaling →
transmembrane ion movement →
membrane de- / hyper-polarization

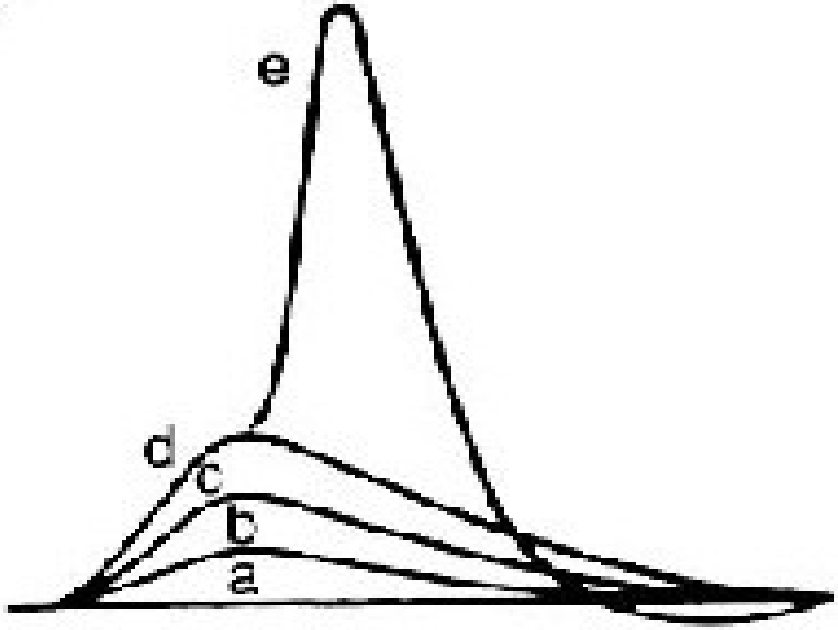
ion channel :

mechanically-gated channel in spindle,
and in cochlea

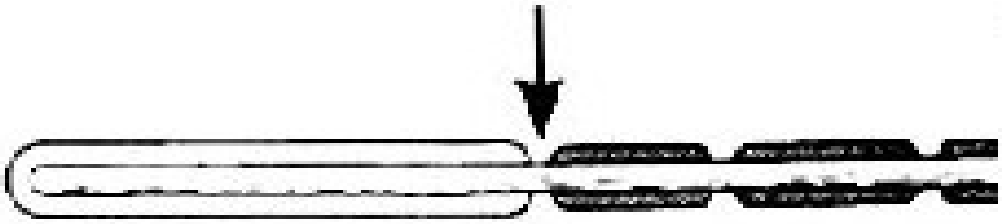
membrane receptor :

GPCR : in rod, Na^+ influx
in olfactory mucous membrane





the first node of Ranvier



Properties *of receptor / generator potentials* :

transitional slow potential, like endplate p. :

* within a range,

amplitude $\propto$ stimulus intensity

* not "All-or-None"
* summation (temporal, spatial)
* electrotonic propagation

p40 fig. 2-16

#3. Encoding

information are encoded in trains of spikes

- encoding , is in *as put in electronic terms,*
  " FM frequency-modulation " , *ie:*

all parameters of a stimulus
are expressed in spike frequency.

a sensation (or perception) :
cortical function, is formed in, and defined by,
the centers that afferent impulses arrived

labeled line

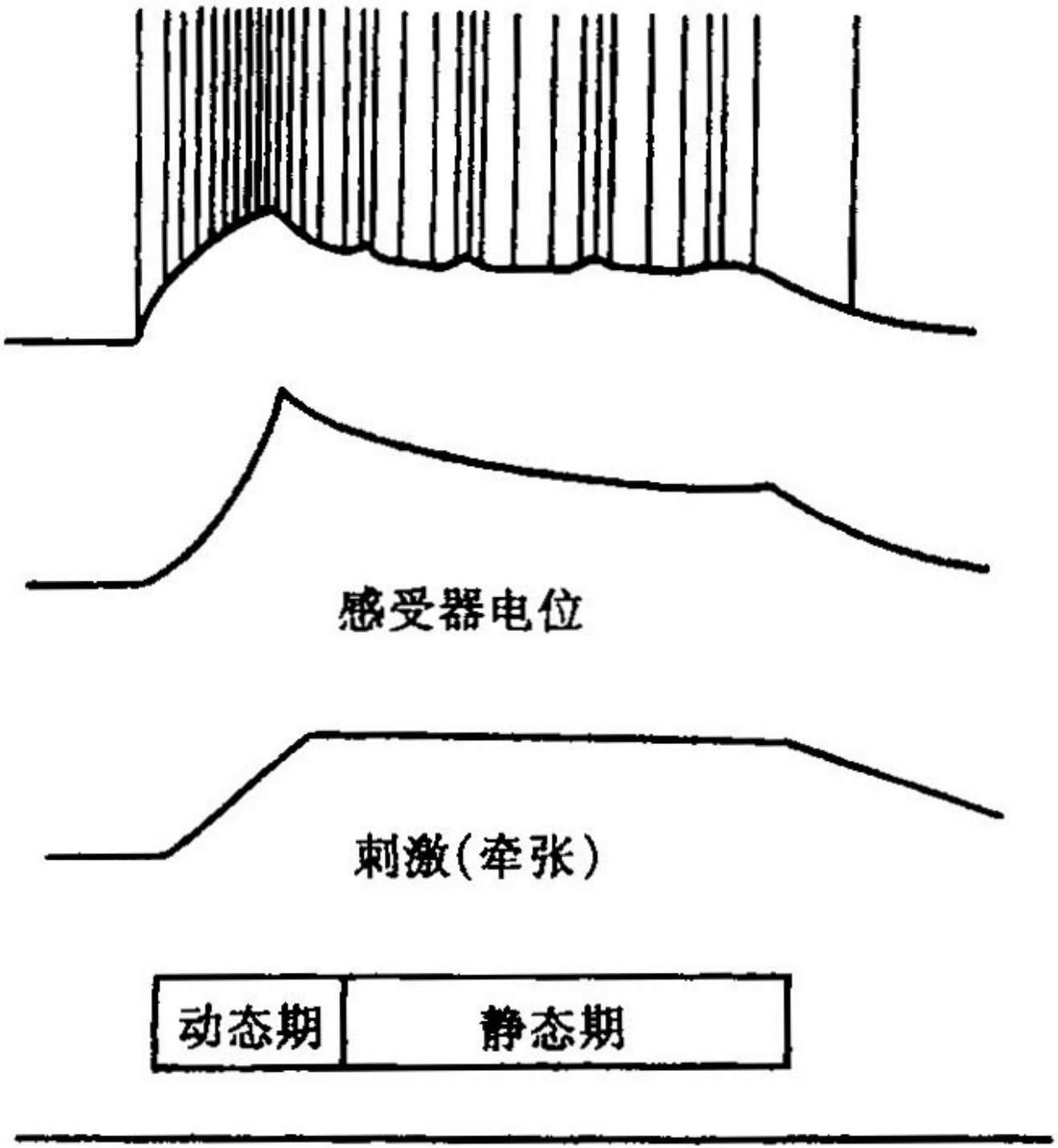


图 9-1 蛙肌梭中刺激强度的编码模式图

B. 河豚毒 tetrodotoxin 阻断Na+通道, 取消动作电位

#3. Encoding

Information are encoded in trains of spikes

- " FM frequency-modulation "

- Numbers of responsive receptors/nerves

  esp. vestibular and cochlear encodings (inner ear)

#4. adaptation

Spike frequency in afferent nerves
gradually decrease (to zero), though
the causative stimuli are still there .

Rapid adaptation :
phasic ~ , rate ~

smell, touch-pressure

#4. adaptation

Slow adaptation :

tonic receptor

spindle
aortic arch / carotid sinus baroreceptor
aortic body / carotid body (to hypoxia)
pulmonary stretch reflex

mechanisms: complicated, different steps

3

Visual function of the eyes

95% (70%) of environmental information

Functional anatomy :

retinal photoreceptive cells

auxiliary light-refracting system

Adequate stimulus : light of λ 370 ~ 740 nm

1. Light-refracting system

1.1 Optical properties of…

composite lens : ……

cornea

principal focus (right on the retina)

in normal,

without Accommodation,

parallel light rays focalize on retina

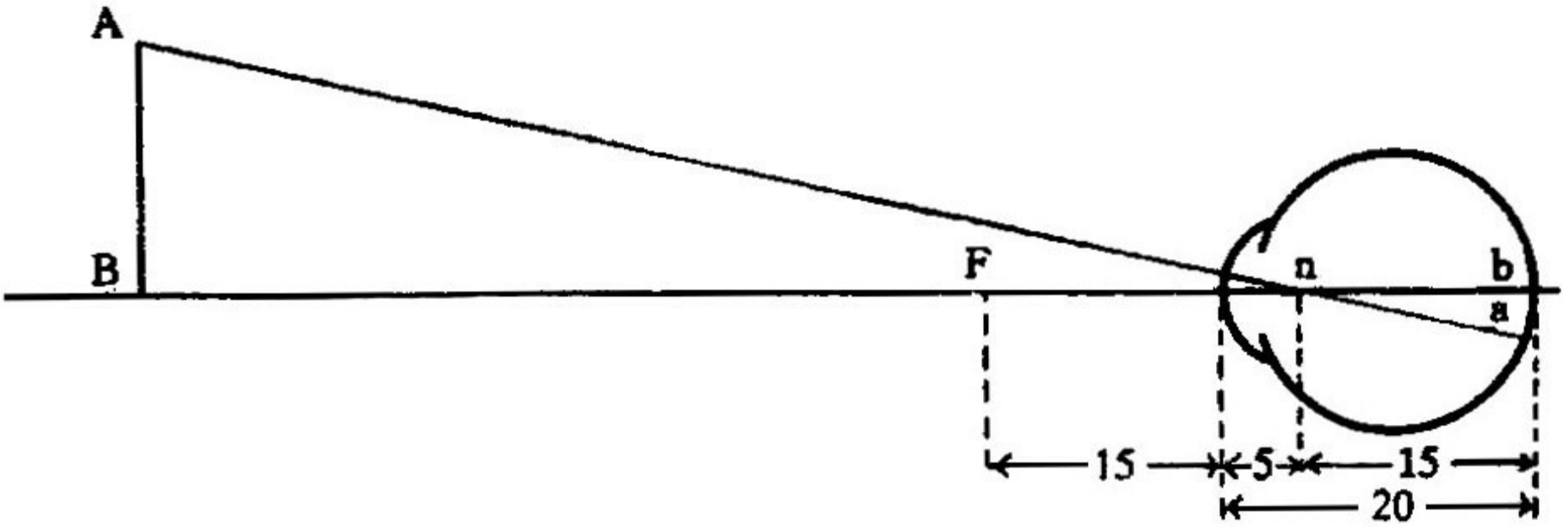
1.2 Reduced schematic eye

Equivalent optical model :

Gullstrand's eye:

* single spherical light-refracting surface ;
* radius of curvature, *i.e.* nodal point: 5 mm
* index of refraction : 1.333
* the distance from posterior principal focus to nodal point : 15 mm

the posterior pole of lighting-refracting body is the retina



单位：mm

图 9-3　简化眼及其成像情况

n 为节点，AnB 和 anb 是两个相似三角形；如果物距为已知，就可由物体大小算出物像大小，也可算出两三角形对顶角（即视角）的大小

other design(s) , but not as popular, *e.g.*:

屈光指数	1.33
角膜弯曲度	5.0 mm
前焦点在角膜前	15.0 mm
后焦点在角膜后	20.0
屈光力	66.67 D
节 点在视网膜前	15.0 mm

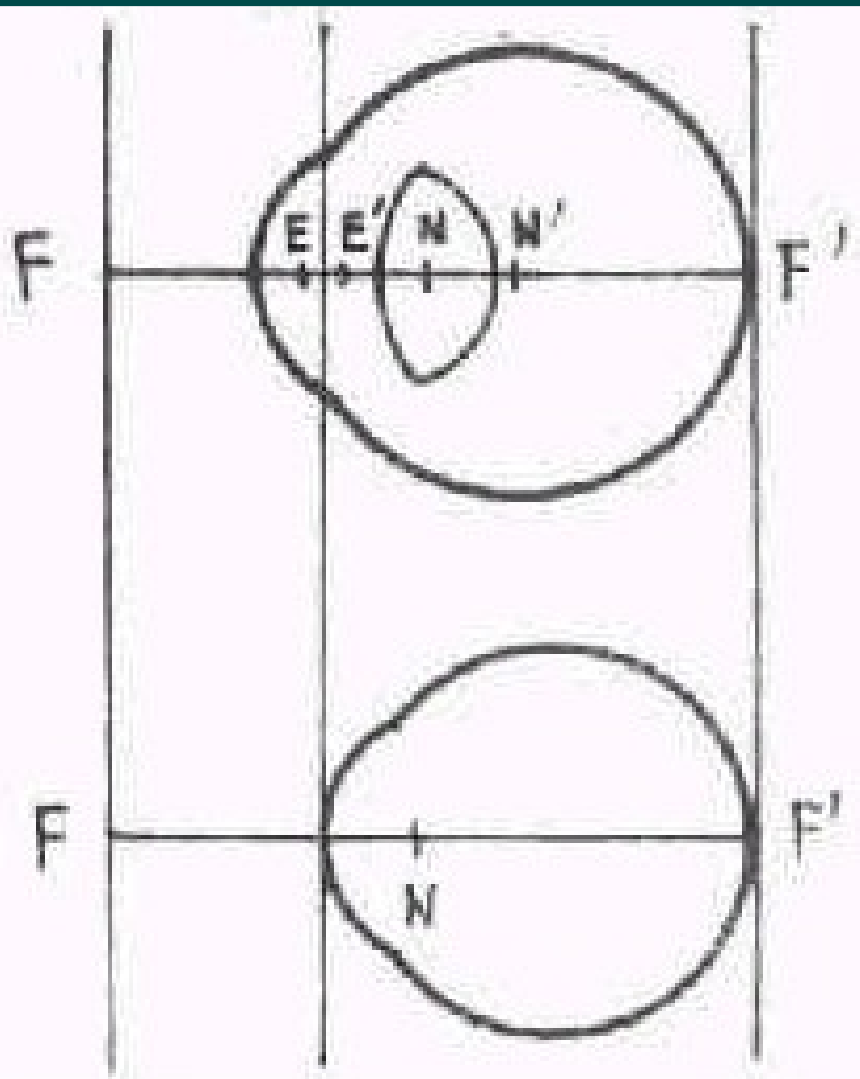


图16-1 简化眼

上：FF′前后主焦点，EE′两主点，
NN′两节点

下：简化眼的基点，包括两个
主焦点FF′，一个节点N及代表EE′的平均数的角膜的屈光面

visual acuity

height of image on the retina ~
diameter of a single cone : 5 μm

visual acuity chart :

1.3 Accommodation

As in classic optics,

light rays from >= 6 m

are regarded as parallel ,

focus on the retina, and

form a clear image without accommodation

light rays from a closer light source (<6 m),

are divergent , and

form a blurred image; in this case :

the lens changes its shape, and

retinal image becomes clear

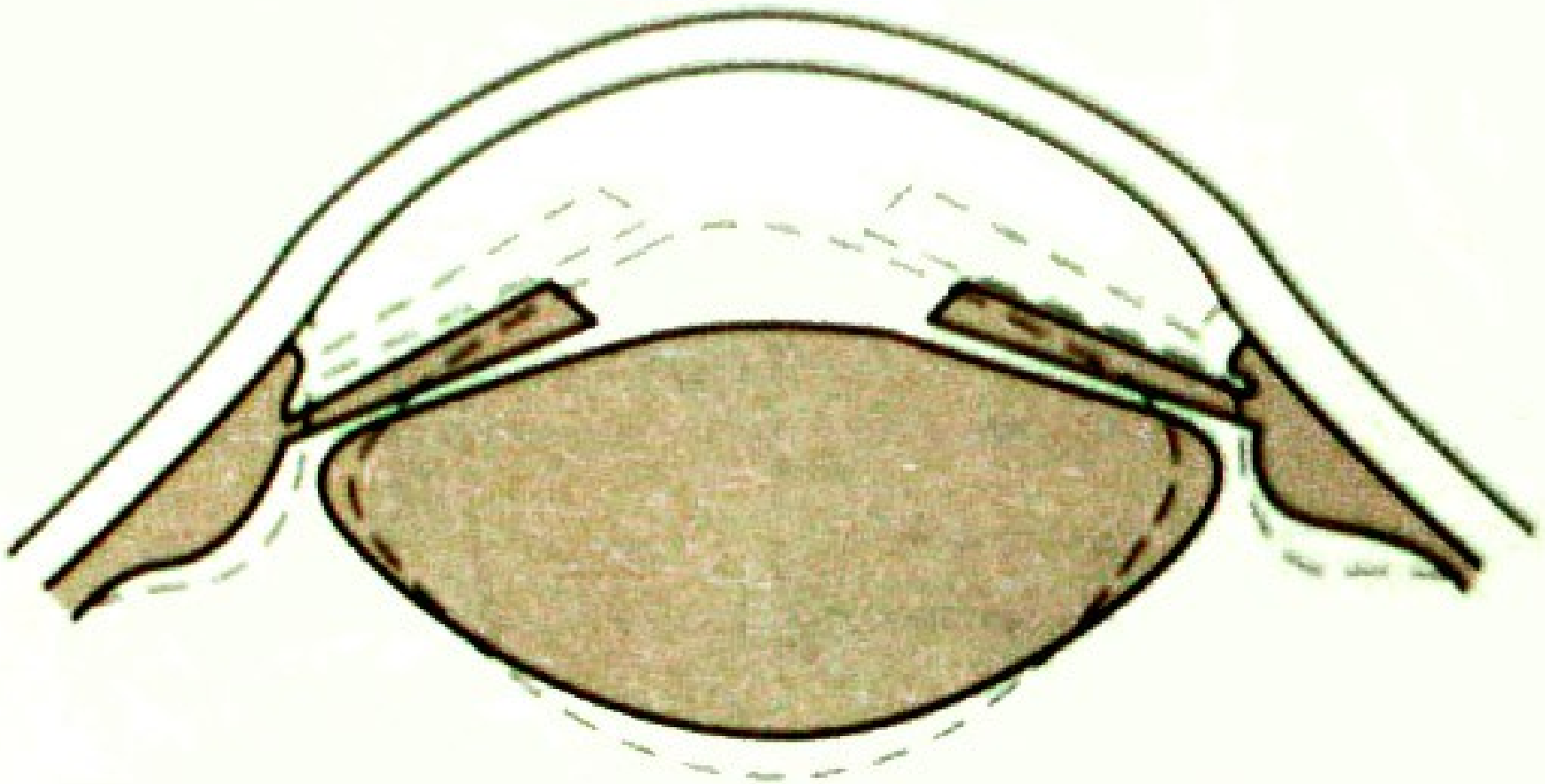


Figure 8-10. Accommodation. The solid lines represent the shape of the lens, iris, and ciliary body at rest, and the dashed lines represent the shape during accommodation.

=1 Accommodation of the lens

information of a retinal blurred image arrives in visual cortex *(Brodmann 17,18,19)*

↓ *occipitotectic tract*

pretectal nuclei → *bilateral* Edinger-Westpal n.

↓ *III*

ciliary ganglion (*parasympathetic*)

↓ *ciliary nerves*

ciliary muscles (circular :

when contract, the lens

Near Point of vision

reflects accommodation power, *i.e.*
the elasticity of the lens ,

age: childhood : 8.6 cm
20yr : 10.4 cm
60yr : 83.3 cm

nearsightness / myopia : < emmetropia
farsightness / hyperopia : >

=2 accommodation of the pupils

pupillary aperture: pupillary diameter:1.5~8.0 mm

pupillary near reflex : pupils constrict

classic optics : near-axis light rays imaging :
chromatic / spherical aberration

pupillary light reflex :

strong light: II impulses → midbrain pretectal n. →
bilateral E-W n.→ ciliary ganglions →
pupillary sphincter → constriction

consensual light reflex

the superior center of pupillary light reflex are in midbrain :
localization of central lesions

=3 Convergence of visual axes

occurs,
when an individual looks at a near object
-------- convergence reflex

----------> *in Summary :*

When one looks at a near object,
accommodation
pupillary near reflex
convergence of visual axes :::

The Near Response

1.4 Refraction & errors of refraction

emmetropia (optically normal eye)
ametropia (optically defected eye)

myopia / nearsightness

hyperopia / farsightnes
presbyopia

astigmatism

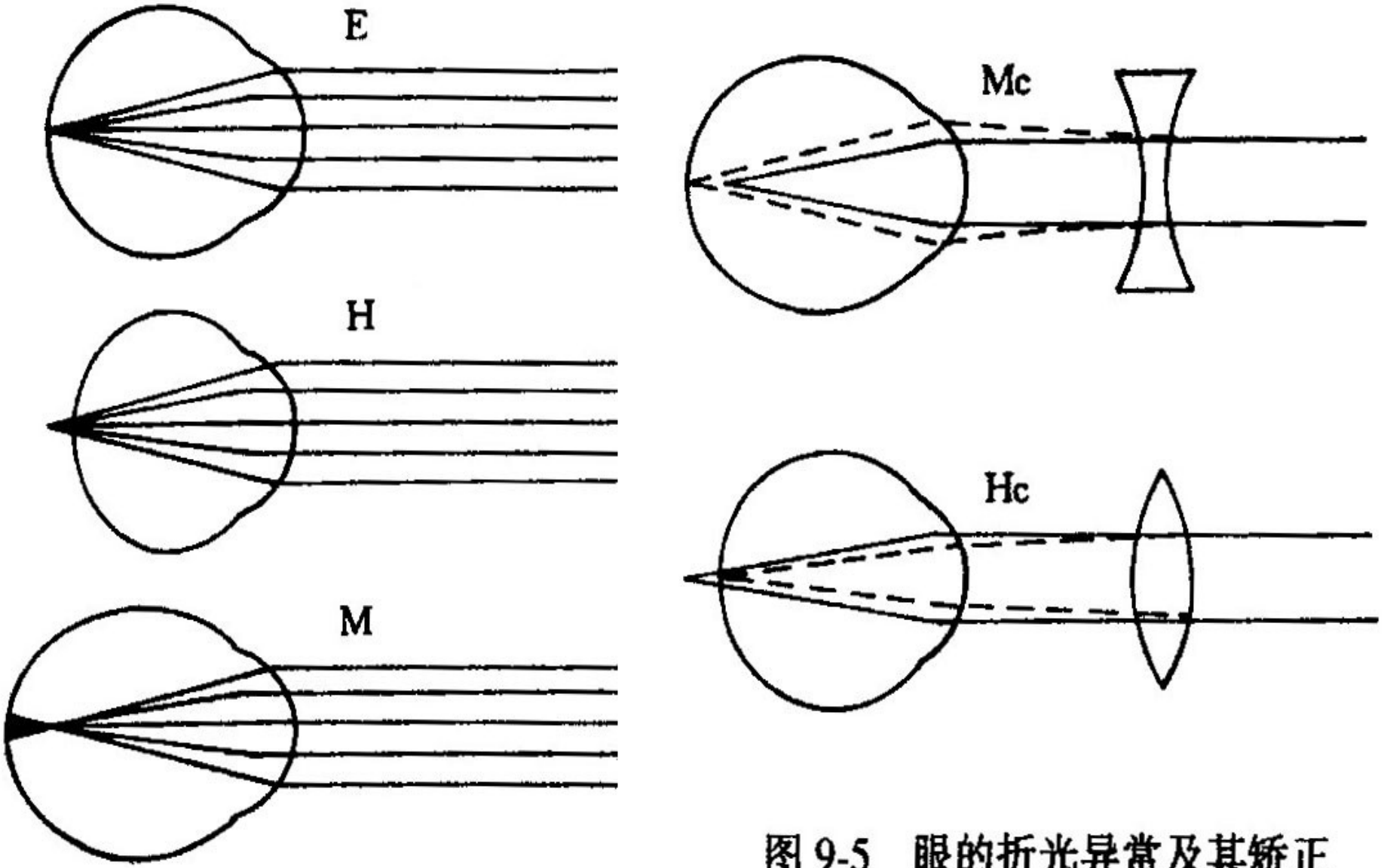


图 9-5　眼的折光异常及其矫正

E：正视眼　H：远视眼　M：近视眼　Mc：近视眼的矫正　Hc：远视眼的矫正

2. The Retina histology & 2 photoreceptive systems

physical image *vs* sensation

2.1 *Histology*

a transparent of neural tissue membrane of

0.1~ 0.5 mm thick;

histology. 10 , functionally 4 layers :

Pigment cell layer : pigment epithelial cells

non-neural tissue, makes up a "dark room"

function: Relaying nutrients to …

Phagocytosis of discs & metabolites

Dopamine-mediated light-protection

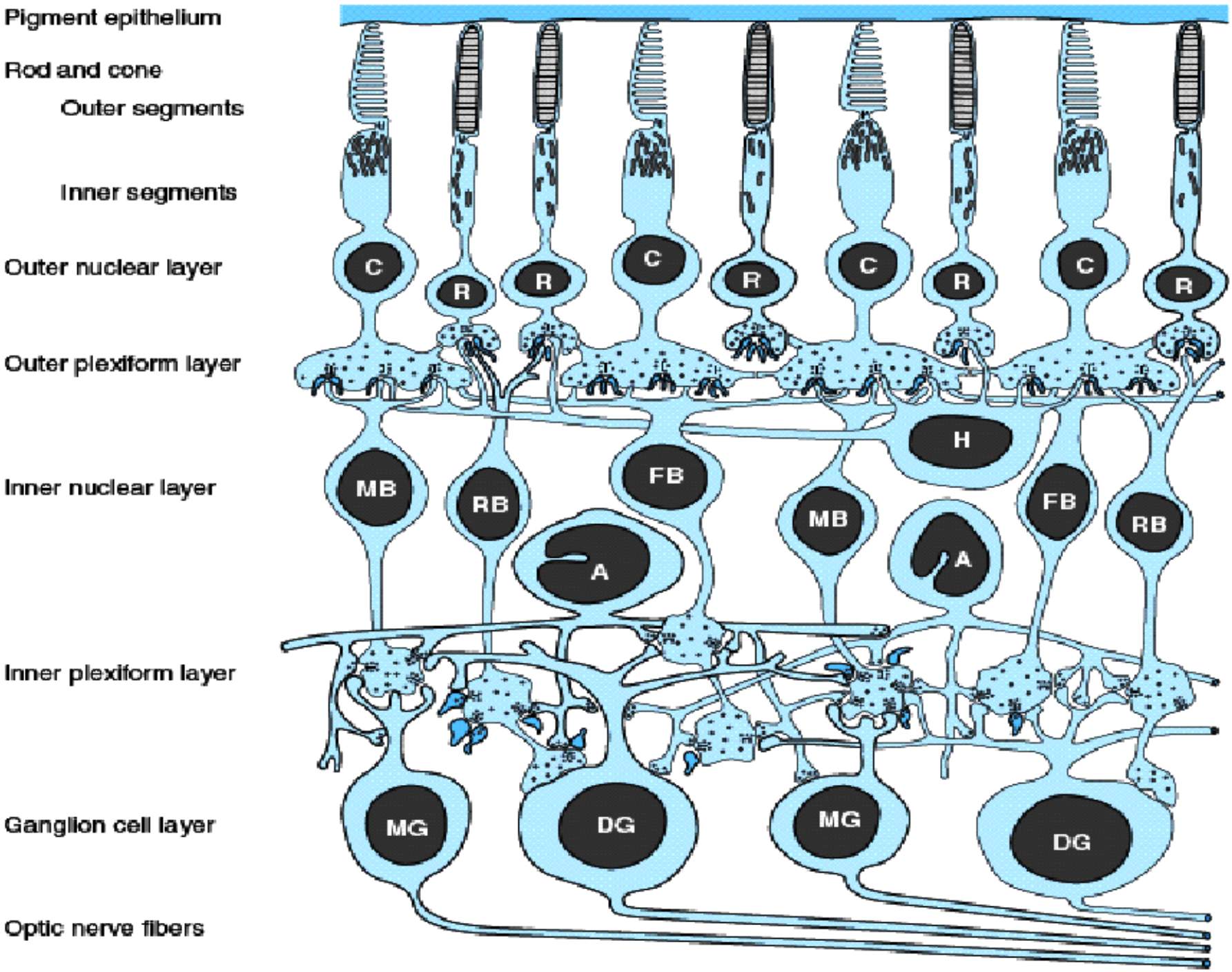
Photoreceptive cell layer : rod, cone

outer segment : membranous discs , opsins

inner segment (neuclus, mitochondria)

synaptic terminal

in between : horizontal cells


Pigment epithelium
Rod and cone
Outer segments
Inner segments
Outer nuclear layer
Outer plexiform layer
Inner nuclear layer
Inner plexiform layer
Ganglion cell layer
Optic nerve fibers
C
R
H
MB
RB
FB
A
MG
DG

Bipolar cell layer

in between : amacrine cells

Ganglion cell layer : generates A.p.

Other: neuroglial cells (*e.g.* Müller's ~)
interplexiform cells (bipolar layer)

Signal Xmission: chemical & electrical synapses

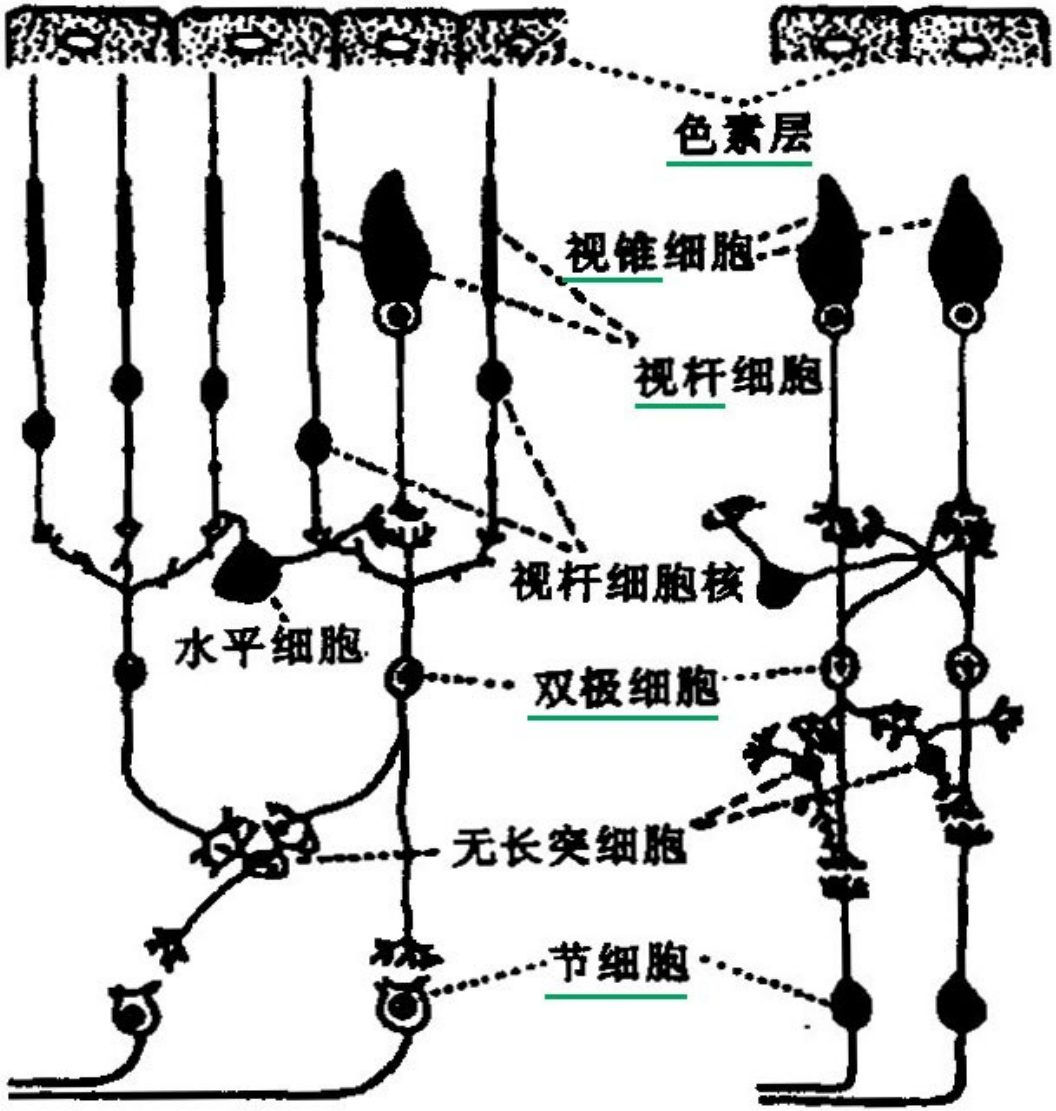


图 9-6　视网膜的主要细胞层次及其联系模式图

（左半部示周围区域，右半部示中央凹）

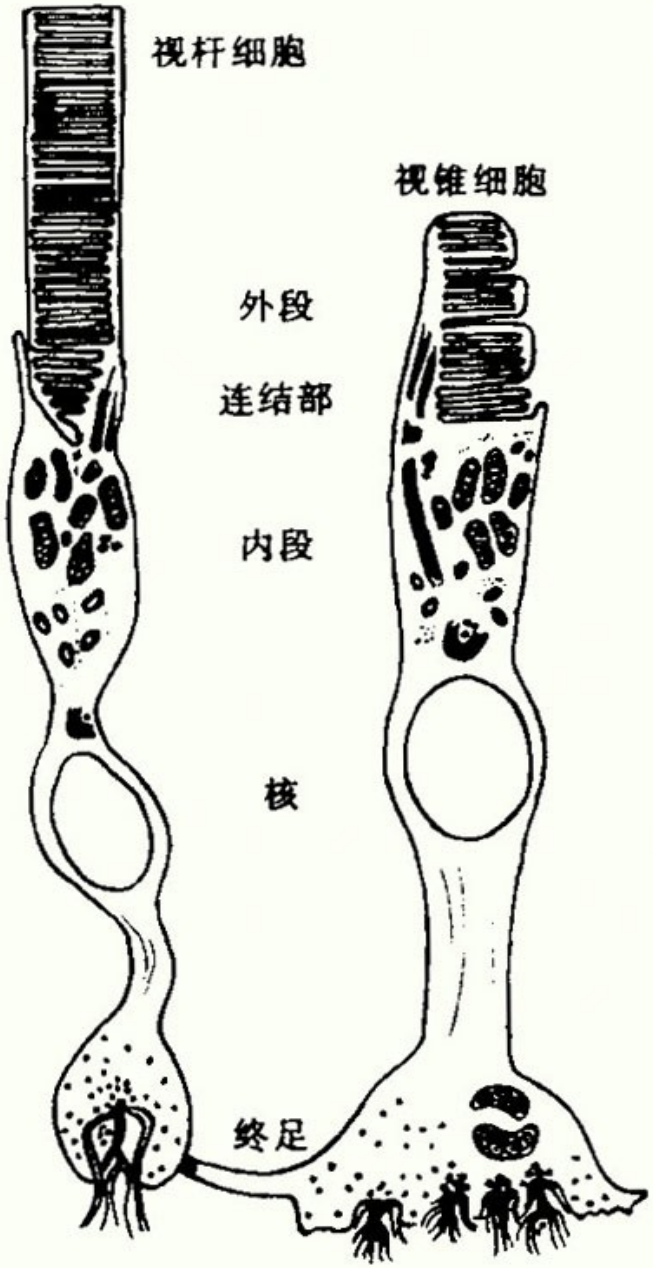


图 9-7　哺乳动物光感受器细胞模式图

2.2 Two photoreceptor systems

The rod system (night vision , scotopic vision) :

bright/dark,
low resolution,
high sensitive

The cone system (color vision, photopic vision):

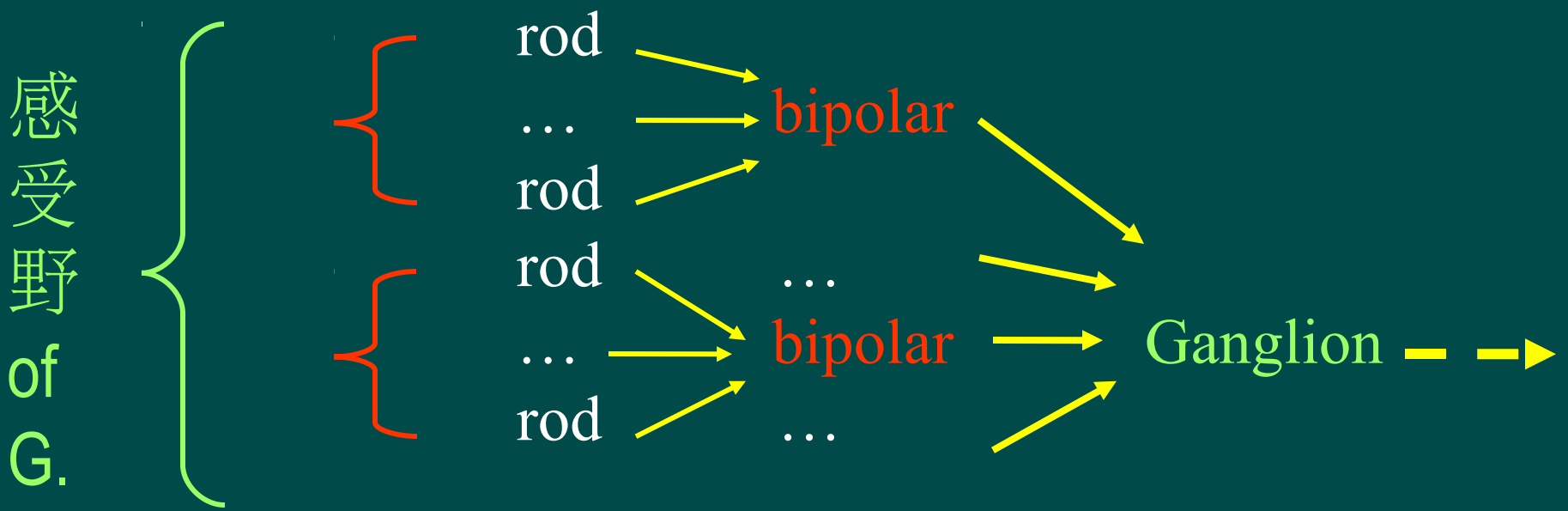
color and details,
high resolution,
low sensitive

They are independent; *the evidences*:

^1 spatial distribution

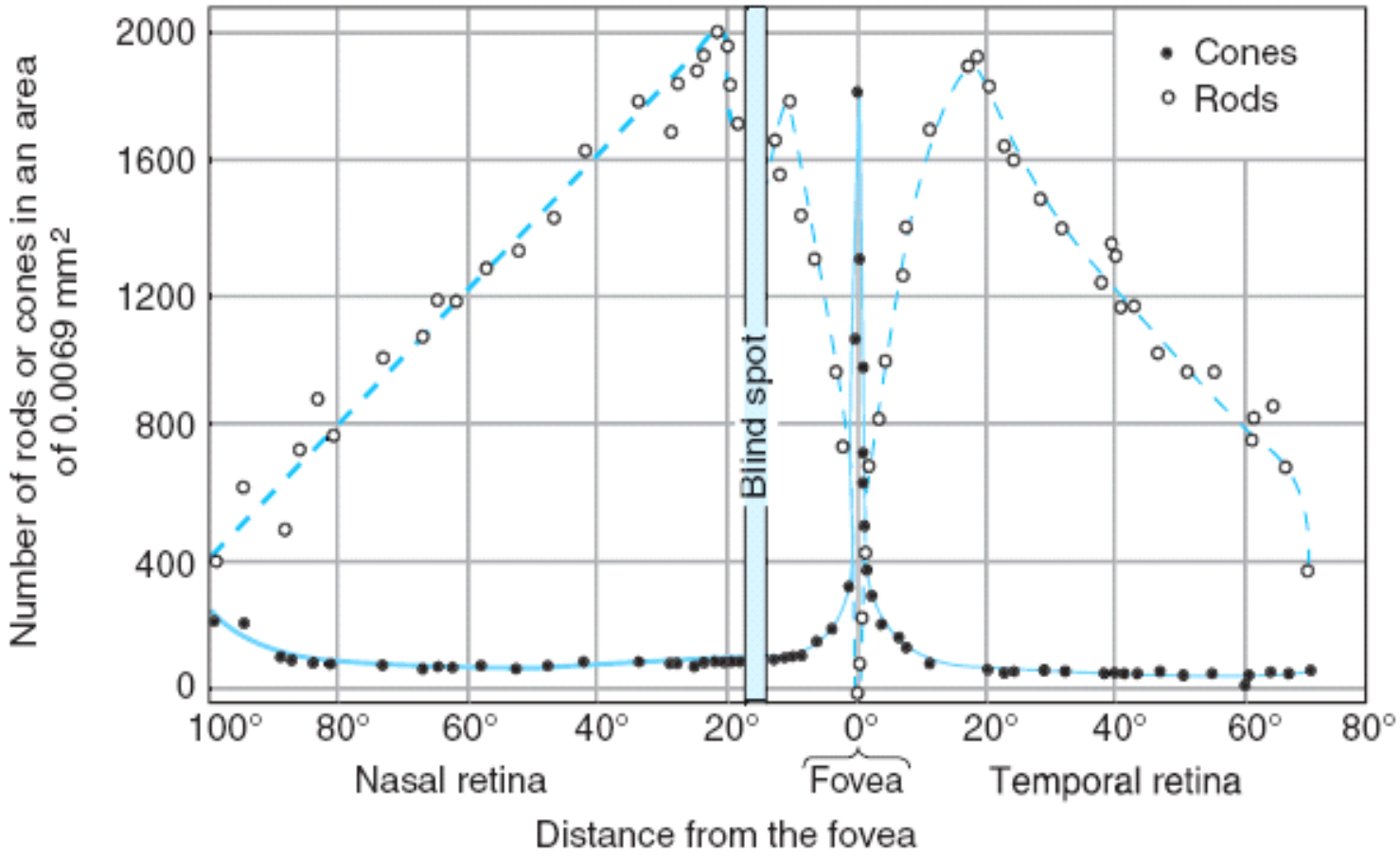
^2 photoreceptor-bipolar-ganglion links :

converge:



single line: cone - bipolar - ganglion

cone*sss* - bipolar*s* - ganglion



Rod and cone density along the horizontal meridian through the human retina. A plot of the relative acuity of vision in the various parts of the light-adapted eye would parallel the cone density curve; a similar plot of relative acuity of the dark-adapted eye would parallel the rod density curve.

They are independent; *the evidences*:

^3 specices : reptiles, chicks : cone system only

owl : rod system only

^4 photosensitive compounds :

rod system : only rhodopsin only

cone system : 3 different opsins

absorption peak in spectrum

3. *the* Rod : Mechanism of Photoreception

=1 Rhodopsin : Property

rhodopsin: sensitive to B-G light,
single absorption peak at 500 nm,
but eliciting a sense of "brightness"

opsin: GPCR, highly homologous to β_2-R

retinene / retinal, 11-*cis*-retinene *covalently !*

Vit. A -derived chromophore

all-*trans* : straight

11-*cis* : bent

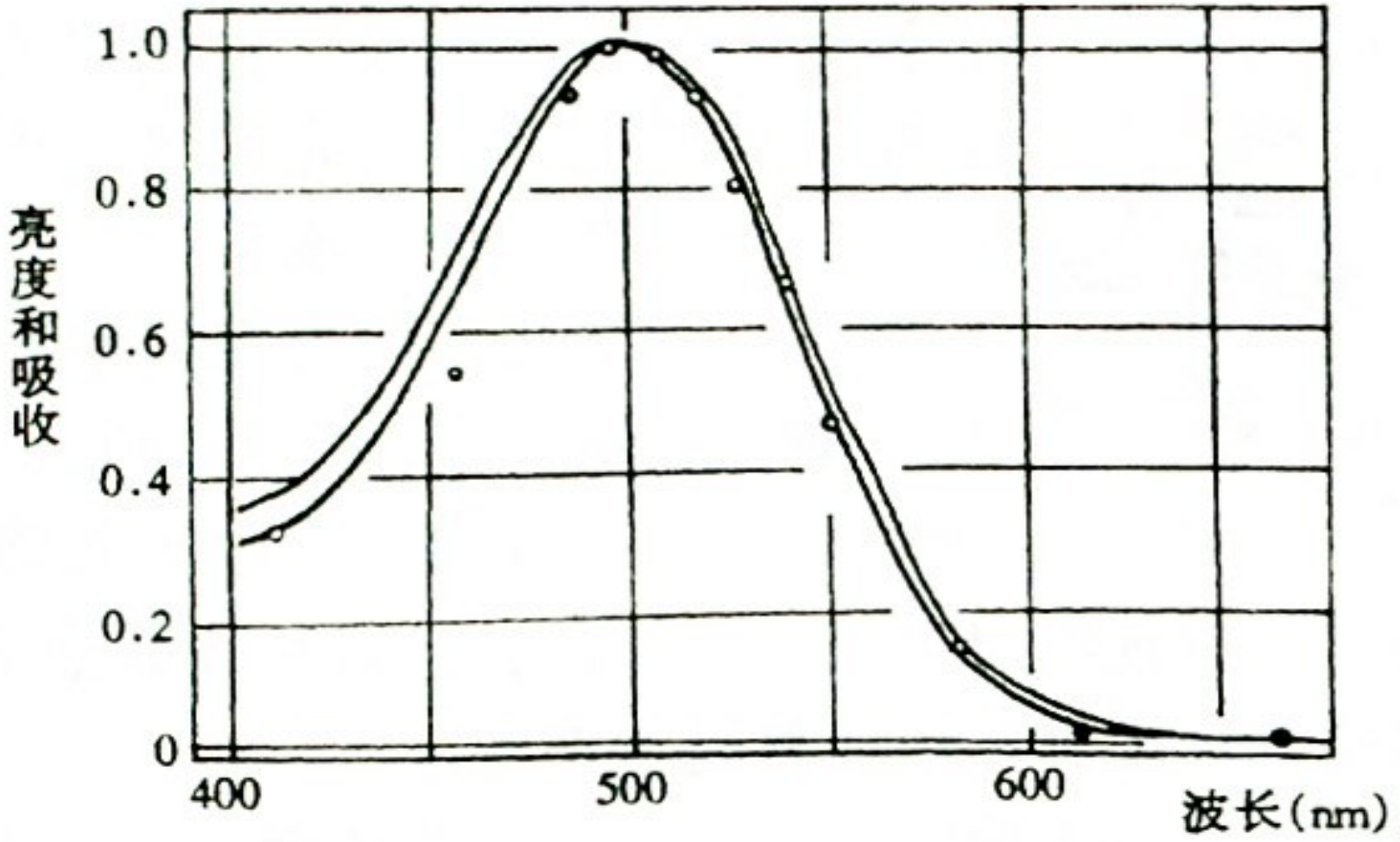


图 9-8　弱光条件下人眼所感到的光谱亮度曲线和实验条件下视紫红质对光谱不同部分的吸收曲线

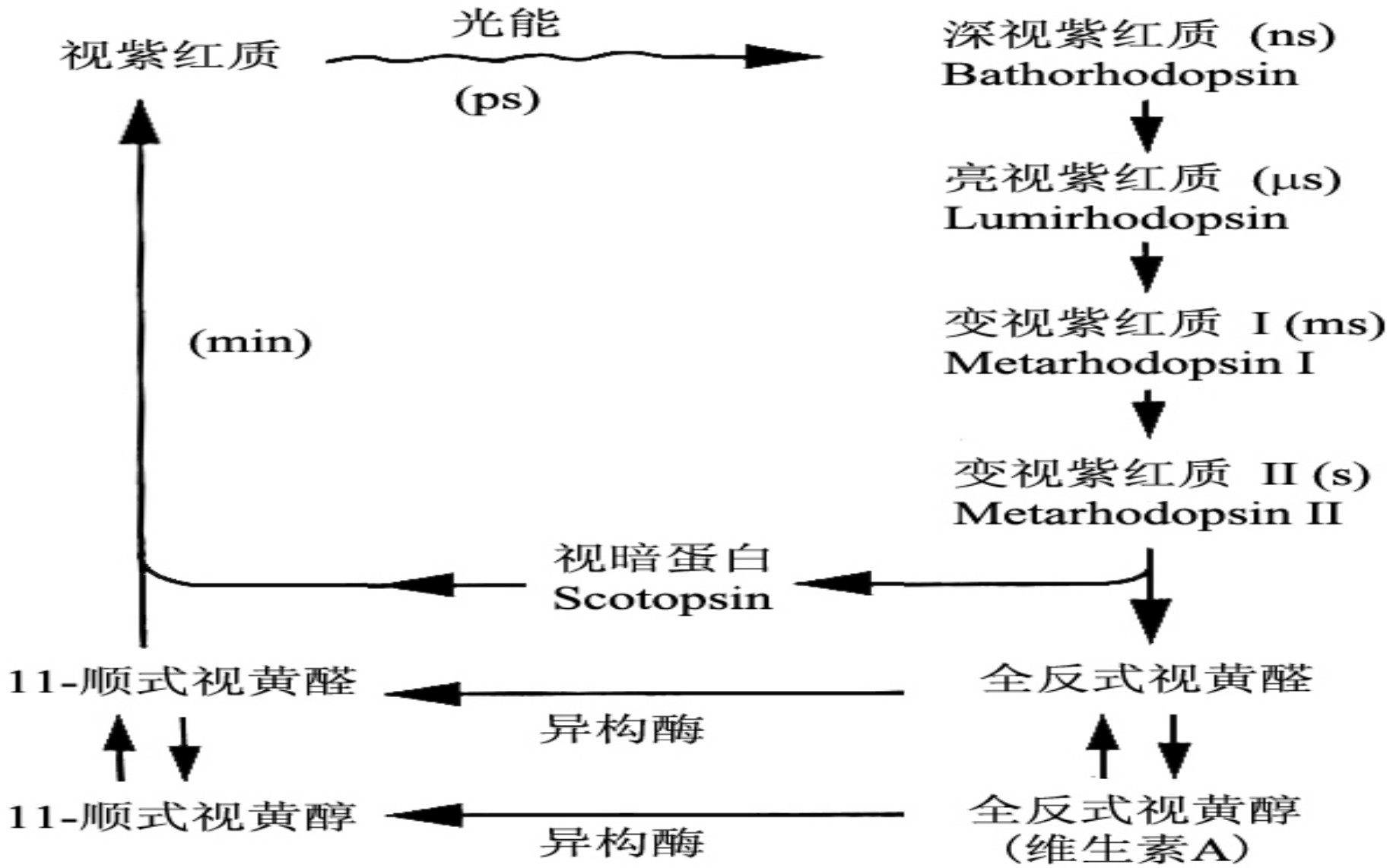
视觉中最明亮的区域和视紫红质吸收能力最强的部分都在 500nm 的波长附近

=2 Rhodopsin : Photochemical reaction

rhodopsin (11-*cis*) → opsin+all-*trans*

(in membranous disc, receptor p. occurs)

fine analysis : *bleached* rhodopsin :



9-10. 视杆细胞中视紫红质的光分解反应及视黄醛的再利用循环

括号内为各过程或中间产物的持续时间的数量级

=3 Rhodopsin: Metabolism

* Decomposition of *bleached* rhodopsin :

  opsin-kinase : add –P to opsin

  visual arrestin : bind to rhodopsin-P

  retinal dehydrogenase

  protein phosphatase 2A

* Recycling of retinene :

all-*trans* retinenes → *ECF*

pigment cell :

uptake all-*trans*- ;

all-*trans* →11-*cis* (retin*al iso*merase)

feedback ;

rod :

opsin+ 11-*cis* → rhodopsin

covalently !

* Vitamine A : all-*trans* retinol

presents both in plasma and

in retina (pigment cells & rods)

retinal isomerase :

all-*trans* retinol → 11-*cis* retinol

11-*cis* retinol ← → 11-*cis* retinal

Compensates the loss of 11-*cis* in recycling

Nyctalopia / night blindness

* Balance of Synthesis / Decomposition

light intensity : *roughly linear*

strong light : syn. << dec. :

lose sensitivity (cones…)

dim light : syn. = dec. :

maintain sensitivity

in dark : syn. >> dec. :

more sensitive

=4 Capture of photons

photo-electricity transduction happens at outer segment – membranous disc

efficient in capturing $h\nu$:

- tall outer segment
- lots of discs
- ~ 10^6 rhodopsin mol./disc

∴ a single $h\nu$ is enough to elicit a sensation of lightness

3.2 Generation of Receptor potential

Electrophysiology : *intra*-cellular recording

in dark:

Resting p. : -30 ~ -40 mV, much smaller

shone:

transient slow hyperpolarization : receptor p.

Resting potential :

* K^+ equilibrium potential, but with a ,
* Na^+ leak / dark current :

diskal Na^+ channels open, Na^+ influx *constantly*

inner seg., Na^+ pumps *constantly* extrude Na^+ ,
maintain a low intracellular [Na^+]

Receptor potential:

dark current stops : *hyper*-polarization

Molecular mechanism

rhodopsin + $h\nu$

↓

11-*cis* retinal conformational change

↓

meta-rhodopsin II

↓

G_{t1} (transducin) → ***p***hospho-***d***i-***e***sterase (+)

↓

cGMP → 5'-GMP →

intracellular cGMP ↓ →

Na^+ channel shut → Na^+ influx ↓ :

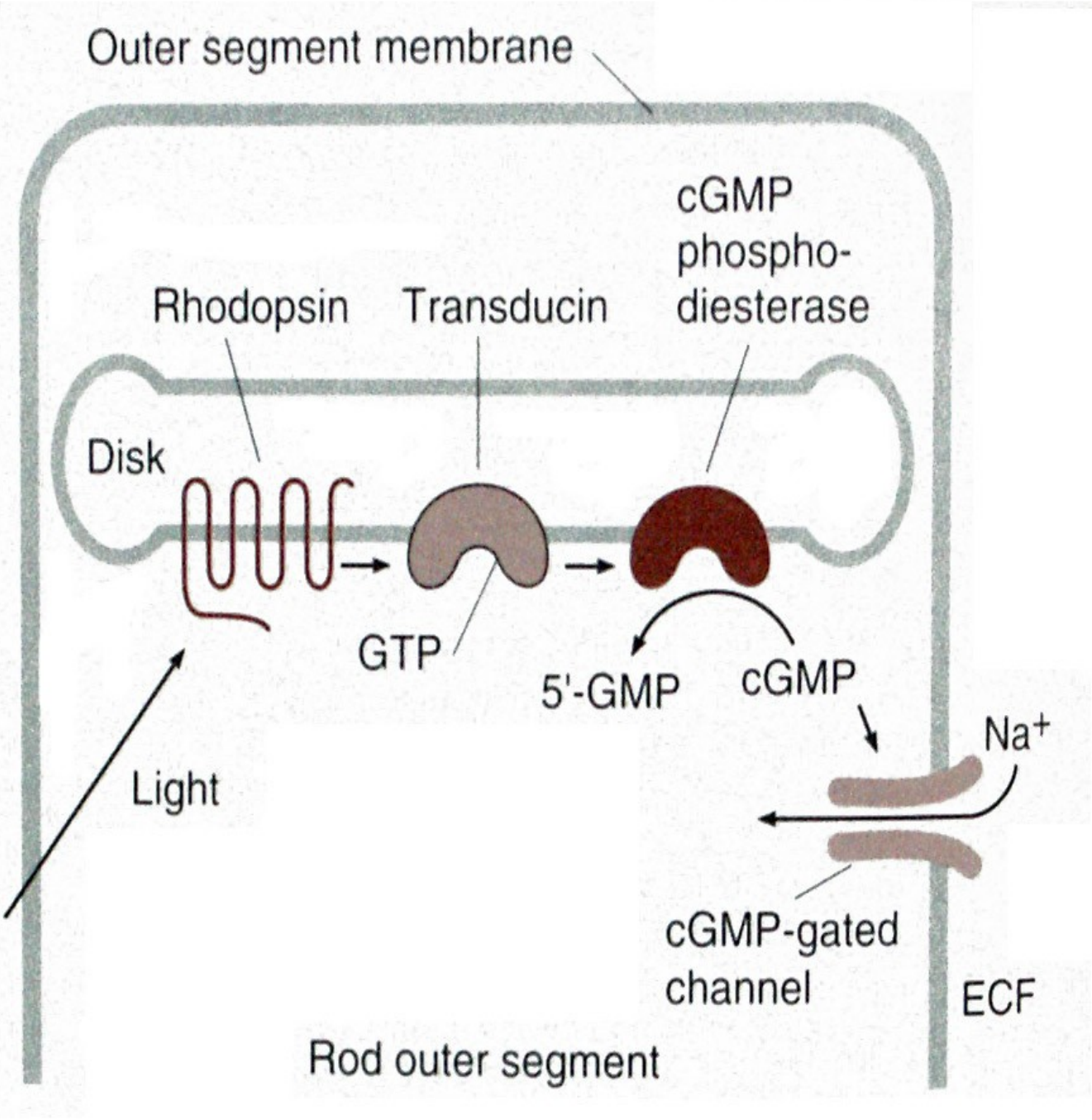
(single channel lasts for 200 ms)

disc membrane *hyper*polarizes (receptor p.)

Figure 8-18.

Initial steps in photo-transduction in rods.

Light activates rhod-opsin, which activates transduction to bind GTP. This activates photophodiesterase, which catalyzes the conversion of cGMP to 5'-GMP. The resulting decrease in the cytoplasmic cGMP concentration causes cGMP-gated ion channels to close.



Amplification: metarhodopsin II → 500 G_{t1}

PDE : 4, 000 cGMP /s

Na^+ channel :

intracellularly-chemically-gated

Ca^{2+} influx : depolarizes , and

inhibits *guanylyl cyclase* :

cGMP → Na^+ 、 Ca^{2+} influx

Negative feedback : in dim twilight,

maintain stable cGMP level 、 Rp

The rods do not generate action potential ;

(NOT excitable cells)

receptor potentials

propagate electrotonically to

the synaptic terminal, and

trigger transmitters release there

4. The Cones & Color vision

3 different cone pigments :

11-*cis* retinal

3 different opsins : minute but critical (G_{t2})

Color vision & the cones :

Color vision is a complicated physio-psychological phenomenon

human eye : 150+ colors (λ : 400~750 nm)

i.e. photons of 3~5 nm wavelength apart can be distinguished as different colors

Tri-chromatic theory : (Young & Holmholtz)

* 3 types of Cones ;
* 3 types of opsins ;

sensitive *max. resp.* to 3 primary colors :

R 560 **G** 530 **B** 430 nm

* a type of opsin / cone, but response to most λ
* a given λ, excites all 3 type of cones, but spike frequency (ganglion) …

(retina, film)

complimentary colors (printer , paint)

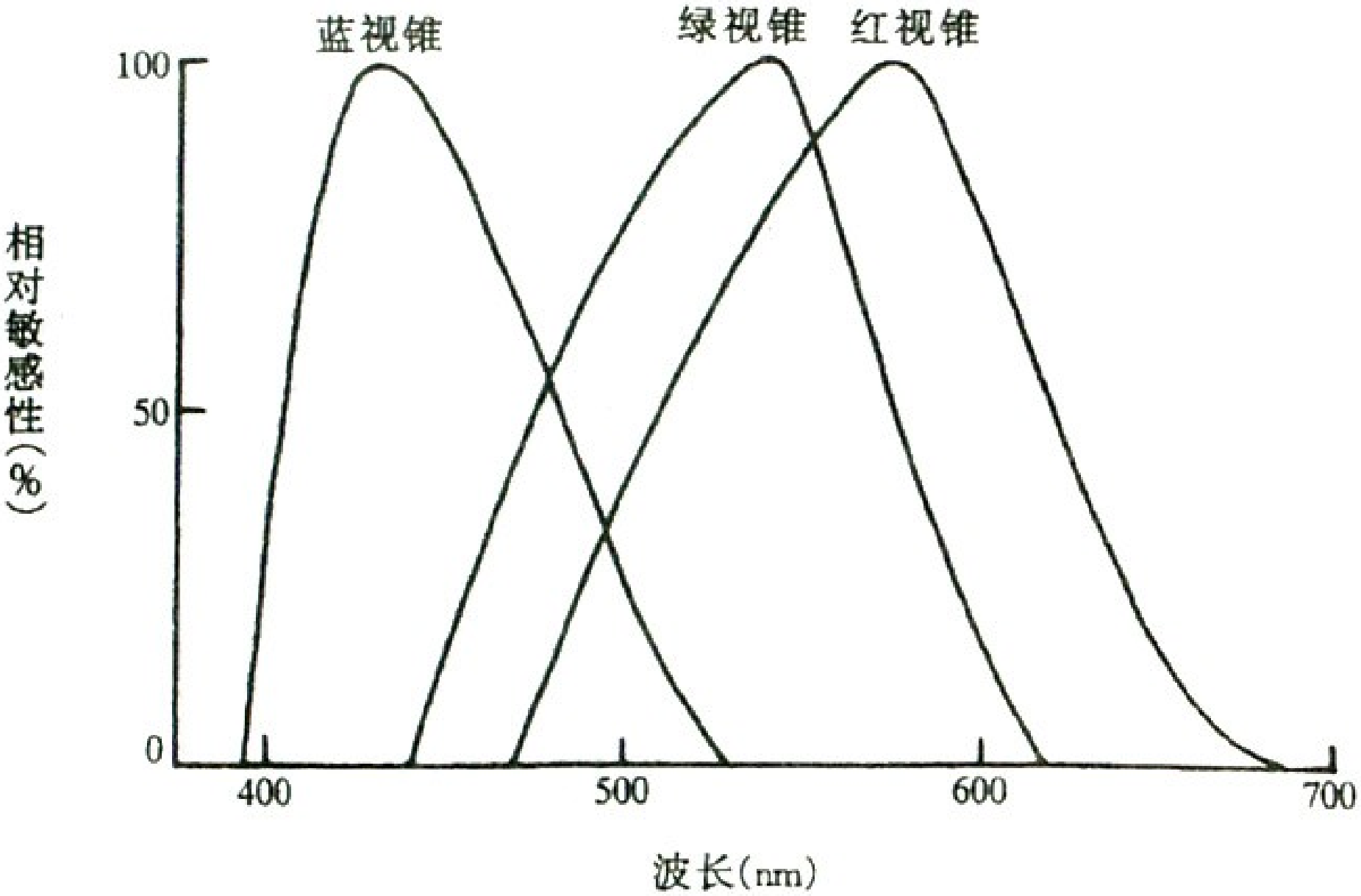


图 9-10　人视网膜中三种不同视锥细胞的光谱相对敏感性

Defected color vision :

Color blindness (*suffix* -anopia)

*prot*anopia : **R**

*deuter*anopia : **R** + **G**

*tri*anopia : **R** + **G** + **B**

Color weakness (*suffix* -anomaly)

*prot*anomaly : **R**

*deuter*anomaly : **R** + **G**

*tri*anomaly : **R** + **G** + **B**

Color blindness is most frequently inherited.

Sildenafil (Viagra) inhibits retinal form of PDE and transiently

5. Information Process in the Retina

the rods and cones are the first neurons of visual pathway ; the neural circuits of retina are : extremely complicated as well as organized , with complicated interneuronal communication and numerous transmitters.

Conclusive results :

^1 only ganglion cells and a few amacrine cells are excitable (generate spikes).

signal transmission before ganglion cells are mainly in the form of electrotonic propagation :

analogue, computation

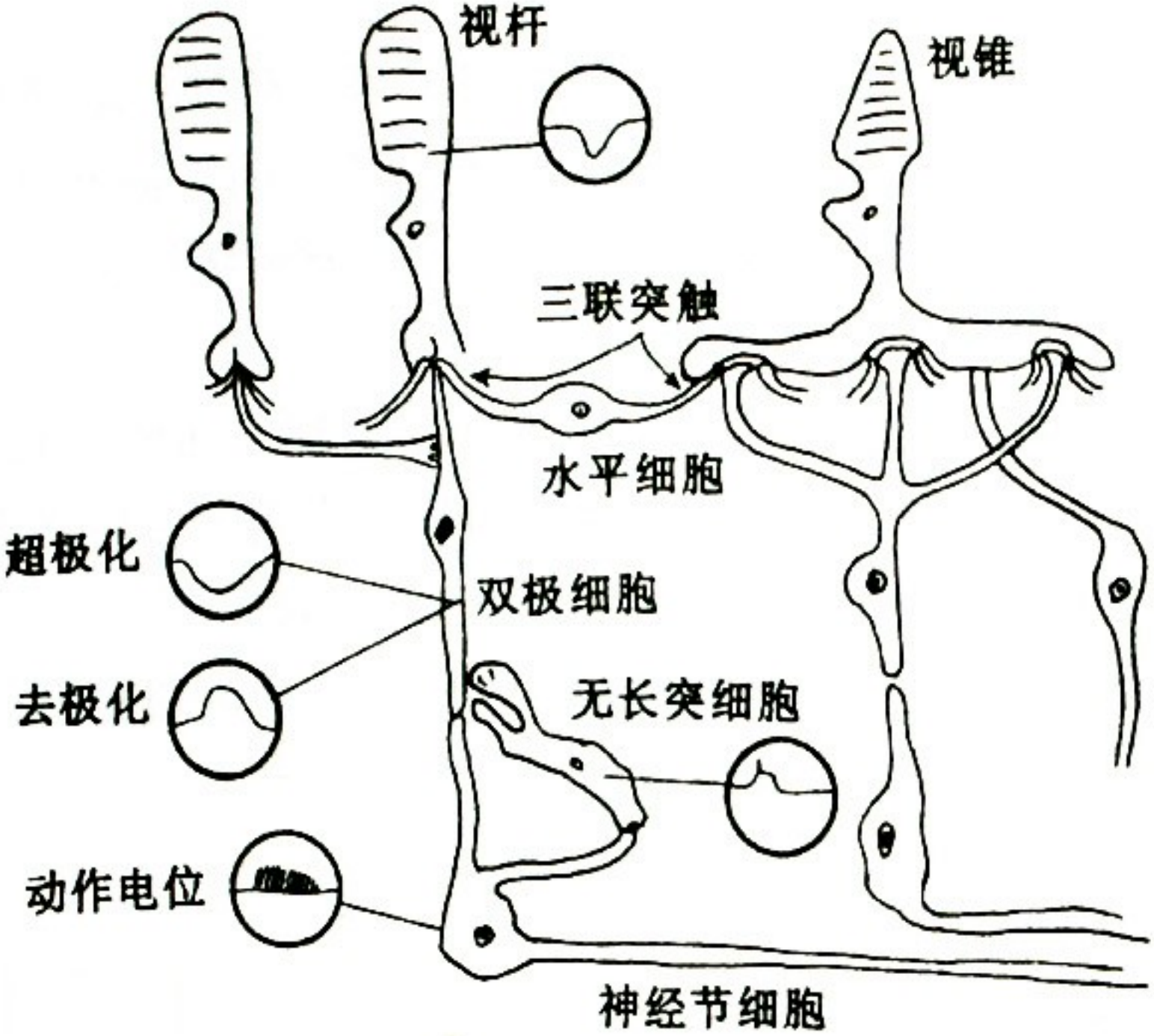


图 9-11 视网膜中各类细胞排列及其产生的电反应的类型示意图只有神经节细胞能产生动作电位

^4 On / Off centers : ganglion cells

on-center field
off-center field

X tonic response
Y phasic
W amacrine → ganglion

edge detection / motion detection (image analysis)

lateral inhibition

（三）视觉信息的中枢分析

1. 视觉传入通路的特点（见下页图）

鼻侧视网膜传入纤维交叉，颞侧传入纤维不交叉

一侧外膝体接受双眼传入纤维，但投向同侧皮层

∴ 来自一侧眼的视觉信号可传至双侧视皮层

2. 初级视皮层 (primary visual cortex)

位于枕叶皮层内侧面距状沟上下缘（ 17 区）

视觉纤维投射规律（如下表）

来自视网膜的纤维	皮层投射部位	来自视网膜的纤维	皮层投射部位
鼻　　侧	交叉（对侧）	颞　　侧	不交叉（同侧）
上半部	距状沟上缘	下半部	距状沟下缘
黄斑区	距状沟后部	周边区	距状沟前部

- 功能柱
  - * 方位柱 (orientation column)
  - * 眼的优势柱 (见下页图) (ocular dominance column)
  - * 颜色柱 (color column)

5. 与视觉有关的其他皮层

- 17 区以外的视觉相关皮层

  次级 (18 区) 和高级 (19 区) 视皮层

  顶叶、颞叶、额叶皮层联络区 (association area)

- 与这些皮层有联系的脑结构有

  脑干控制眼球运动 (eye ball movement) 的区域

  语言中枢 (language center) 与语言功能相联系

  通过胼胝体 (callosum) 联系另一侧脑

6. other aspects of visual function

=0 visual acuity and useful charts

=1 dark / light adaptation

description. Duration

=2 visual field definition

measurement : angle

color : white > yellow-blue > red > green

other : facial structures

6. other aspects of visual function

=3 binocular vision

compensation of blind points; 3-D sensation

=4 after image and fusion

(rod 200 ms
(cone 50 ms
(critical fusion frequency

3 Hearing Function of the Ears

hearing threshold and audiogram
outer and middle ears
internal ear : the cochlea
auditory nerve impulses

1. Hearing threshold & *auditory area*

adequate stimulus (of the cochlea) : sound wave

frequency range 16 ~ 20,000 Hz (*infra-* & *ultra*sound)

intensity range 0.0002 ~ 1000 dyn/cm^2 (loudness)

Hearing (auditory) threshold

Maximum audible threshold

auditory field (听域) on audiogram

1000 ~ 3000 Hz

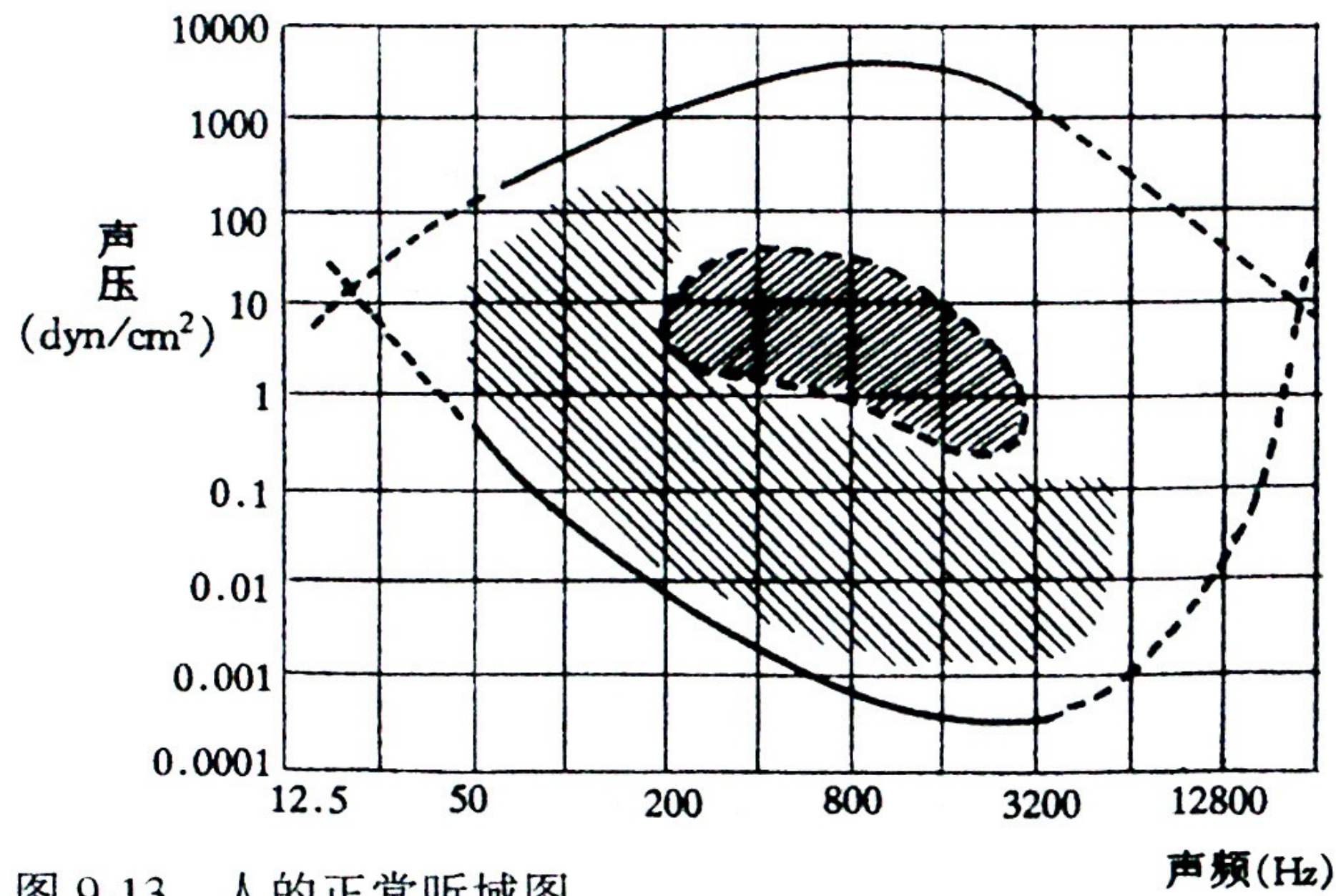


图 9-13　人的正常听域图

中心斜线区：通常的语言区，下方斜线区：次要的语言区 $1dyn = 10^{-5}N$

2. external and middle ear

2.1 The External Ear

pinna collects sound waves

auditory canal resonates :

resonance cavity effect : 3500 Hz

intensity x10

2.2 The Middle Ear

// Acoustics : dense *vs* thin
// density and incident energy
// air → bone , endolymph

tympanic membrane (eardrum) :

its mechanical property:

excellent response & little distortion

ossicles :

lever effect : 1.3 :1

'nail effect' : eardrum ----- oval window:

~ 55 mm^2 *vs* ~ 3.2 mm^2

Totally, amplitude *de*creases,
pressure *in*creases by 22.4 times

Protection mechanisms :

tensor tampani, *stapedius*: elevate resistance

auditory tube (pharyngotympanic tube) :
balances the pressures across the eardrum

2.3 Conduction of Sound from the Tympanic membrane to the cochlea

=1 air conduction

outer auditory canal

→ tympanic m. vibration →
auditory ossicles → oval window →
cochlear endolymph

→ airs in tympanic cavity →
round window → endolymph

=2 bone conduction

sound vibrates the skull, and endolymph :
efficiency is extremely low

nerve deafness : impaired cochlea &/or
auditory tract &/or
cortex, *etc.*

(usually *bi*-lateral)

conduction deafness : impaired ….
examples…..

(usually *uni*-lateral)

3. Properties of inner ear *Hair Cells*

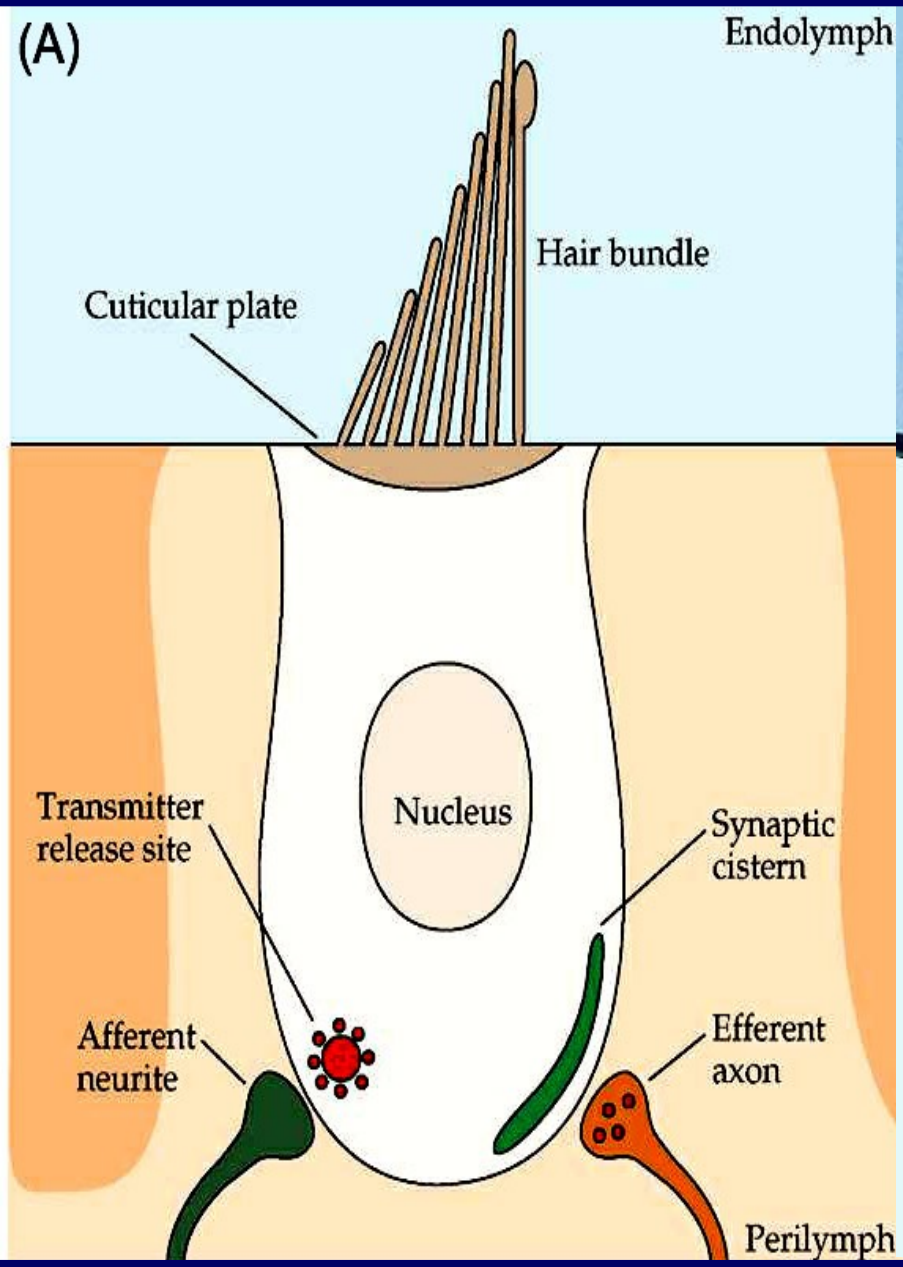
* 3 types of sensory cells (localizaions)

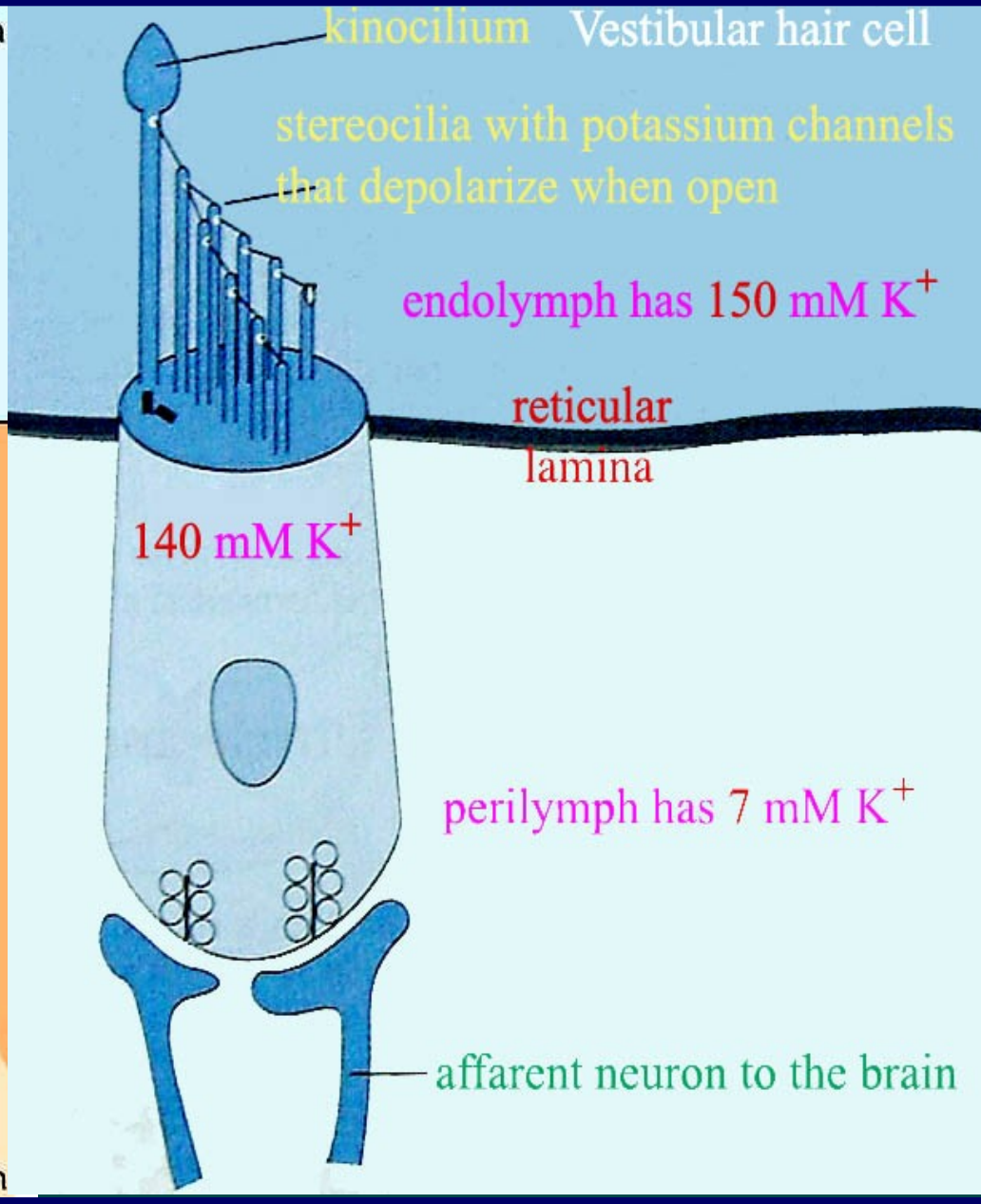
  * different, but basically similar

* their hairs are *embedded* in different membranous structures

3. inner ear *Hair Cells*

* unique micro-environment


(A)
Endolymph
Hair bundle
Cuticular plate
Transmitter release site
Nucleus
Synaptic cistern
Afferent neurite
Efferent axon
Perilymph


kinocilium
Vestibular hair cell
stereocilia with potassium channels that depolarize when open
endolymph has 150 mM K+
reticular lamina
140 mM K+
perilymph has 7 mM K+
affarent neuron to the brain

at rest, ~10% channels open : steady K^+ influx

Receptor potentials :

*de*polarizational : *stereo*cilia toward *kino*cilium

more channels open,
K^+ influx increases

hyper- : *stereo*- away from *kino*-

less channels open,
K^+ influx decreases

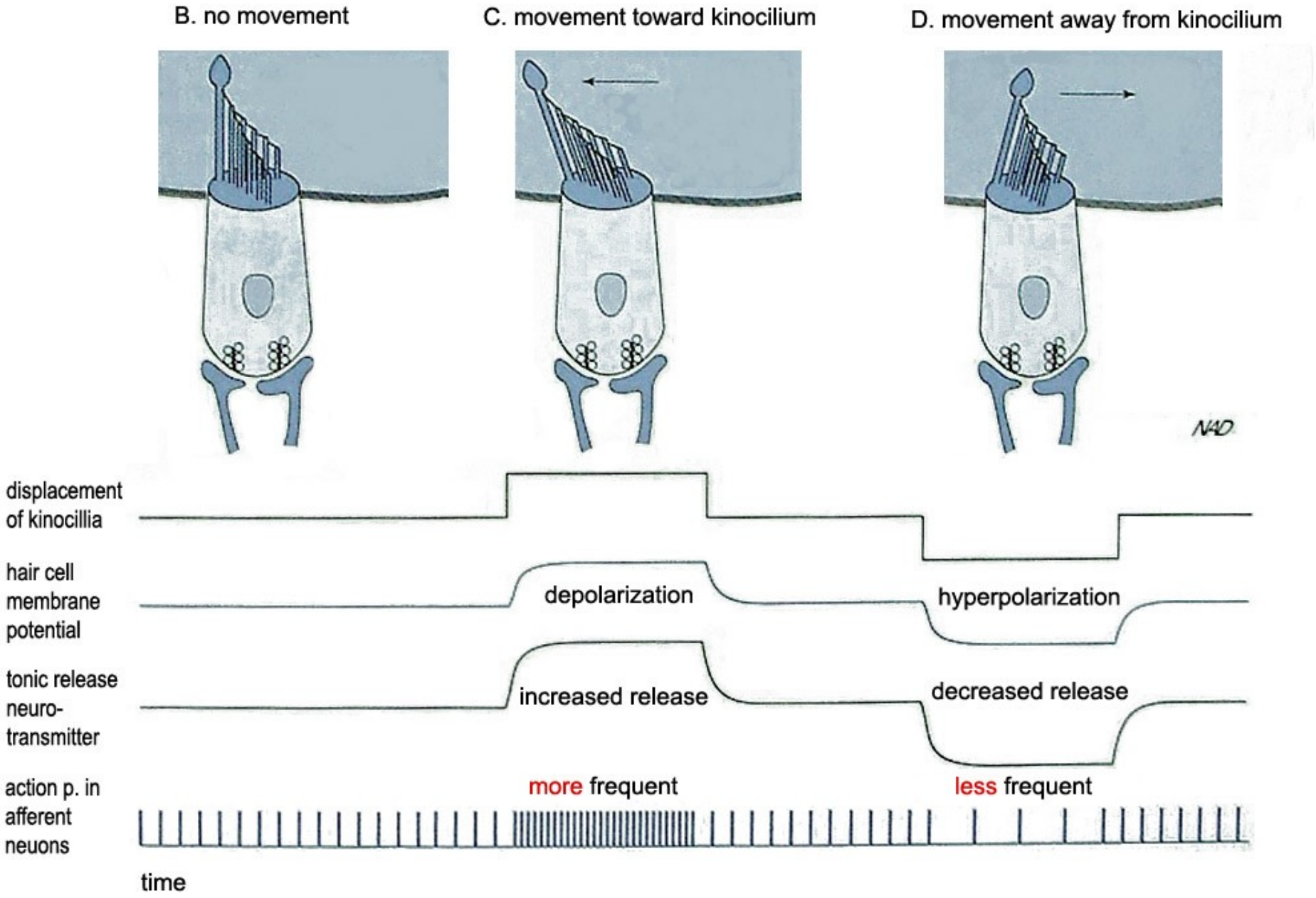


Figure 2. (B-D) Movement changes the membrane potential, regulates the release of neuro-transmitter (glutamate), and changes the frequency of action potentials in the afferent neurons.

4. Inner ear : the function of cochlea

4.1 Structure of the Cochlea

=1 2.5 ~ 2.75 cycles

))))))oval window --- scala vestibuli: perilymph

scala media : endolymph

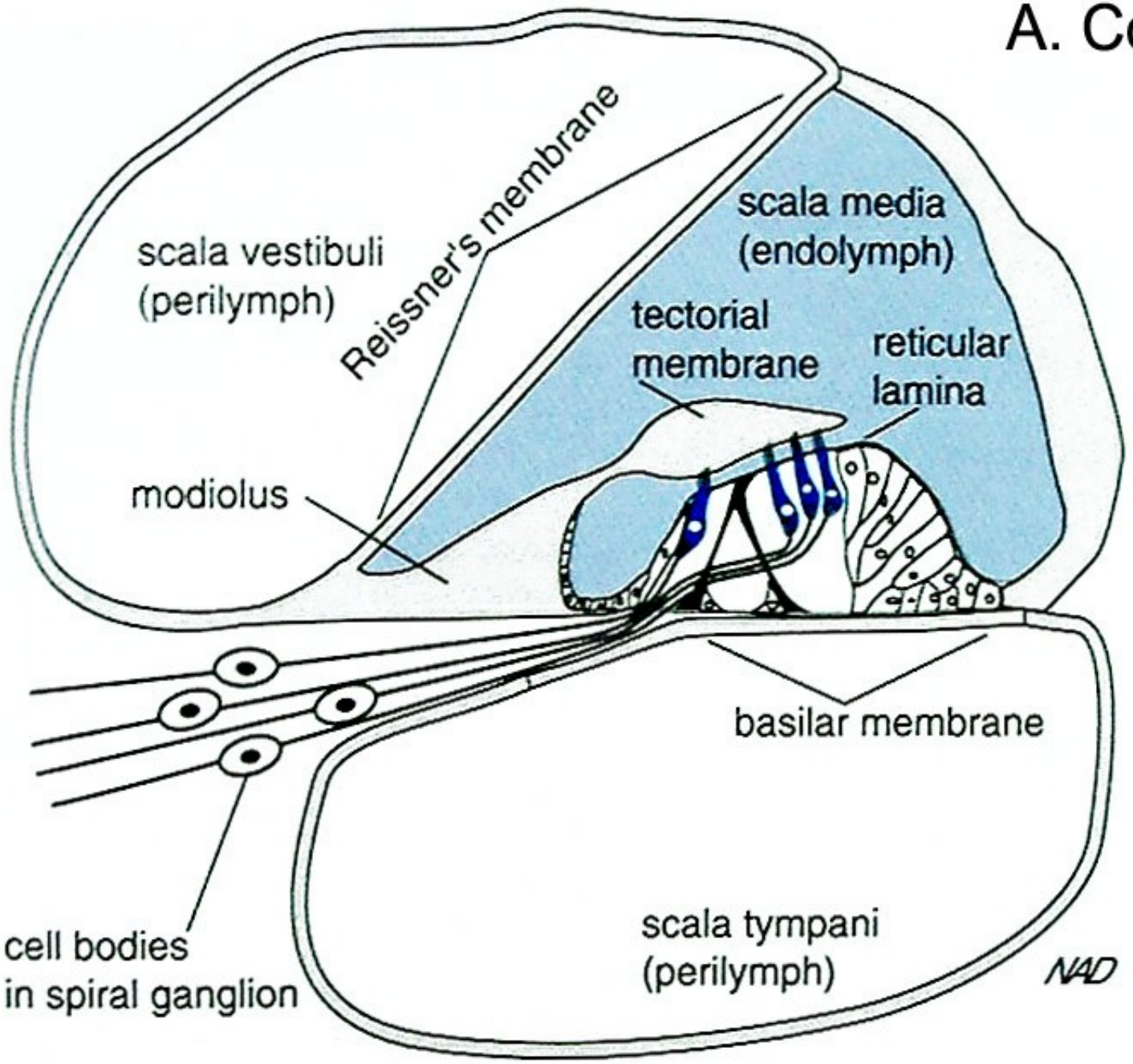
((((round window-- scala tympani : perilymph

endolymph : stria vascularis

Reissner's membrane : floppy

basliar membrane : stiff

A. Cochlear ducts



Structure of the organ of Corti. (A) Cross-section of cochlear ducts showing the placement of the organ of Corti.

=2 The Organ of Corti

inner hair cells (1 row)
outer hair cells (3~5 rows)

tectorial membrane: gel-like materials, fringe in endolymph

reticular lamina : “isolates” endo-/perilymph

(supporting cells)

The ‘auditory strings’ : basilar fibers

lengths increase progressively

from the base up to the apex :

0.04 mm at the base,

0.5 mm at the apex : by 12 times

diameters decrease progressively ,

by 100 times

=3 Mechanical property of the Organ of Corti

shearing force :

up-and-down movement

to-and-fro movement

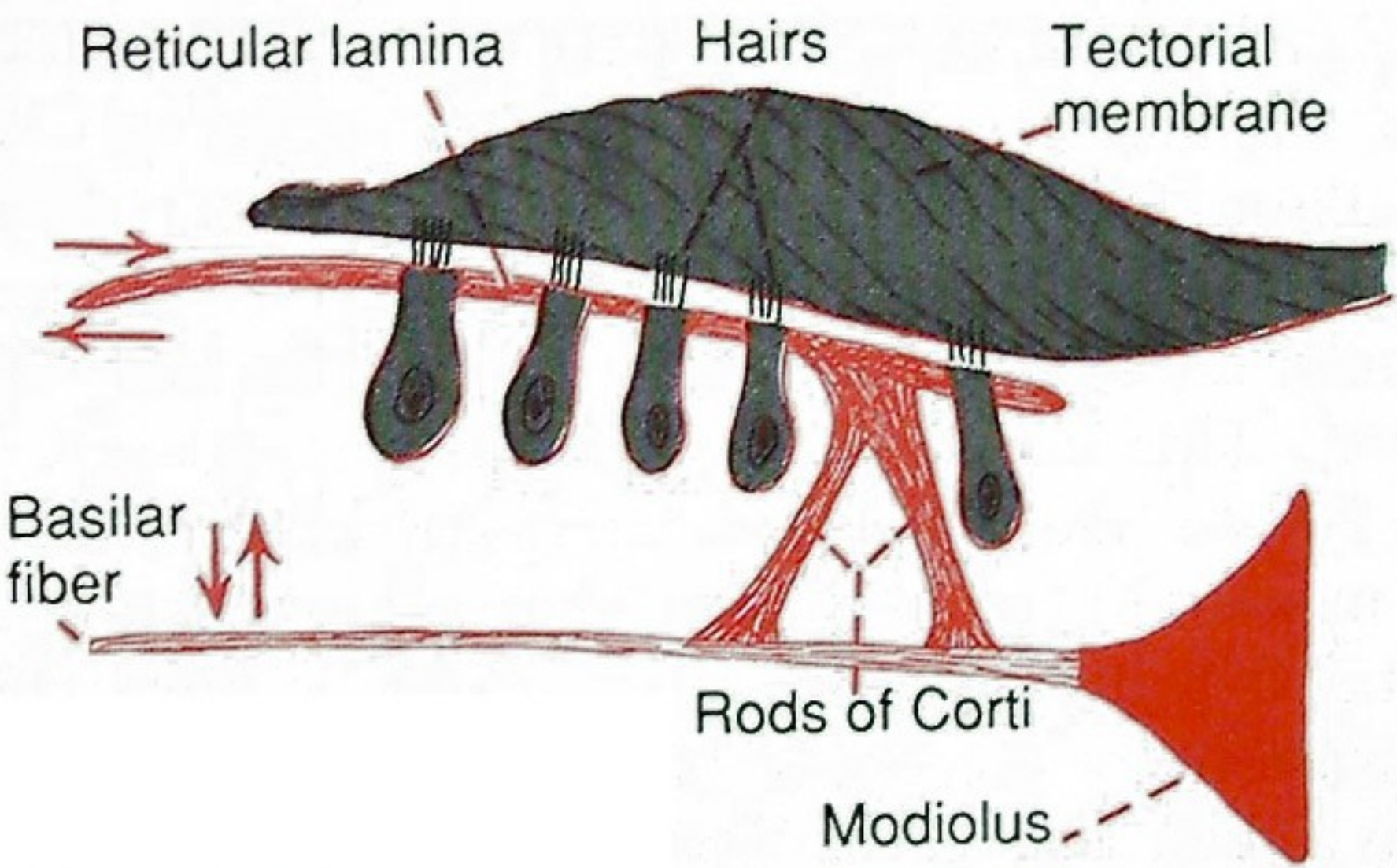


Figure 52-8. Stimulation of the hair cells by the to-and-fro movement of the hairs projecting into the gel coating of the tectorial membrane.

4.2 Vibration of Basilar Membrane and Traveling Wave theory

----- analysis of acoustic vibration in the cochlea

Auditory string :

narrow , stiff at the base
wide , floppy at the apex

high pitch sound :
low pitch sound :

Vibration Energy transmission :

scala vestibuli / media → scala tympani

Resonance of 'auditory string'
with input vibration

A resonating string has

maximal amplitude of vibration, and

maximally passes the energy to….

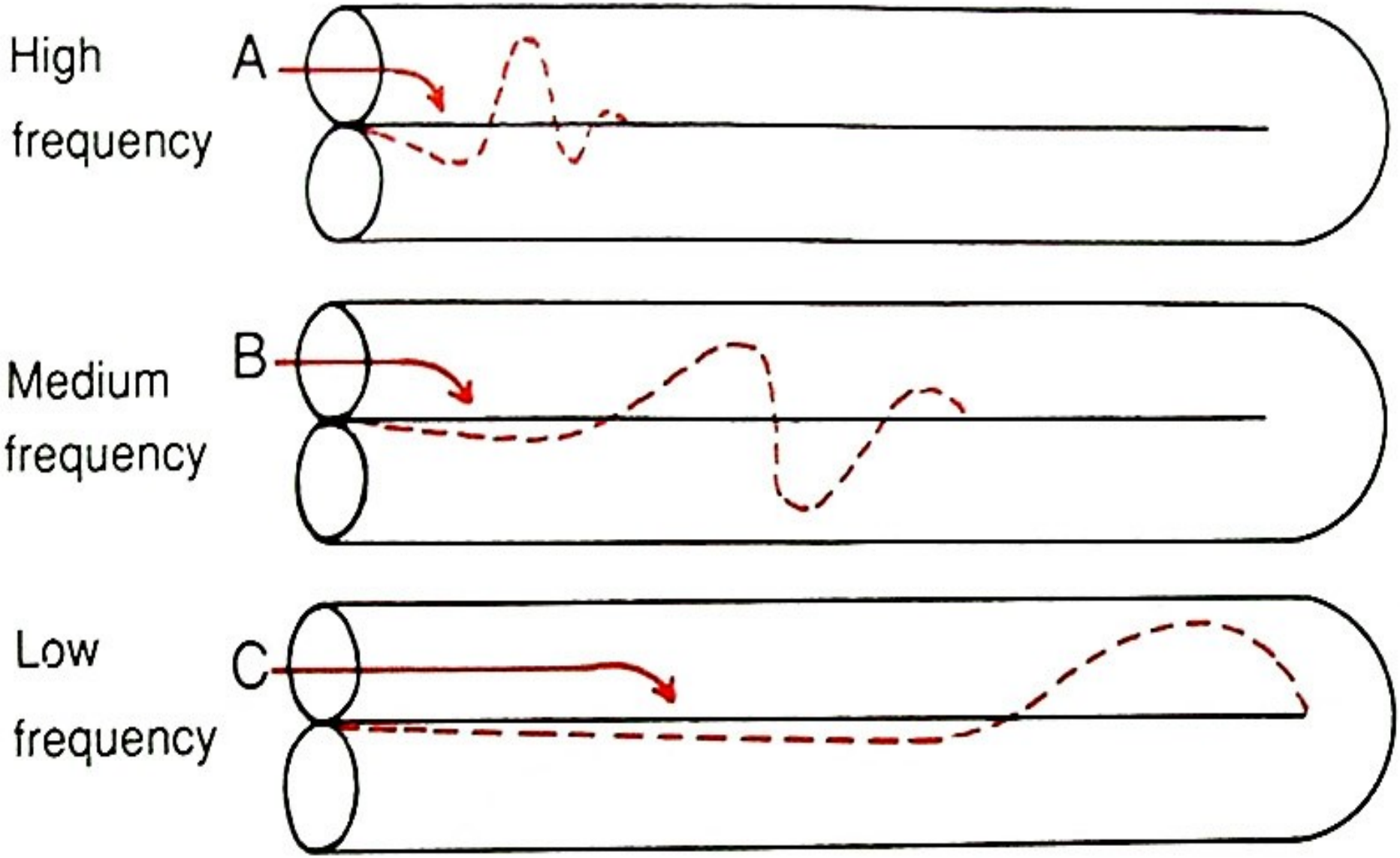


Figure 52–5. "Traveling waves" along the basilar membrane for high-, medium-, and low-frequency sounds.

4.3 Cochlear Bio-electricity

=1 endocochlear / endolymphatic potential

Resting: +80 mV

Mechanism :

----- Cellular activity of stria vascularis:

* Na^+ Pumps extrude K^+ into endolymph :

$[K^+]_{endolymph}$ >>>> all other $[K^+]_{ECF}$

> $[K^+]_{intracellular}$

* Apical m. is immersed in *endo*lymph, while basolateral m. is in *peri*lymph

voltage across apical m. is up to 160 mV

* Hypoxia , ouabain decrease endolymphy p.

=2 Microphonic potential

alternative current-like,
in the cochlea / vicinity

frequency
phase } = those of acoustic vibration
amplitude ∝ ~

duration : extremely short
no refractory period
insensitive to hypoxia.

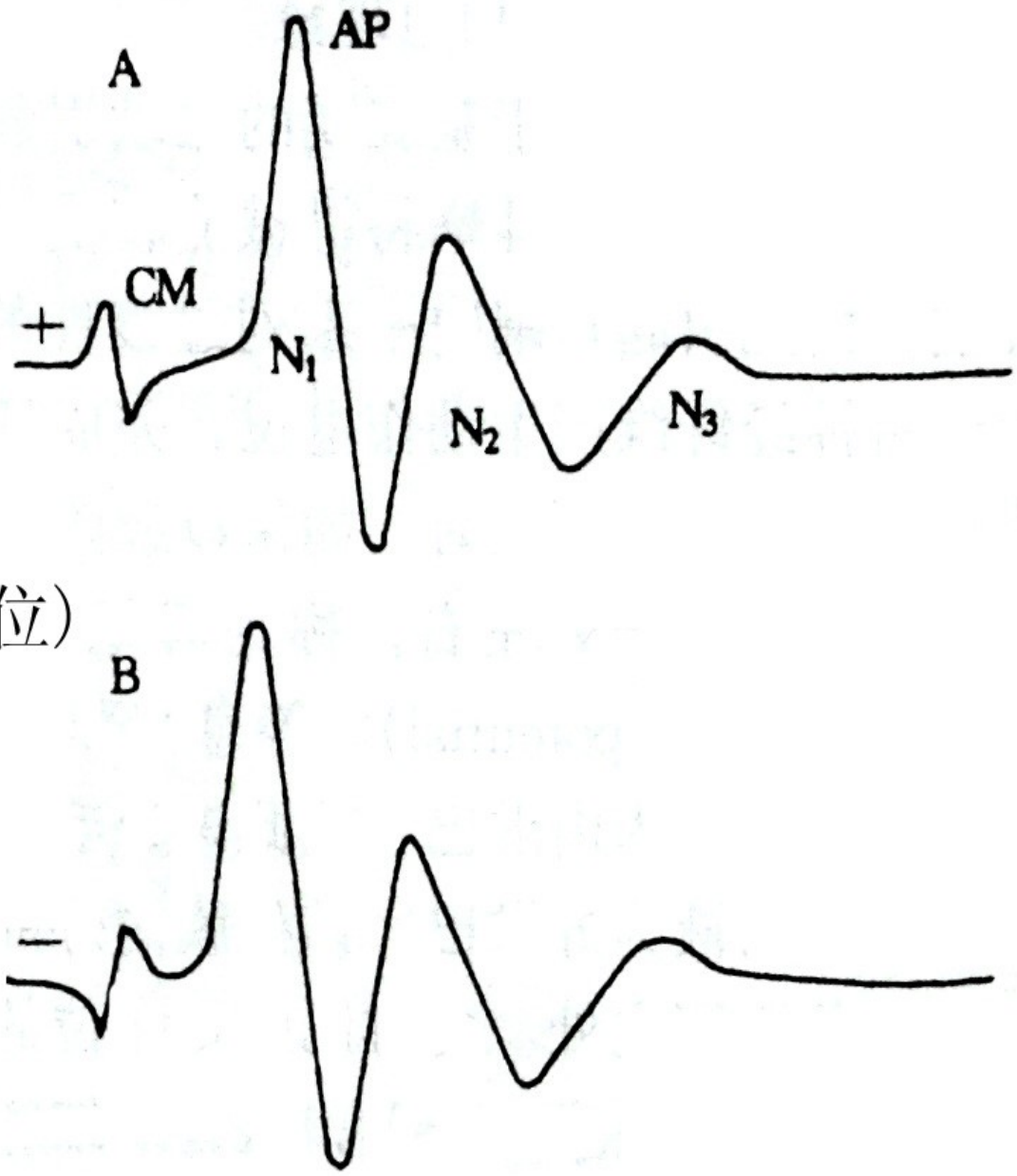
the summation of receptor potentials

图 9-18

由短声刺激引起的微音器电位和听神经动作电位

CM：微音器电位
AP ：耳蜗神经动作电位
（包括N_1, N_2, N_3三个负电位）

A与B对比表明：
声音位相改变时，
微音器电位倒转，
但神经动作电位位相没有变化



=3 Intracellular Recording

Resting potential : -80 mV

Receptor potential : *de- / hyper-*

Mechanism:

shearing force :

displace of cilia :

Frequency Response : excellent !

=4 NO action potential !

Hair cells are NOT excitable cells !

tonic release of neurotransmitter : glutamic acid

*de*polarizational receptor potentials :
release *in*crease

hyper- : release *de*crease

Secondary neuronal terminals : Ap
(in spiral ganglions/
the ganglions of cochlea)

5. action potentials in auditory nerves

at rest, spontaneous firing

characteristic frequency

Vestibule/equilibrium

5 Vestibular function : Equilibrium

Vestibular apparatus and adequate stimulus

Vestibular autonomic reactions & nystagmus

1. vestibular apparatus and adequate stimulus

semicircular canals (3) :
angular / rotational acceleration :
3-dimensional (3D)

utricle (1) : horizontal linear acceleration :
for-/backward, and
left-/rightward

saccule (1) : vertical linear acceleration :
up-/downward , and
left-/rightward

otolith organs : utricle + saccule

=1. Vestibular hair cells

kinocilium and stereocilia

adequate stimulus : shearing force

receptor potential (generator potential) :

depolarizational

hyperpolarizational

neurotransmitter : glutamic acid

=2. Semicircular canals

3 canals each side, perpendicular to each other, representing 3 dimensional planes :

lateral / horizontal

superior / anterior

posterior

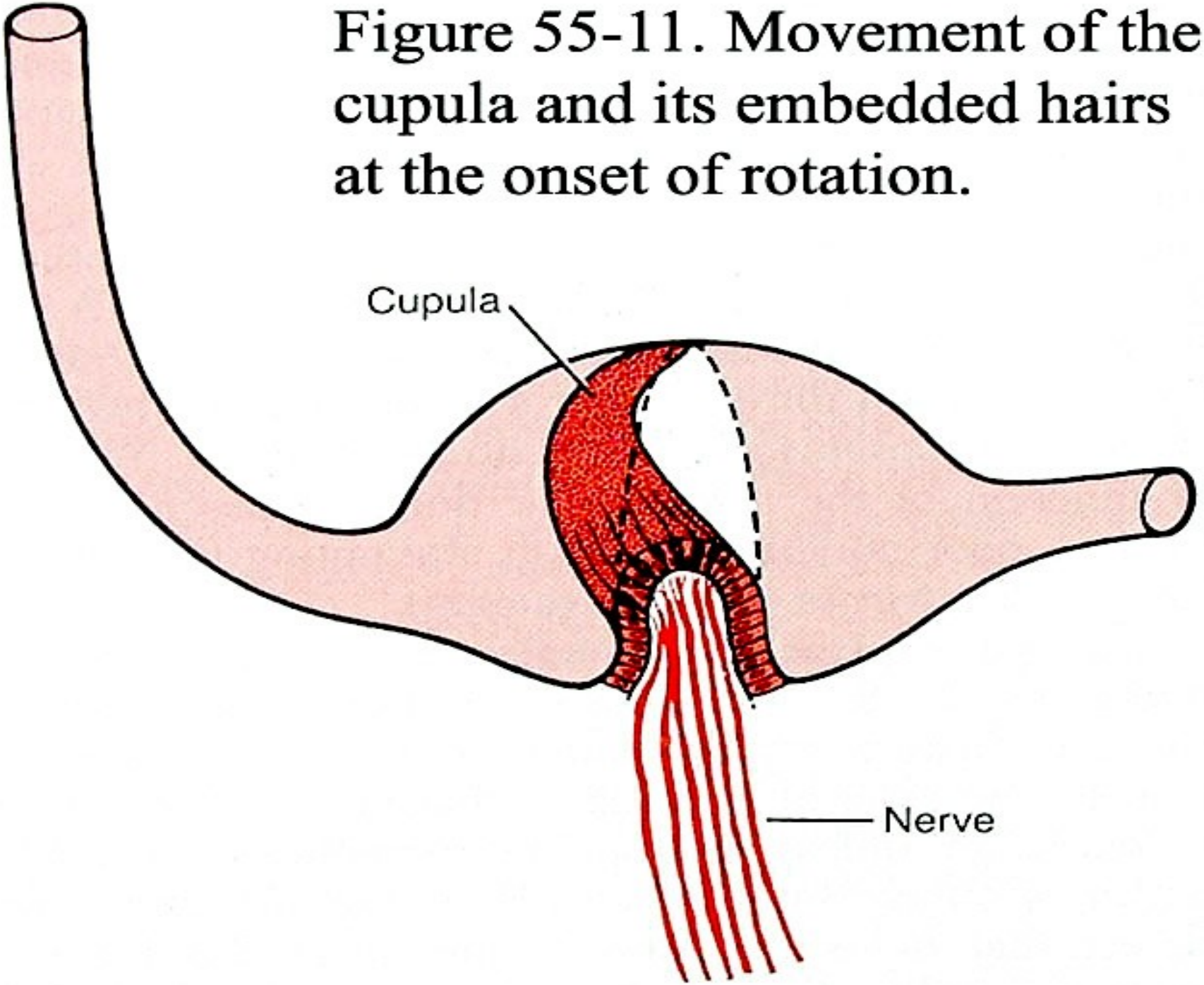
ampulla

ampullary crest (crista)

cupula : a diaphragm-like mass, in which the kinocilium & stereocilia are embedded

detecting threshold of the crest: $2^{o}/s^{2}$ of positive/negative angular acceleration

Figure 55-11. Movement of the cupula and its embedded hairs at the onset of rotation.



Stimulation and Effects

at the onset of leftward rotation ,

endolymph, because of its inertia , move

toward left ampulla →

leftside hair cells *de*polarize →

left vestibular nerve impulse-freq. 

away from right ampulla →

rightside hair cells *hyper*polarize →

right vestibular nerve impulse-freq. 

stopping : opposite changes

constant angular velocity: no change

=3. Otolith organs : the utricles & saccules

macula

otolithic membrane :

plate-like, cilia of hair cells embedded;

protein + $CaCO_3$, density > endolymph

macula of utricle " lies on the floor "

its plane parallels to the ground;

macula of saccule " hangs on the wall " :

its plane is perpendicular to the ground.

orientation / functional polarity of each hair cell

is unique;

ensures that linear acceleration

in ANY direction on the macula plane

may maximally stimulate

a population of hair cells.

Vestibular afferent impulses :

control equilibrium and posture , via

descending spinal tracts :

vestibulospinal tract
reticulospinal tract
rubrospinal tract

extensor muscle tonus (+) (a stretch reflex)

2 Vestibular autonomic reactions & Nystagmus

V.A.R. are incurred when vestibular apparatuses

are exposed to stimulus

of too high intensity, or/and

for too long duration, or/and

when apparatuses are too sensitive.

Manifestations: nausea, vomiting,

vertigo, pallor,

sweating, Bp changes *etc*.

Nystagmus : vestibulo-ocular reflex VOR

semicircular canals.

clinically : vestibular function

Description:

---------- a jerky movement of the eyeballs

horizontal nystagmus:

slow component : central position → one end

quick component: one end →central position

and repeat for …

horizontal nystagmus : horizontal canals

vertical nystagmus : posterior/superior canals

Mechanism:

at the onset of leftward rotation ,

vestibular afferents inhibit left *rectus lateris*

and right *rectus medialis*

→ eyeball movement : slow component

when reach a limit,

CNS interferes, corrects the discrepancy

in the fixation point : quick ~

opposite reactions …

Apparently, the fixation point is inertial

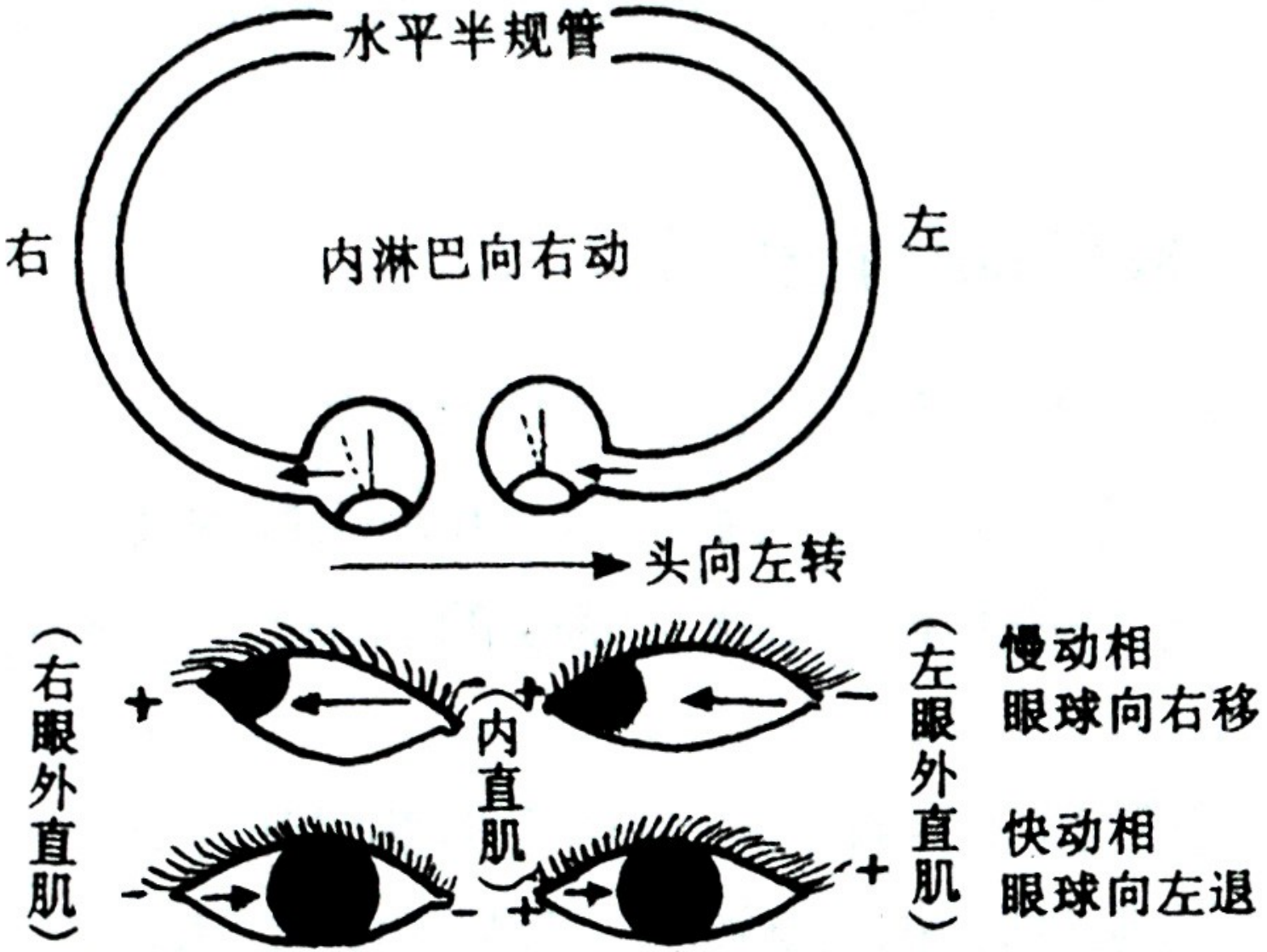
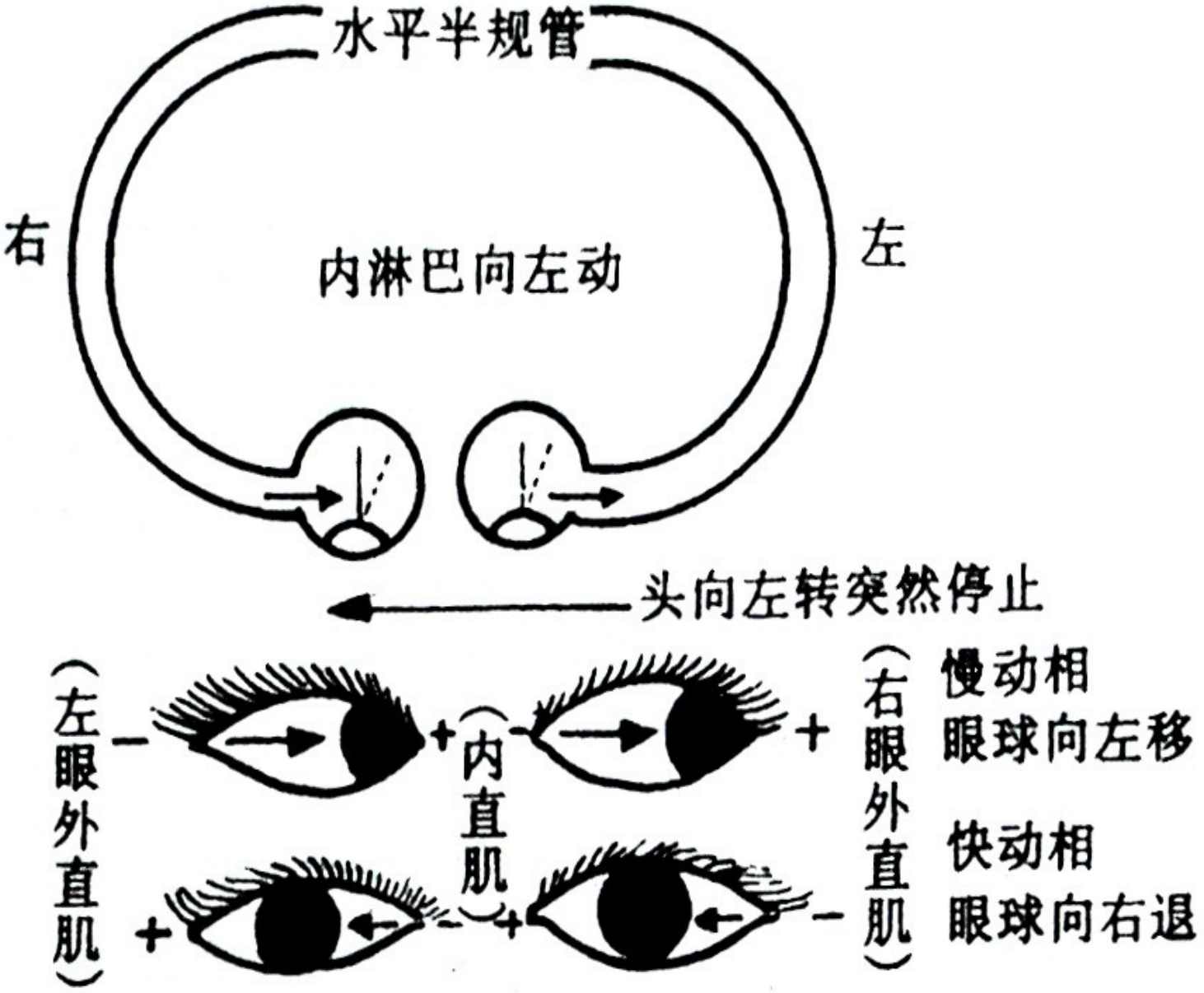


图 9-21 旋转变速运动时两侧水平半规管壶嵴毛细胞受刺激情况和眼震颤方向示意图

（1）头前倾 30 度、旋转开始时的眼震颤方向

图 9-21 旋转变速运动时两侧水平半规管壶嵴毛细胞受刺激情况和眼震颤方向示意图



(2) 旋转突然停止后的眼震颤方向

6 olfaction and gustation

olfactory epithelium, olfactory cells

“primitive” sense :

chemical receptors : 1000+ GPCR (G_{olf})

: sampling exterrior…

fast adaptation

unique pathway

6 olfaction and gustation

taste bud
“primitive” sense

voltage-gated channels

smell >> taste

第六节　　嗅觉 (olfactory sensation)

一、嗅觉感受器和嗅觉的一般性质

1. 嗅感受器 ：

位于嗅上皮 (olfactory mucous membrane)

适宜刺激 ： 空气中的化学物质

2. 嗅觉的一般性质

(1) 嗅觉的产生机制

化学物质与嗅纤毛表面膜上的受体结合

G 蛋白　腺苷酸环化酶　　胞内 cAMP↑

钠 / 钙通道开放　Ca^{2+} 、Na^{+} 内流

去极化型感受器电位　　轴丘　　动作电位

嗅球

嗅觉中枢　　嗅觉

第七节　　味觉 (gustatory sensation)

一、味觉感受器

1. 味感受器：味蕾 (taste bud)

味细胞 (gustatory cell)

2. 味觉的一般性质

① 基本味质 ： 五种

酸、咸、苦、甜、鲜味，

“鲜味”（umami）

④ 一个味感受器可对酸、甜、苦、咸都起反应，但反应的程度不同。

⑤ 五种基本味觉的换能或信号转导机制不完全相同。

3. 味觉的特点：

① 随年龄增长其敏感度降低： 60 岁以上的人，对食盐、蔗糖和硫酸奎宁的检知阈比 20~40 岁的人高 1.5~2.2 倍。

② 适应快