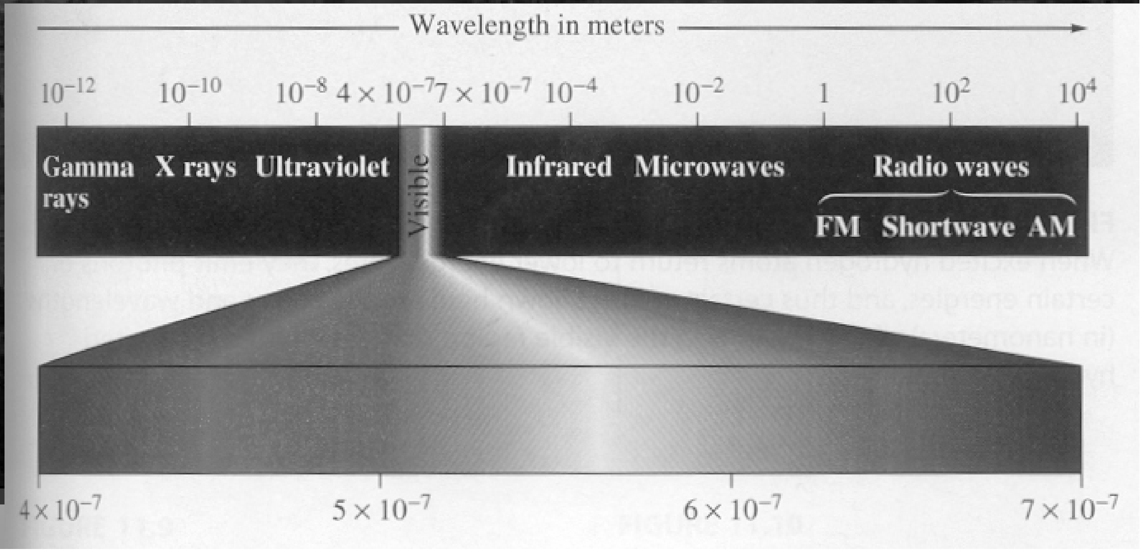
Fotorecepce

Využití vlastností světla a jeho absorpce při průchodu a odrazu.
Zrakem až 90% informací.
Tvar, barva, umístění v prostoru, rychlost a směr pohybu.



Proteiny teprve ve spojení s chromoforem – část molekuly
odpovědná za absorbci záření (také zvaná prostetická skupina – nebílkovinná sl.)
mohou absorbovat viditelné spektrum.

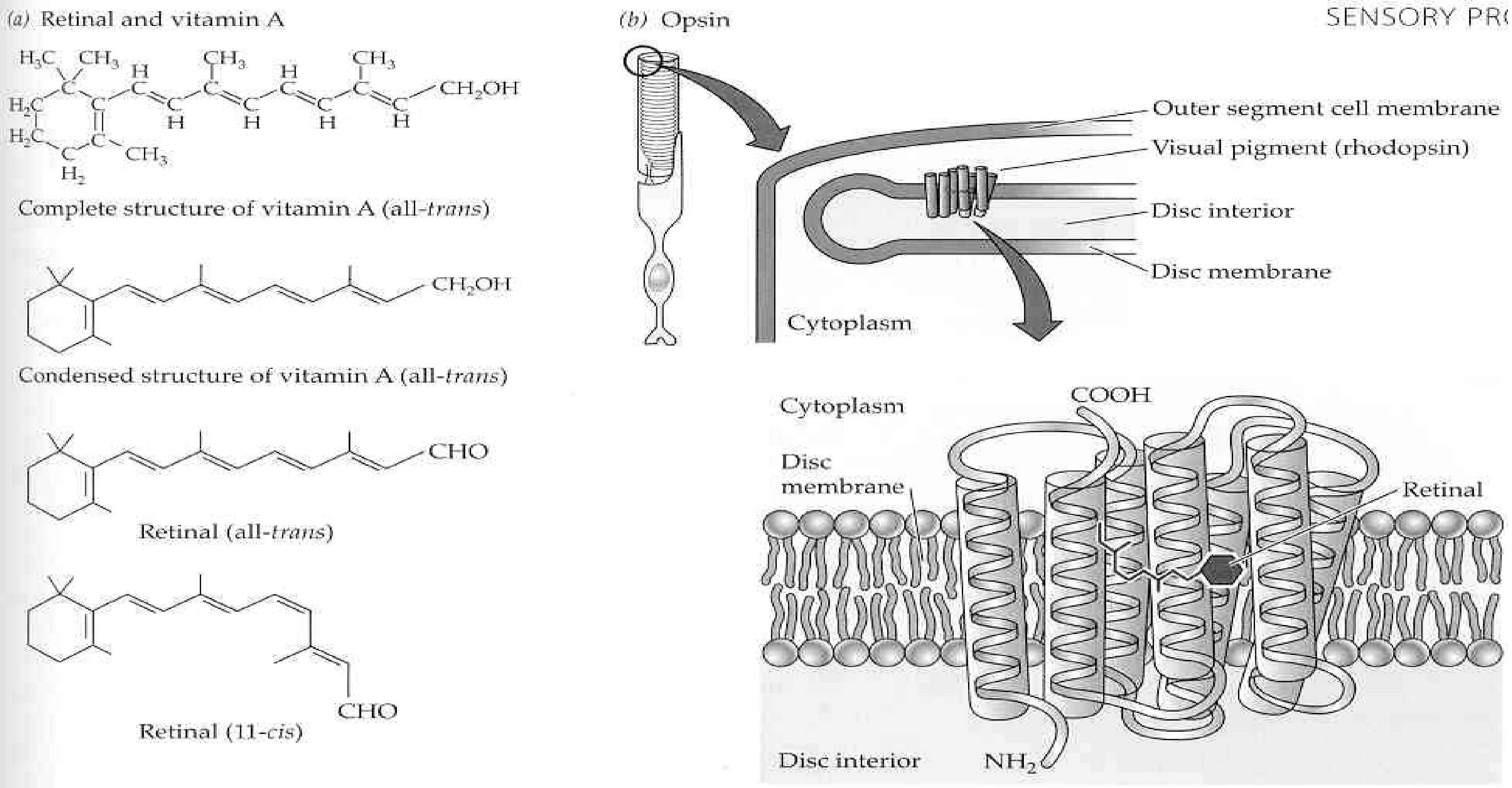
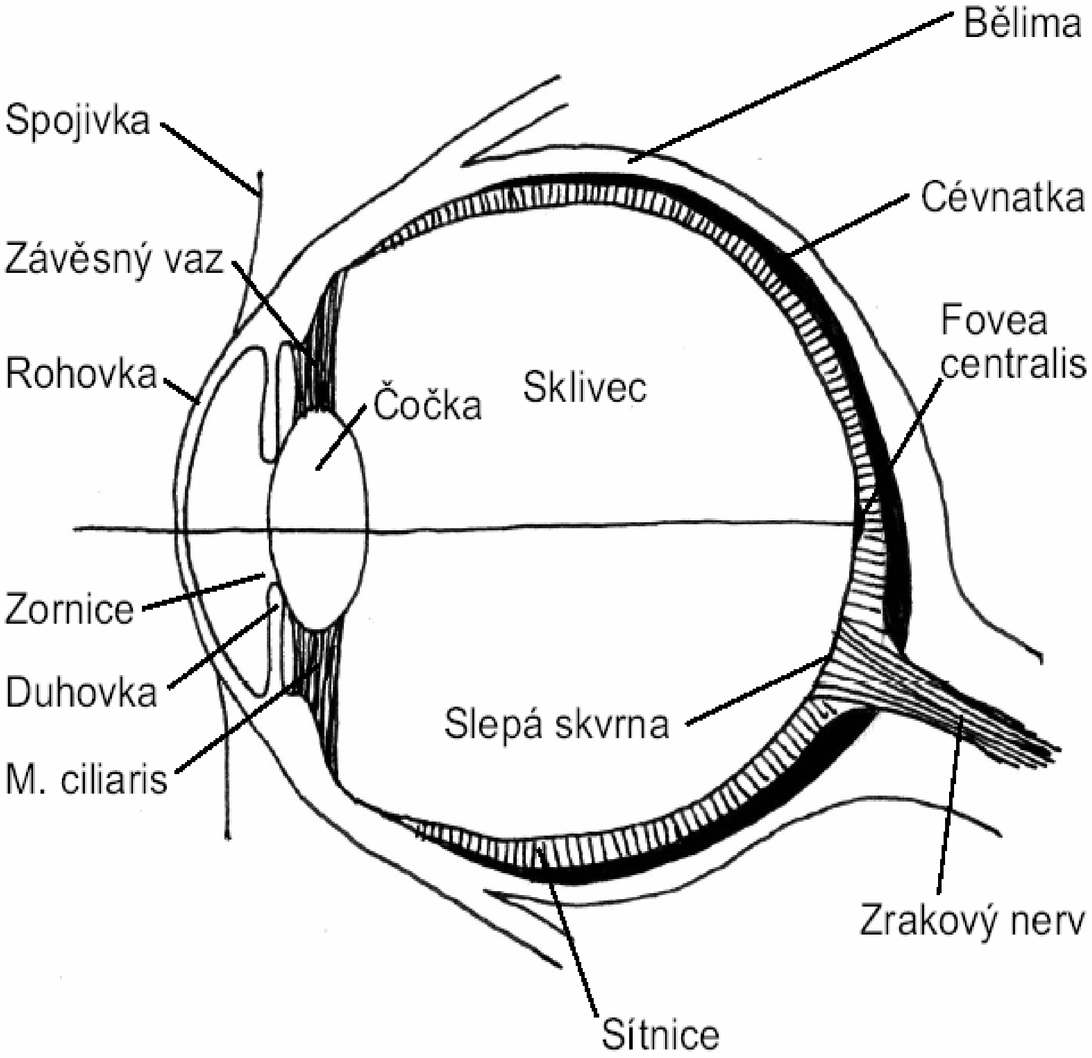


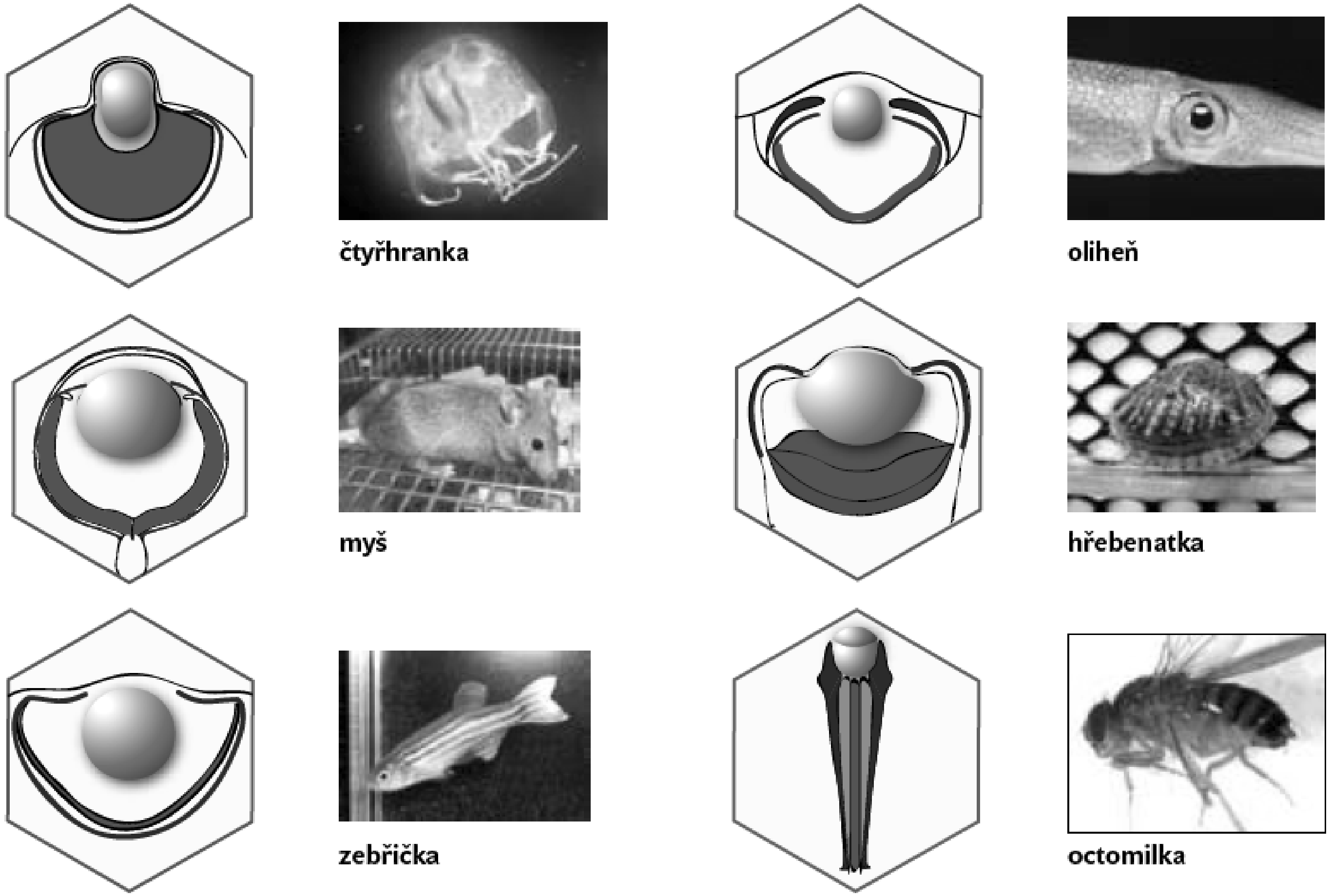
Figure 13.13 Rhodopsin is a photopigment composed of two parts: retinal and opsin *(a)* Chemical structures of vitamin A and of retinal. Vitamin A is shown both as a complete structure (top) and as a skeleton structure (middle). Vitamin A is converted to retinal, which has two isomers (11-*cis* and all-*trans*). *(b)* Three-dimensional structure of the protein (opsin) portion of vertebrate rhodopsin. Seven α-helical regions of the protein span the membrane; retinal is attached to an amino acid residue within the seventh membrane-spanning region.

- Optický systém oka
- Fotoreceptory sítnice
- Optická dráha
- Korová zraková oblast

David Hubel’s web page

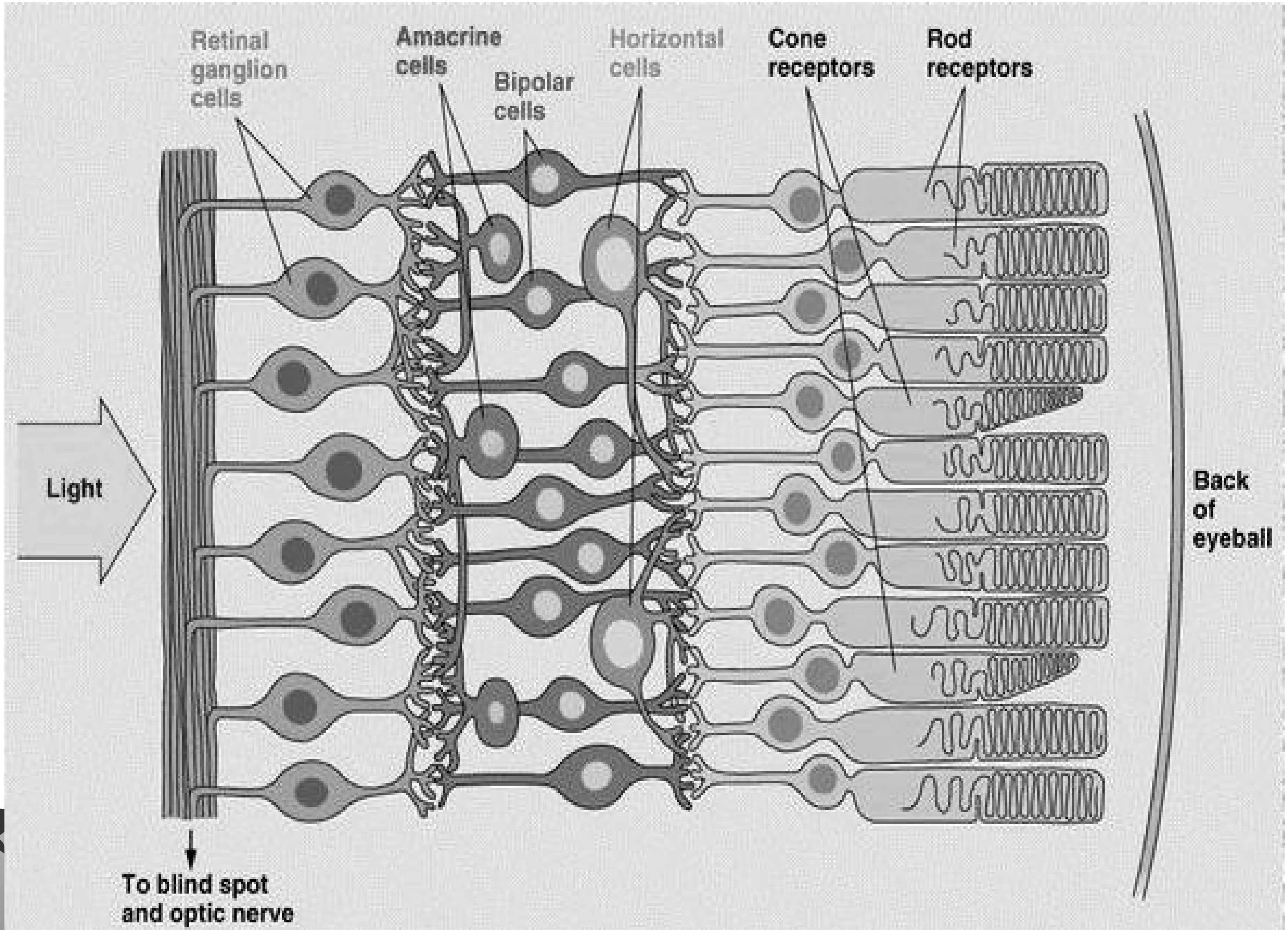
Od baktérií schopnost detekce.
Komorové oko – dokonalý optický nástroj

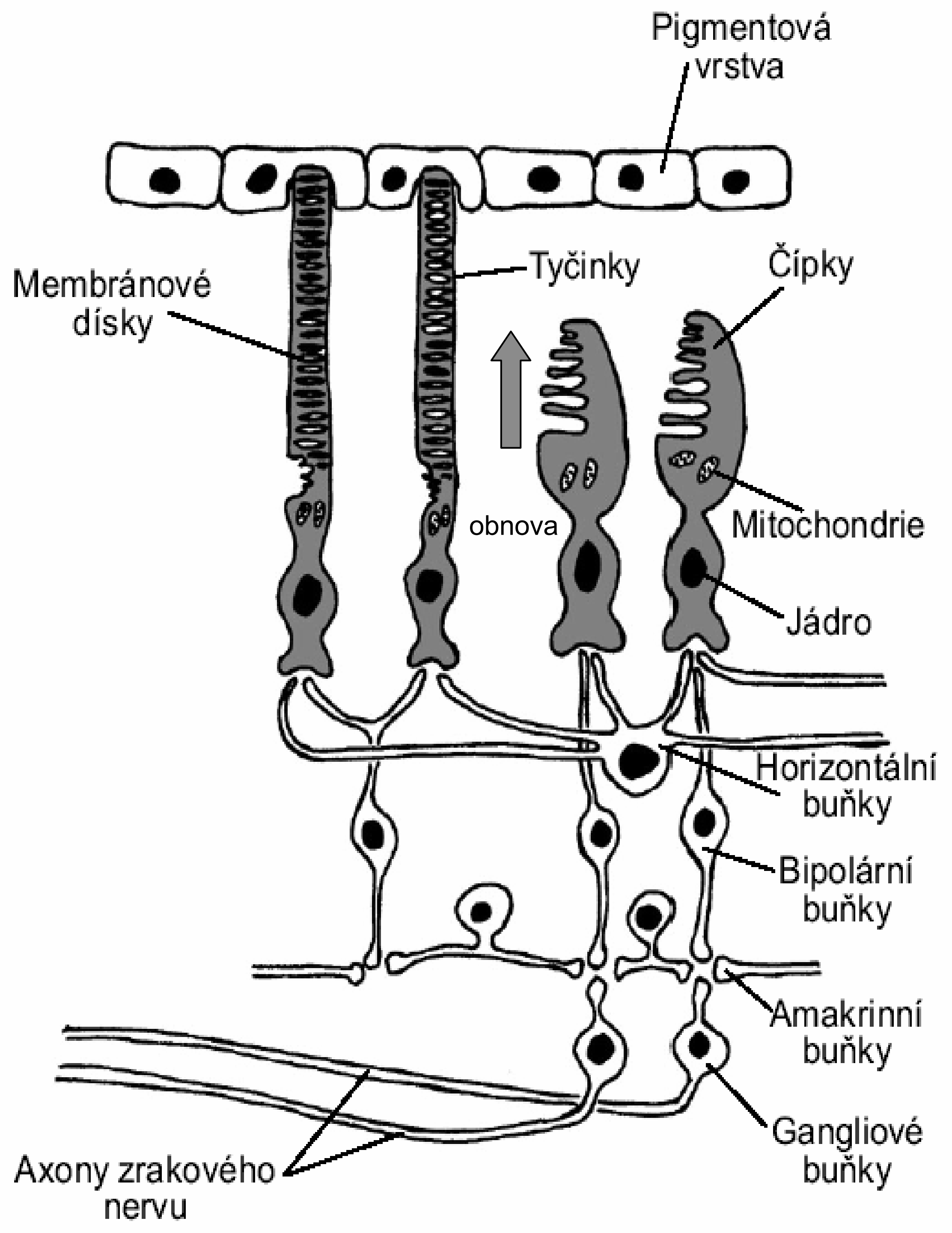


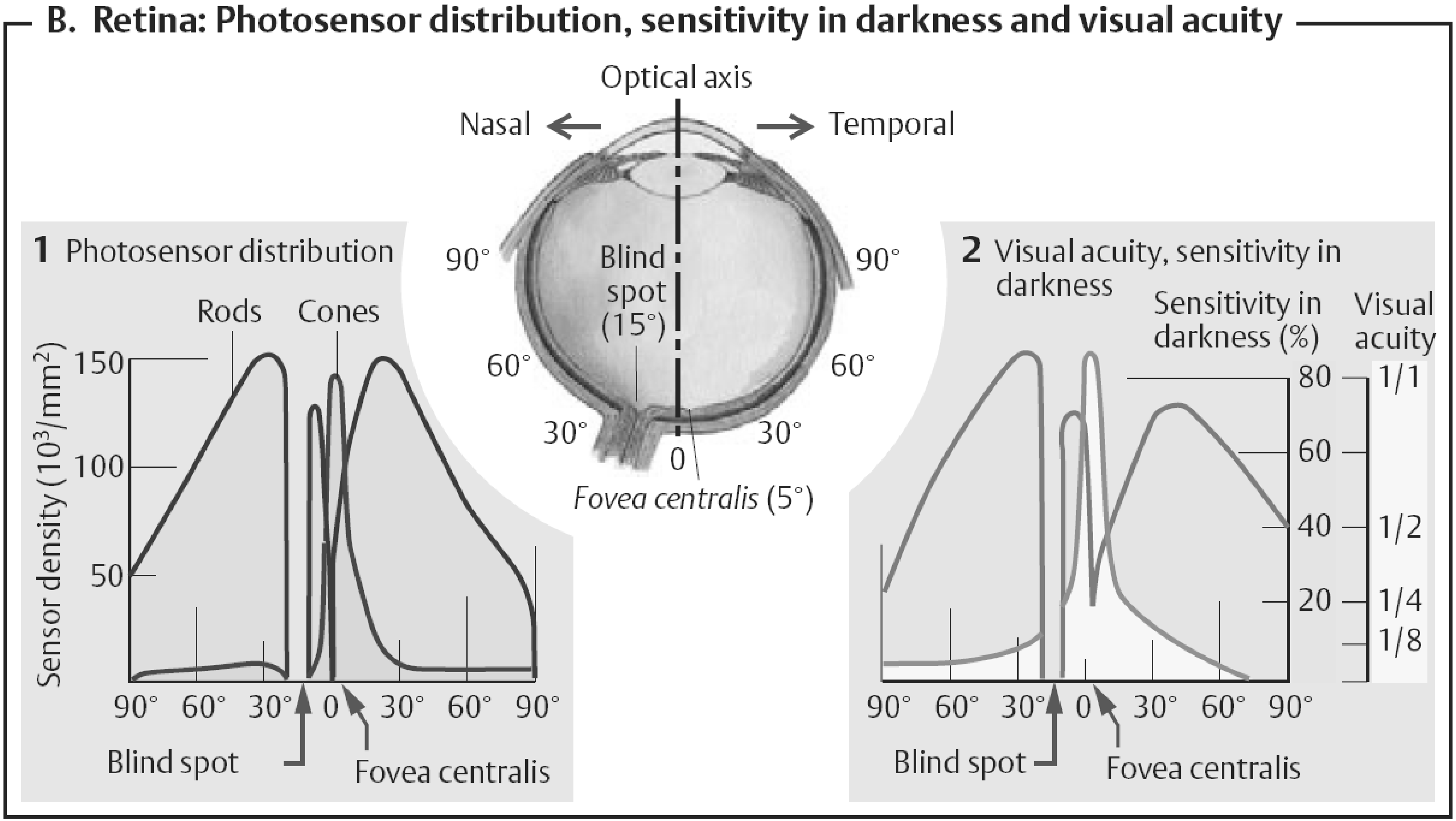


1. Šest modelových organizmů a šest různých typů očí. Fotografie živočicha je vždy doplněna o schematizovaný průřez jeho okem. Snímky © Kristýna Marková-Jonášová, Jana Růžičková, Roger Hanlon a Marek Jindra.

Inverzní sítnice savců.
120 mil. tyčinek, 6 mil. čípků.




Pigmentová vrstva
Membránové dísky
Tyčinky
Čípky
obnova
Mitochondrie
Jádro
Horizontální buňky
Bipolární buňky
Amakrinní buňky
Gangliové buňky
Axony zrakového nervu


B. Retina: Photosensor distribution, sensitivity in darkness and visual acuity

RGB čípky, ale jen RG ve fovei.

Absorbce světla - Karotenoidy (vit.A) a pyrolové kruhy

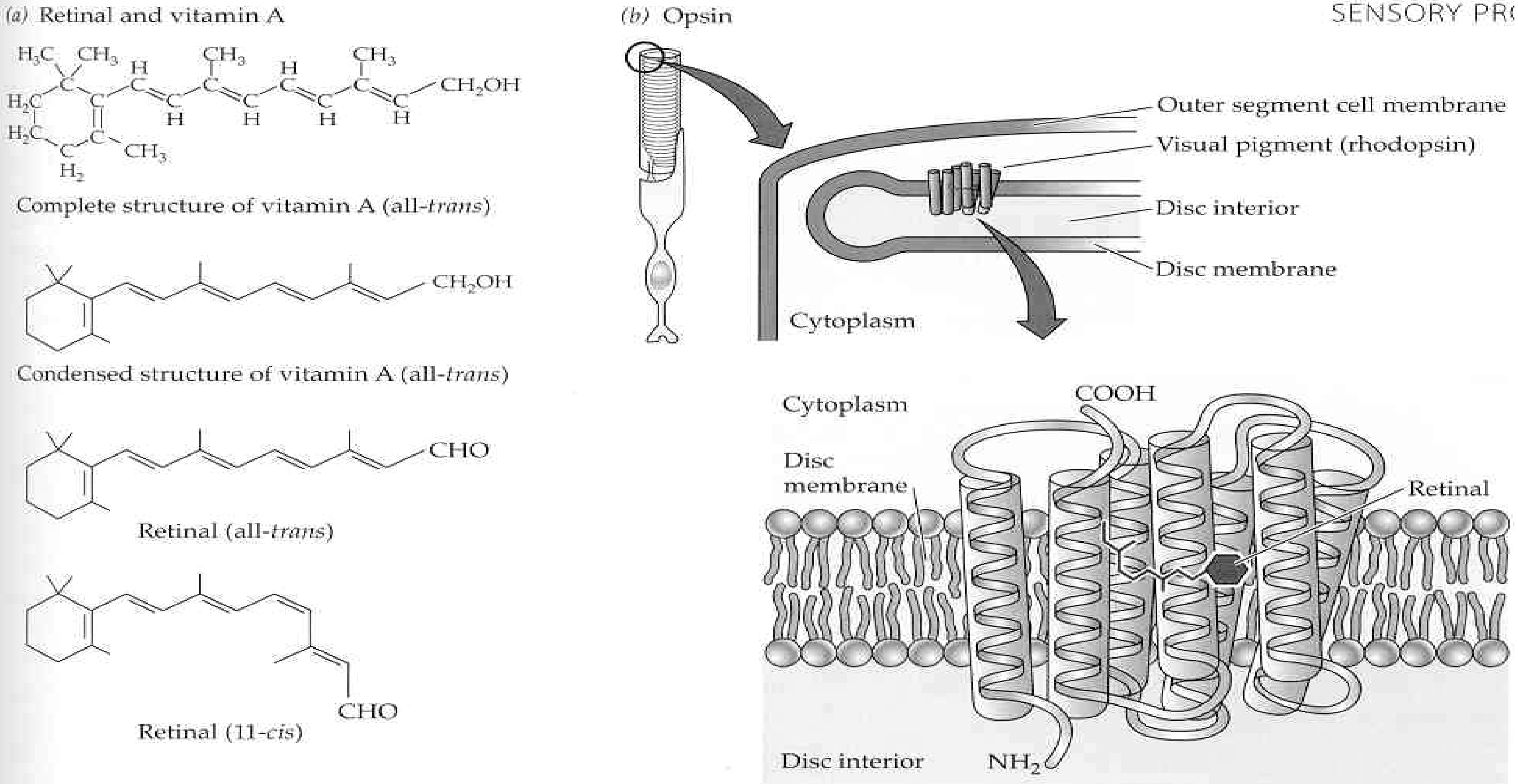
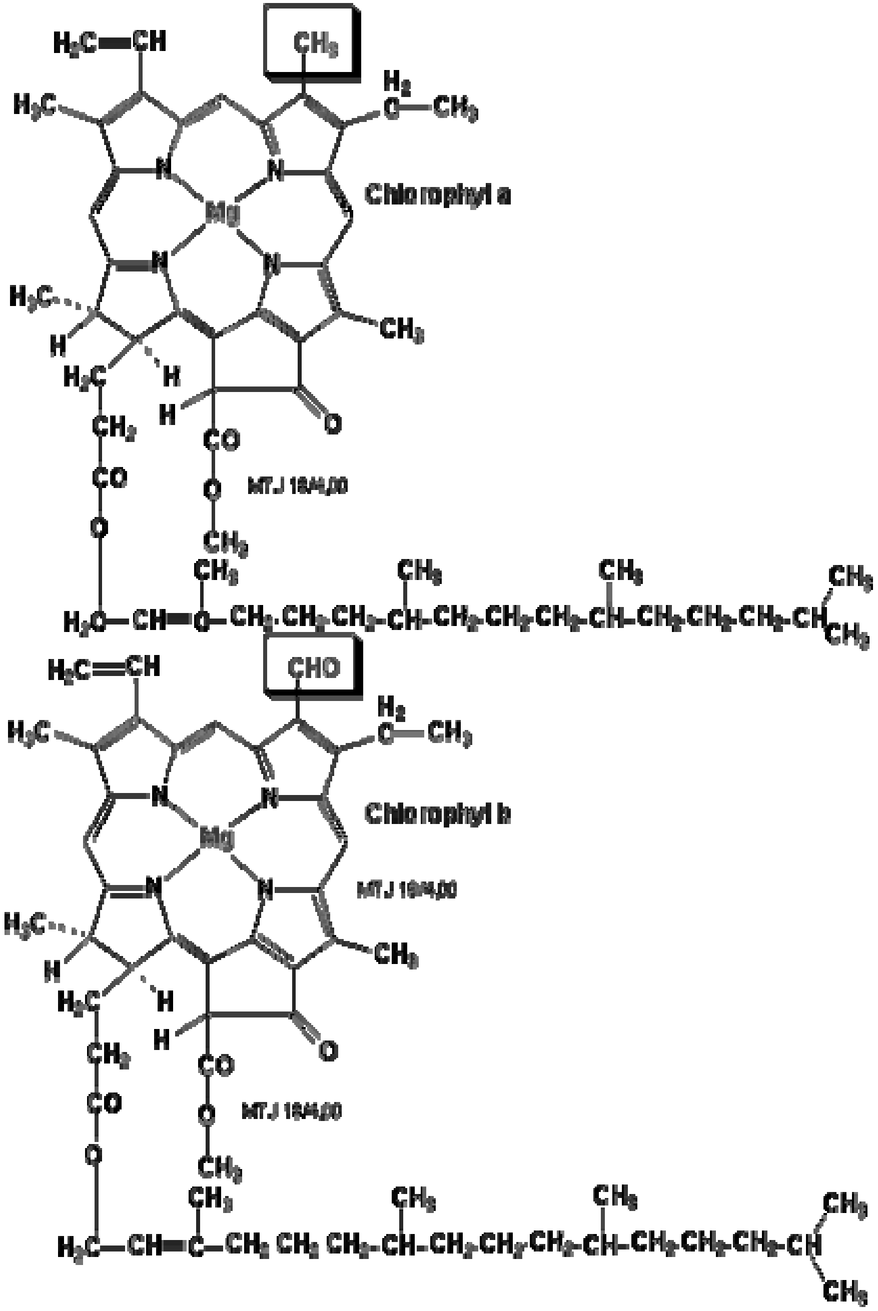


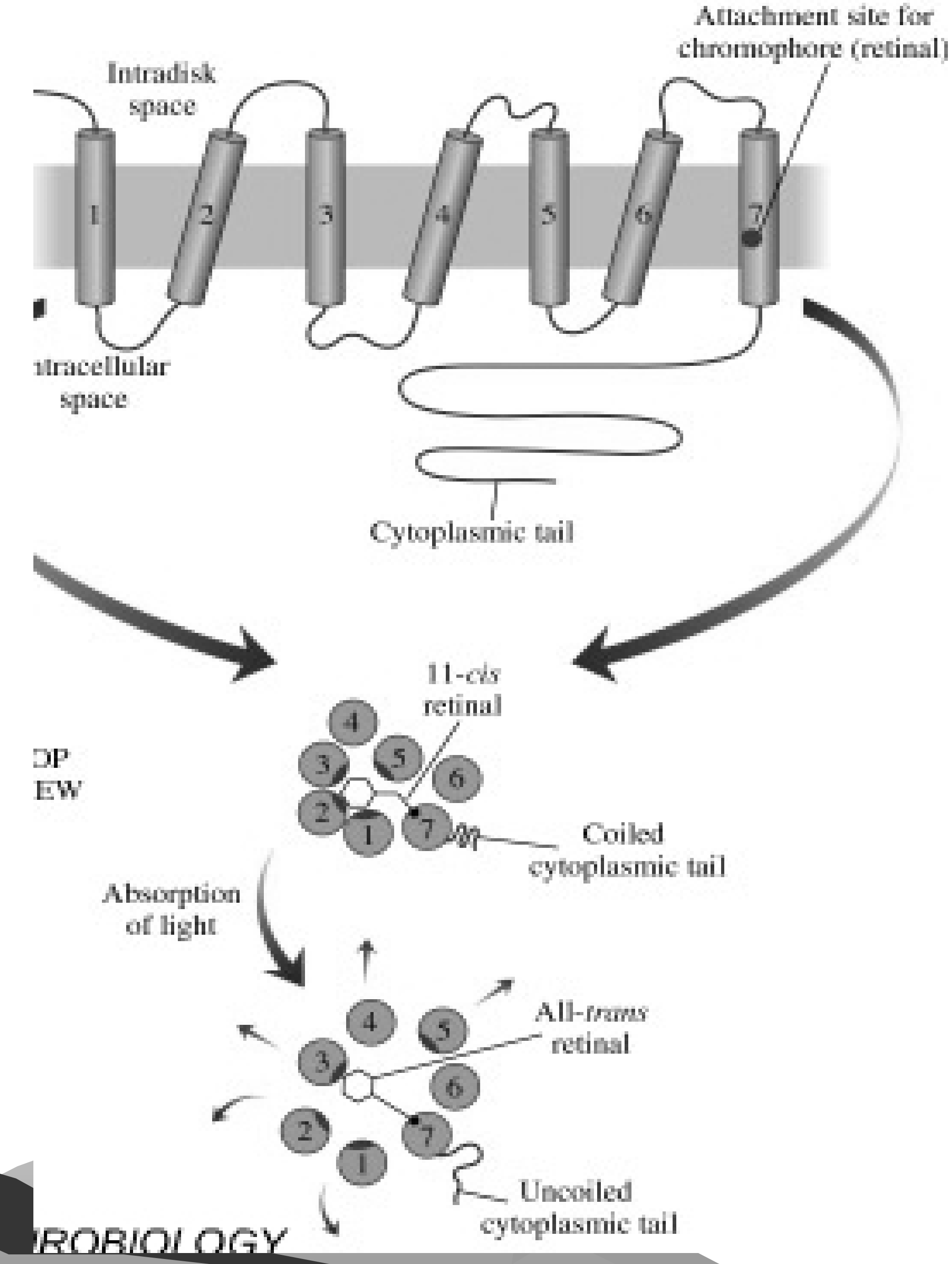
Figure 13.13 Rhodopsin is a photopigment composed of two parts: retinal and opsin *(a)* Chemical structures of vitamin A and of retinal. Vitamin A is shown both as a complete structure (top) and as a skeleton structure (middle). Vitamin A is converted to retinal, which has two isomers (11-*cis* and all-*trans*). *(b)* Three-dimensional structure of the protein (opsin) portion of vertebrate rhodopsin. Seven α-helical regions of the protein span the membrane; retinal is attached to an amino acid residue within the seventh membrane-spanning region.

Video cis - trans

Absorbce světla - Karotenoidy (vit.A) a pyrolové kruhy (chlorofyl)



Spolupráce chromoforu retinalu
a apoproteinu opsinu.



Video aktivace rhodopsinu

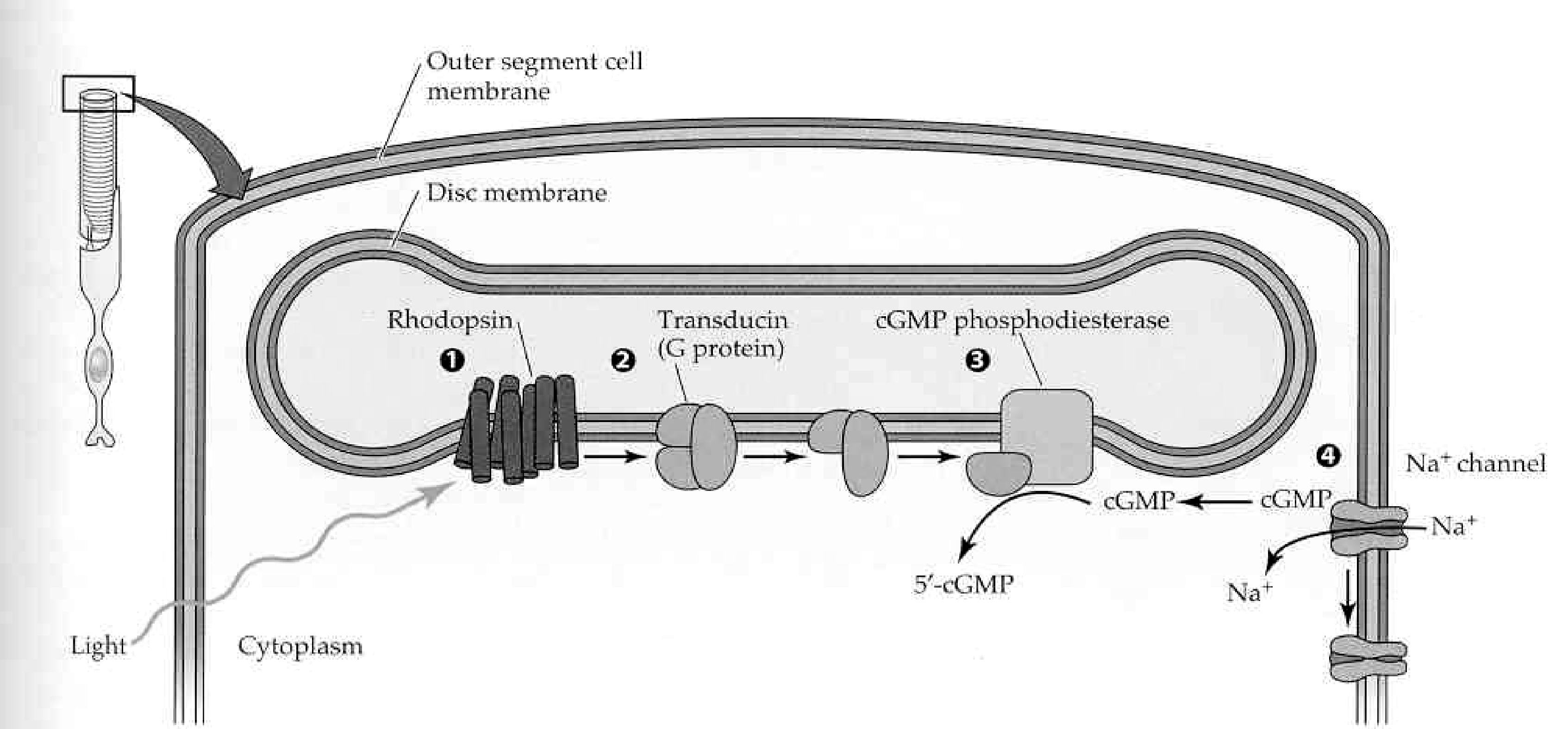
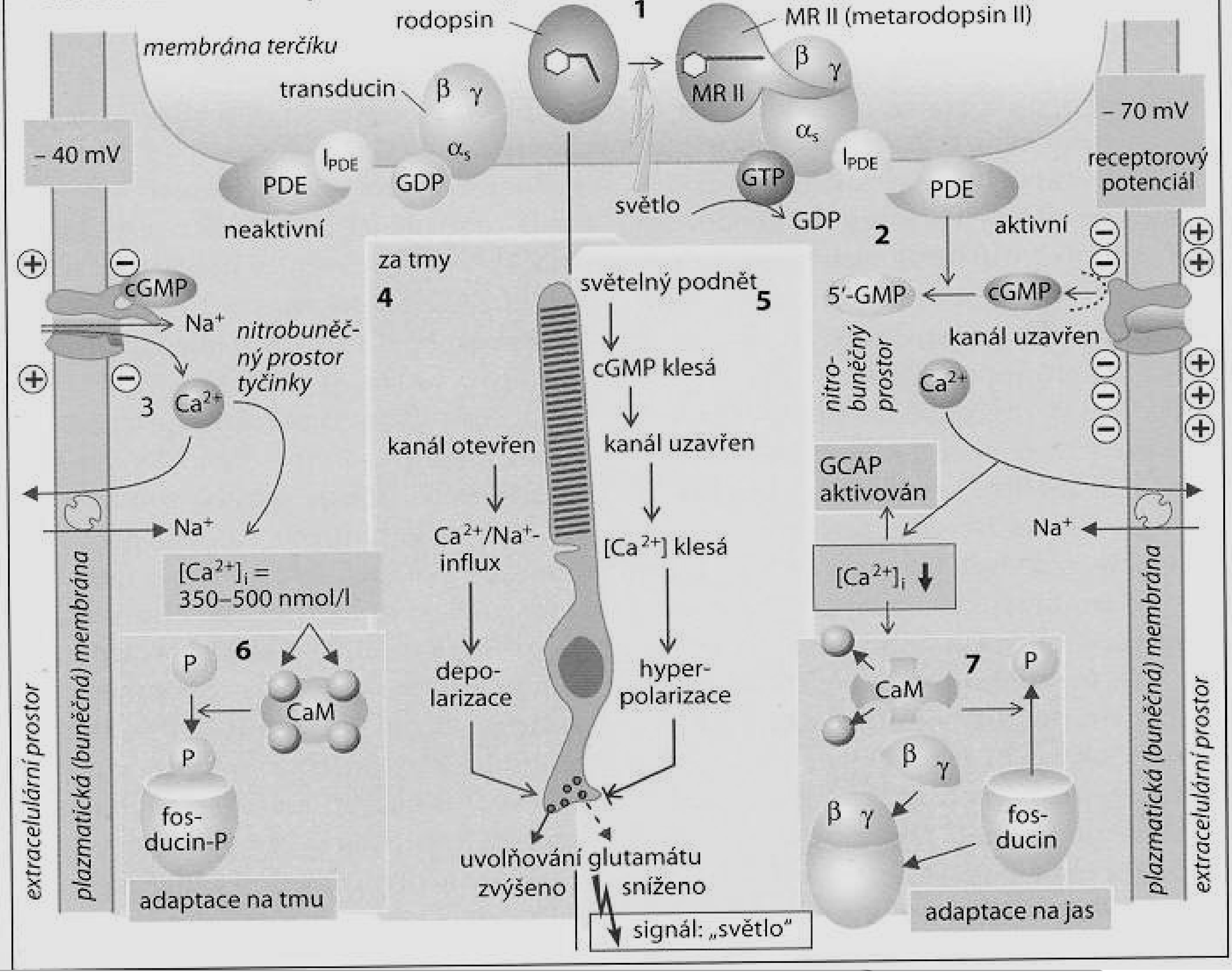
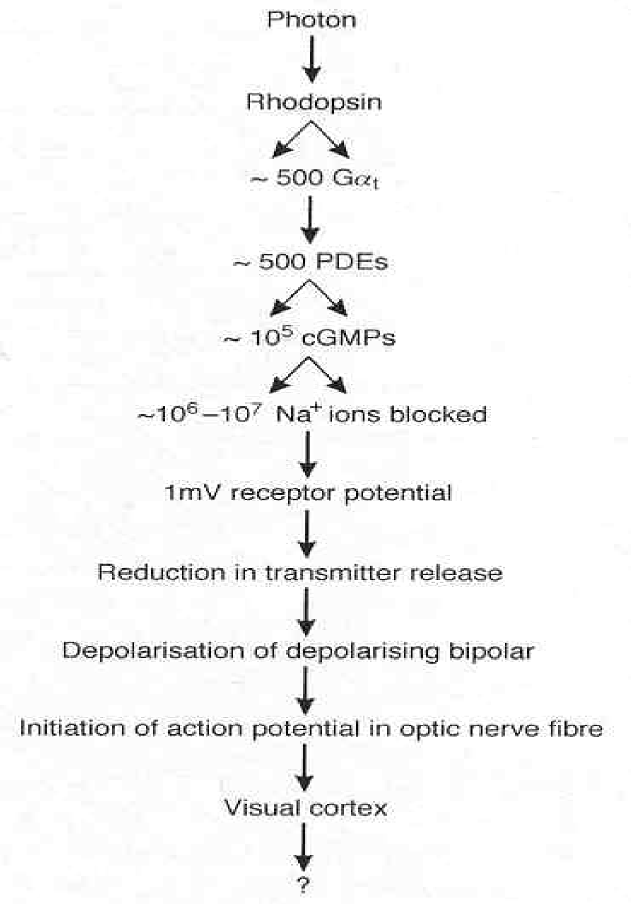


Figure 13.14 Phototransduction closes cation channels in the outer segment of the photoreceptor membrane In the dark, the cation channels are kept open by intracellular cGMP and conduct an inward current, carried largely by Na^+. When light strikes the photoreceptor, these channels are closed by a G protein–coupled mechanism. ❶ Rhodopsin molecules in the disc membrane absorb light and are activated. ❷ The activated rhodopsin stimulates a G protein (transducin in rods), which in turn activates cGMP phosphodiesterase. ❸ The phosphodiesterase catalyzes the breakdown of cGMP to 5′-GMP. ❹ As the cGMP concentration decreases, cGMP detaches from the cation channels, which close.

D. Podráždění a adaptace fotoreceptorů



Zesílení



Photon

Rhodopsin

~ 500 $G\alpha_t$

~ 500 PDEs

~ 10^5 cGMPs

~10^6–10^7 Na^+ ions blocked

1mV receptor potential

Reduction in transmitter release

Depolarisation of depolarising bipolar

Initiation of action potential in optic nerve fibre

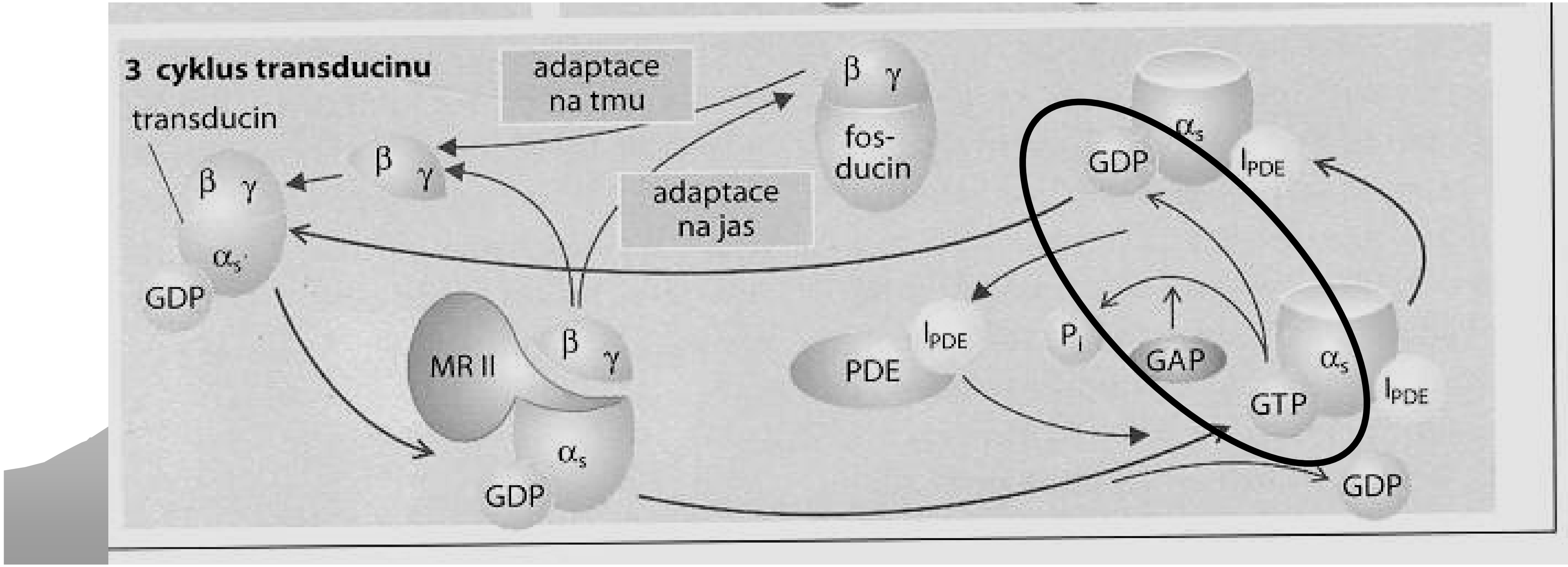
Visual cortex

?

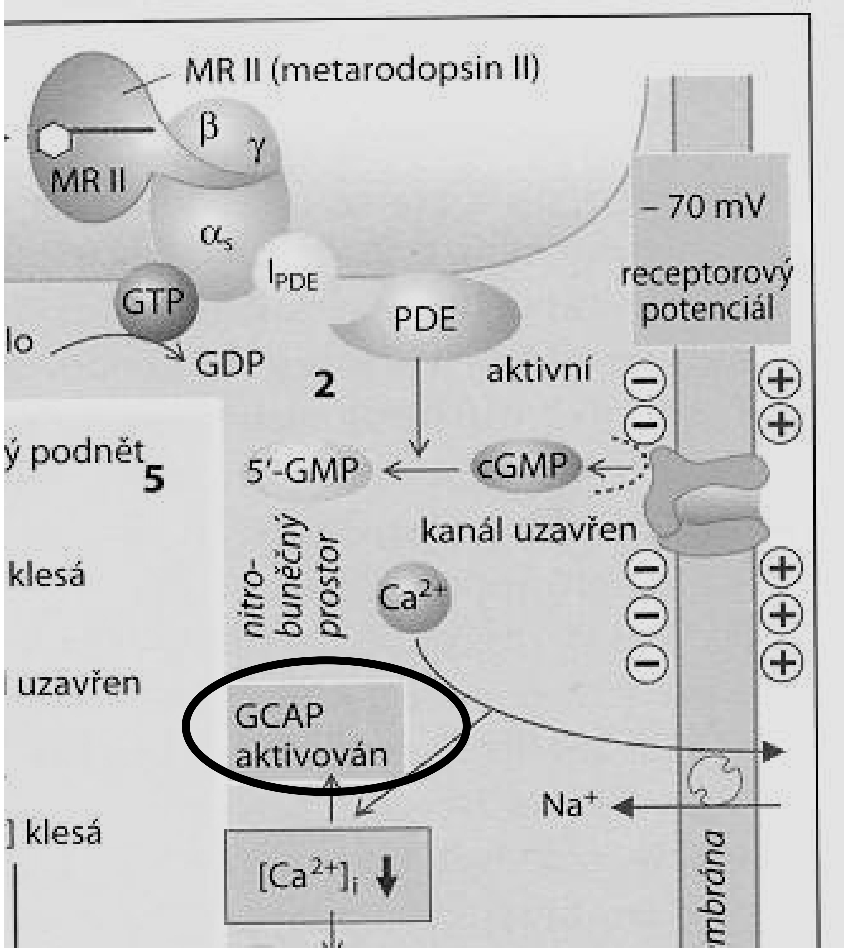
Řada zpětných vazeb:

- Vypnutí – Arestin v G-prot. signalizaci, Ca
- Adaptace – rozsah od 1 po 10^6 fotonů / sec, úloha Ca iontů (čich, sluch)
- Regenerace

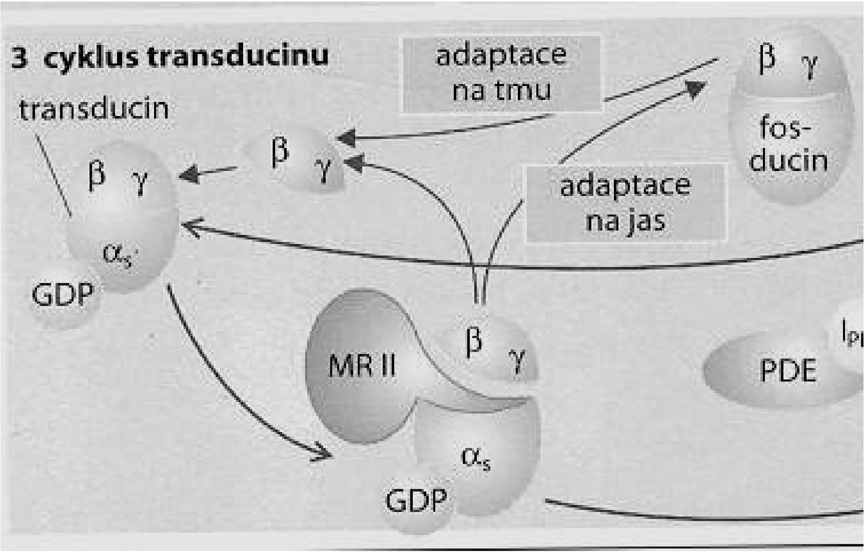
Inaktivace:
Samozhasnutí alfa Transducinu. Vlastní aktivitou štěpí GTP na GDP.

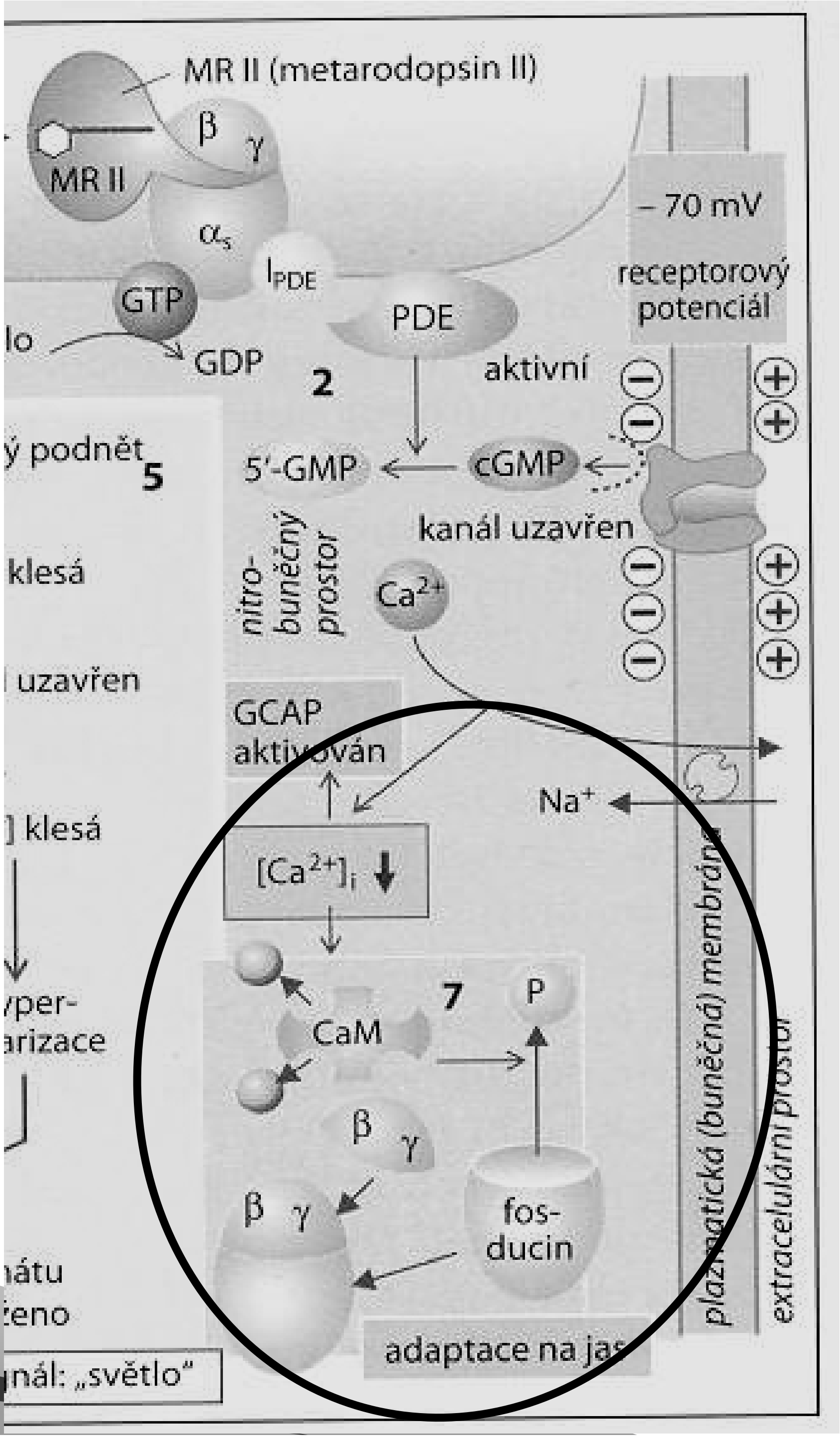


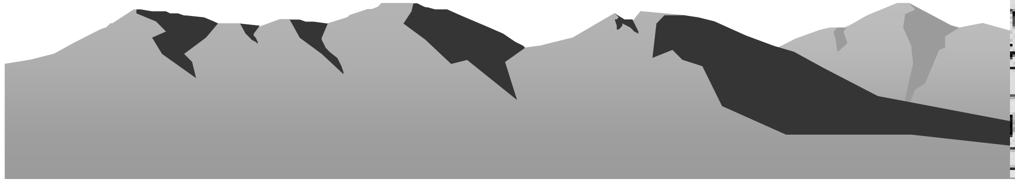
Inaktivace:
GCAP (guanylyl cyclase activating Protein) ztratí 4 Ca a aktivuje GC. Ta zvýší cGMP a kanály se zase otevřou



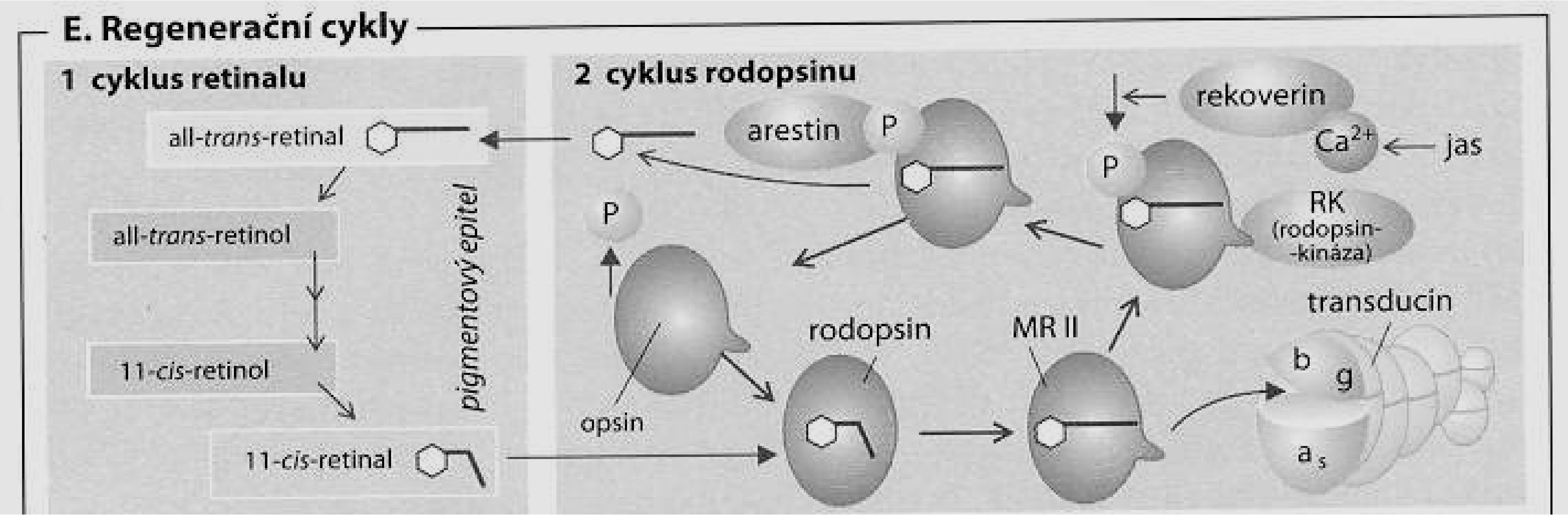
Adaptace:
Soutěž mezi fosducinem a alfa podjednotkou o beta a gama pod.
Ve světle je váže a tak blokuje regeneraci transducinu







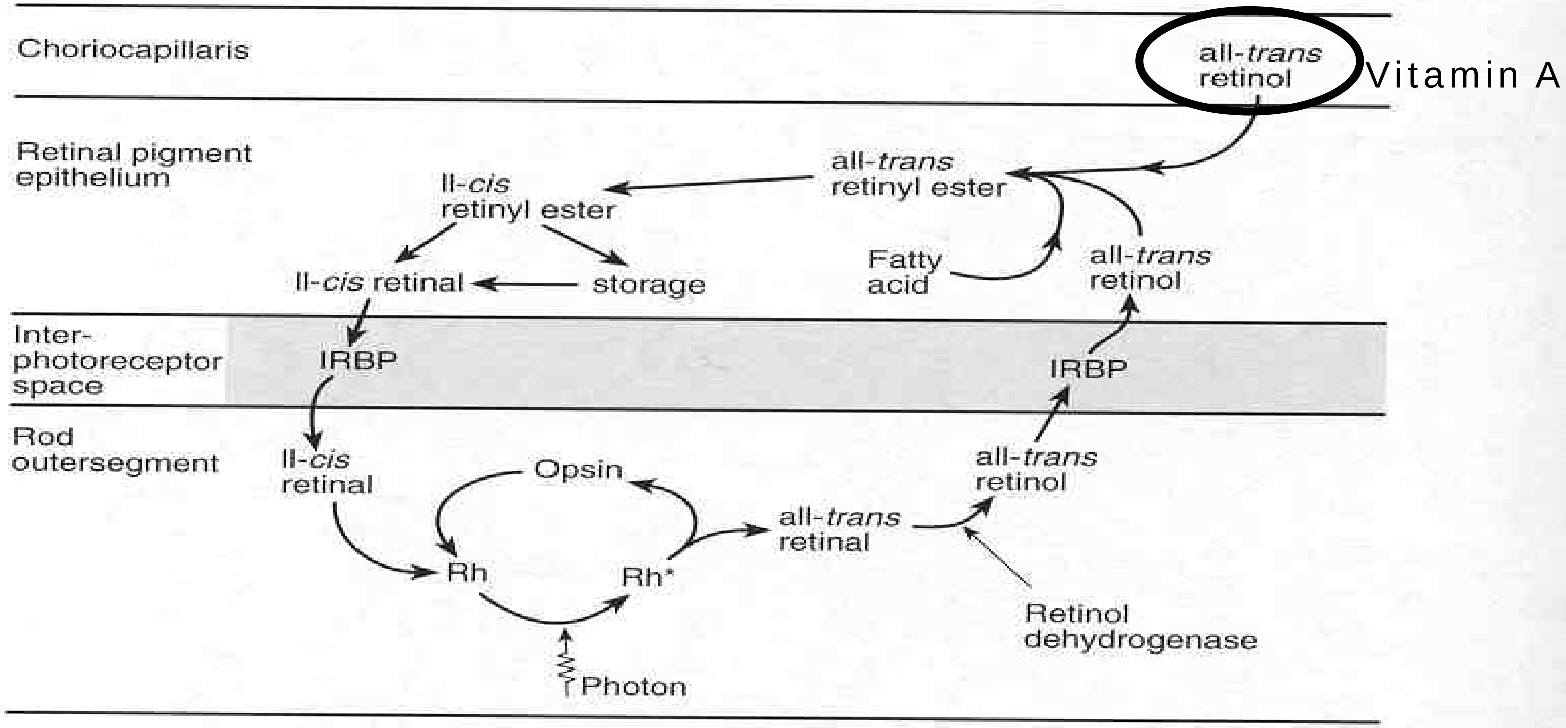
Regenerace retinalu v pigmentovém epitelu



Inaktivace:
MRII odhalí vazebné místo RK. Fosforyluje se, naváže arestin a dál už nereaguje s transducinem. All–trans-retinal se oddělí.

Ca adaptace:
Rekoverin citlivý na Ca se podílí na redukci životnosti rodopsinu

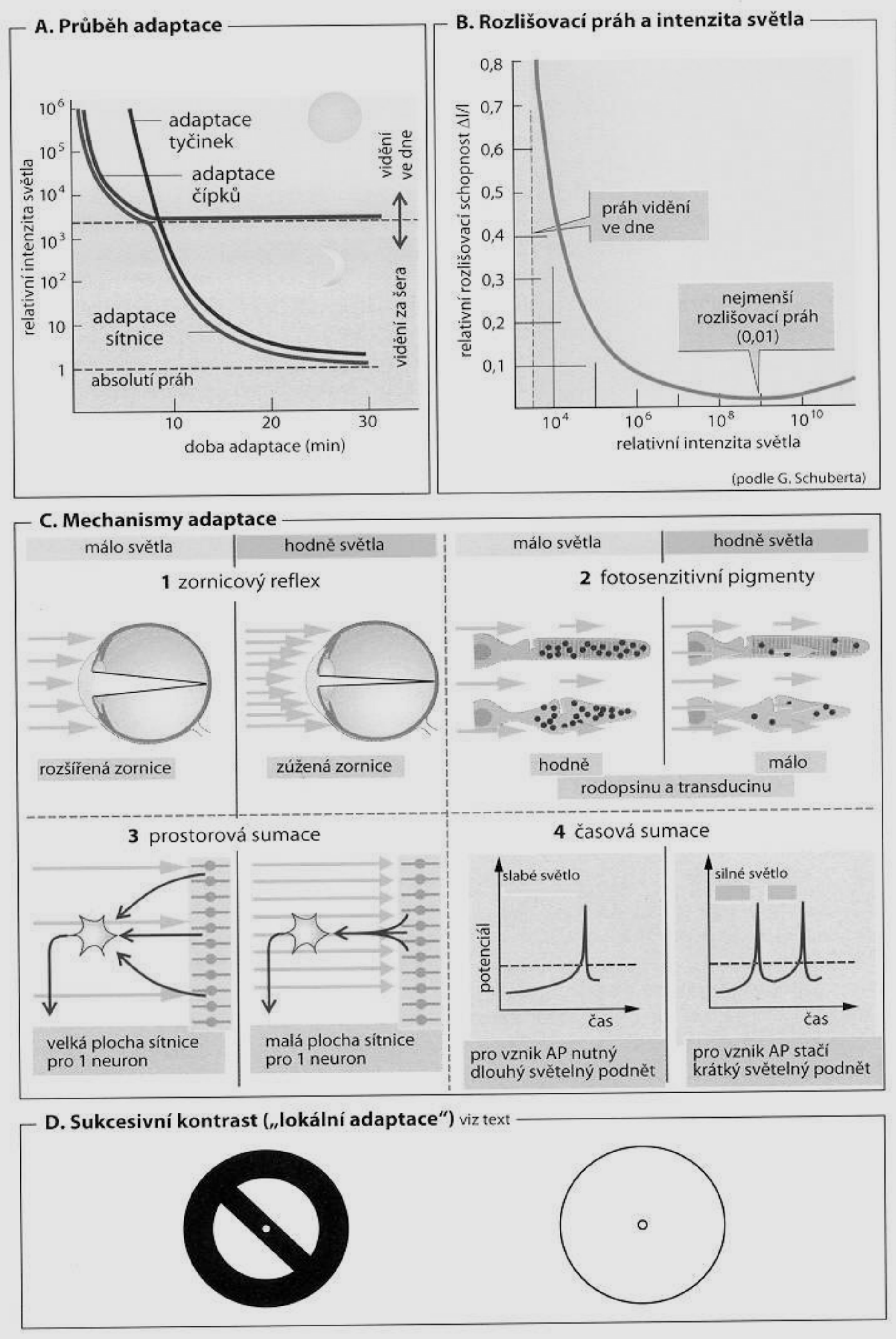
Regenerace retinalu v pigmentovém epitelu



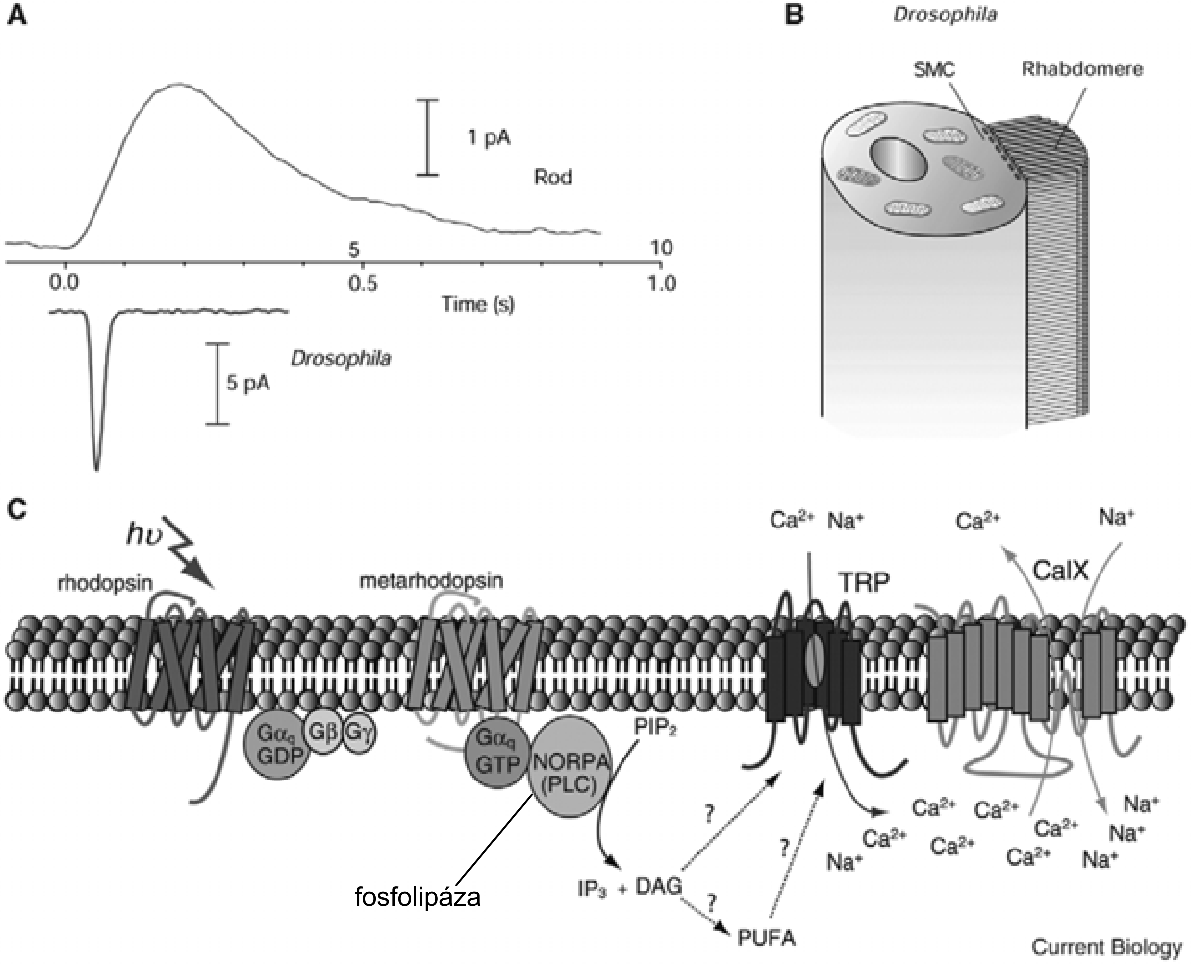
Vitamin A

Figure 16.13 Regeneration of 11-*cis* retinal. Explanation in text. IRBP = interphotoreceptor retinoid binding protein; Rh = rhodopsin; Rh* = activated rhodopsin. Simplified from Harding, 1997

Adaptace:


A. Průběh adaptace
10^6
10^5
10^4
10^3
10^2
10
1
relativní intenzita světla
adaptace tyčinek
adaptace čípků
adaptace sítnice
vidění ve dne
vidění za šera
absolutí práh
10
20
30
doba adaptace (min)
B. Rozlišovací práh a intenzita světla
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
relativní rozlišovací schopnost ΔI/I
práh vidění ve dne
nejmenší rozlišovací práh (0,01)
10^4
10^6
10^8
10^10
relativní intenzita světla
(podle G. Schuberta)
C. Mechanismy adaptace
málo světla
hodně světla
1 zornicový reflex
rozšířená zornice
zúžená zornice
málo světla
hodně světla
2 fotosenzitivní pigmenty
hodně
málo
rodopsinu a transducinu
3 prostorová sumace
velká plocha sítnice pro 1 neuron
malá plocha sítnice pro 1 neuron
4 časová sumace
slabé světlo
silné světlo
potenciál
čas
čas
pro vznik AP nutný dlouhý světelný podnět
pro vznik AP stačí krátký světelný podnět
D. Sukcesivní kontrast („lokální adaptace“) viz text

Drosophila jako užitečný model zrakové transdukce:
Mimořádné zesílení – reakce na jediný foton
Nízký šum ve tmě (spontánní termální izomerizace)
Široká adaptace – rozsah až 10^6 (arestin, Ca)
Rychlá terminace odpovědi
Nejrychlejší známá G signální dráha – 10x než obratlovci



Drosophila jako užitečný model zrakové transdukce:
Taková rychlost? PLC octomilky je jeden z nejvýkonnějších známých enzymů- limitem je jen přísun cGMP
Výkonnost transdukce omezena pouze difuzním pohybem v membráně.

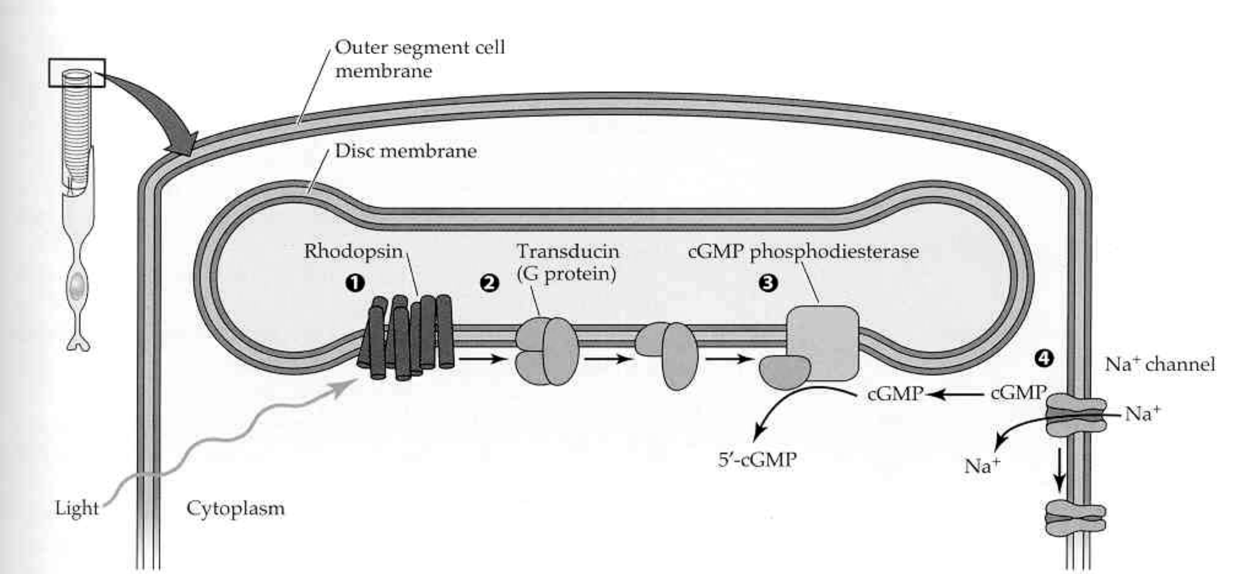
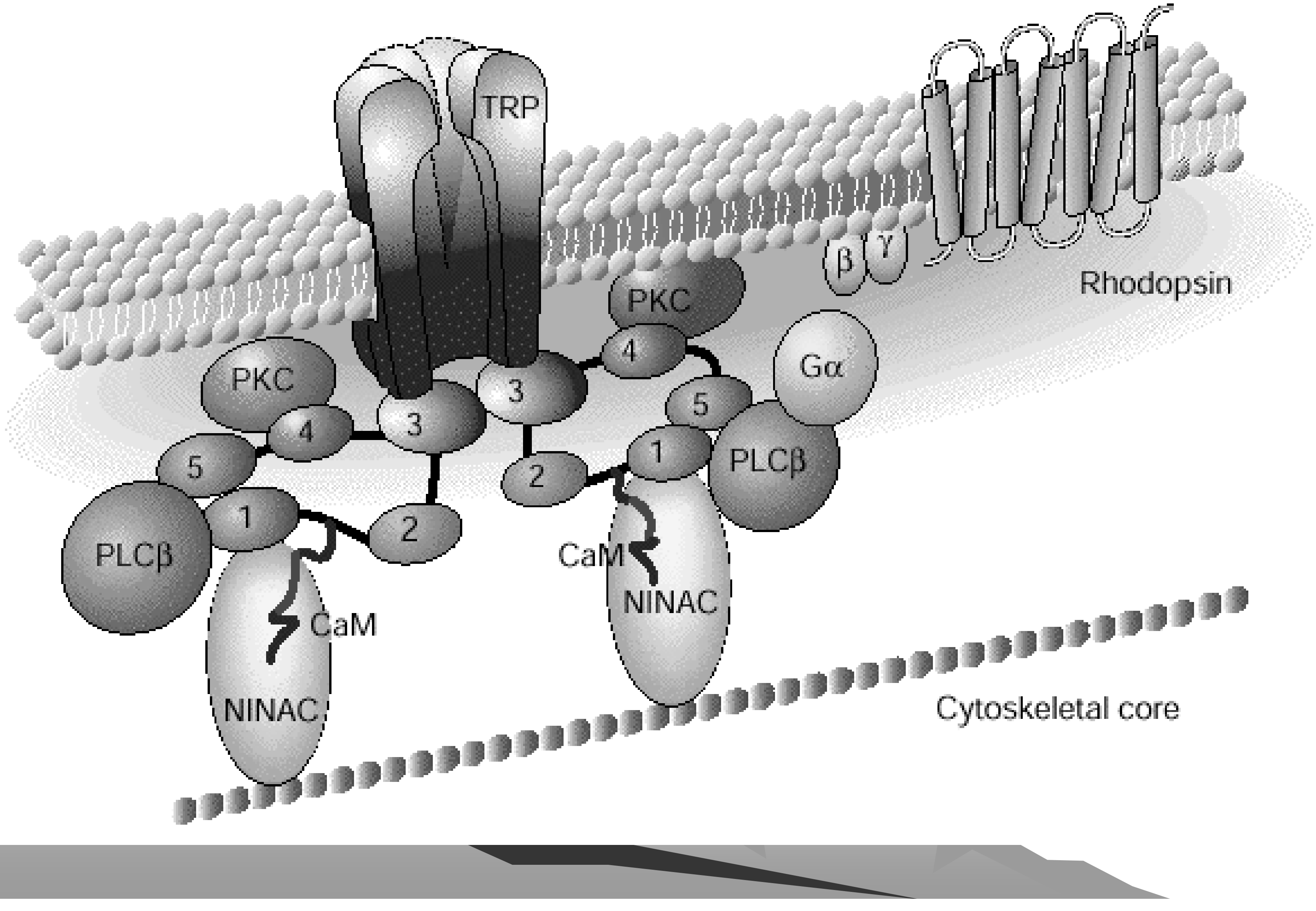


Figure 13.14 Phototransduction closes cation channels in the outer segment of the photoreceptor membrane In the dark, the cation channels are kept open by intracellular cGMP and conduct an inward current, carried largely by Na^+. When light strikes the photoreceptor, these channels are closed by a G protein–coupled mechanism. ❶ Rhodopsin molecules in the disc membrane absorb light and are activated. ❷ The activated rhodopsin stimulates a G protein (transducin in rods), which in turn activates cGMP phosphodiesterase. ❸ The phosphodiesterase catalyzes the breakdown of cGMP to 5′-GMP. ❹ As the cGMP concentration decreases, cGMP detaches from the cation channels, which close.

Drosophila jako užitečný model zrakové transdukce:
Difuzní model signálového přenosu x Signalplex, scaffolding proteins
Multimolekulární signalizační komplex



Drosophila jako užitečný model zrakové transdukce:
Organizace signálních proteinů
v čase a prostoru – oddělení, zhášení
v odpověď na světlo

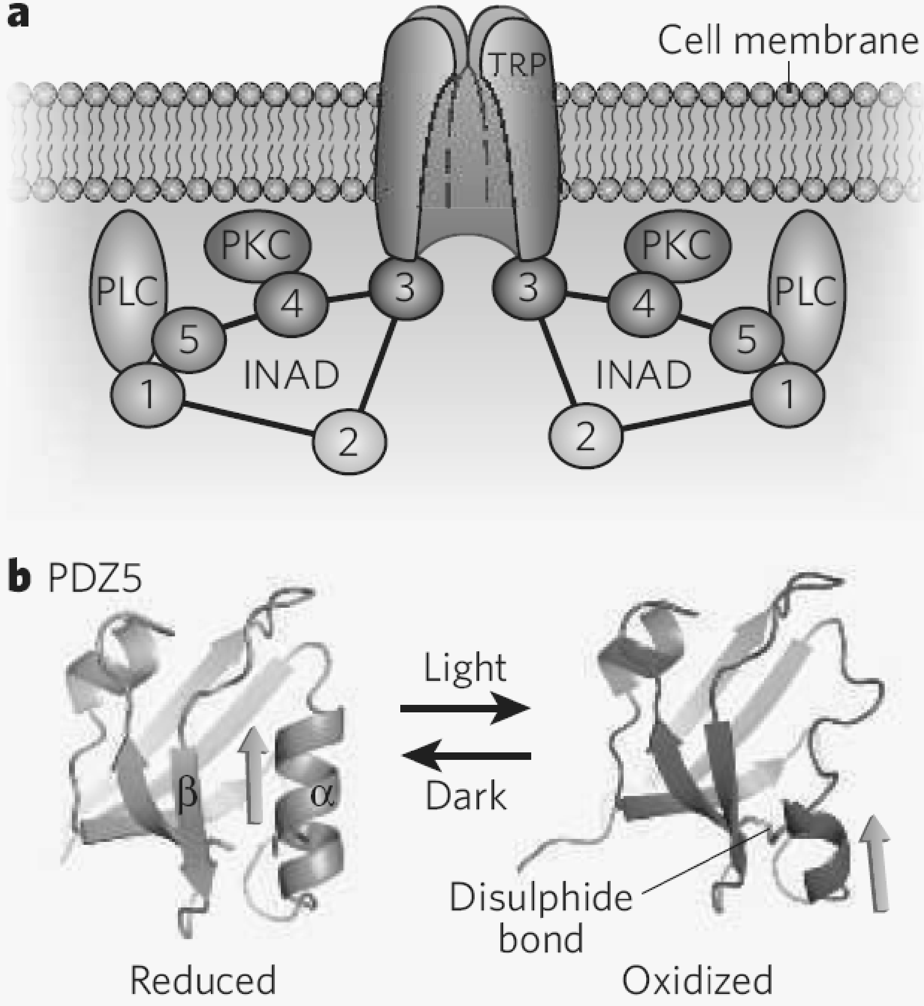
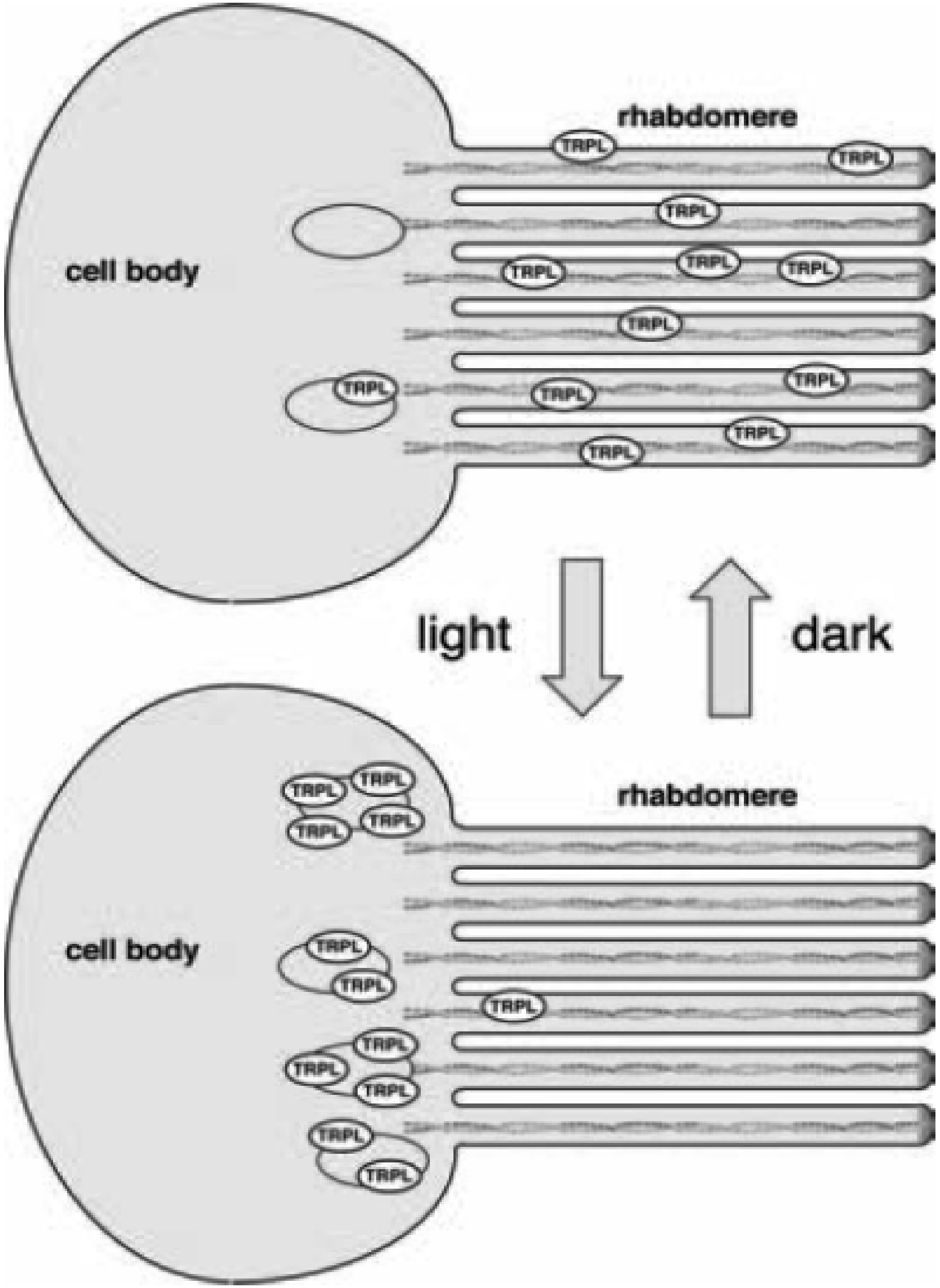
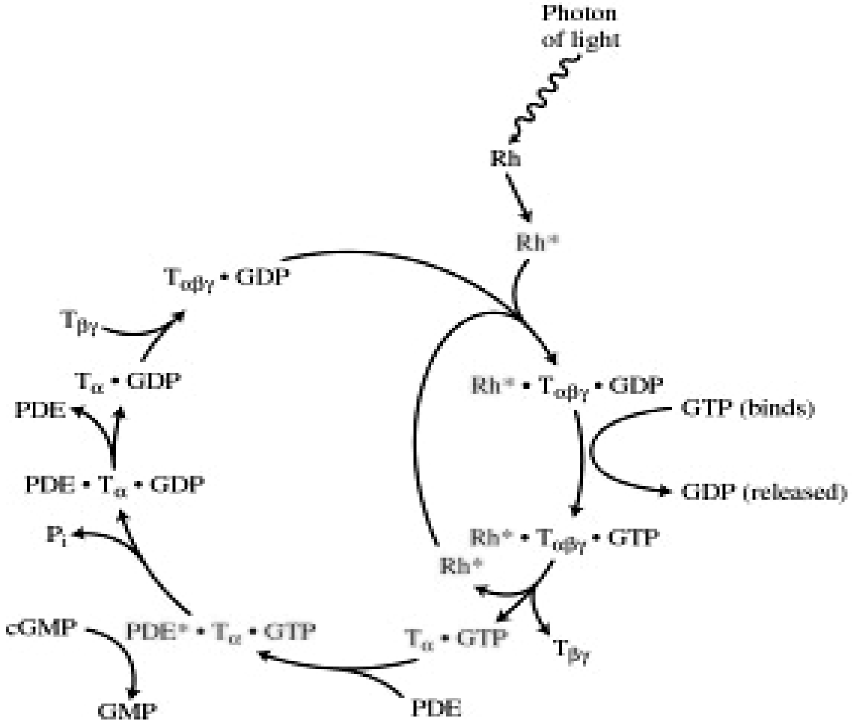


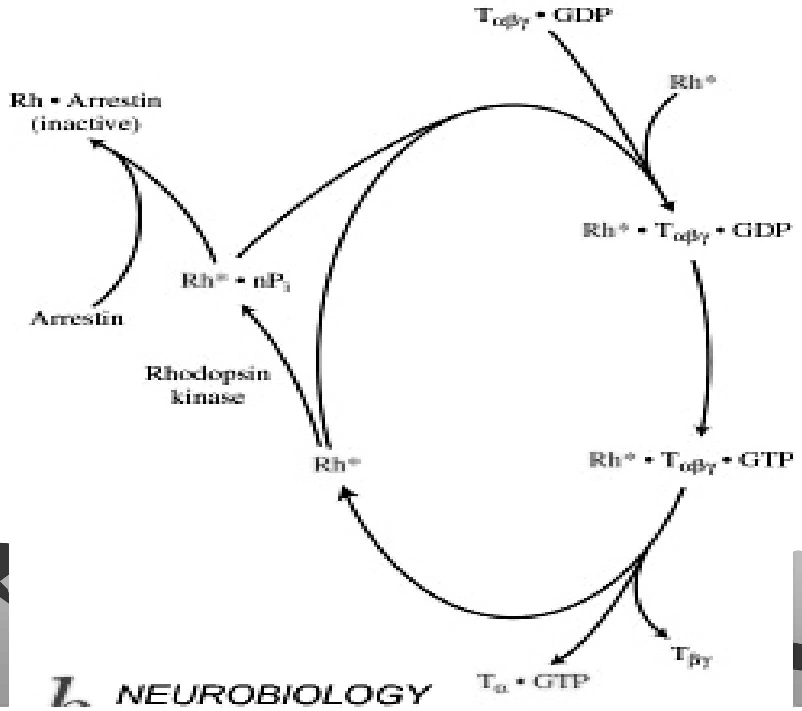
Figure 1 | Phototransduction in *Drosophila* and the INAD complex. a, The five PDZ domains of INAD (1–5) assemble components of the phototransduction cascade, including PLC, the TRP channel and PKC, into a signalling complex at the cell membrane. **b**, Mishra *et al.*[2] report that, in response to light, the PDZ5 domain of INAD undergoes a conformational change. In the dark, PDZ5 is in its canonical, reduced form, in which a groove between an α-helix and a β-sheet serves as a ligand-binding site. After stimulation with light, the PDZ5 domain undergoes a conformational change to an oxidized state, whereby the formation of a disulphide bond between two cysteine residues results in the unravelling of the α-helix and the distortion of the ligand-binding groove. Following this conformational switch, the ligand (arrowed) — putatively part of the PLC enzyme — can no longer bind. (Adapted from ref. 2.)

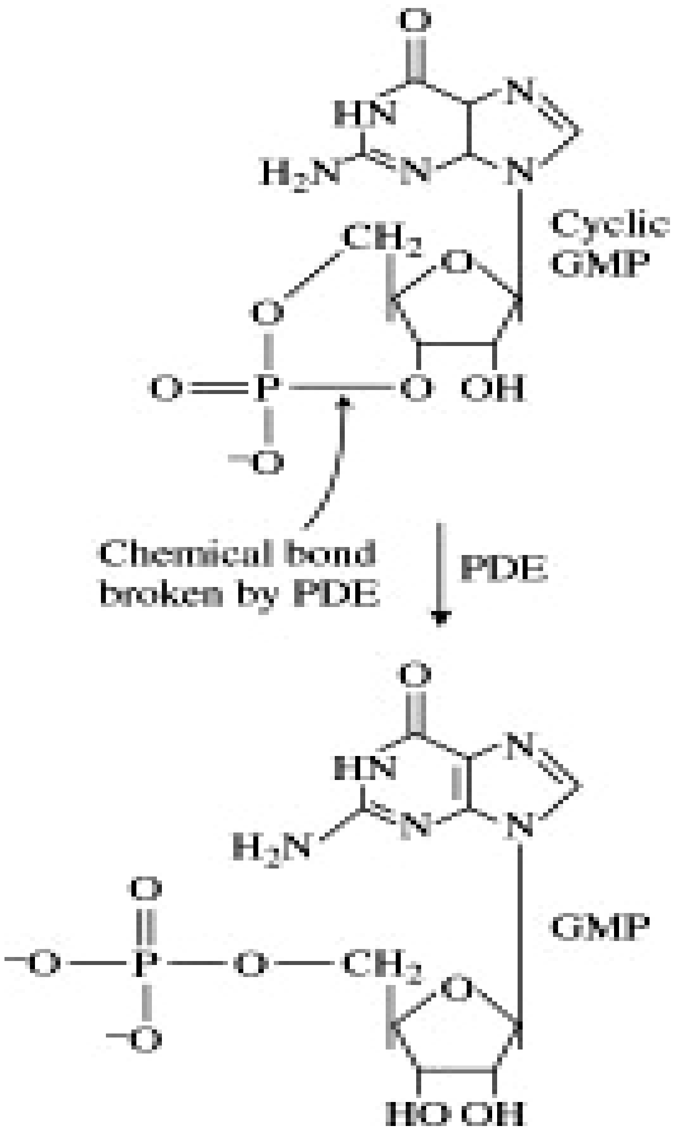
Drosophila jako užitečný model
zrakové transdukce:
Taková adaptace?
Translokace TRP –
mechanismus adaptace
na tmu a světlo



cGMP na GMP


Photon
of light
Rh
Rh*
$T_{\alpha\beta\gamma}$ • GDP
$T_{\beta\gamma}$
T_{α} • GDP
PDE
PDE • T_{α} • GDP
P_i
cGMP
PDE* • T_{α} • GTP
GMP
Rh* • $T_{\alpha\beta\gamma}$ • GDP
GTP (binds)
GDP (released)
Rh* • $T_{\alpha\beta\gamma}$ • GTP
Rh*
T_{α} • GTP
$T_{\beta\gamma}$
PDE

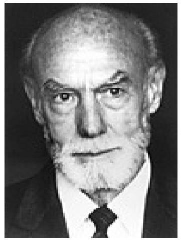

$T_{\alpha\beta\gamma}$ • GDP
Rh*
Rh • Arrestin
(inactive)
Rh* • $T_{\alpha\beta\gamma}$ • GDP
Rh* • nP_i
Arrestin
Rhodopsin
kinase
Rh*
Rh* • $T_{\alpha\beta\gamma}$ • GTP
$T_{\beta\gamma}$
T_{α} • GTP
NEUROBIOLOGY


O
HN
N
H₂N
N
N
Cyclic
GMP
CH₂
O
O
O
P
O
OH
⁻O
Chemical bond
broken by PDE
PDE
O
HN
N
H₂N
N
N
GMP
O
⁻O
P
O
CH₂
O
⁻O
HO OH

The Nobel Prize in Physiology or Medicine 1981

"for his discoveries concerning the functional specialization of the cerebral hemispheres"

"for their discoveries concerning information processing in the visual system"



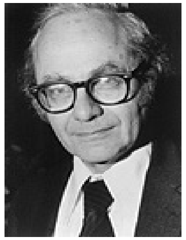
Roger W. Sperry

1/2 of the prize

USA

California Institute of Technology
Pasadena, CA, USA

b. 1913
d. 1994



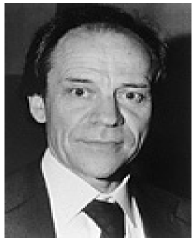
David H. Hubel

1/4 of the prize

USA

Harvard Medical School
Boston, MA, USA

b. 1926
(in Windsor, ON, Canada)



Torsten N. Wiesel

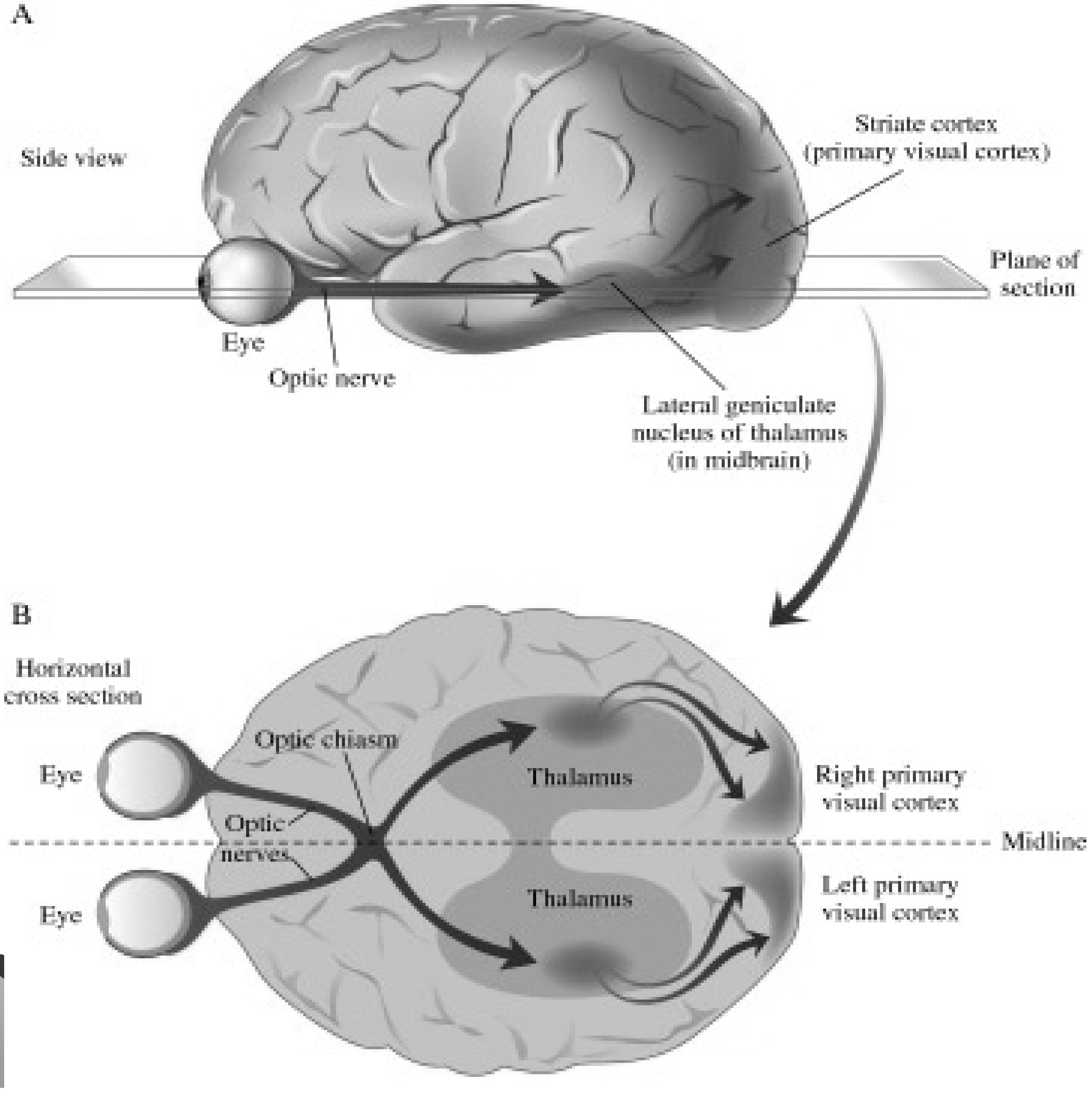
1/4 of the prize

Sweden

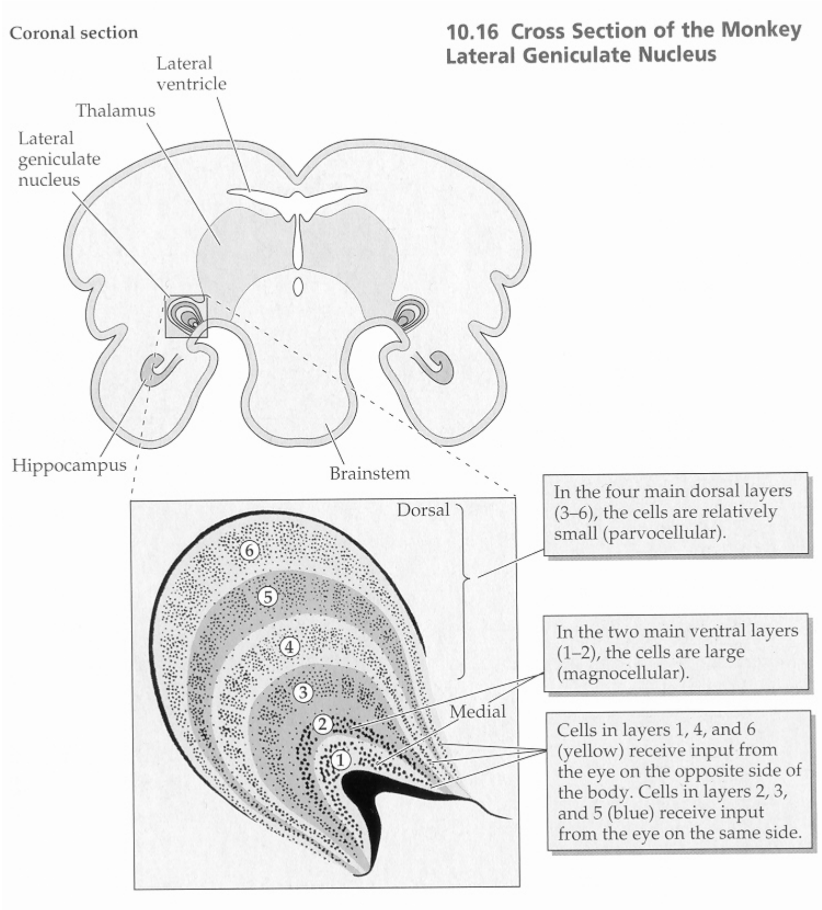
Harvard Medical School
Boston, MA, USA

b. 1924

Zraková dráha



Zraková dráha



10.16 Cross Section of the Monkey Lateral Geniculate Nucleus

In the four main dorsal layers (3–6), the cells are relatively small (parvocellular).

In the two main ventral layers (1–2), the cells are large (magnocellular).

Cells in layers 1, 4, and 6 (yellow) receive input from the eye on the opposite side of the body. Cells in layers 2, 3, and 5 (blue) receive input from the eye on the same side.

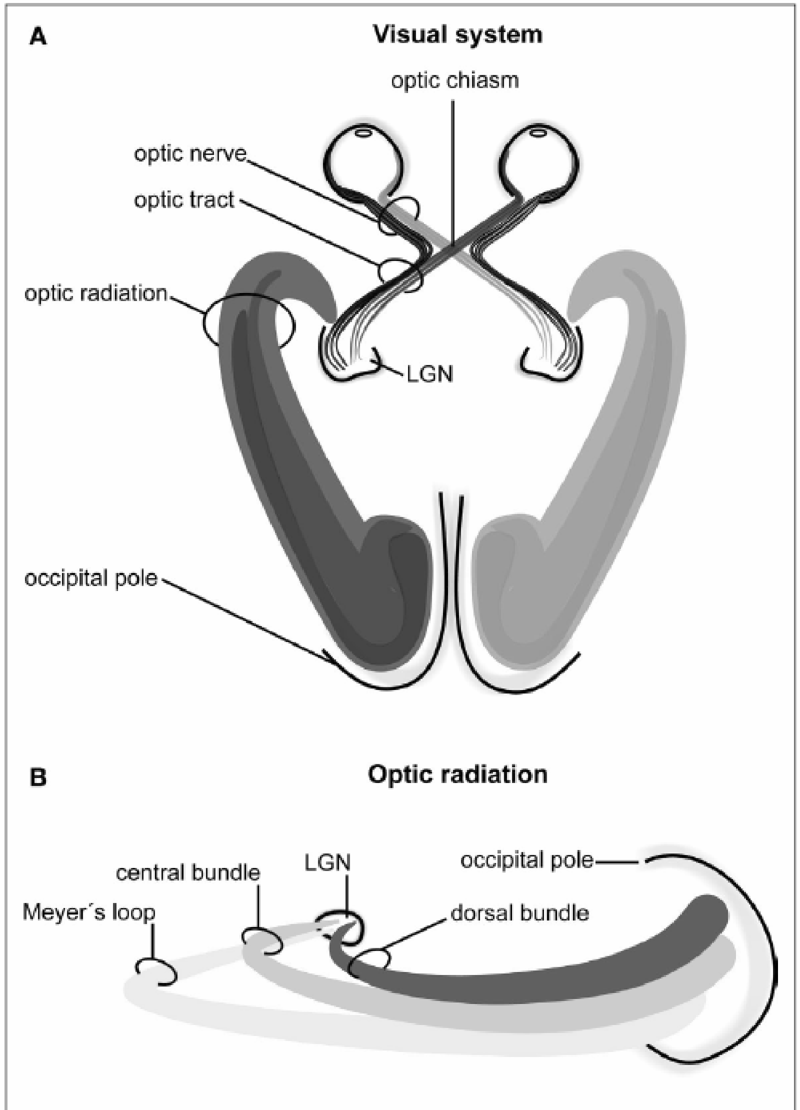
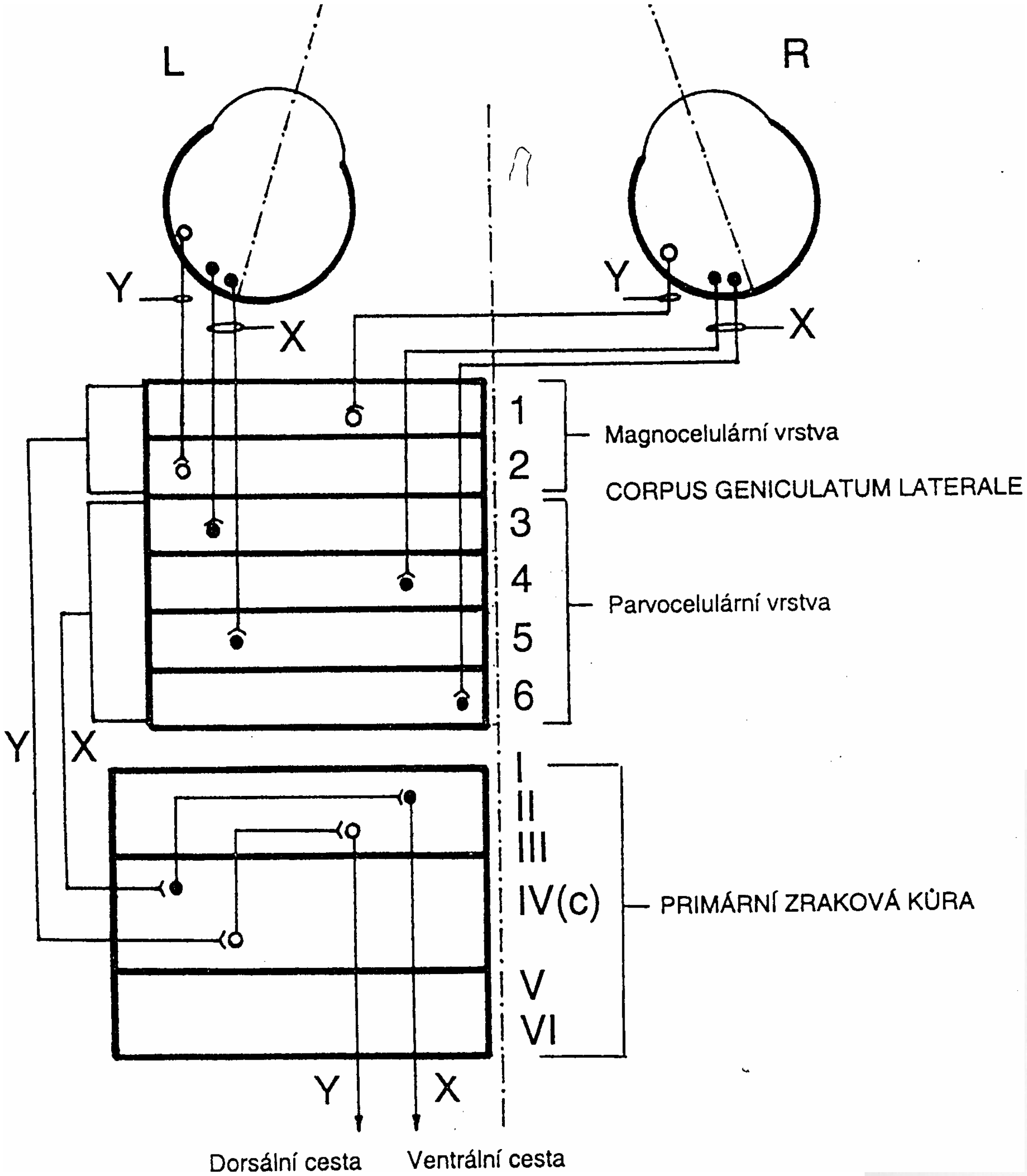
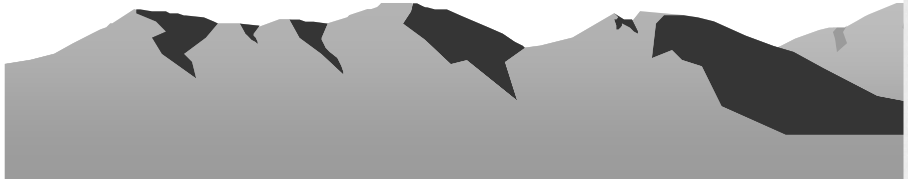
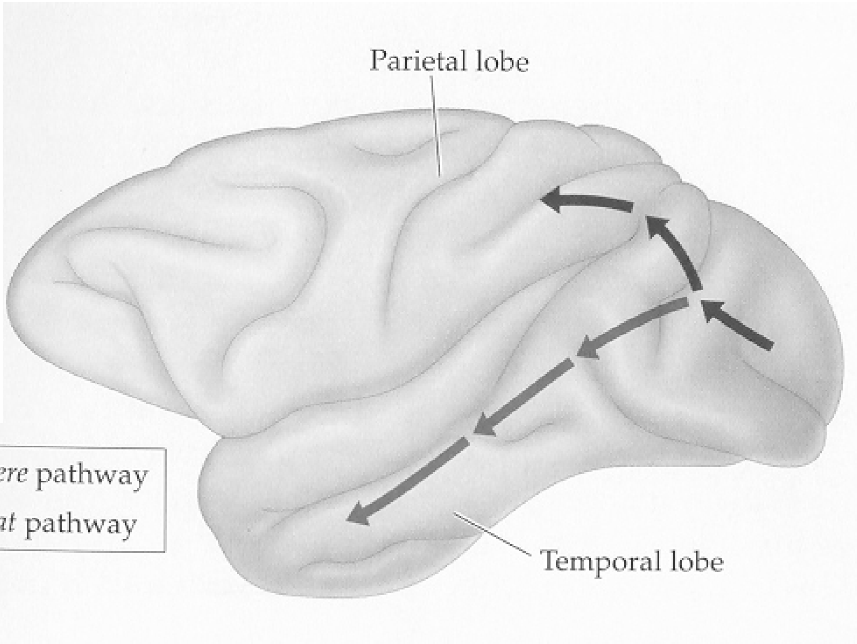


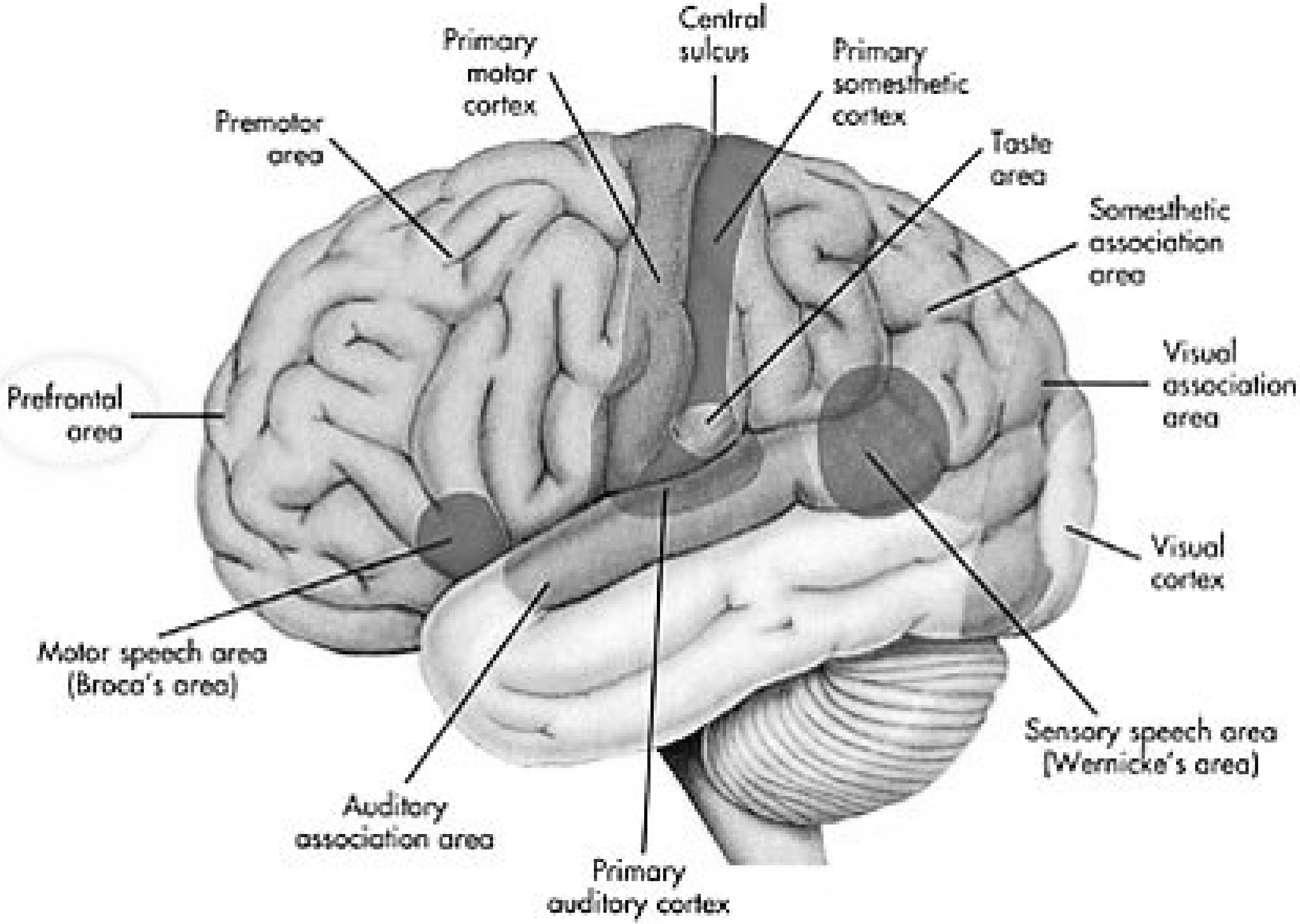
FIGURE 1 | Schematic drawing of the human visual system. (A) Right- and left-hemispheric fiber pathways. **(B)** Left-hemispheric optic radiation comprising the anterior bundle termed Meyer's loop (yellow), the central bundle (green), and the dorsal bundle (blue). LGN, lateral geniculate nucleus.

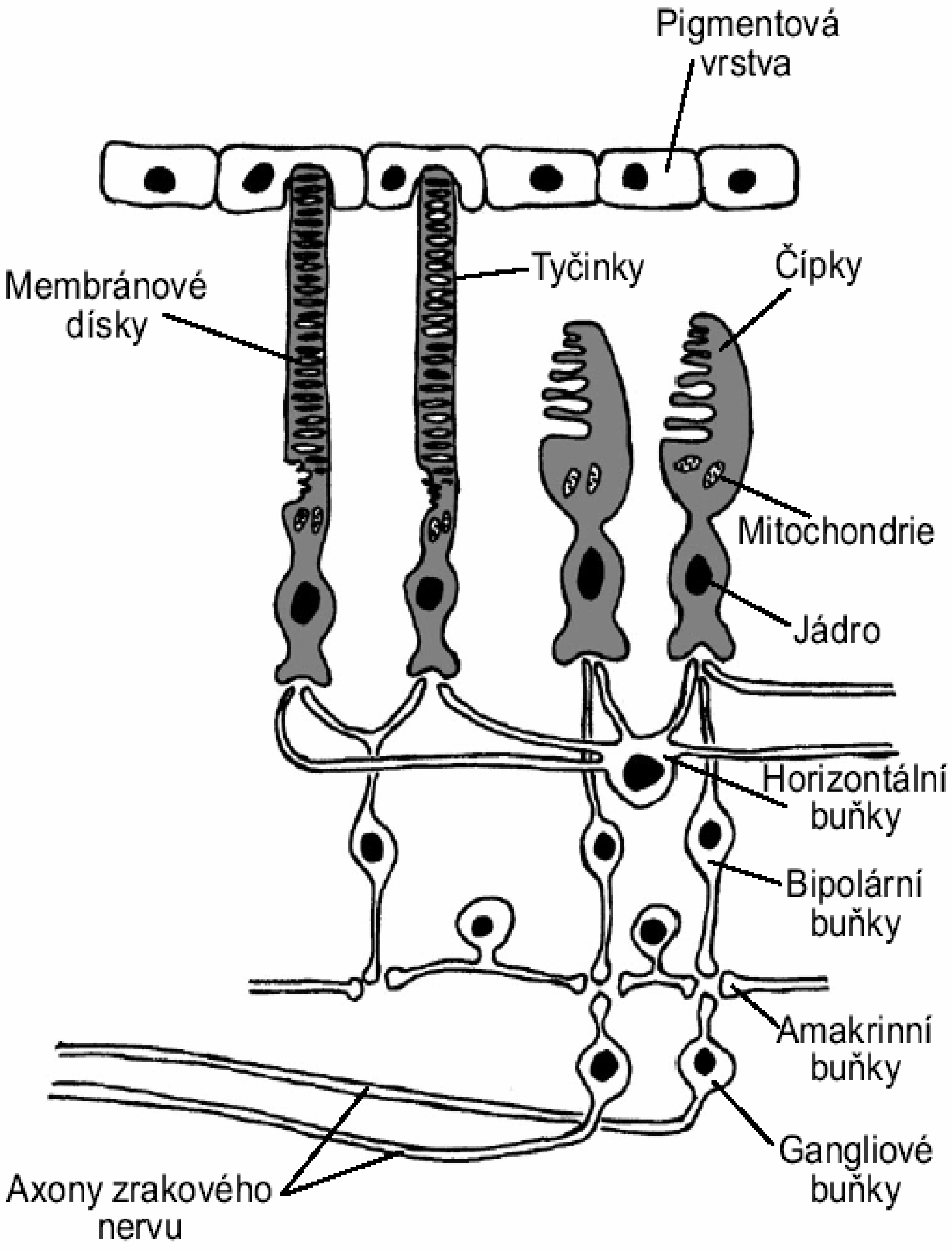


Dvě samostatné sub-dráhy od sítnice až po kůru.
X - 80% gangliových bb
Y – 10% g.b.

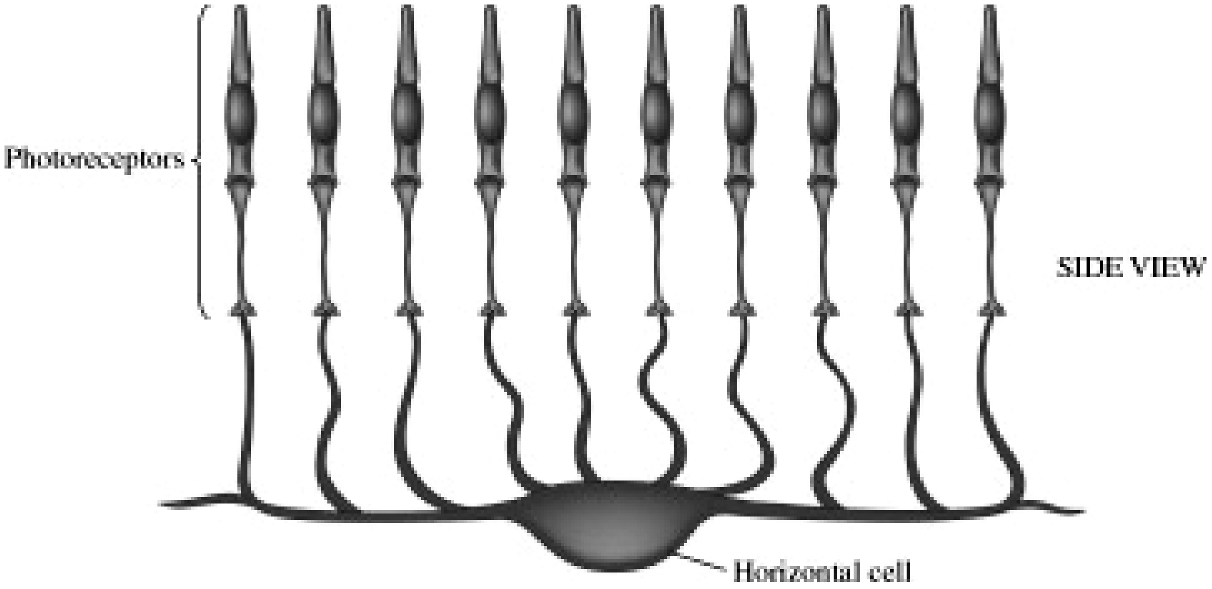


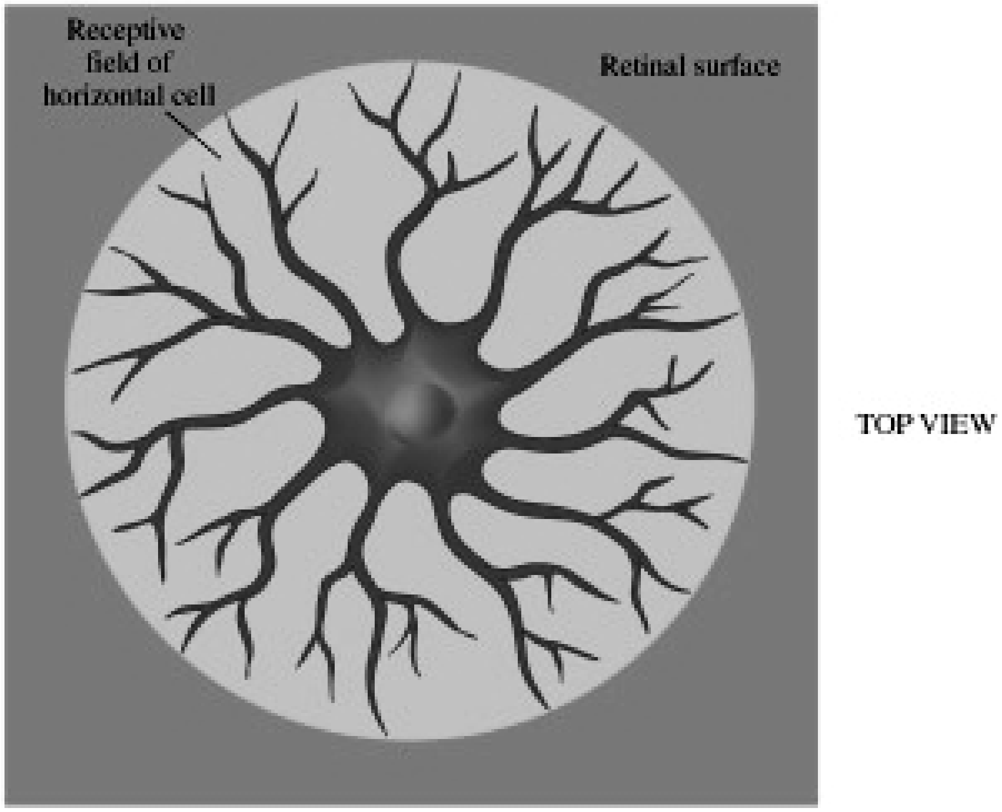



Central sulcus
Primary motor cortex
Primary somesthetic cortex
Premotor area
Taste area
Somesthetic association area
Prefrontal area
Visual association area
Visual cortex
Motor speech area (Broca's area)
Sensory speech area (Wernicke's area)
Auditory association area
Primary auditory cortex

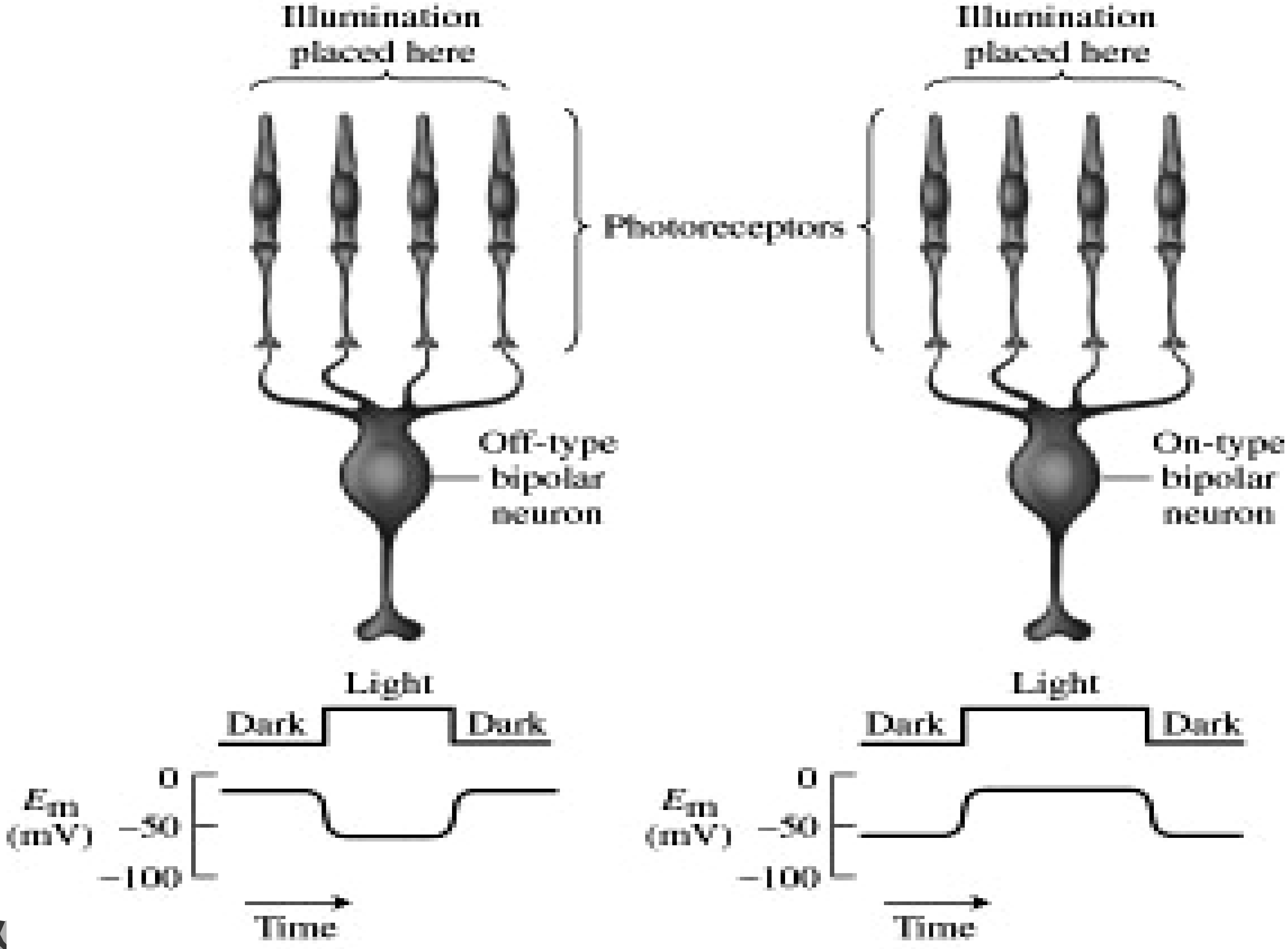

Pigmentová vrstva
Membránové dísky
Tyčinky
Čípky
Mitochondrie
Jádro
Horizontální buňky
Bipolární buňky
Amakrinní buňky
Gangliové buňky
Axony zrakového nervu

Receptivní pole ve zrakovém systému

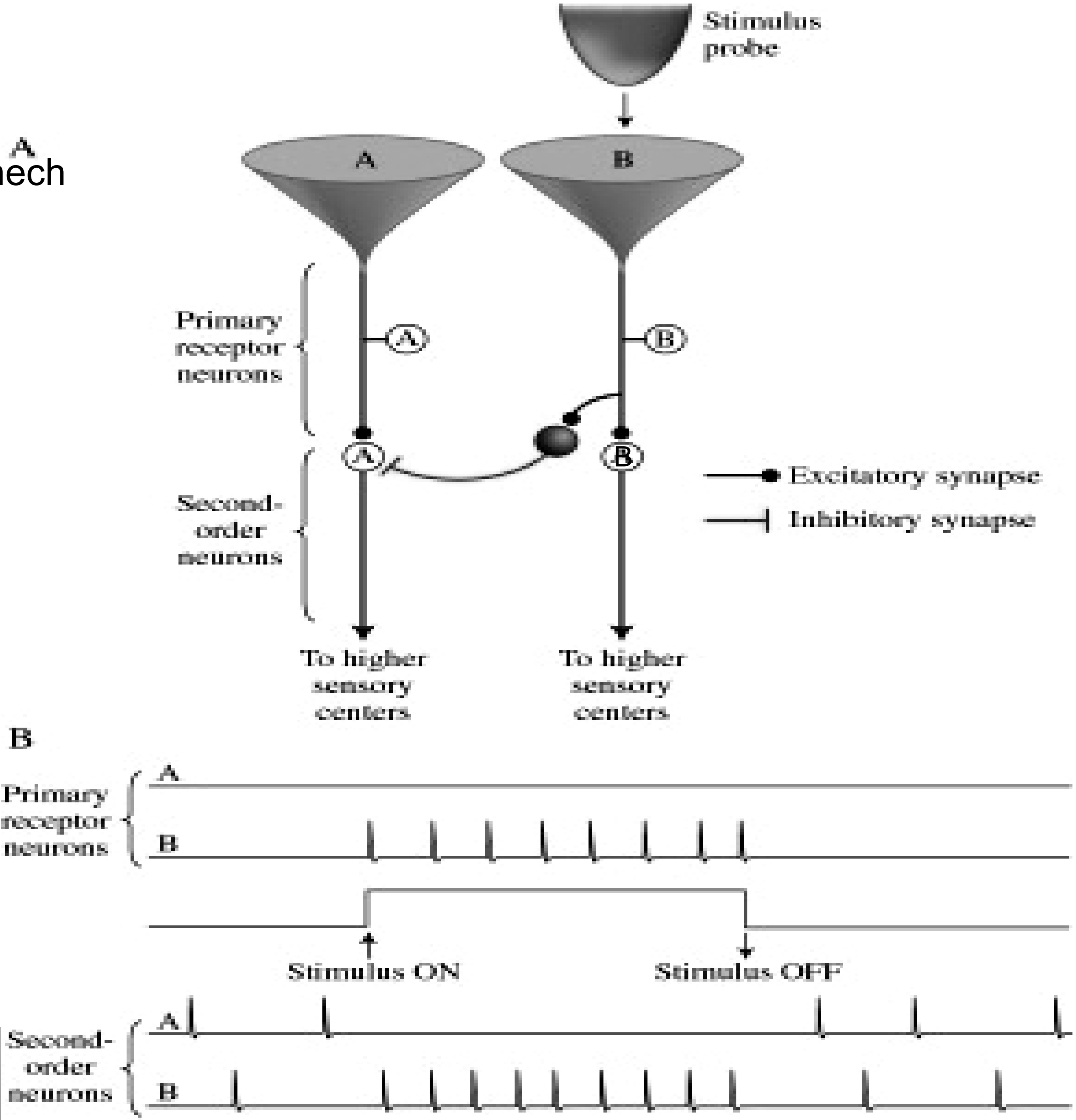


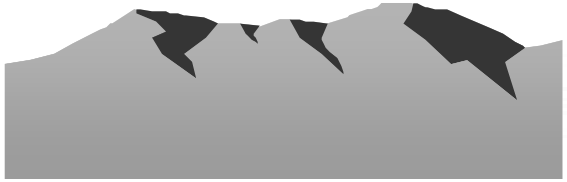


ON a OFF typy bipolárních neuronů.

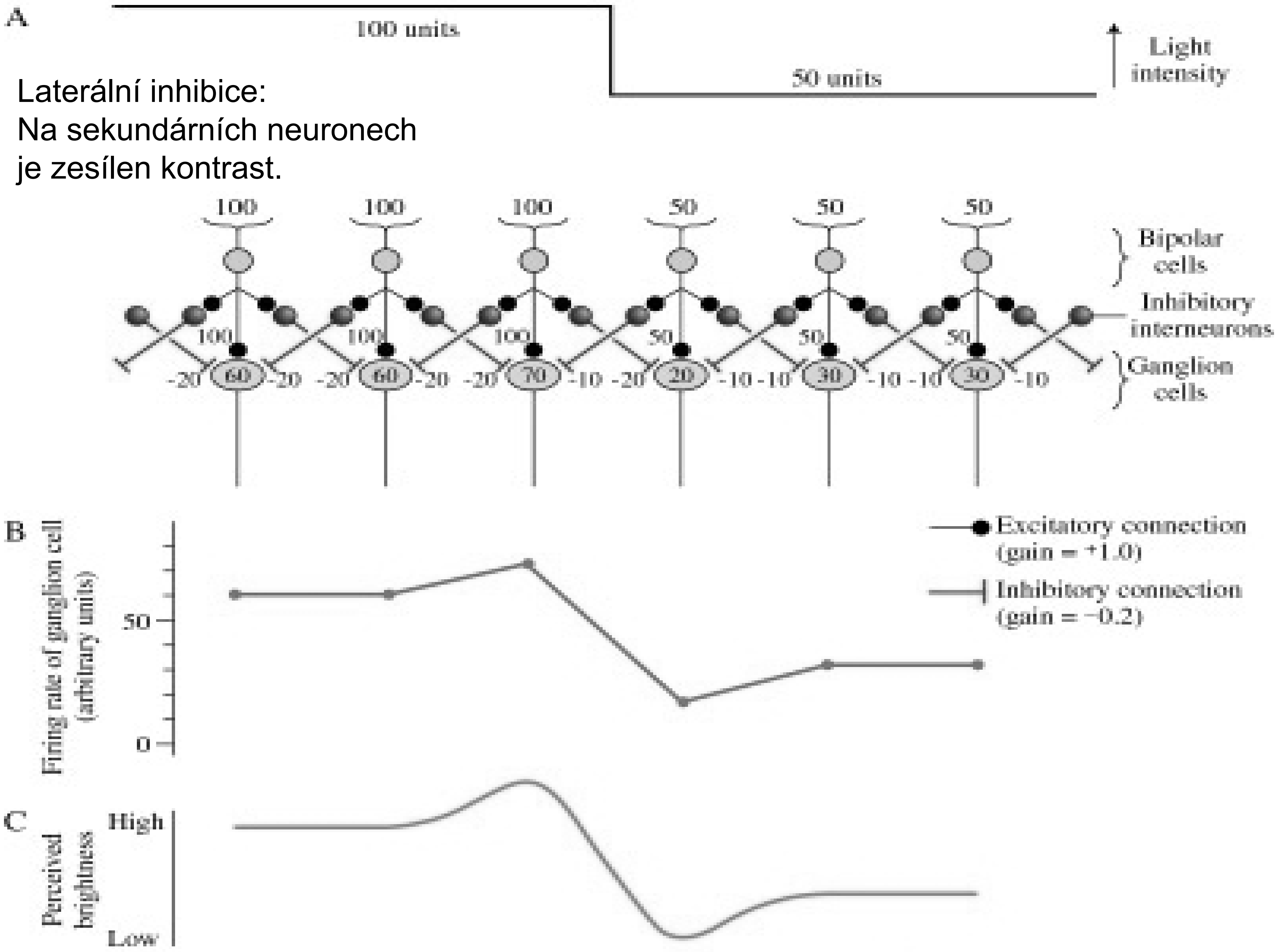


Laterální inhibice:
Na sekundárních neuronech je zesílen kontrast. Silný posílí, slabý oslabí

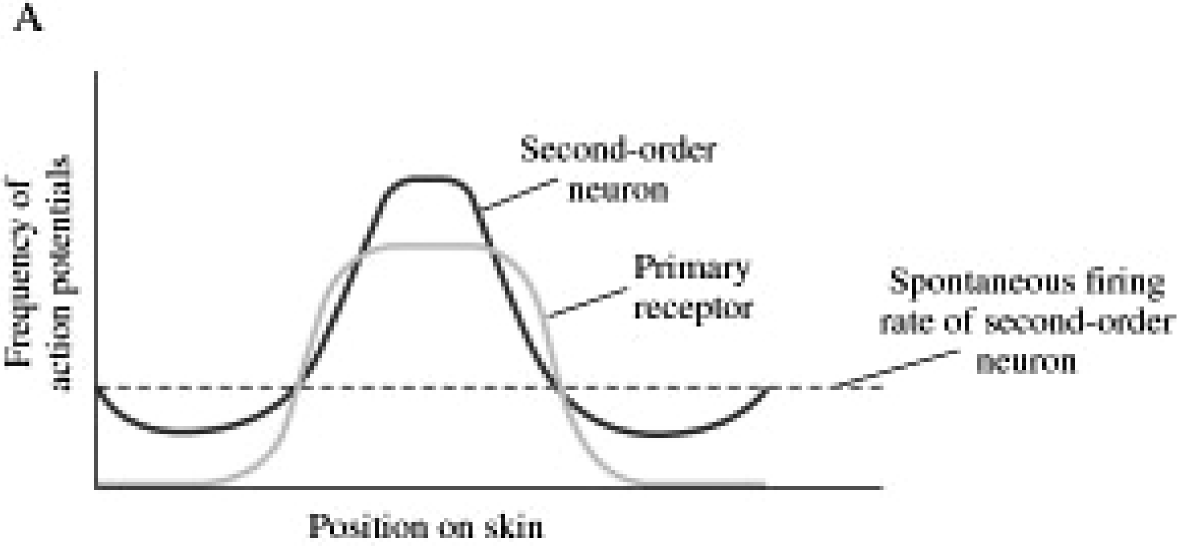


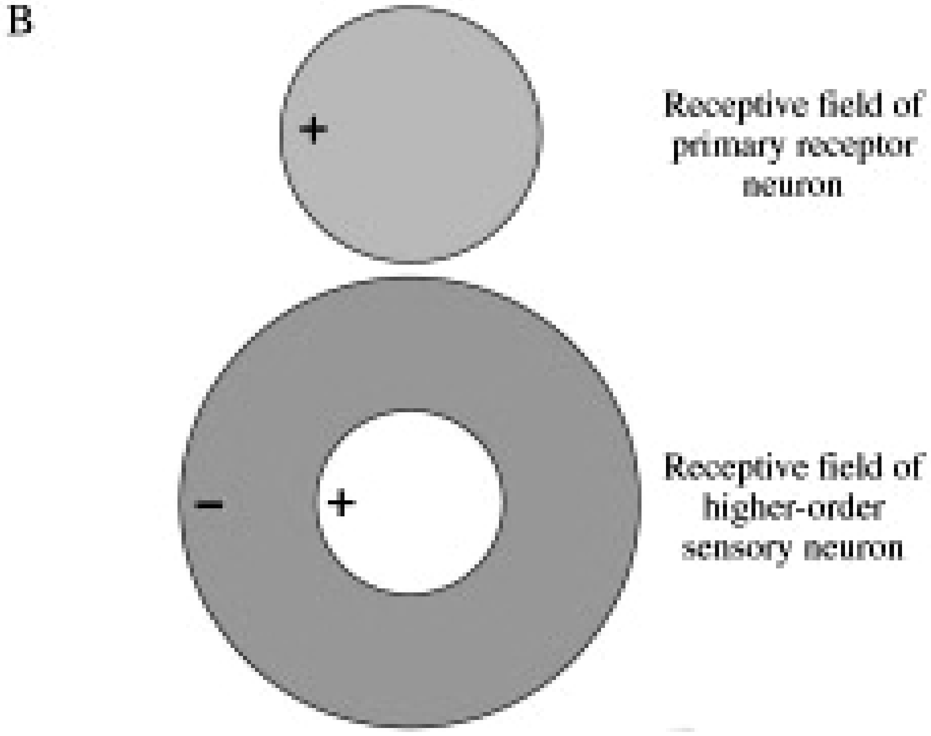


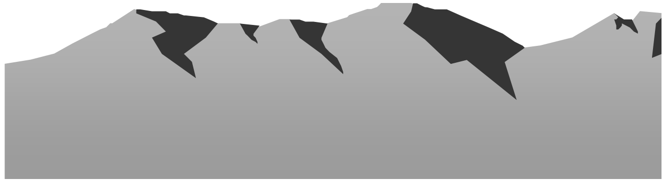
Laterální inhibice:
Na sekundárních neuronech
je zesílen kontrast.



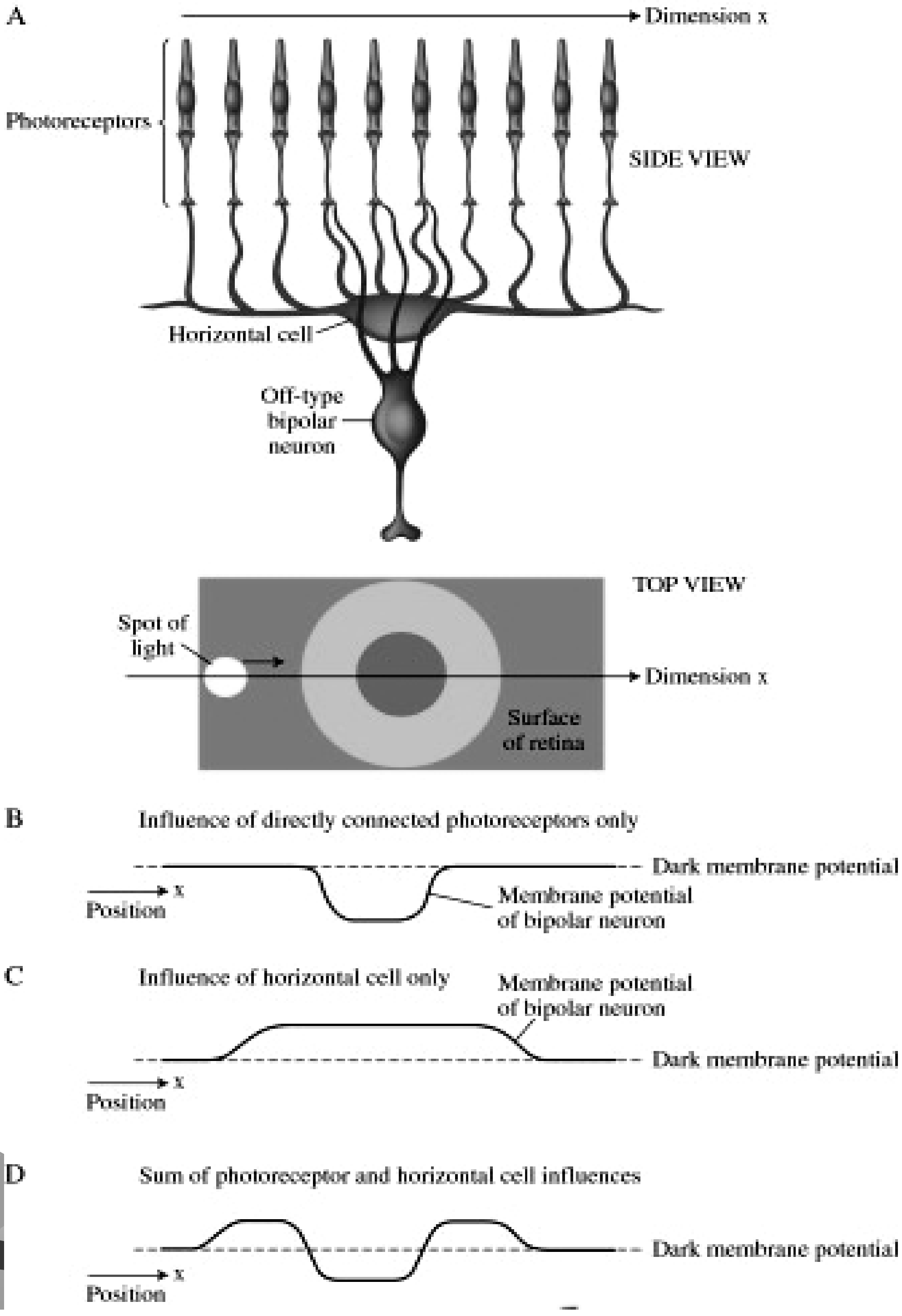
Laterální inhibice:
Na sekundárních neuronech je zesílen kontrast.
Změna velikosti a struktury receptivního pole.





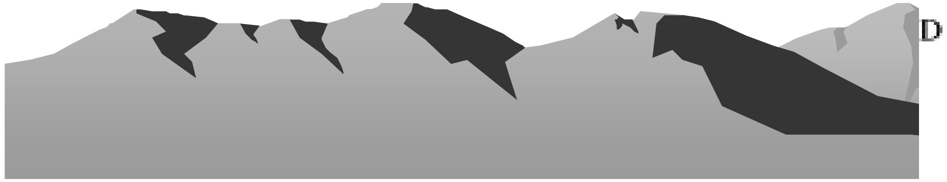


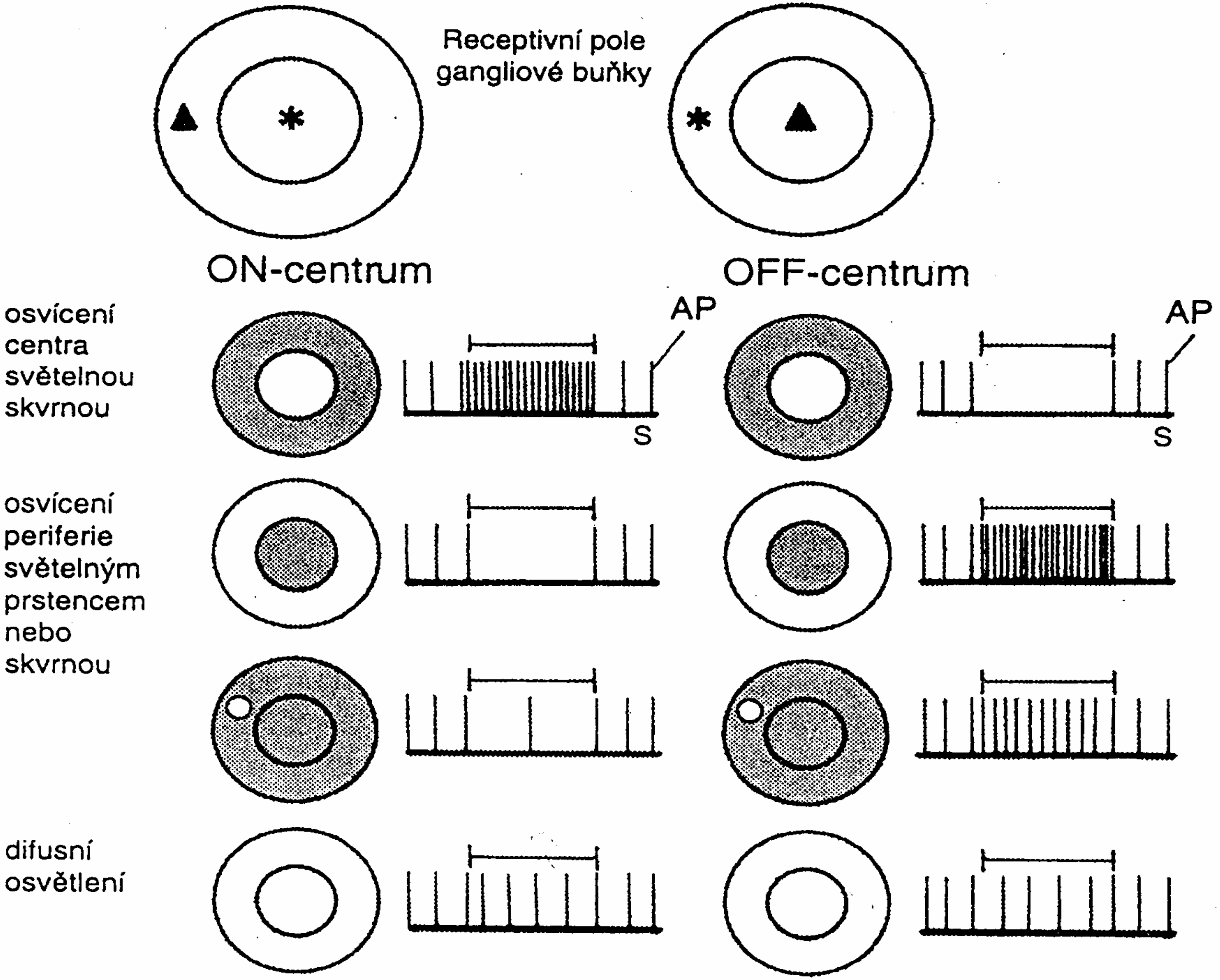
Laterální inhibice:
Na sekundárních neuronech
je zesílen kontrast.
Změna velikosti a struktury
receptivního pole.
Gangliové buňky jsou první rysové
analyzátory



Video receptivní pole

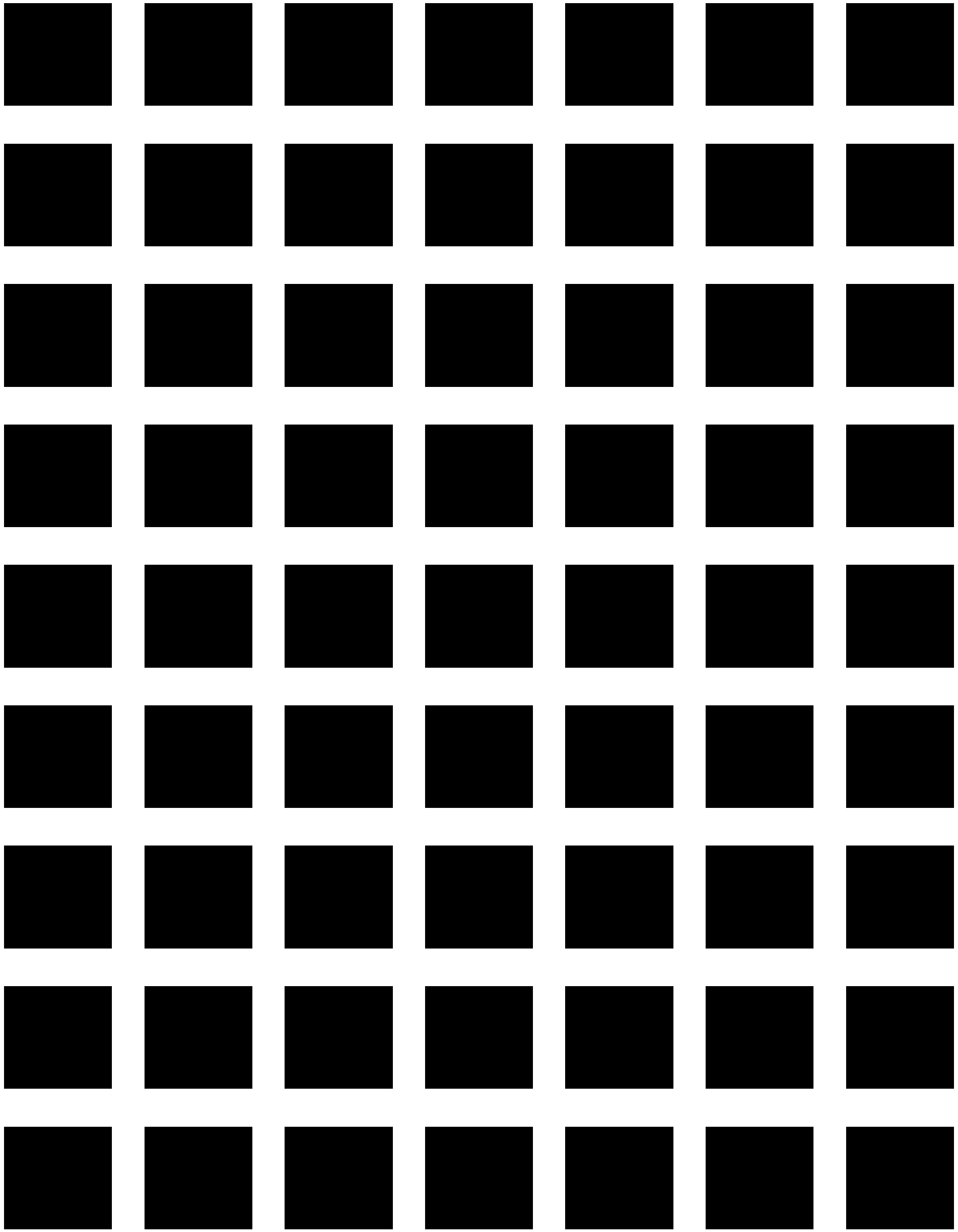
Video receptivní pole

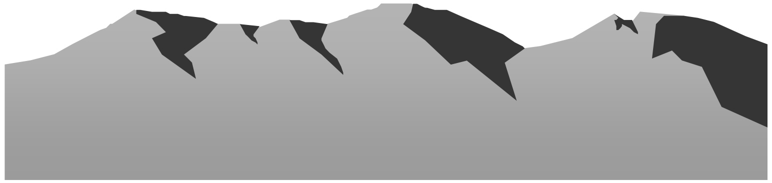




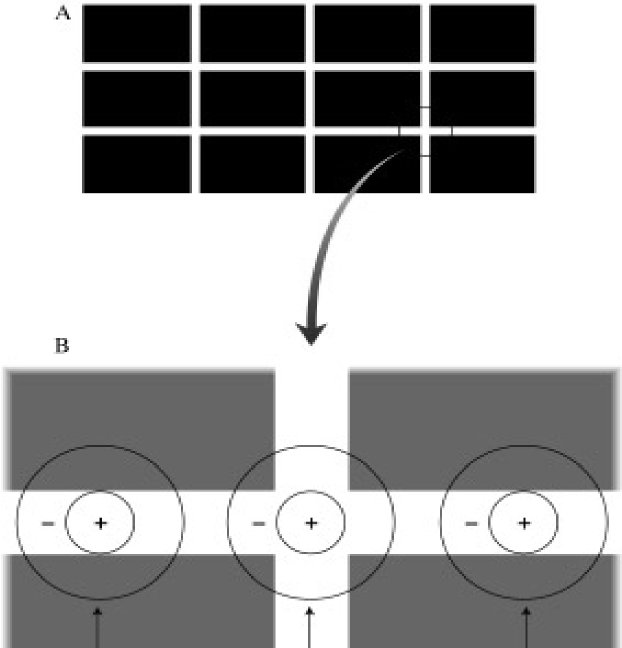
Záznam elektrické aktivity gangliových buněk sítnice s ON a OFF centrem při osvícení jednotlivých částí jejich receptivního pole. Úsečka nad záznamem elektrické aktivity značí trvání osvětlení v sekundách. AP – potenciál. ✻ – excitační zóna ▲ – inhibiční zóna

Proč ty šedé flíčky?

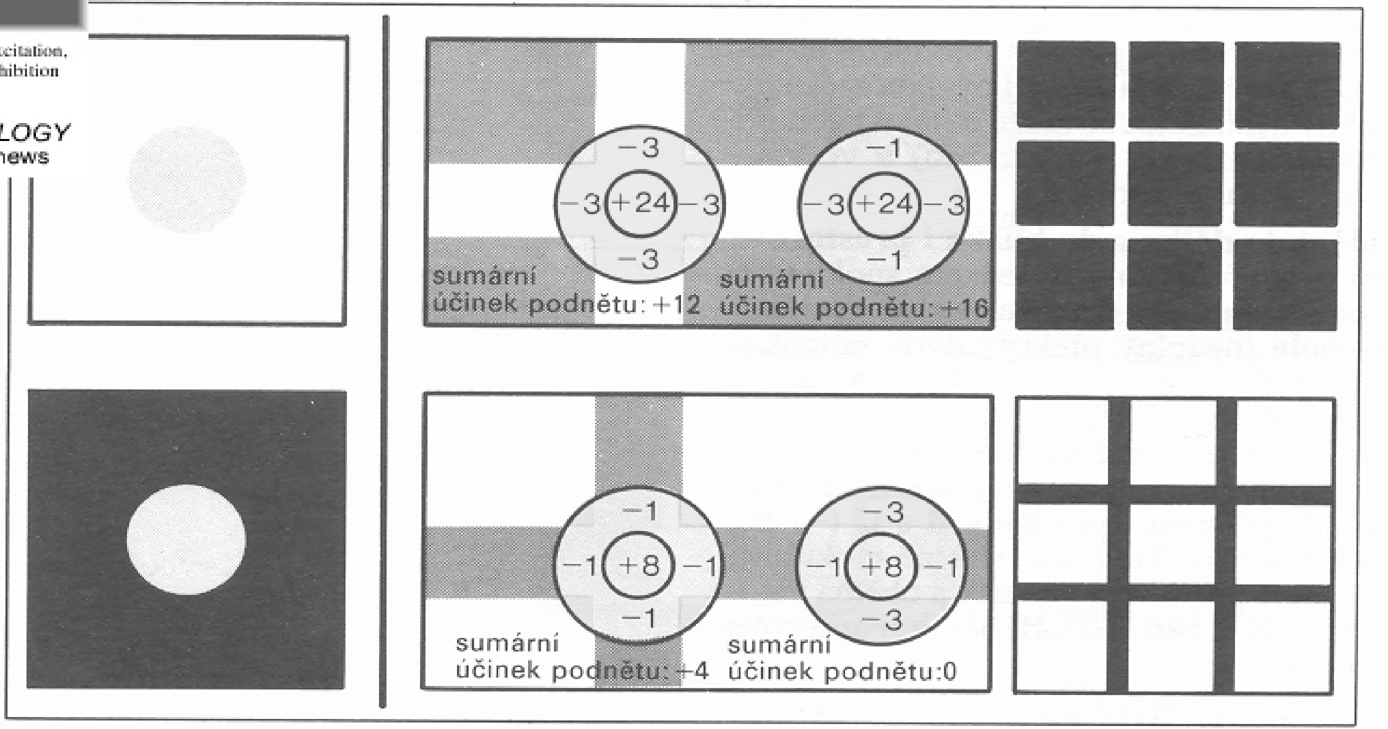




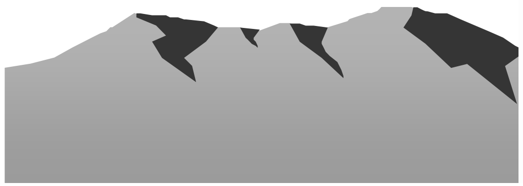
Proč ty šedé flíčky?
Vysvětlení přes recepční pole gangliových buněk.



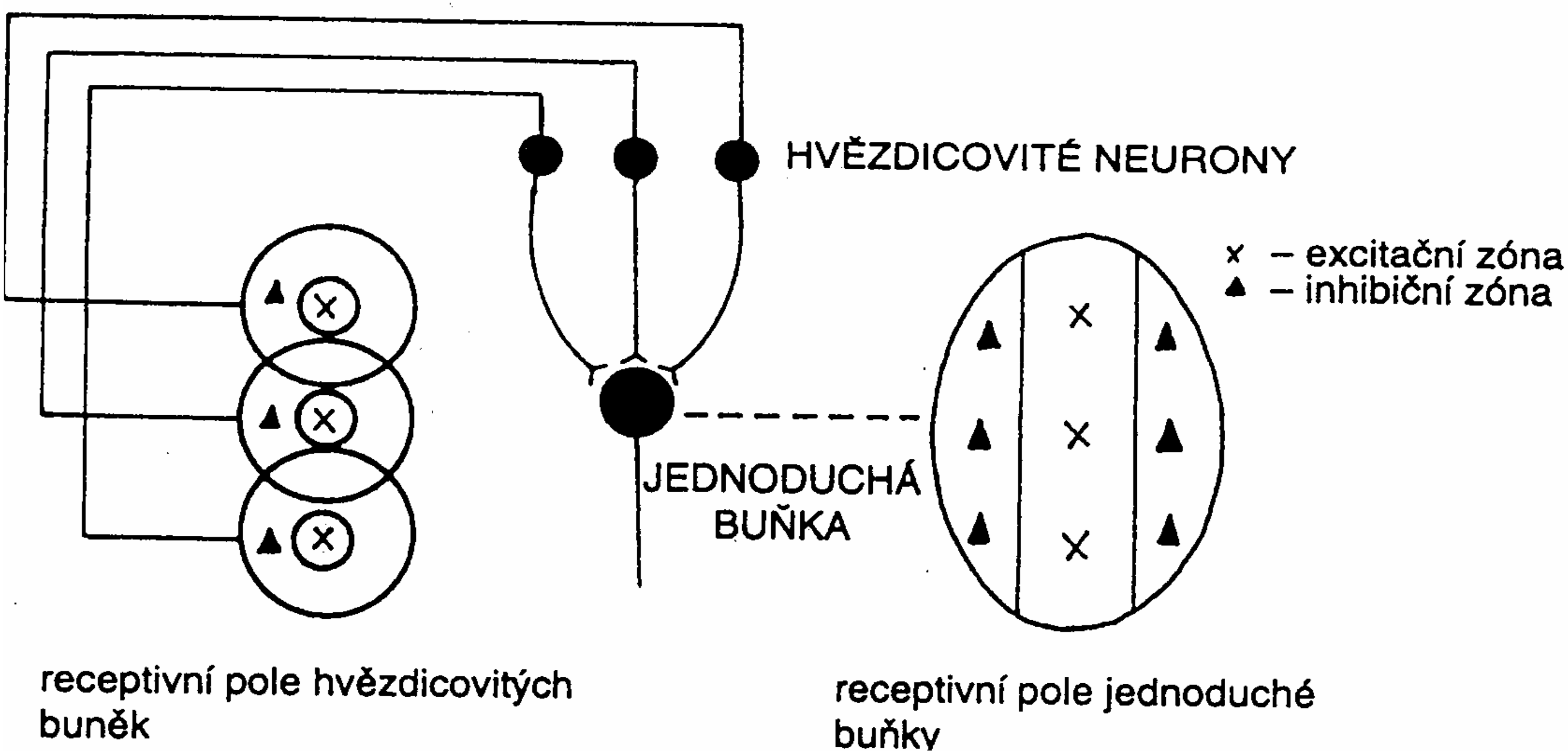
b NEUROBIOLOGY
Gary G. Matthews



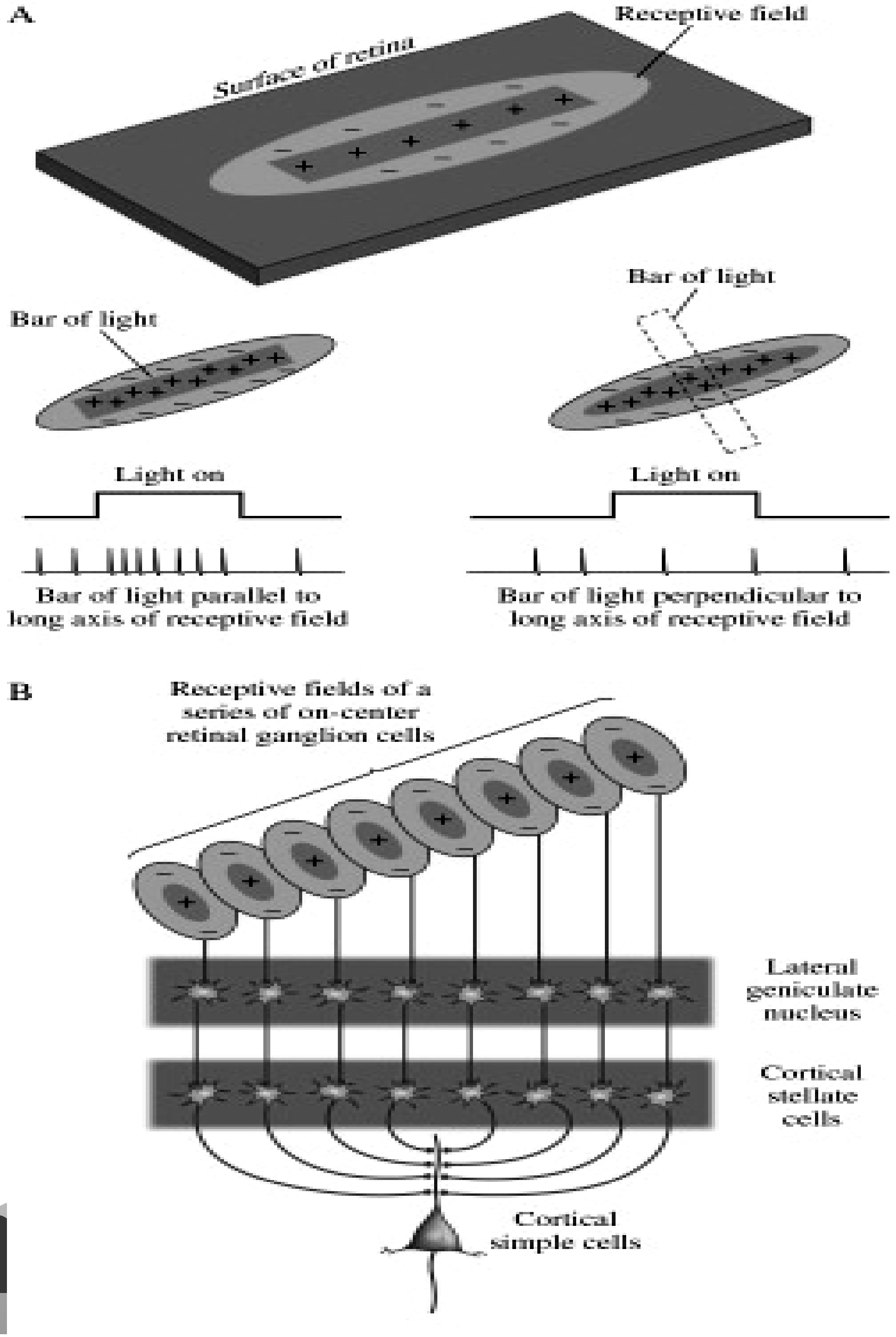
C. Kontrast pomocí recepčního pole (on-centrum)



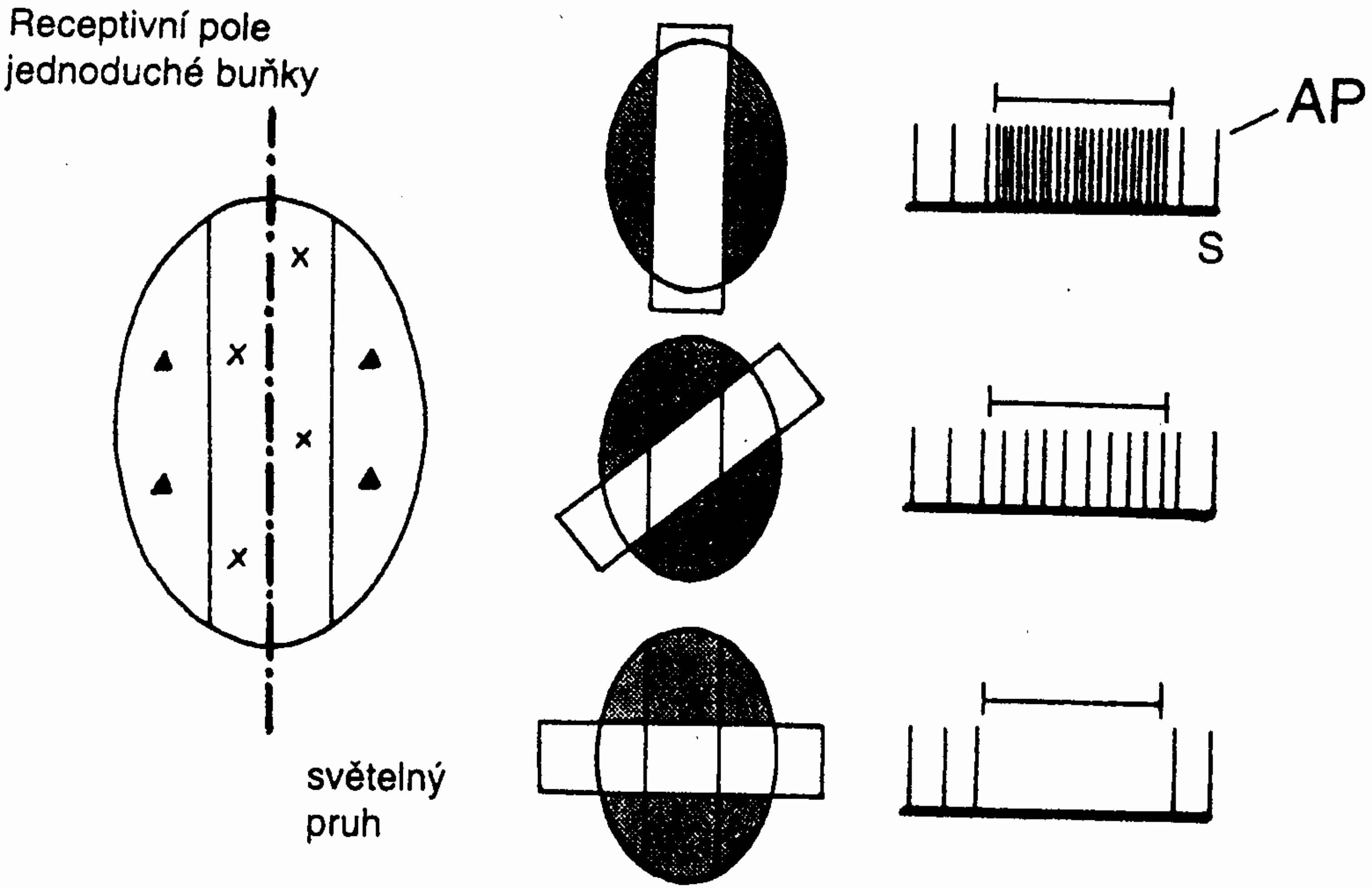
Skládání recepčních polí. Hvězdicové a jednoduché buňky IV. korové vrstvy primární zrakové oblasti.



Jednoduchá buňka „měří“
sklon svého kontrastního pruhu



Jednoduchá buňka „měří“ pozici a sklon svého kontrastního pruhu

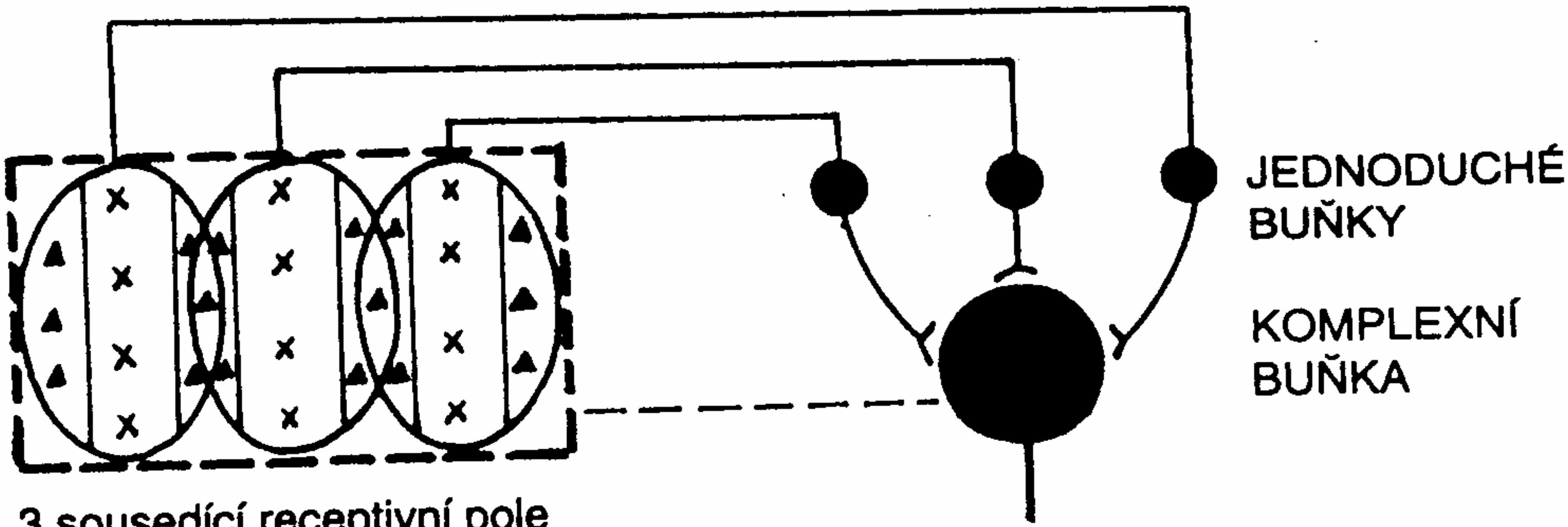


Vliv orientace vizuálního podnětu na elektrickou aktivitu jednoduché buňky.Úsečka nad záznamem elektrické aktivity značí trvání osvětlení v sekundách. AP – akční potenciál.

✗ – excitační zóna ▲ – inhibiční zóna

OBR. 45A

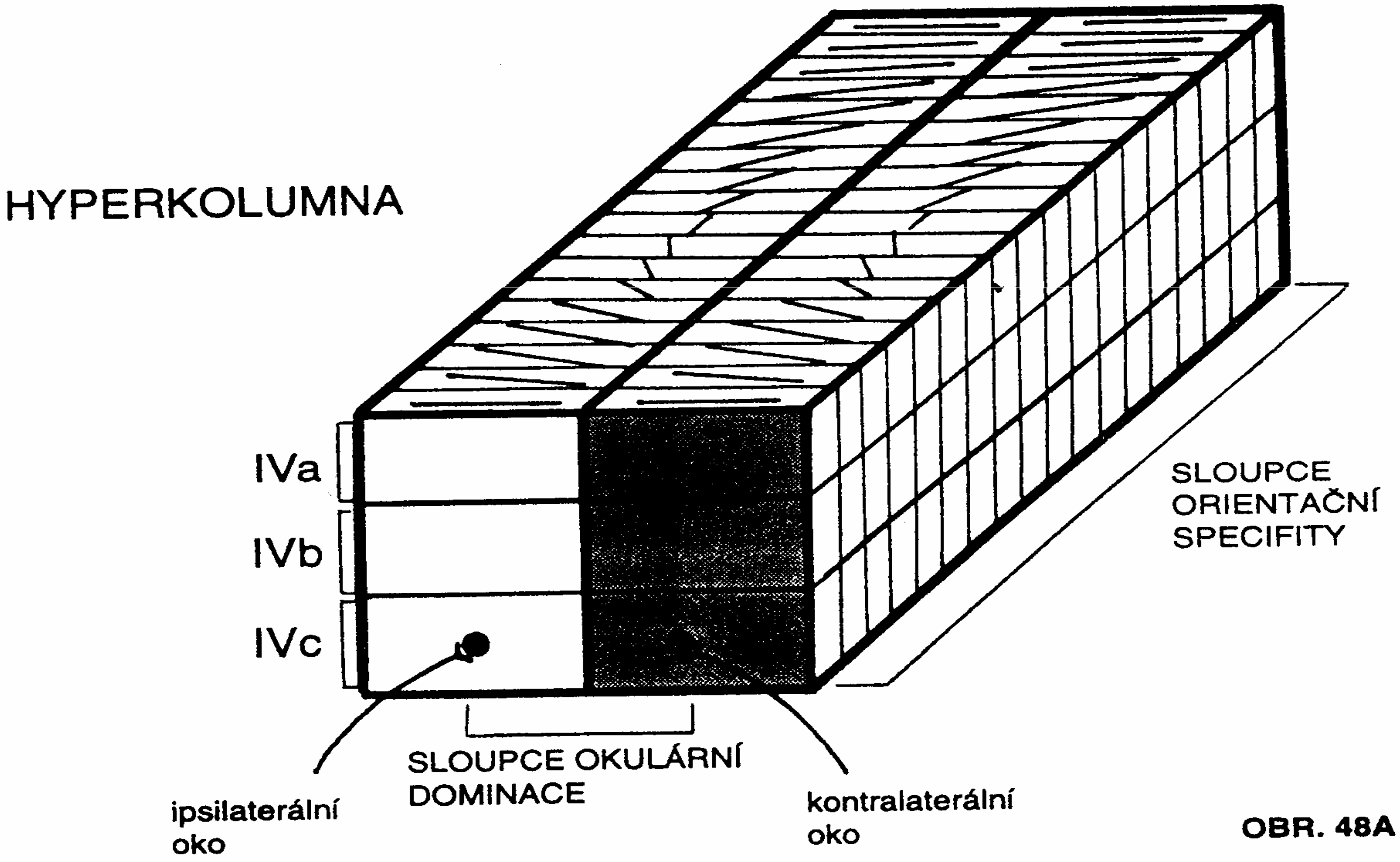
Komplexní buňka „měří“ sklon kontrastního pruhu bez ohledu na pozici na sítnici.



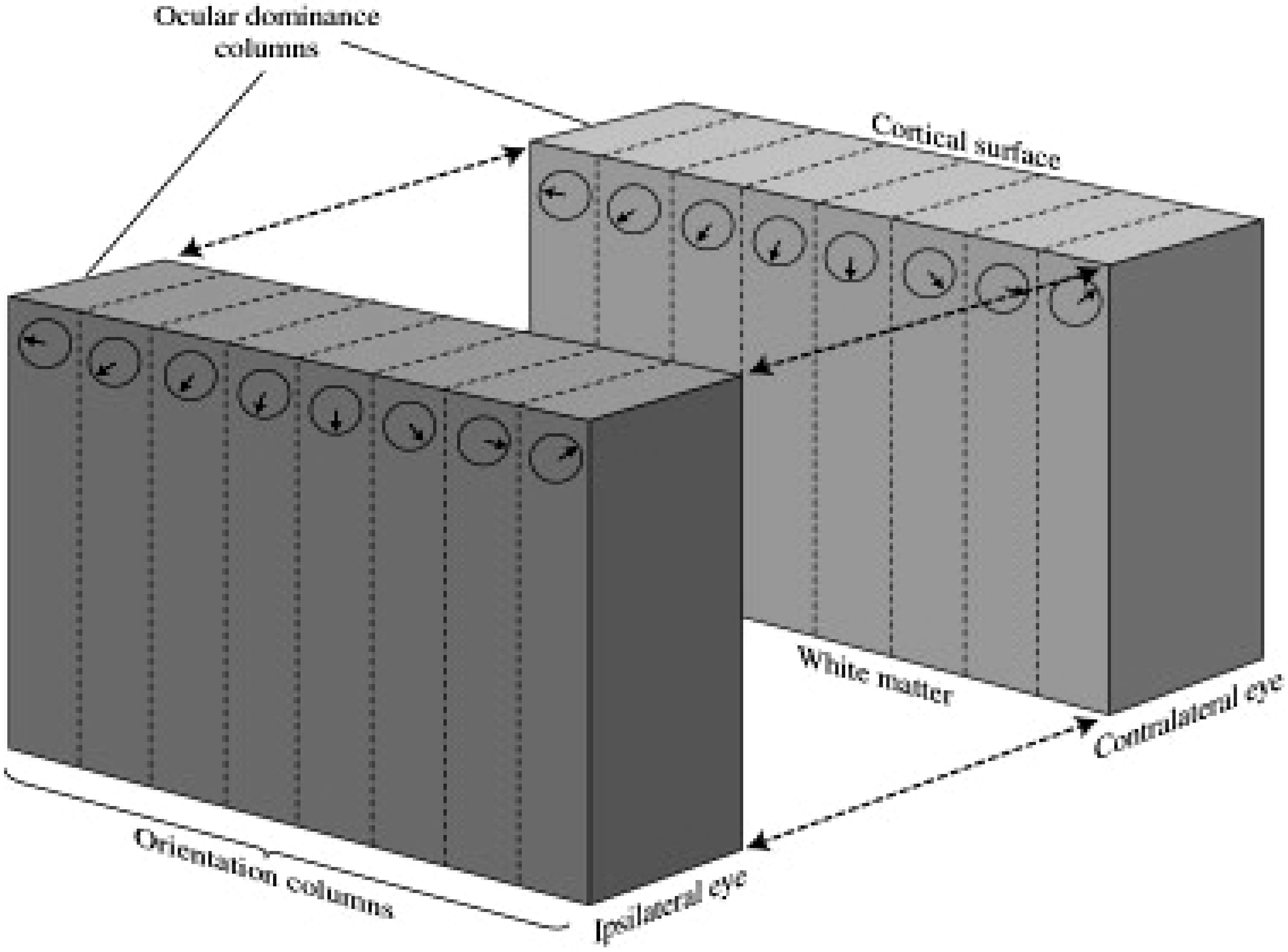
3 sousedící receptivní pole jednoduchých buněk. V rámečku zformované receptivní pole komplexní buňky.

ⓧ – excitační zóna ▲ – inhibiční zóna

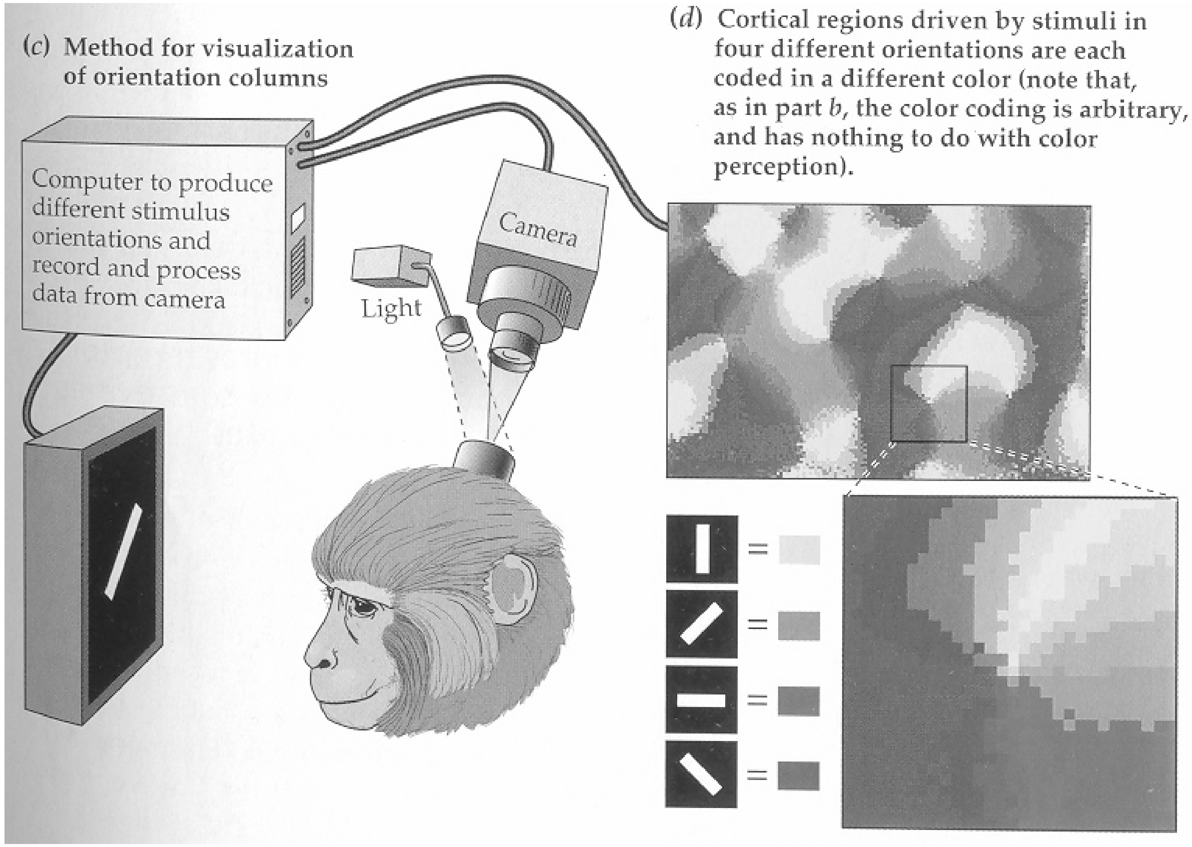
Komplexní orientačně selektivní buňky primární kůry tvoří „klávesnici“ podobnou tonotopické.



OBR. 48A


Ocular dominance columns
Cortical surface
White matter
Contralateral eye
Orientation columns
Ipsilateral eye

Komplexní orientačně selektivní buňky primární zrakové kůry makaka.

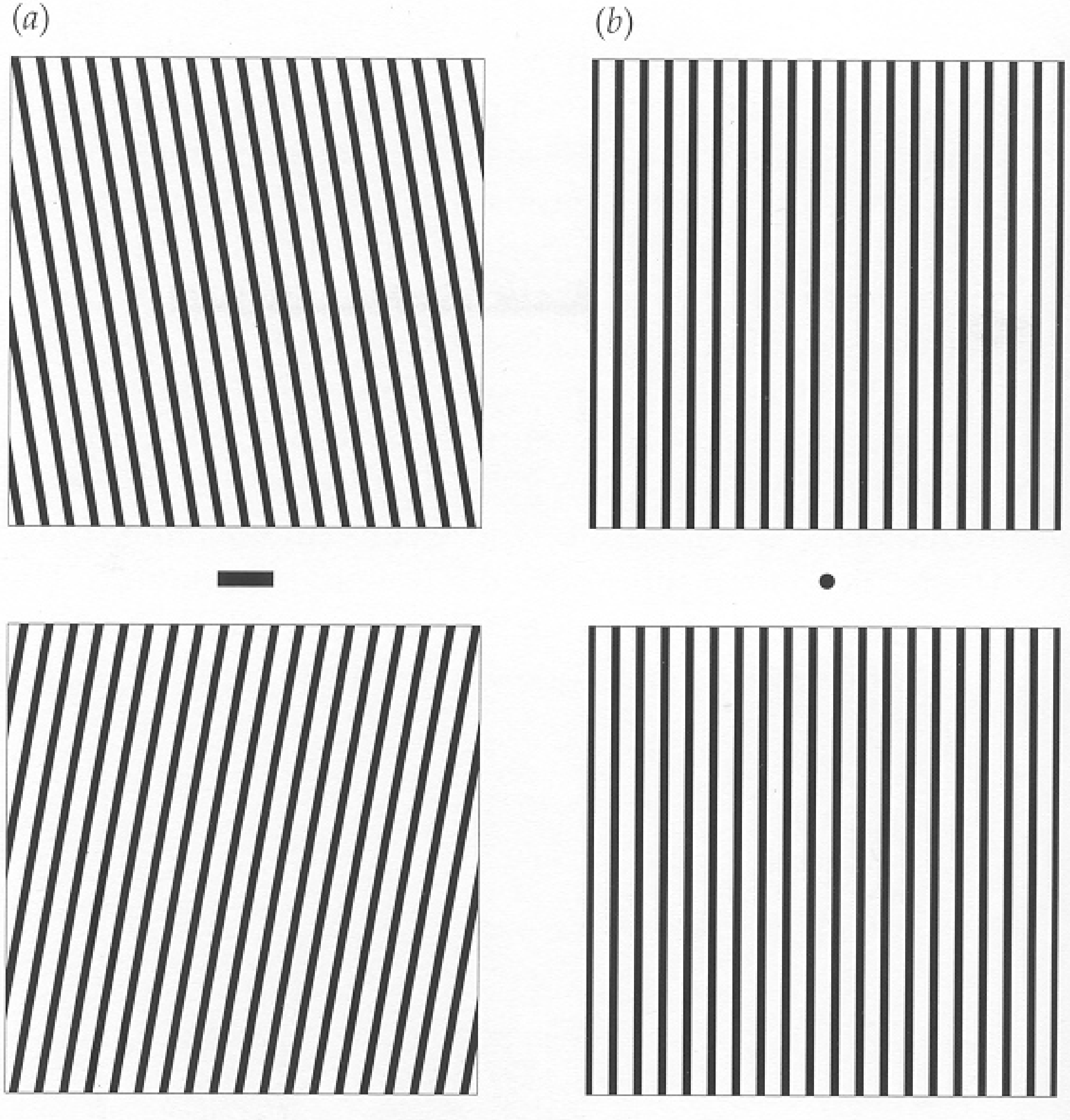


(*c*) **Method for visualization of orientation columns**

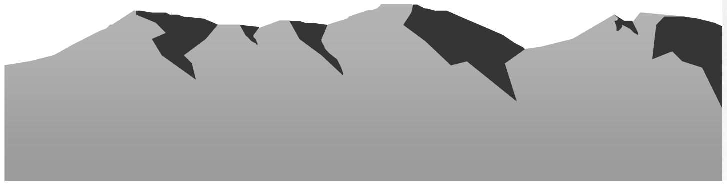
(*d*) **Cortical regions driven by stimuli in four different orientations are each coded in a different color (note that, as in part *b*, the color coding is arbitrary, and has nothing to do with color perception).**

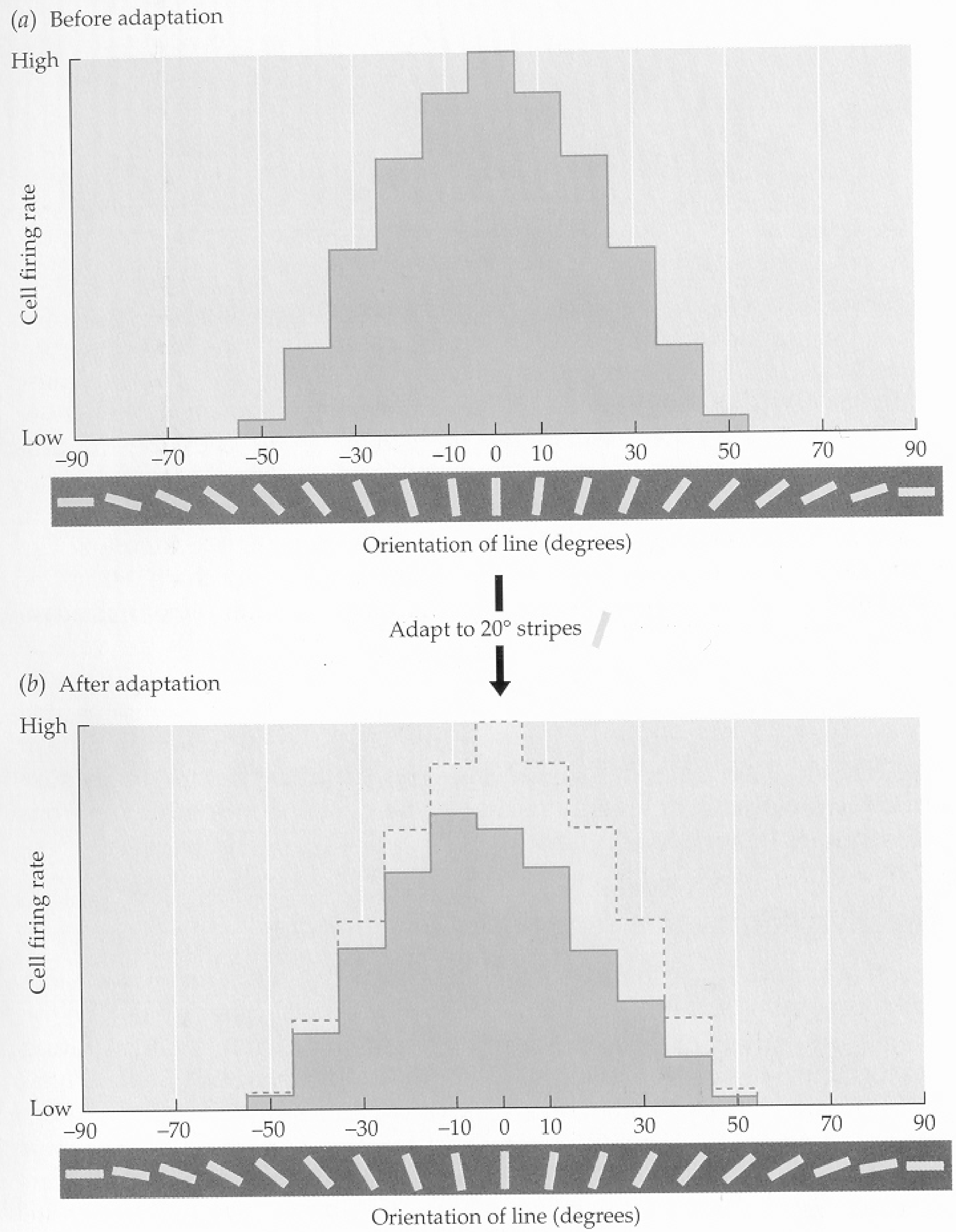
Selektivní adaptace a orientačně selektivní buňky.

Selektivní adaptace: cesta do lidského mozku



Vysvětlení:
20° buňky jsou po 1 min adaptovány, unaveny a přestávají přispívat do vjemu vertikál.
Ve výsledku se vertikální linie kácí.





Selektivní adaptace a
kontrastně
selektivní buňky

Po adaptaci na
Konkrétní „frekvenci“,
je právě tato utlumena

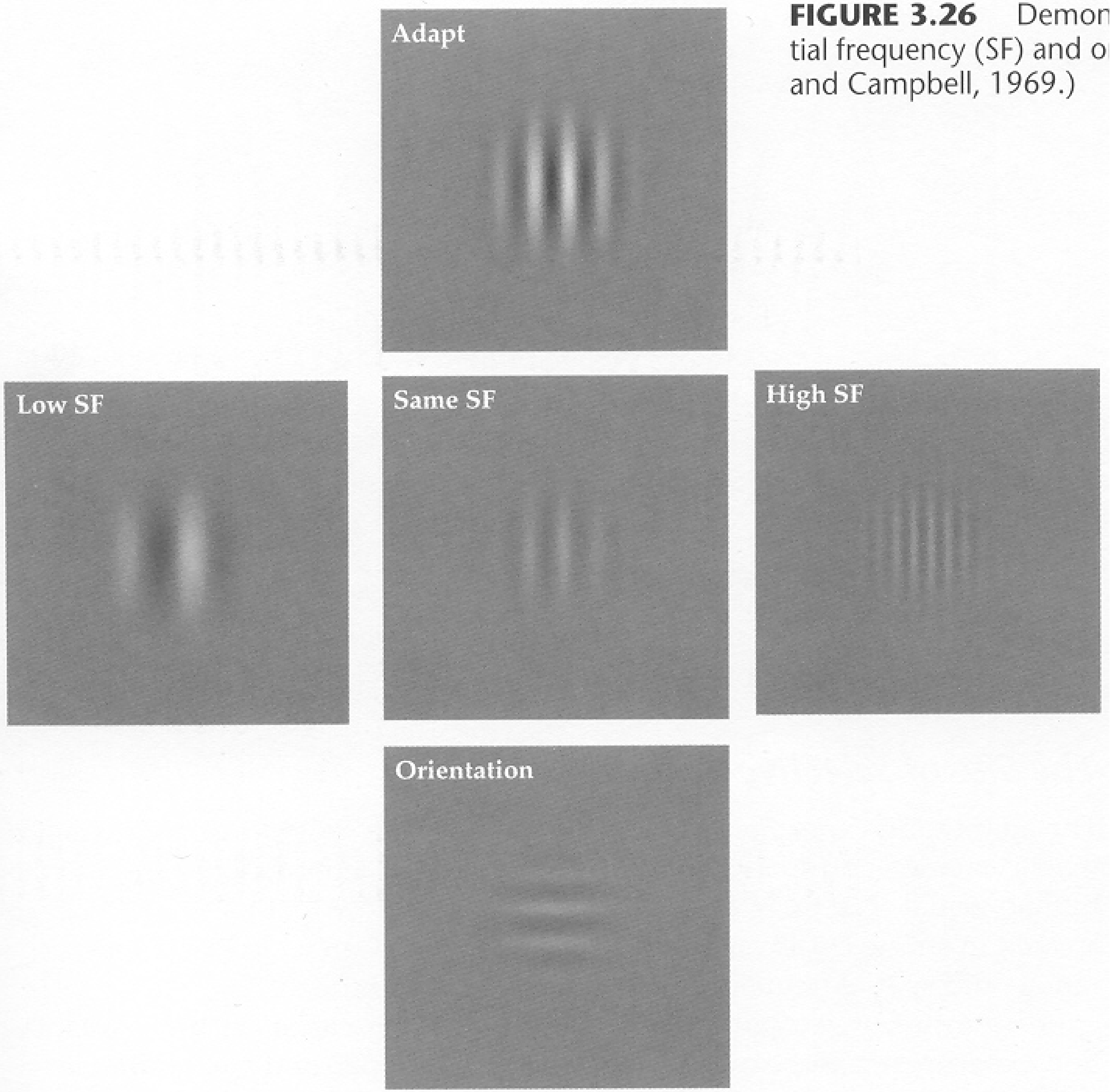
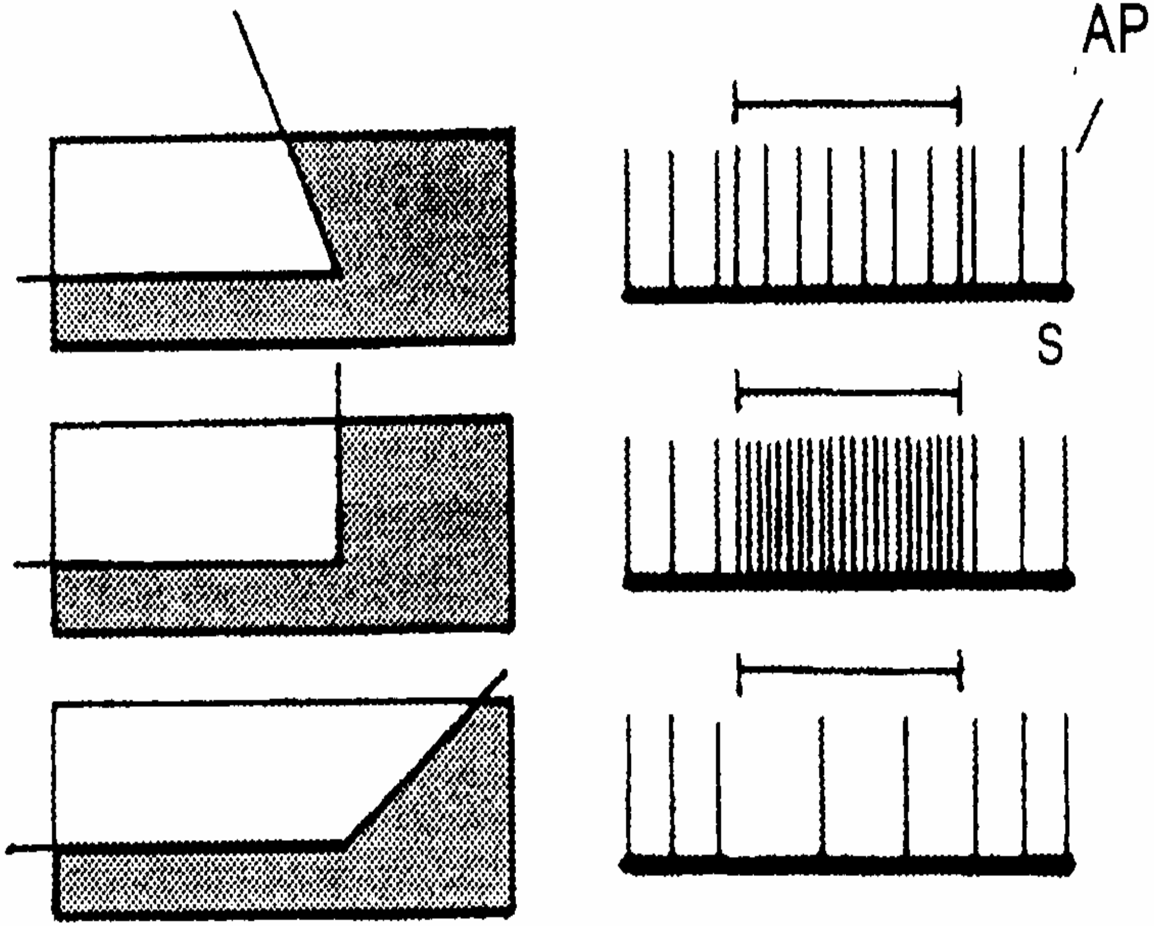


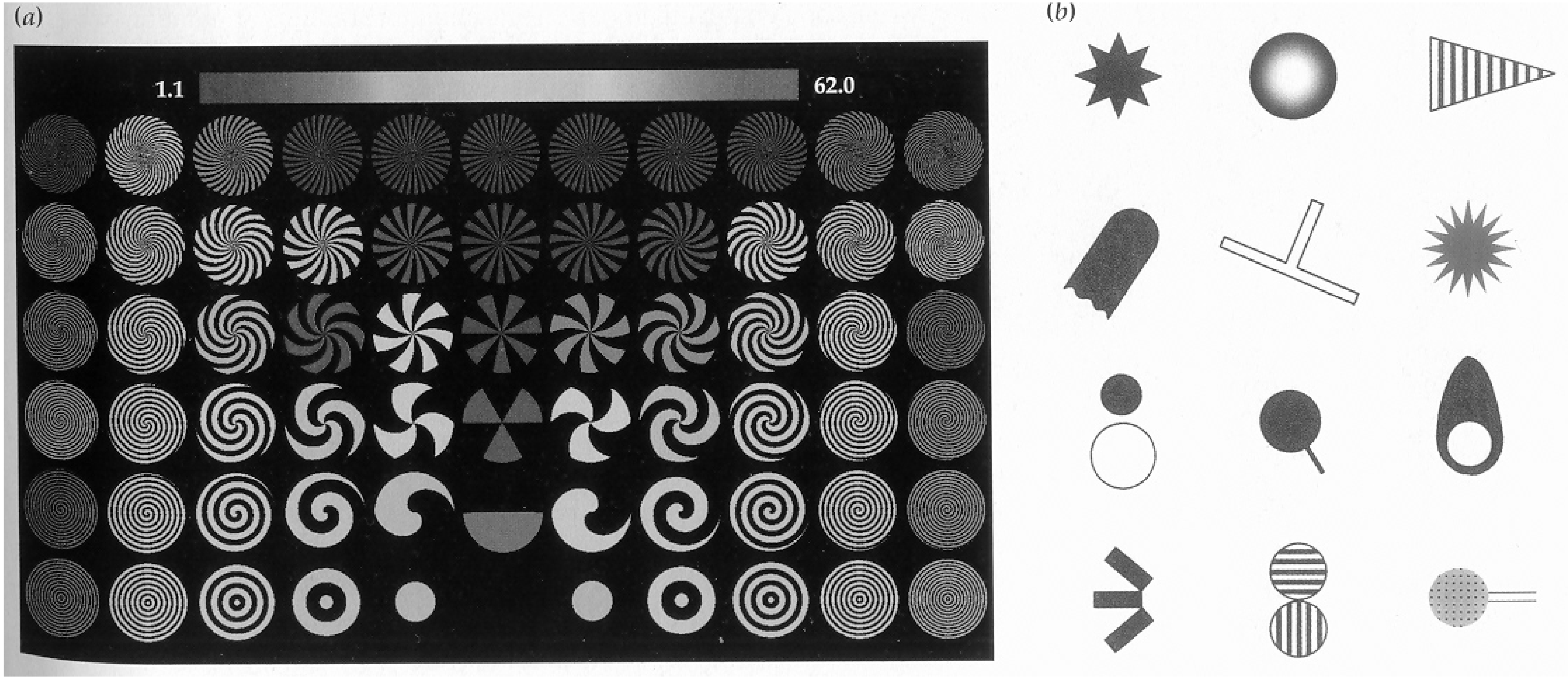
FIGURE 3.26 Demon
tial frequency (SF) and o
and Campbell, 1969.)

Sekundární kůra, hyperkomplexní buňky



Vliv různého úhlu kontrastního vizuálního podnětu na elektrickou aktivitu hyperkomplexní buňky. Úsečka nad záznamem elektrické aktivity značí trvání osvětlení v sekundách.
AP – akční potenciál.

OBR. 49A



10.21 Complex Stimuli Evoke Strong Responses in Visual Cortex (*a*) These concentric and radial stimuli evoke maximal responses from some cells in visual cortical area V4. The stimuli that evoked the highest response rates (see scale bar) are shown in red and orange. (*b*) These 12 examples illustrate the critical features of stimuli that evoke maximal responses from cells in the anterior inferior temporal area. (Part *a* from Gallant et al., 1993, courtesy of Jack Gallant; *b* from K. Tanaka, 1993, courtesy of Keiji Tanaka.)

„Grandmother's cells“
Na tvář selektivní buňky

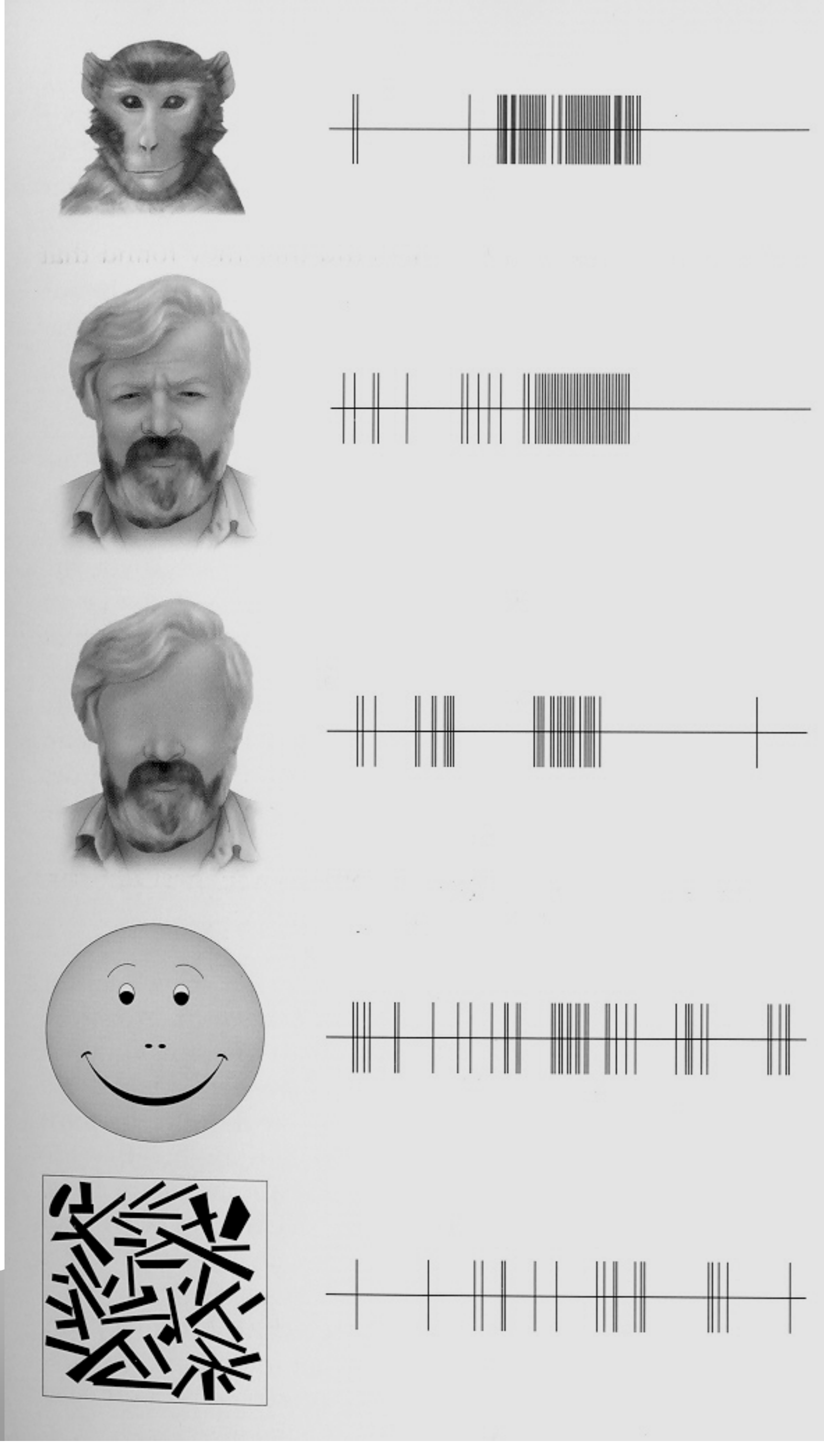
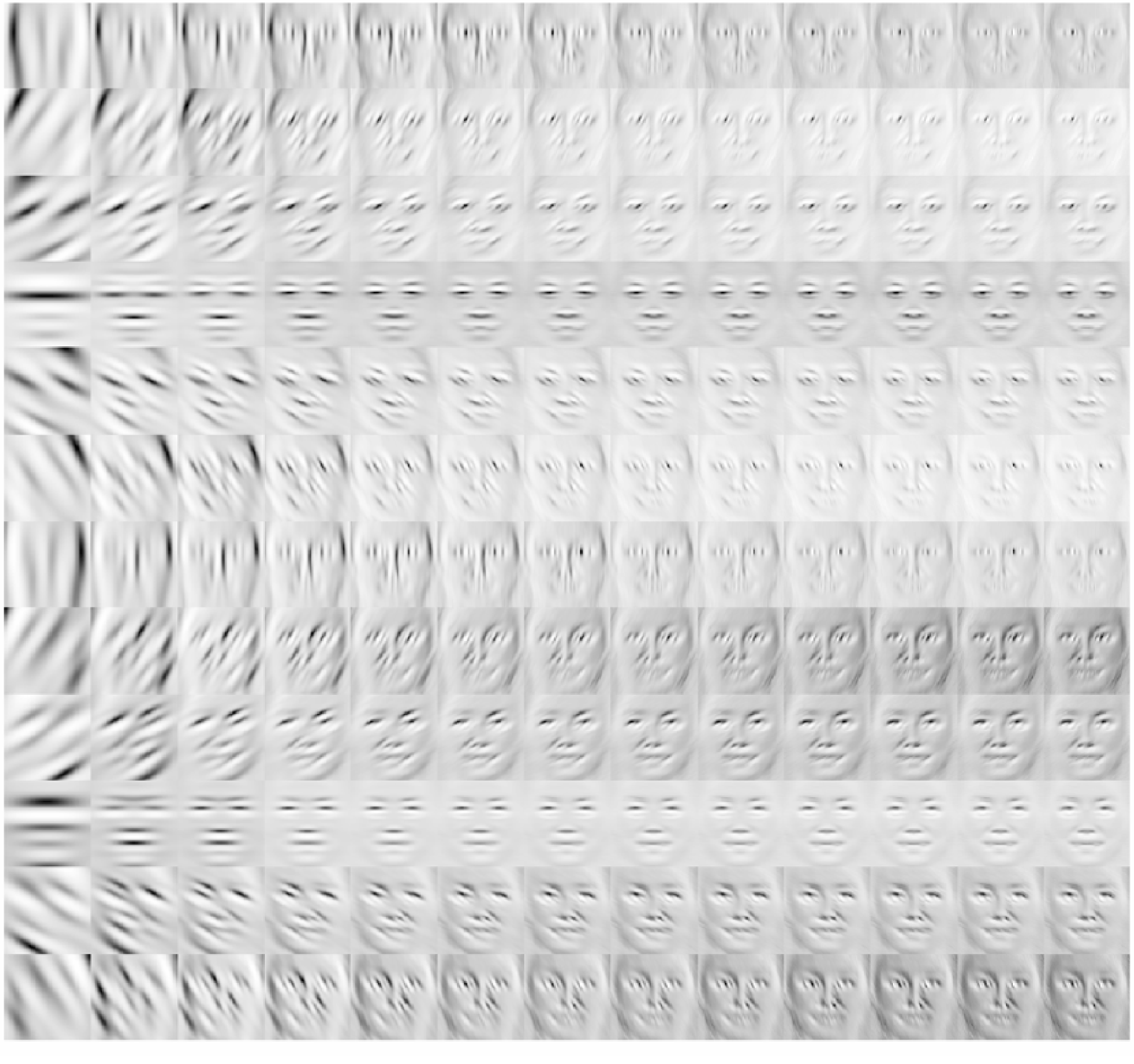


FIGURE 4.33 Cells in the inferotemporal cortex of macaque monkeys are interested in very specific stimuli. In this case, the cell responds vigorously to a monkey face and to some other stimuli that seem related. (After Gross, Rocha-Miranda, and Bender, 1972.)

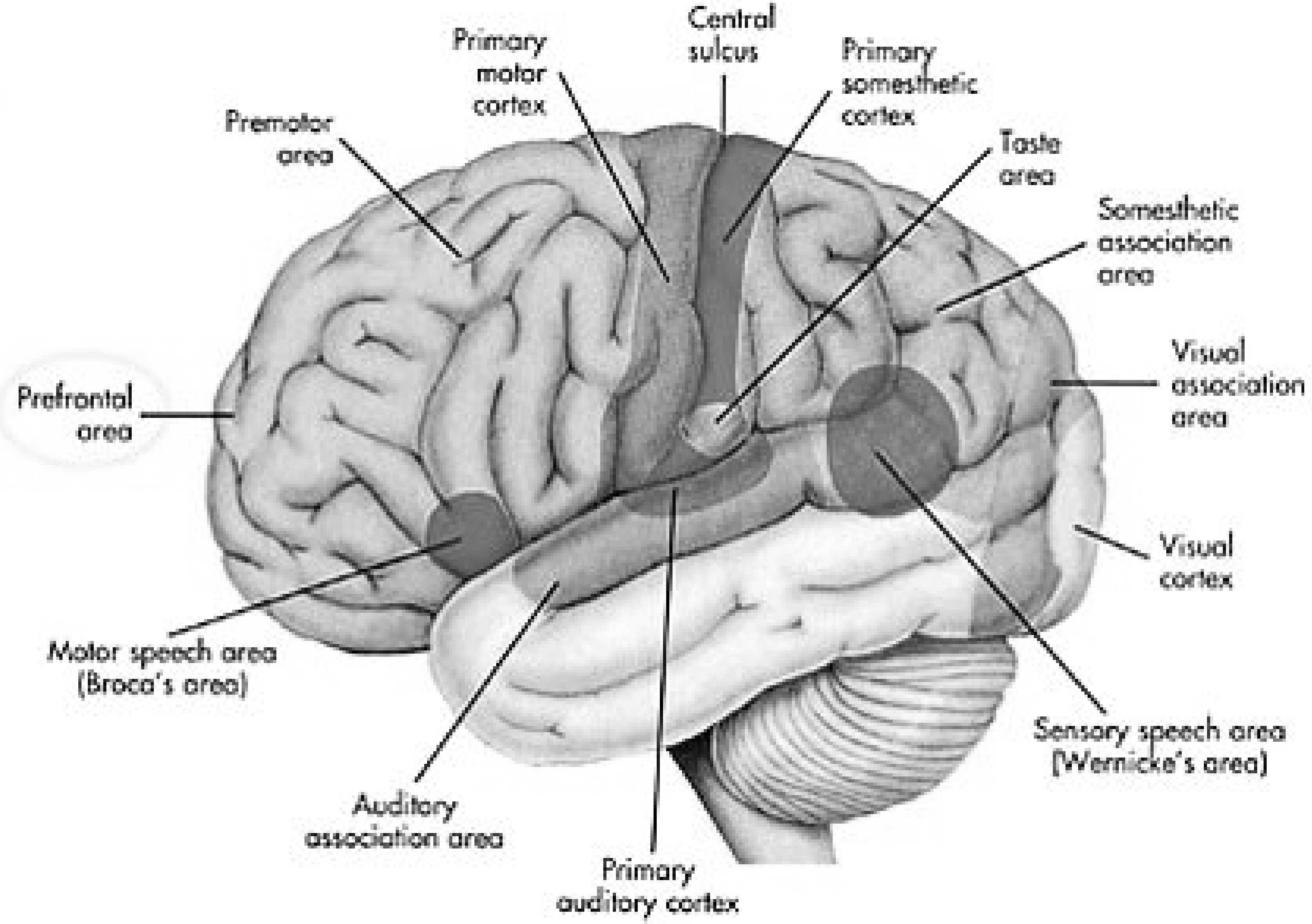
„Skládání“ tváří z jednodušších rysů.



- Iluze osvětlení – světelná stálost

Hnědá čokoláda za jasného dne odráží méně světla než papír za šera, ale stejně ji vnímáme jako tmavou.

Automatické předpoklady našeho vnímání


Primary motor cortex
Central sulcus
Primary somesthetic cortex
Premotor area
Taste area
Somesthetic association area
Prefrontal area
Visual association area
Visual cortex
Motor speech area (Broca's area)
Sensory speech area (Wernicke's area)
Auditory association area
Primary auditory cortex

Barevné vidění

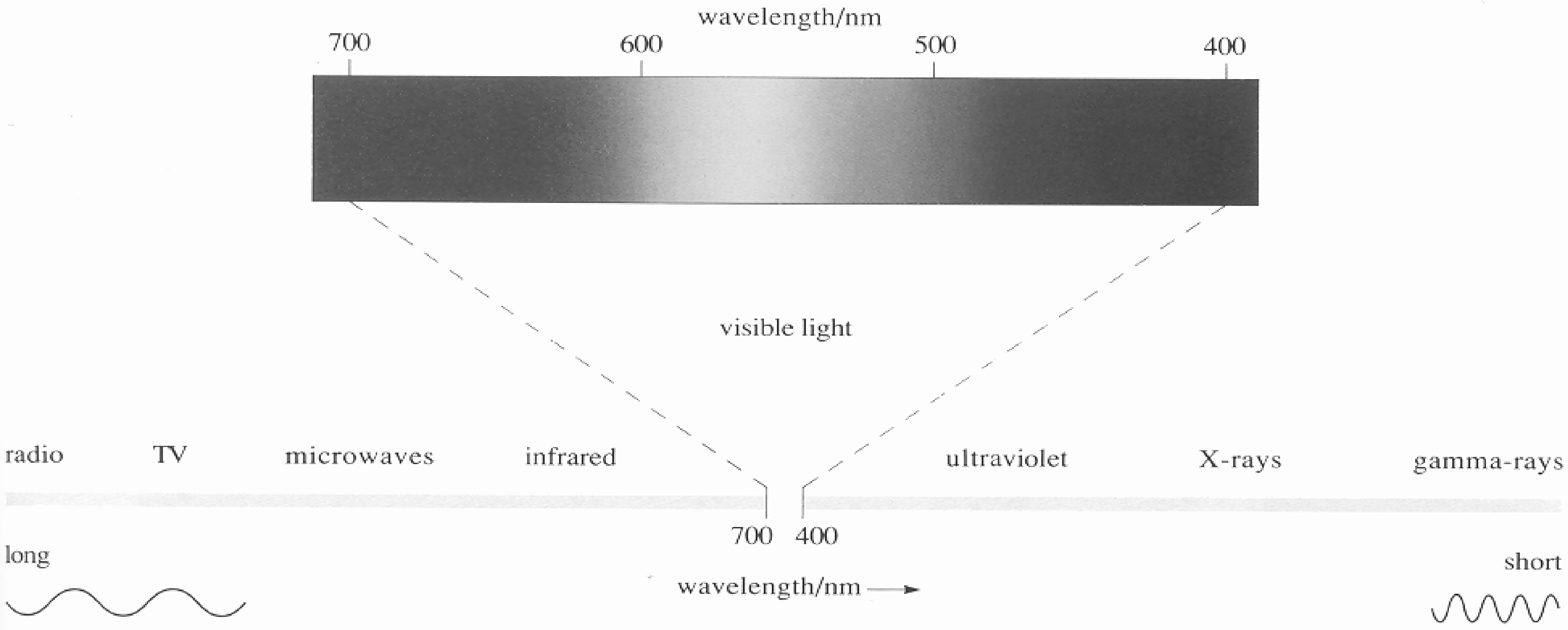
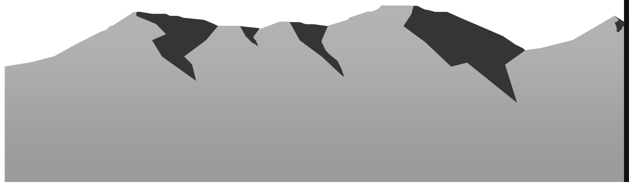
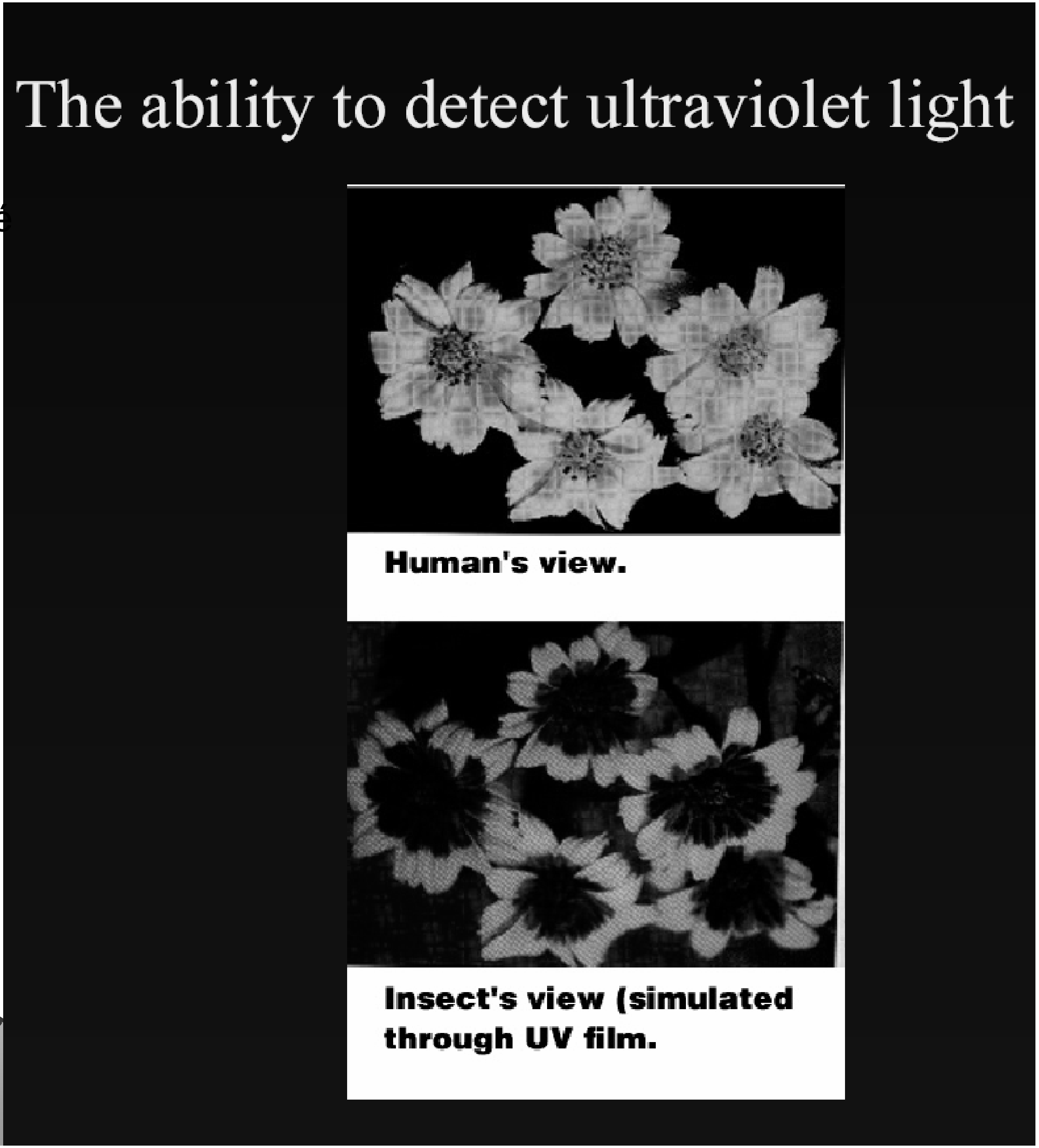


Plate 1 The electromagnetic spectrum. The visible spectrum is shown in colour.

Posunutá spektrální
citlivost = jiný pohled.

Neznamená nutně barevné
vidění





The ability to detect ultraviolet light

Human's view.

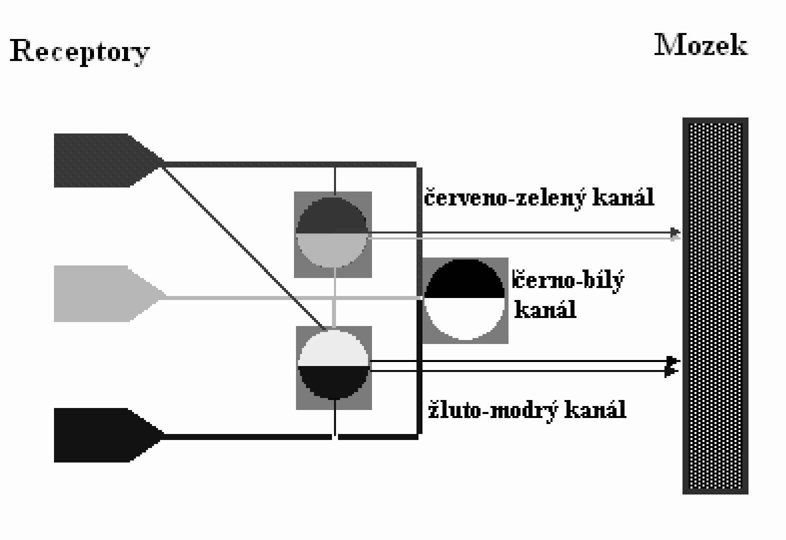
Insect's view (simulated through UV film.

Barevné vidění:

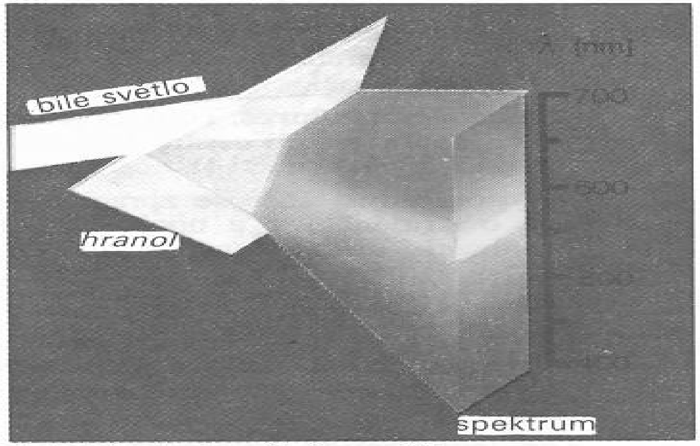
Další kvalita zraku

Jeden receptor barvu nerozezná, je potřeba nejméně dva druhy barevně selektivních fotoreceptorů

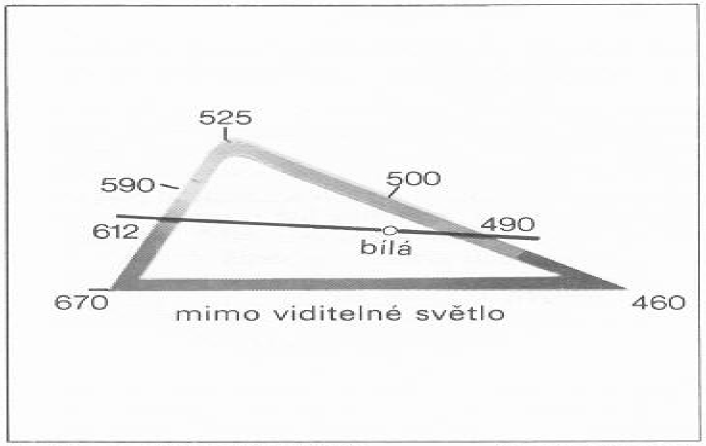
Trichromatické teorie, Young-Helmhotz
Oponentní kódování, Hering



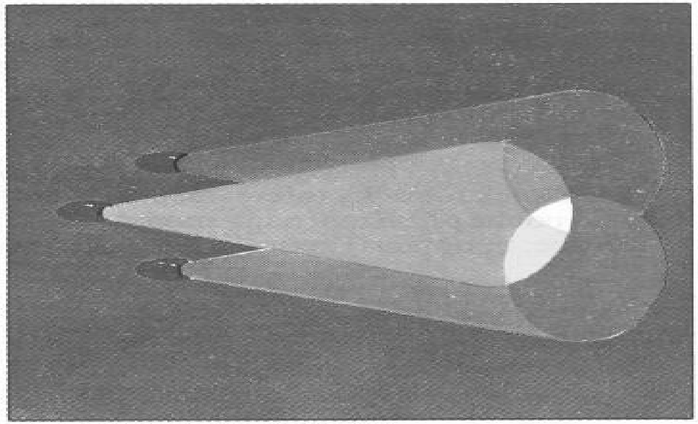
Trichromatické skládání



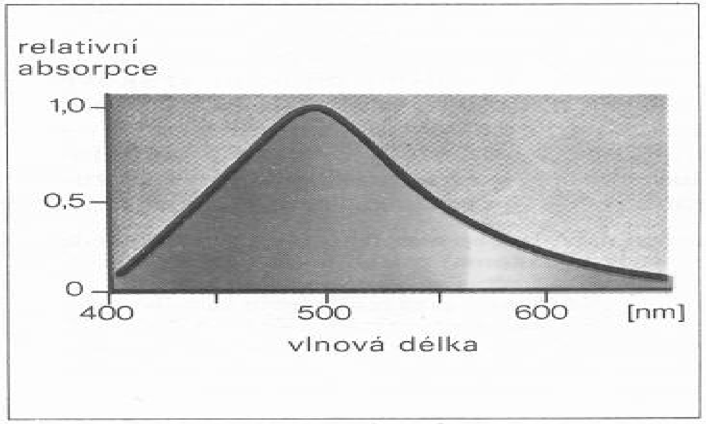
A. Složení slunečního světla



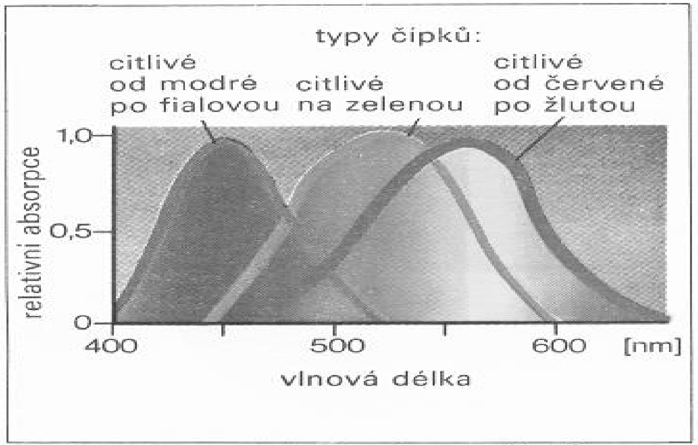
B. Barevný trojúhelník (podle Kriese)



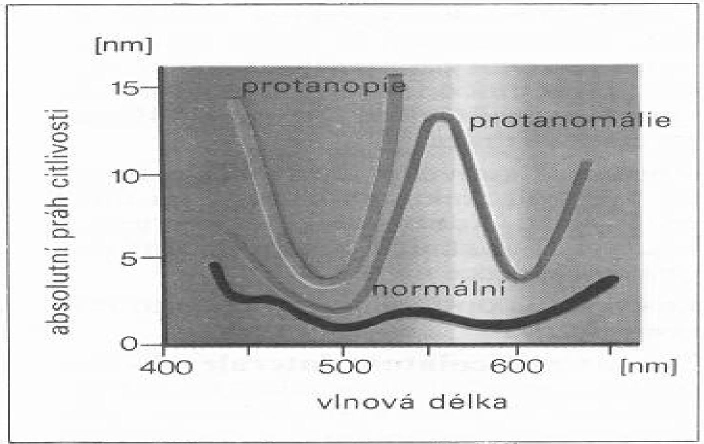
C. Aditivní míšení barev



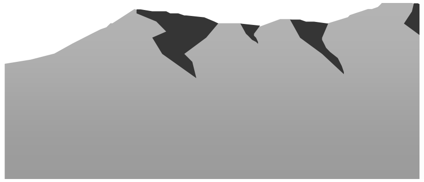
D. Absorpce světla rodopsinem



E. Absorpce světla třemi typy čípků



F. Práh citlivosti pro vlnové délky



Barevná oponence

Neexistuje červenozelená nebo modrožlutá

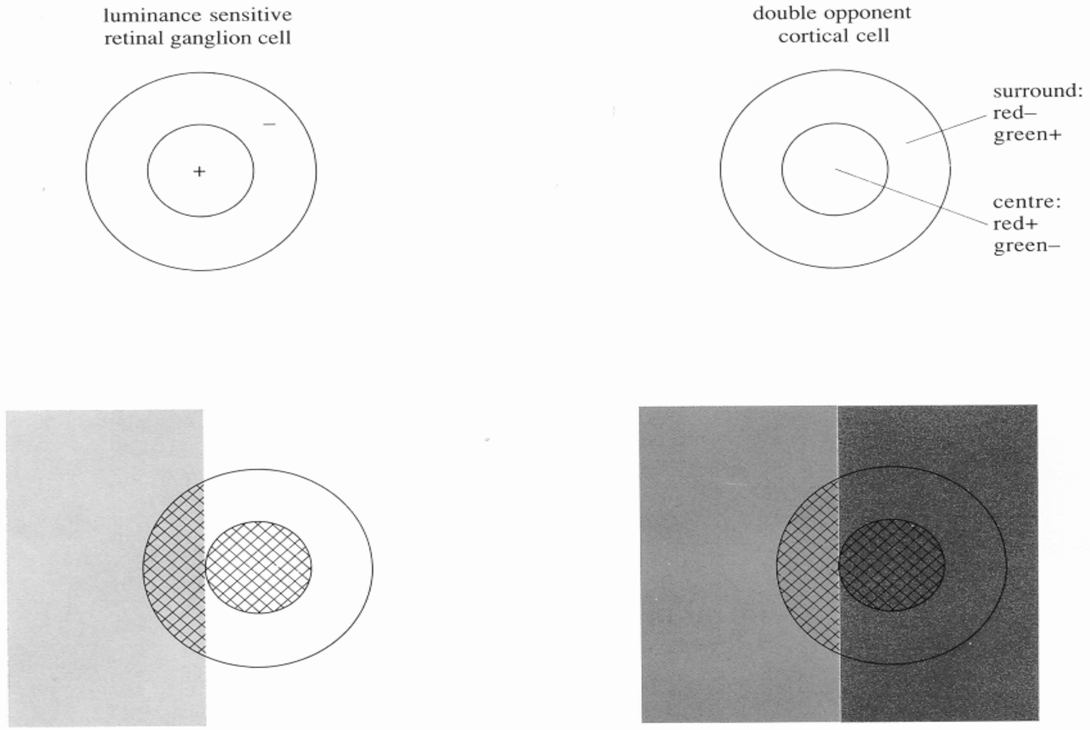


Plate 4 Double opponent receptive fields.

Simultnánní barevný kontrast

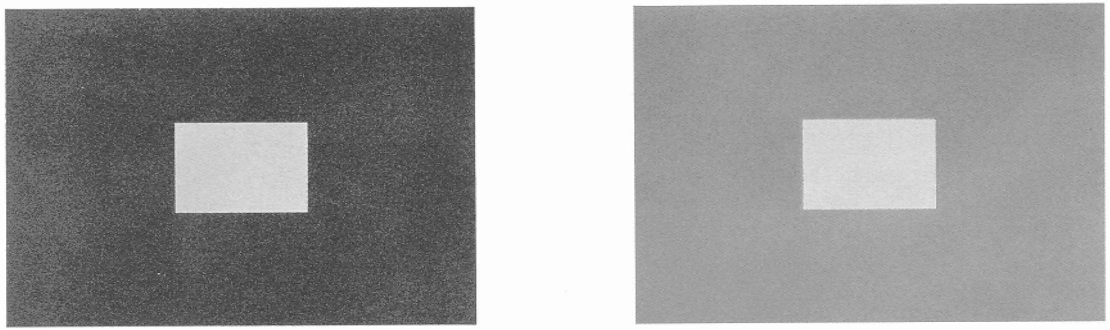
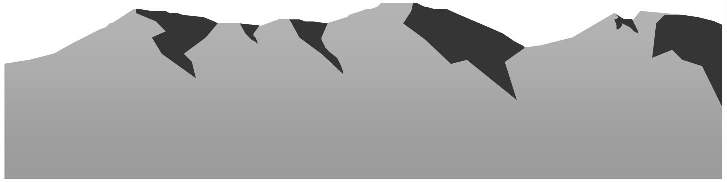
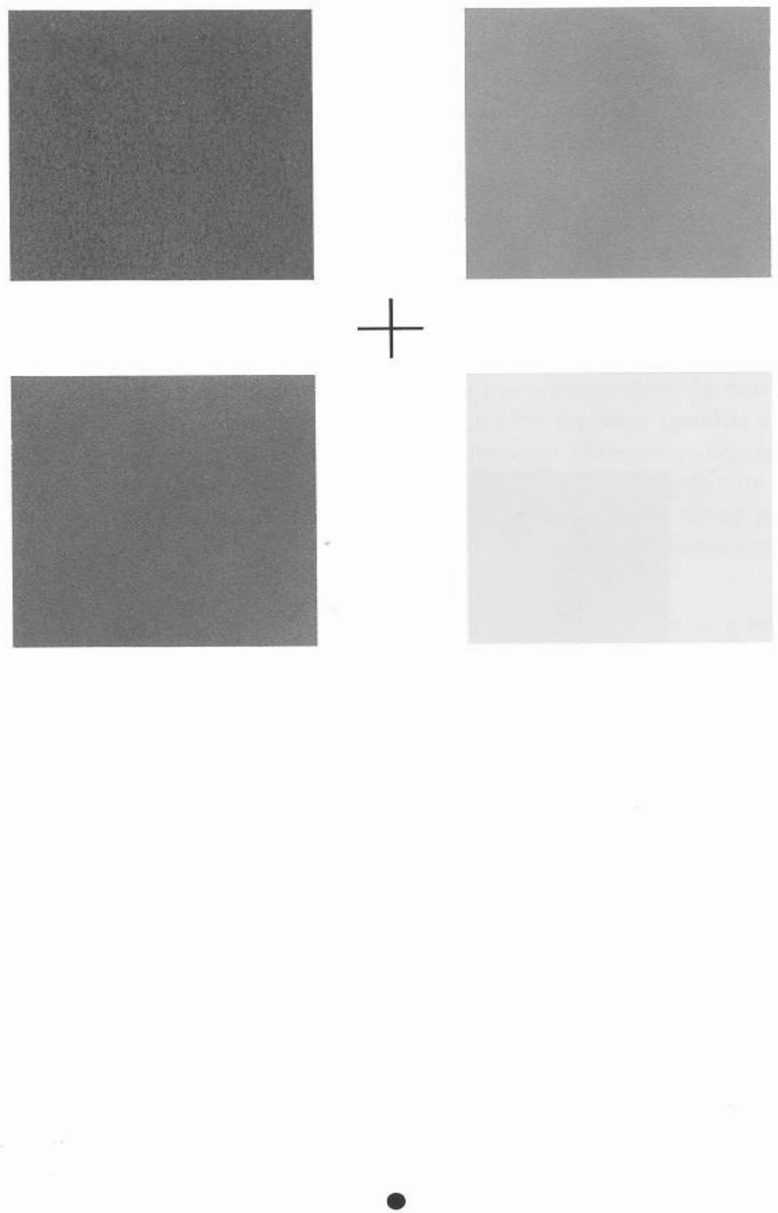


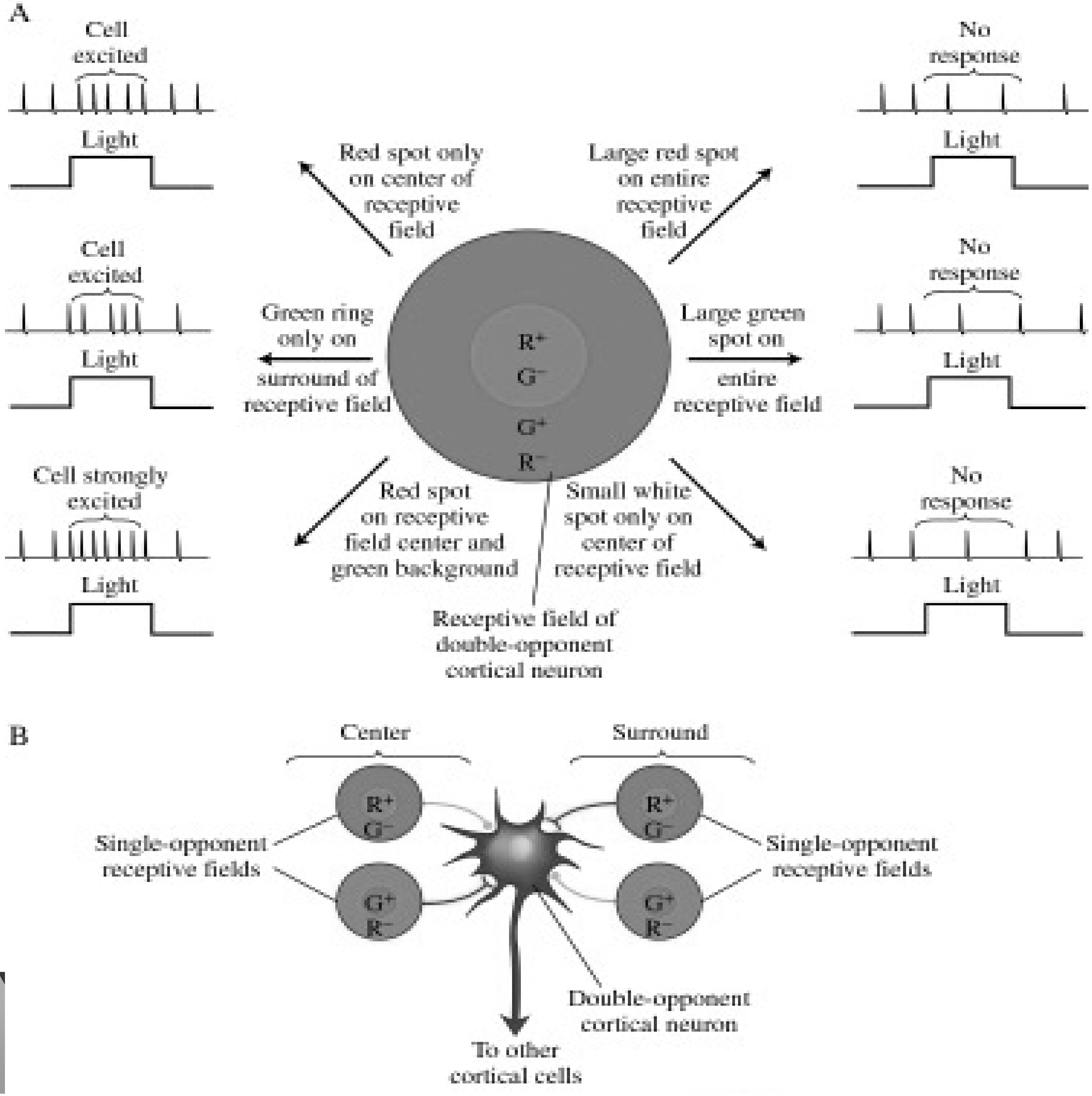
Plate 5 Simultaneous colour contrast.



Negative afterimages
Selektivní adaptace a
barevně
selektivní buňky

http://www.sinauer.com/wolfe
/chap5/afterimagesF.htm




A
Cell excited
Light
Red spot only on center of receptive field
Cell excited
Light
Green ring only on surround of receptive field
Cell strongly excited
Light
Red spot on receptive field center and green background
R+
G−
G+
R−
Receptive field of double-opponent cortical neuron
No response
Light
Large red spot on entire receptive field
No response
Light
Large green spot on entire receptive field
No response
Light
Small white spot only on center of receptive field
B
Center
Surround
R+
G−
G+
R−
R+
G−
G+
R−
Single-opponent receptive fields
Single-opponent receptive fields
Double-opponent cortical neuron
To other cortical cells

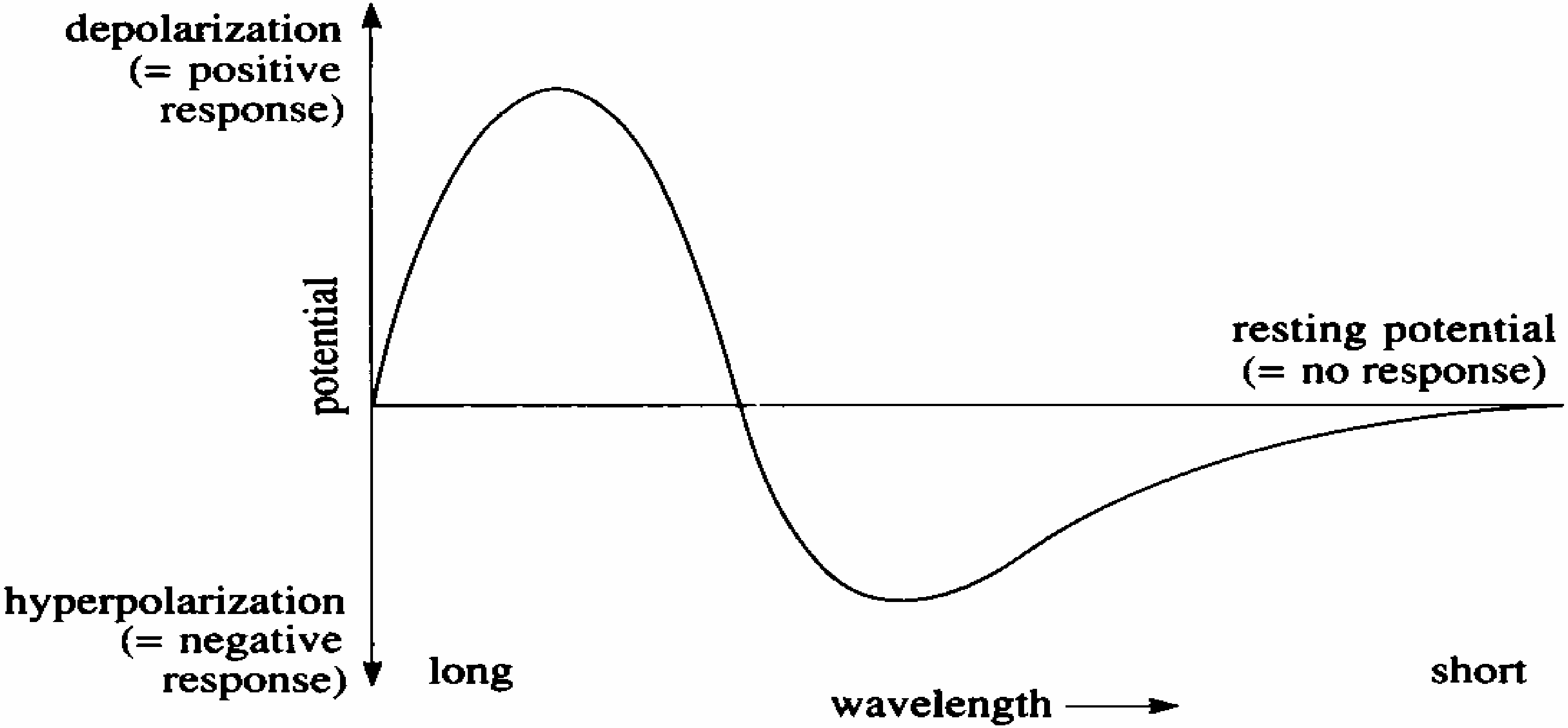
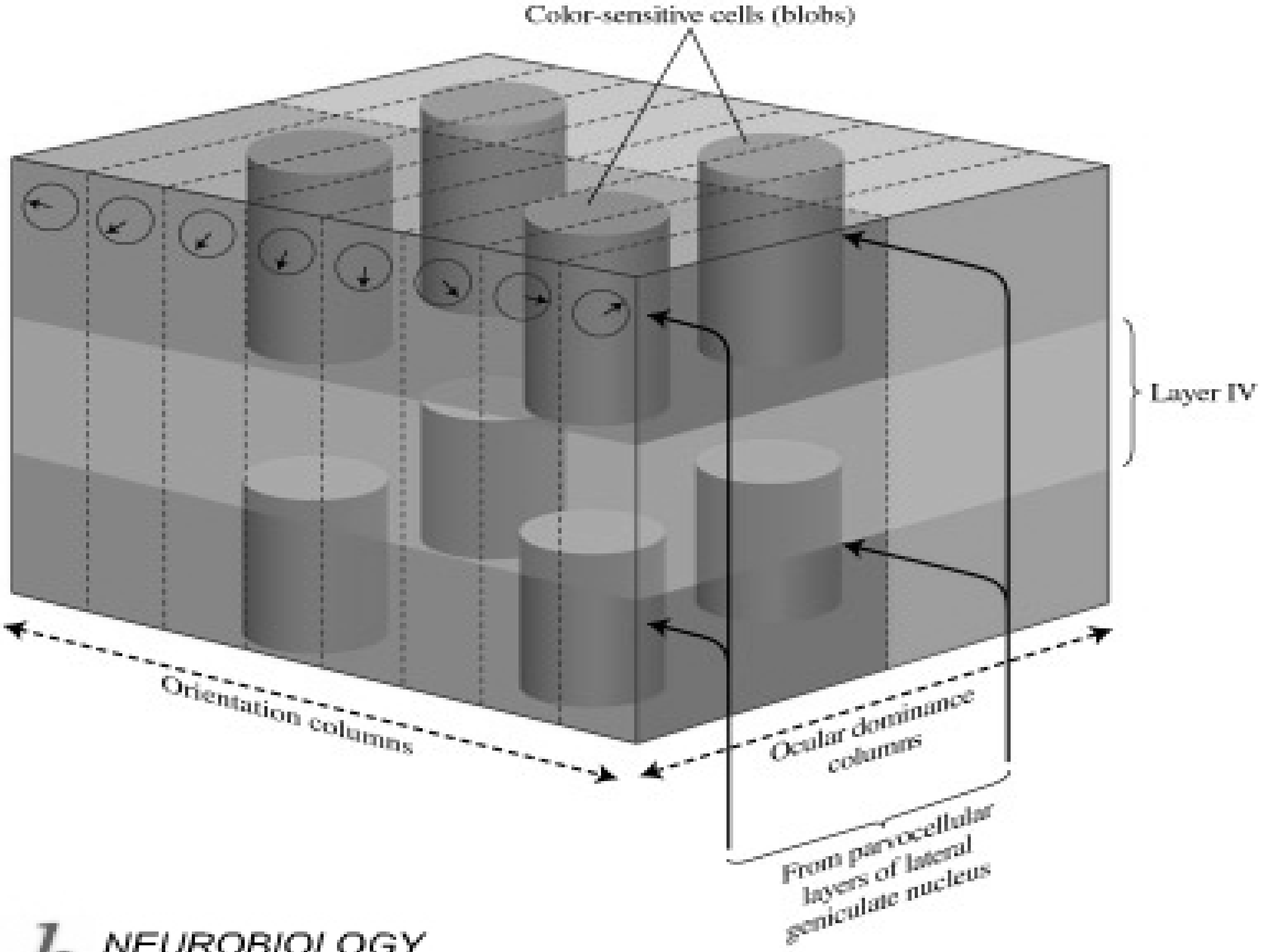
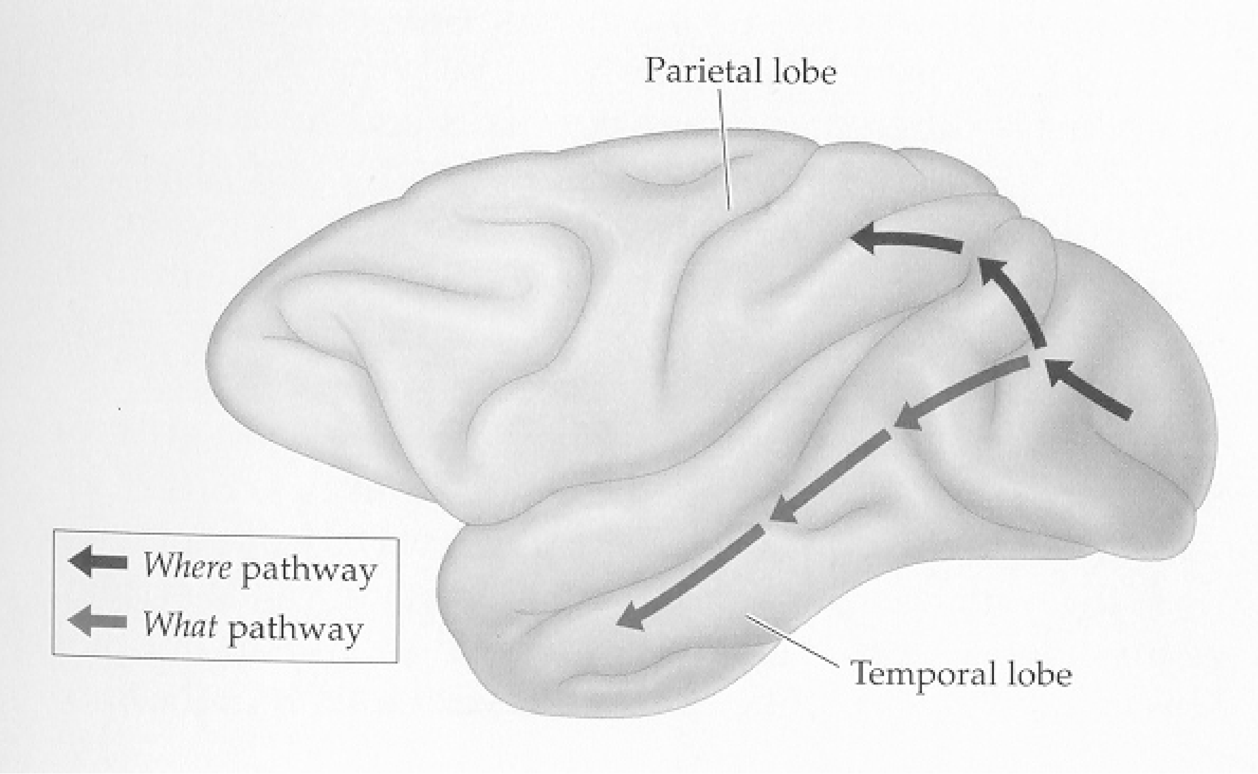


Figure 4.35 Response of a typical colour opponent bipolar cell.


Color-sensitive cells (blobs)
Layer IV
Orientation columns
Ocular dominance columns
From parvocellular layers of lateral geniculate nucleus

- Barevná stálost: barvy předmětů osvětlené různými zdroji světla jsou stálé

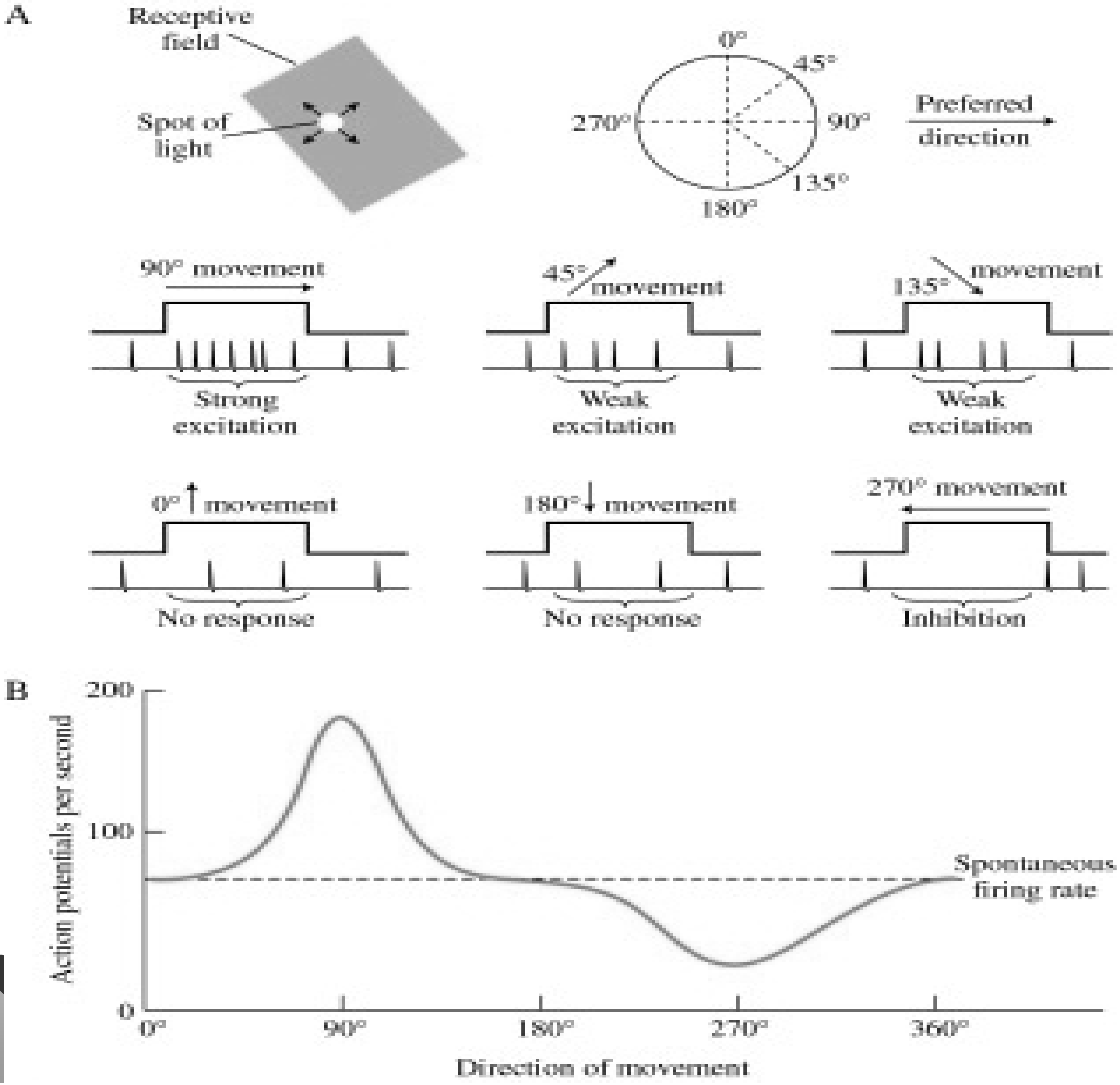
Vnímání pohybu

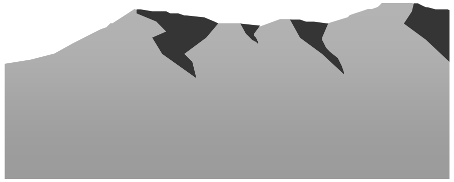


Jak je pohyb důležitý - http://www.sinauer.com/wolfe/chap7/mottypesF.htm

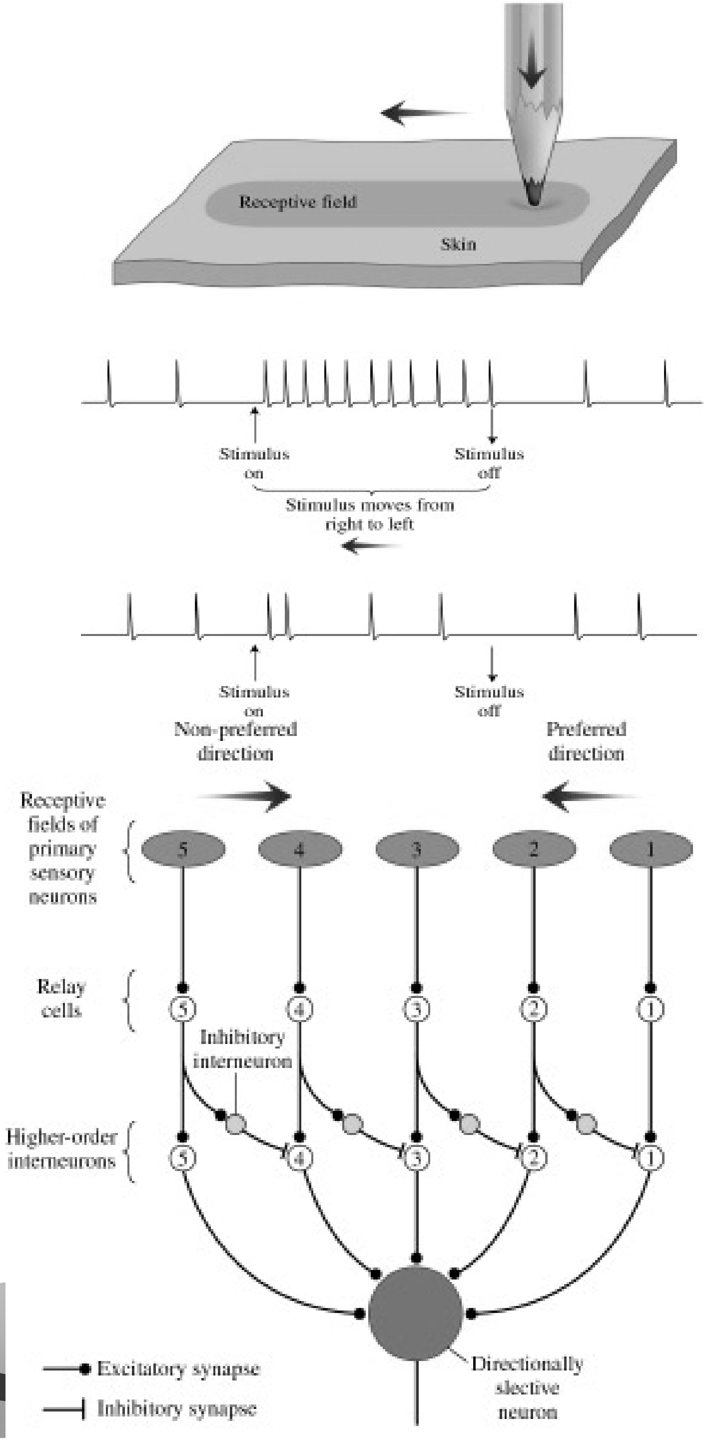
Zdánlivé pohyby

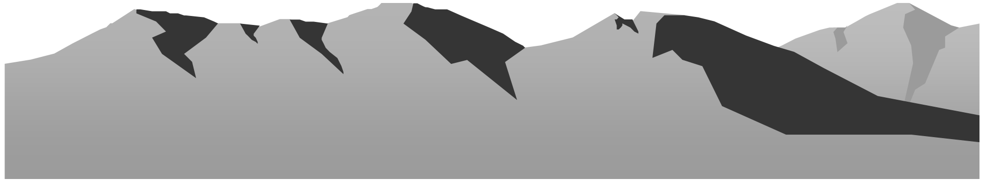
Specialista na směr





Detektor směru pohybu





Detektor rychlosti

- http://www.sinauer.com/wolfe/chap7/motdetectorF.htm

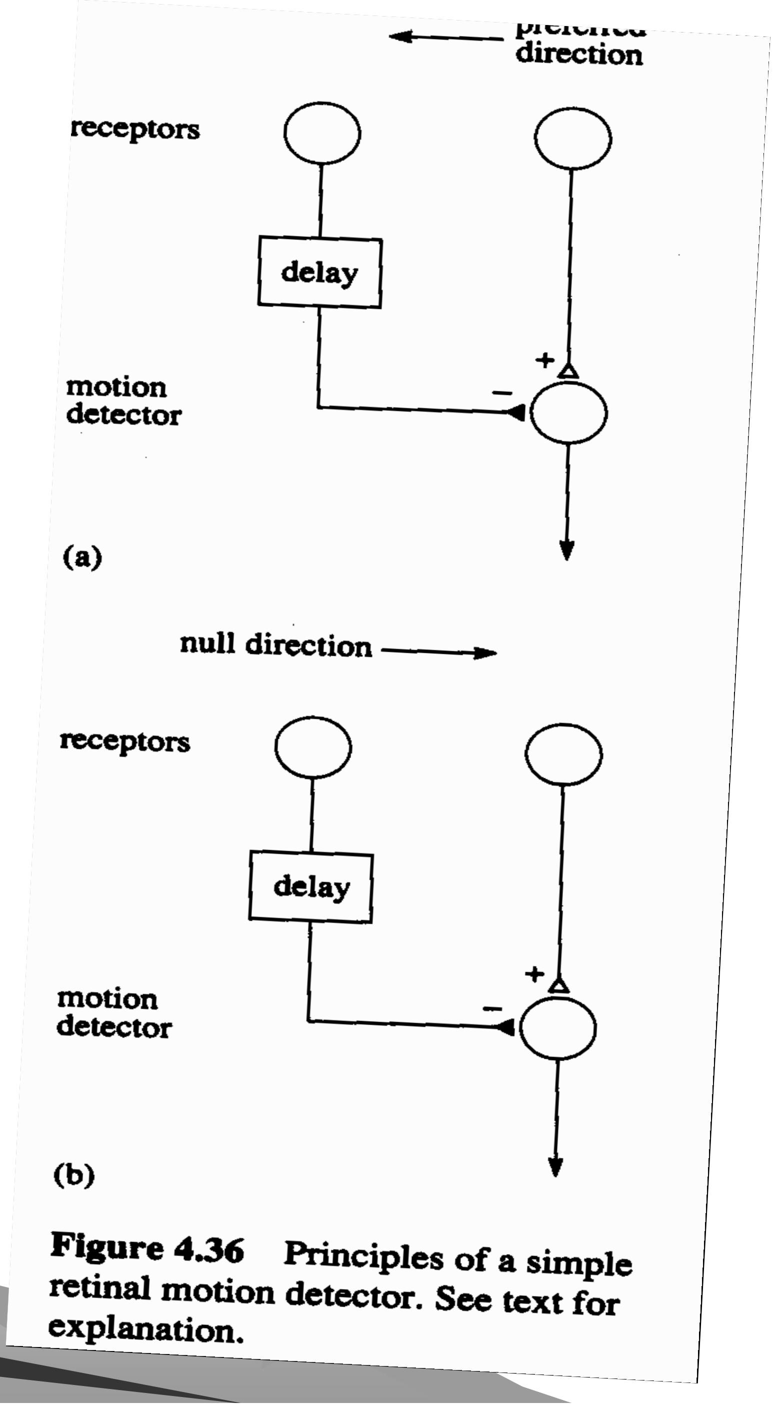


Figure 4.36 Principles of a simple retinal motion detector. See text for explanation.

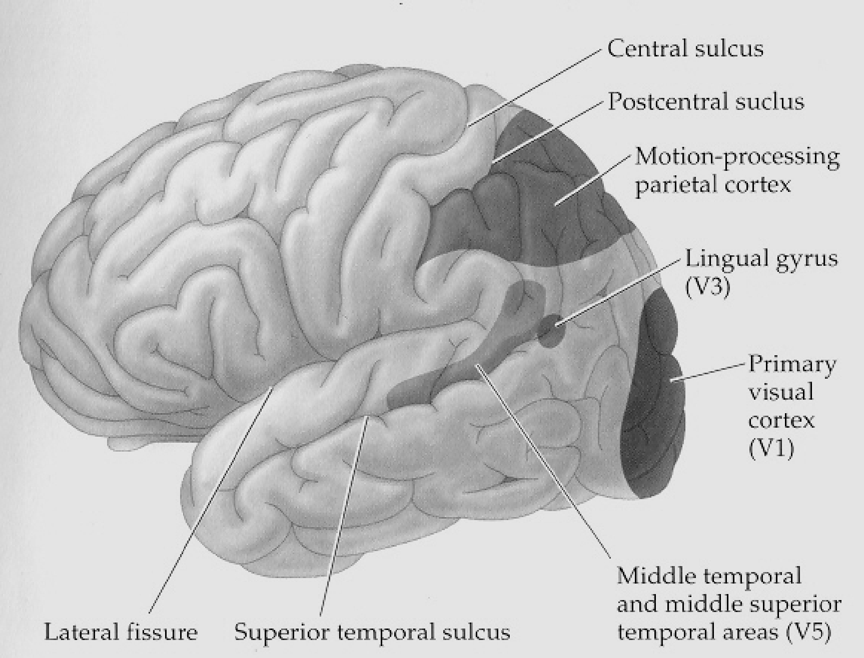
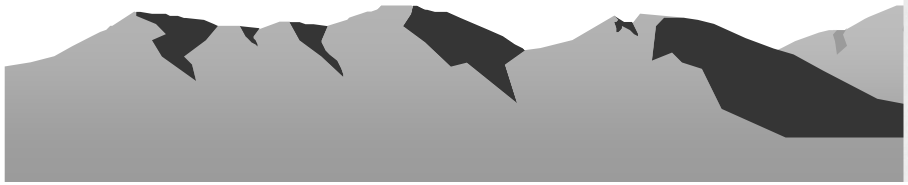
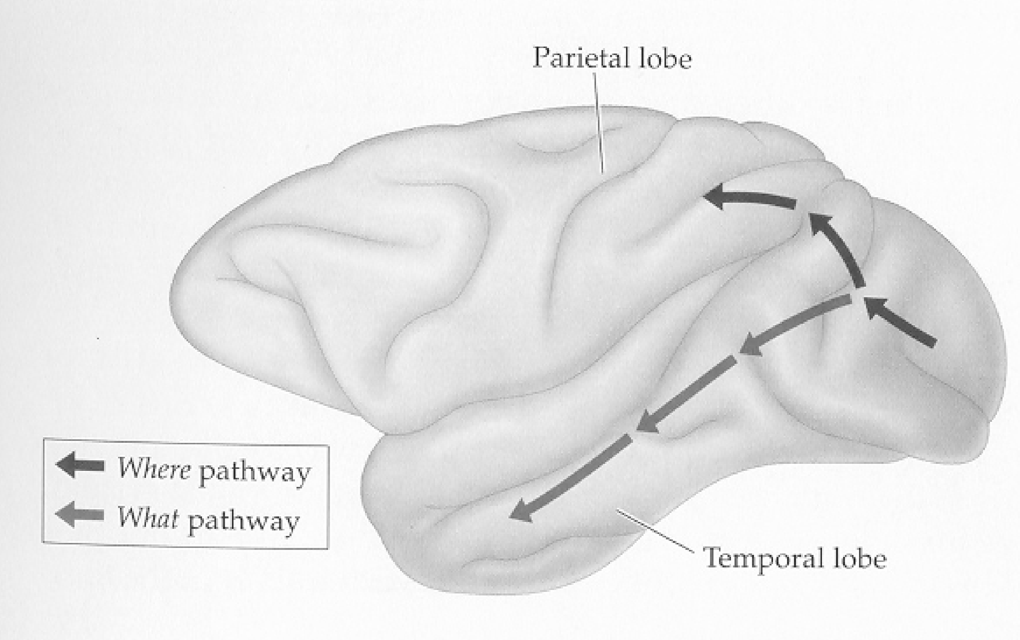
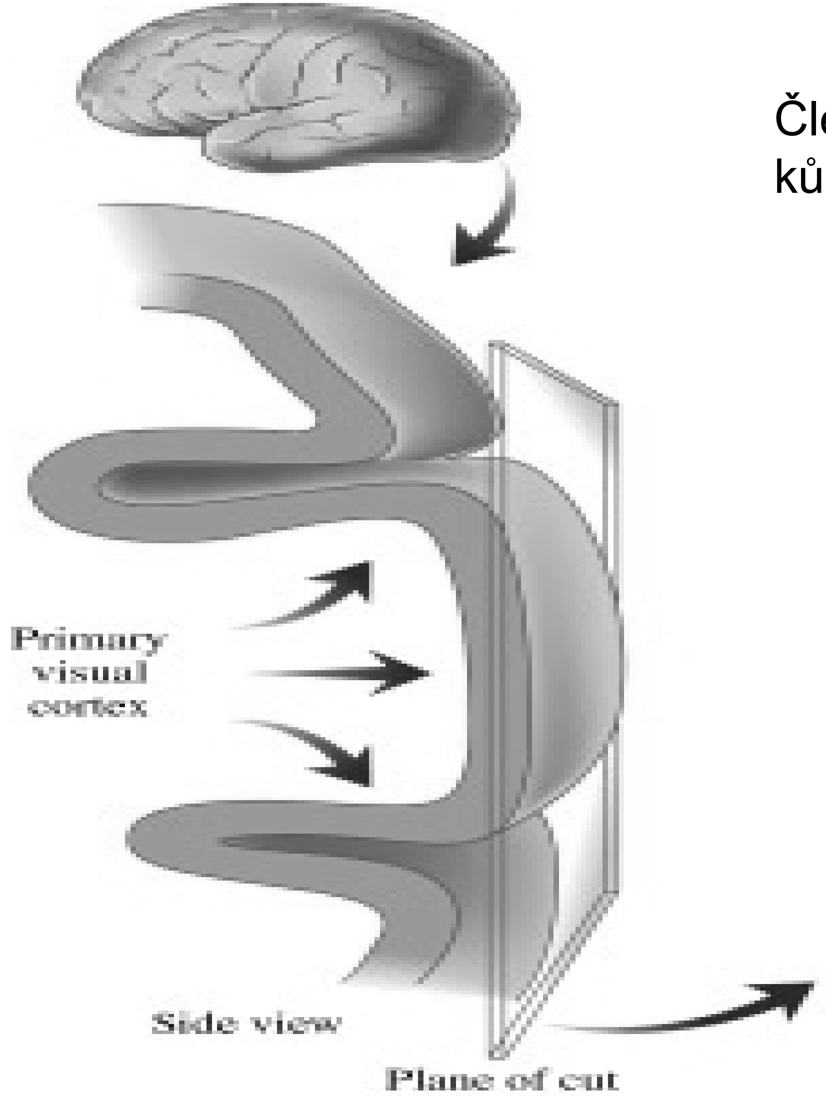


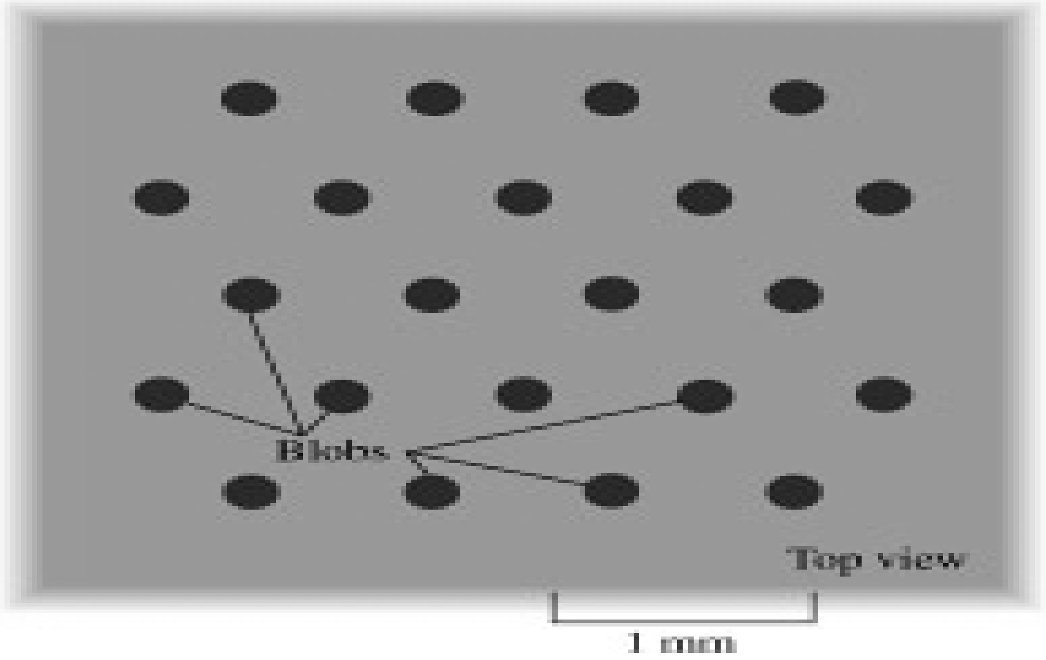
FIGURE 7.7 The middle temporal lobe and other regions of the cortex involved in motion perception.





Členění primární zrakové kůry – barevné sloupce (blobs)

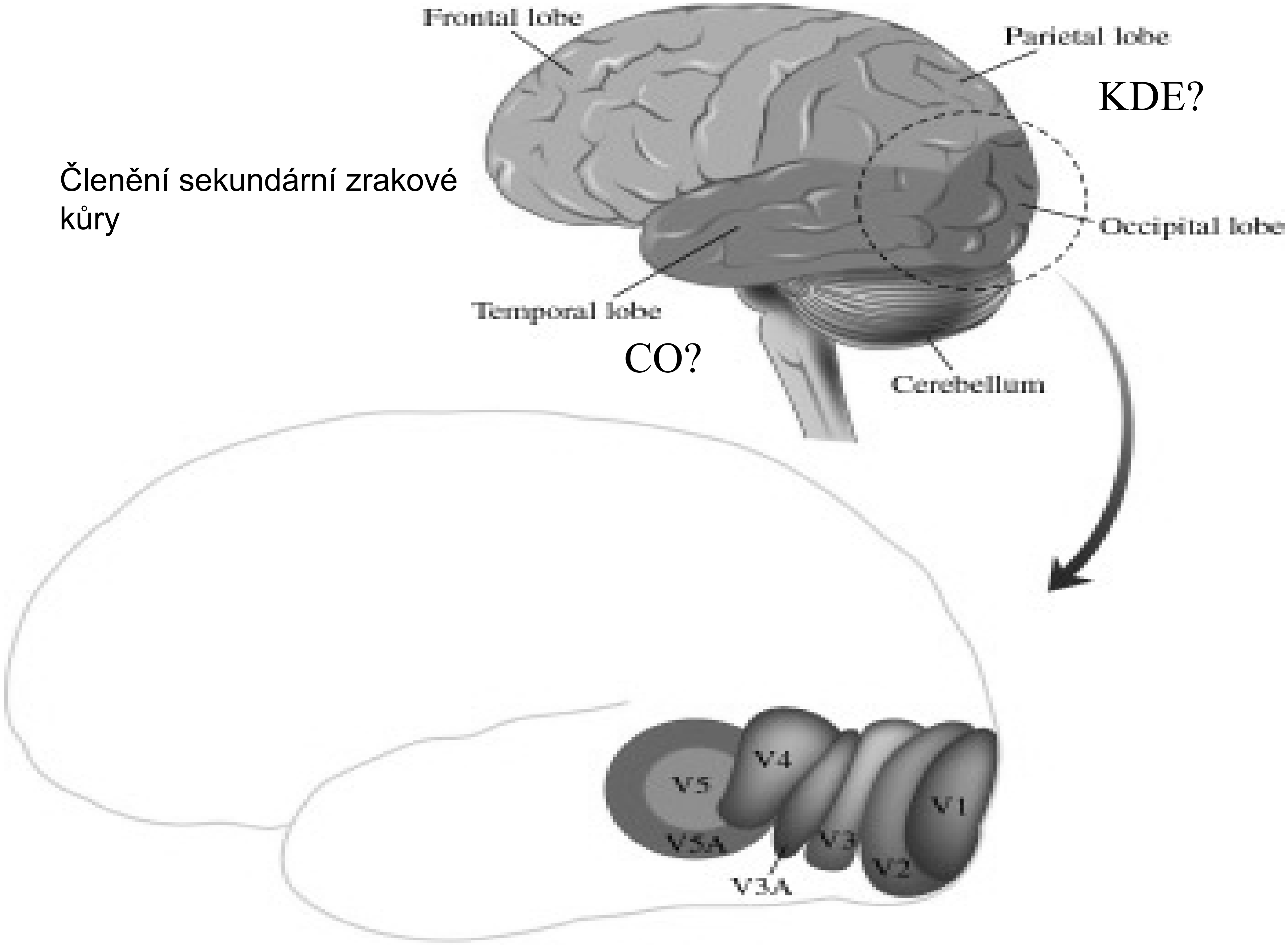




NEUROBIOLOGY
Gary G. Matthews

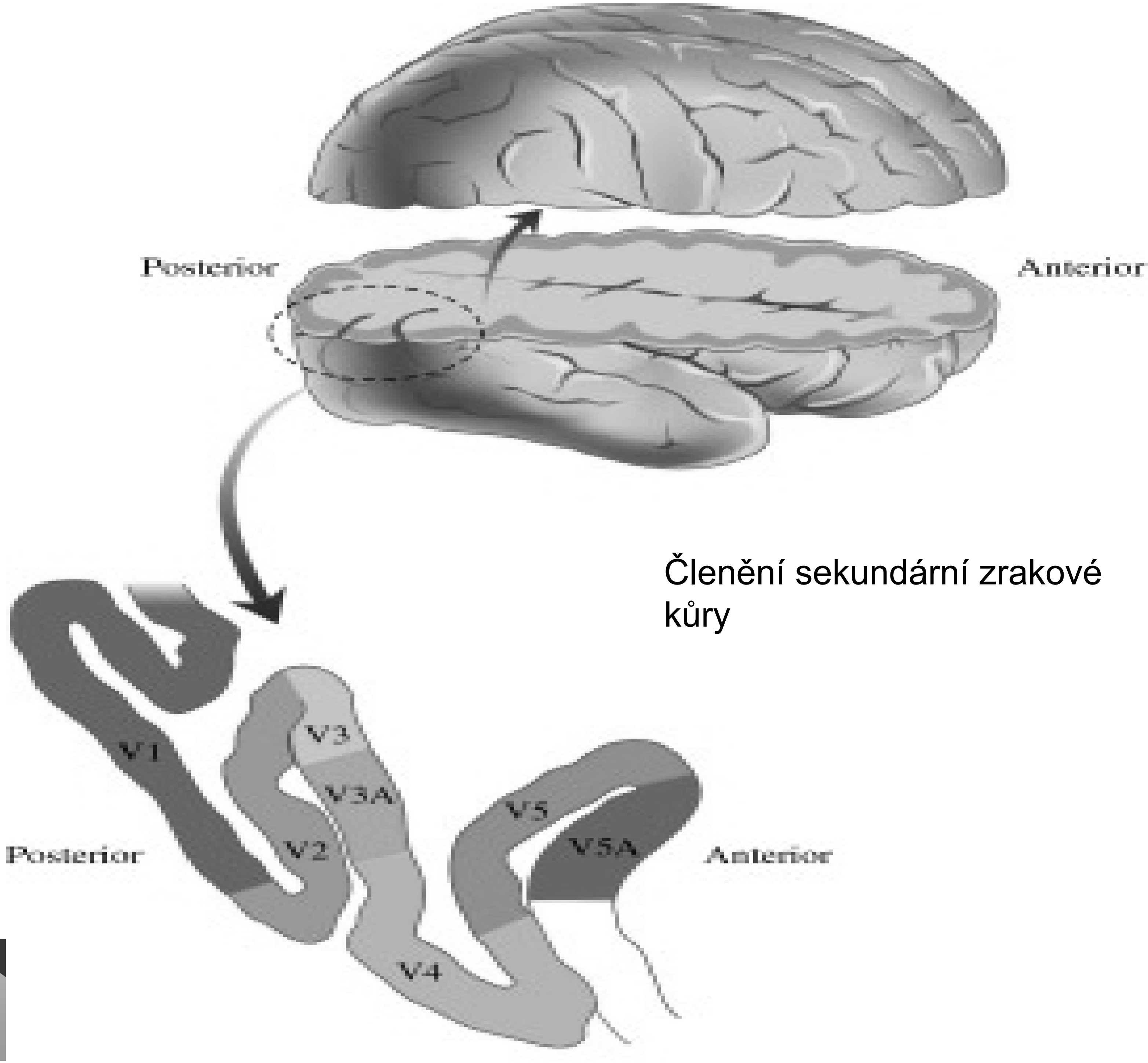
Blackwell Science

Členění sekundární zrakové kůry

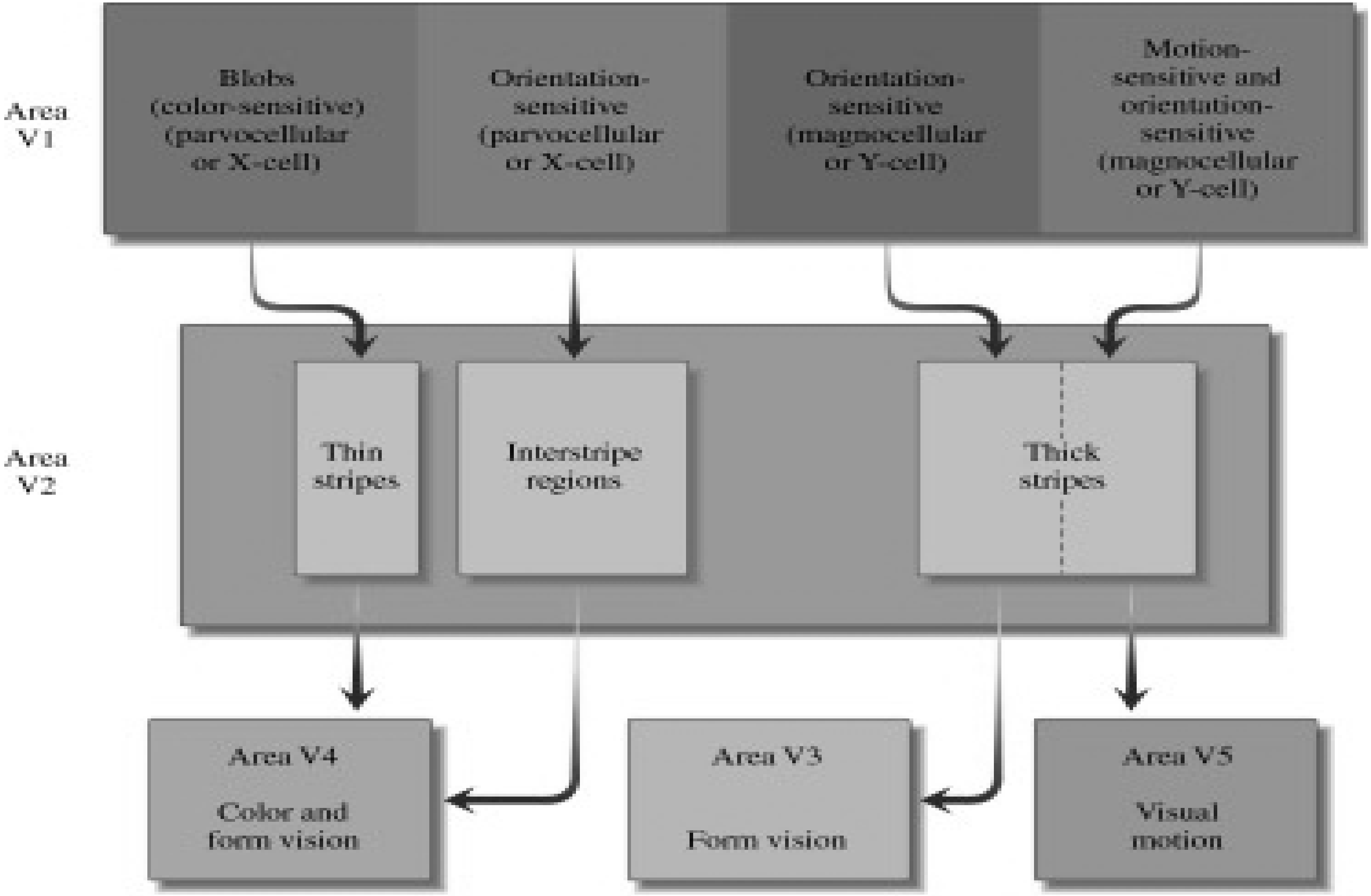


KDE?

CO?

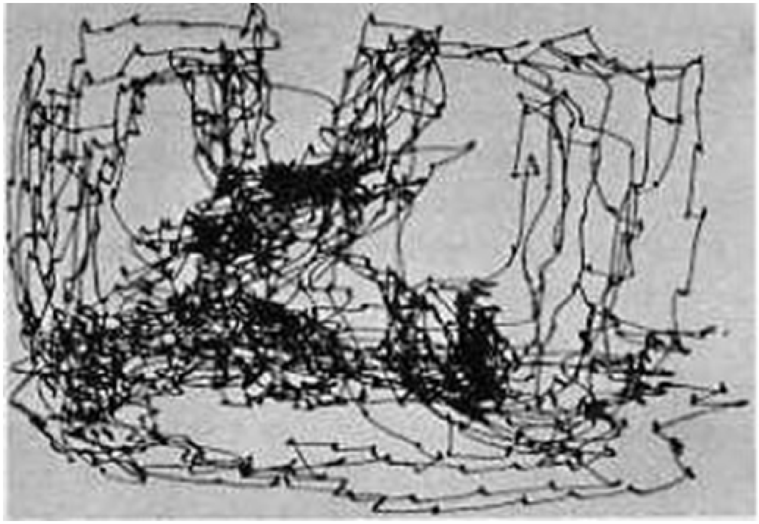


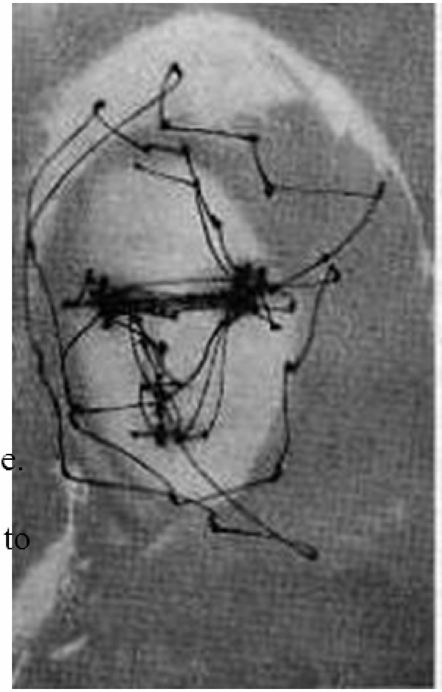
Členění sekundární zrakové kůry



Area V1
Blobs (color-sensitive) (parvocellular or X-cell)
Orientation-sensitive (parvocellular or X-cell)
Orientation-sensitive (magnocellular or Y-cell)
Motion-sensitive and orientation-sensitive (magnocellular or Y-cell)
Area V2
Thin stripes
Interstripe regions
Thick stripes
Area V4
Color and form vision
Area V3
Form vision
Area V5
Visual motion

Pohyby očí – sakkadické pohyby



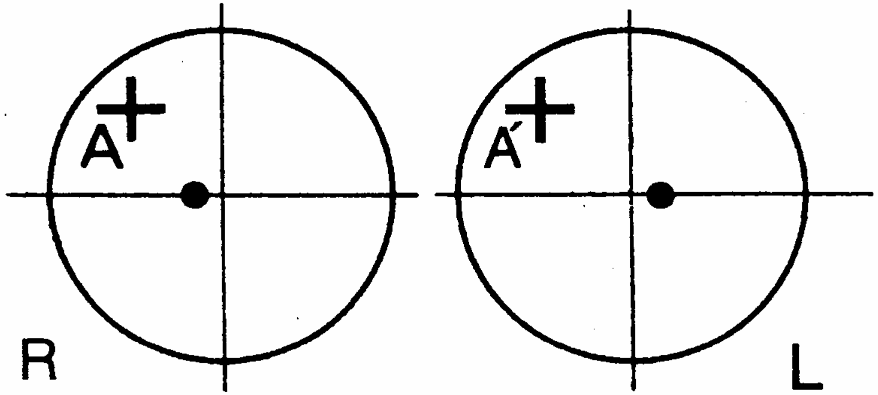


A picture is viewed by an observer while we monitor eye position and hance directinon of gaze. the eyes jump, come to rest momentarily (producing a small dot on the record), then jump to a new locus of interest.
It seems difficult to jump to a void - a place lacking abrupt luminance changes.

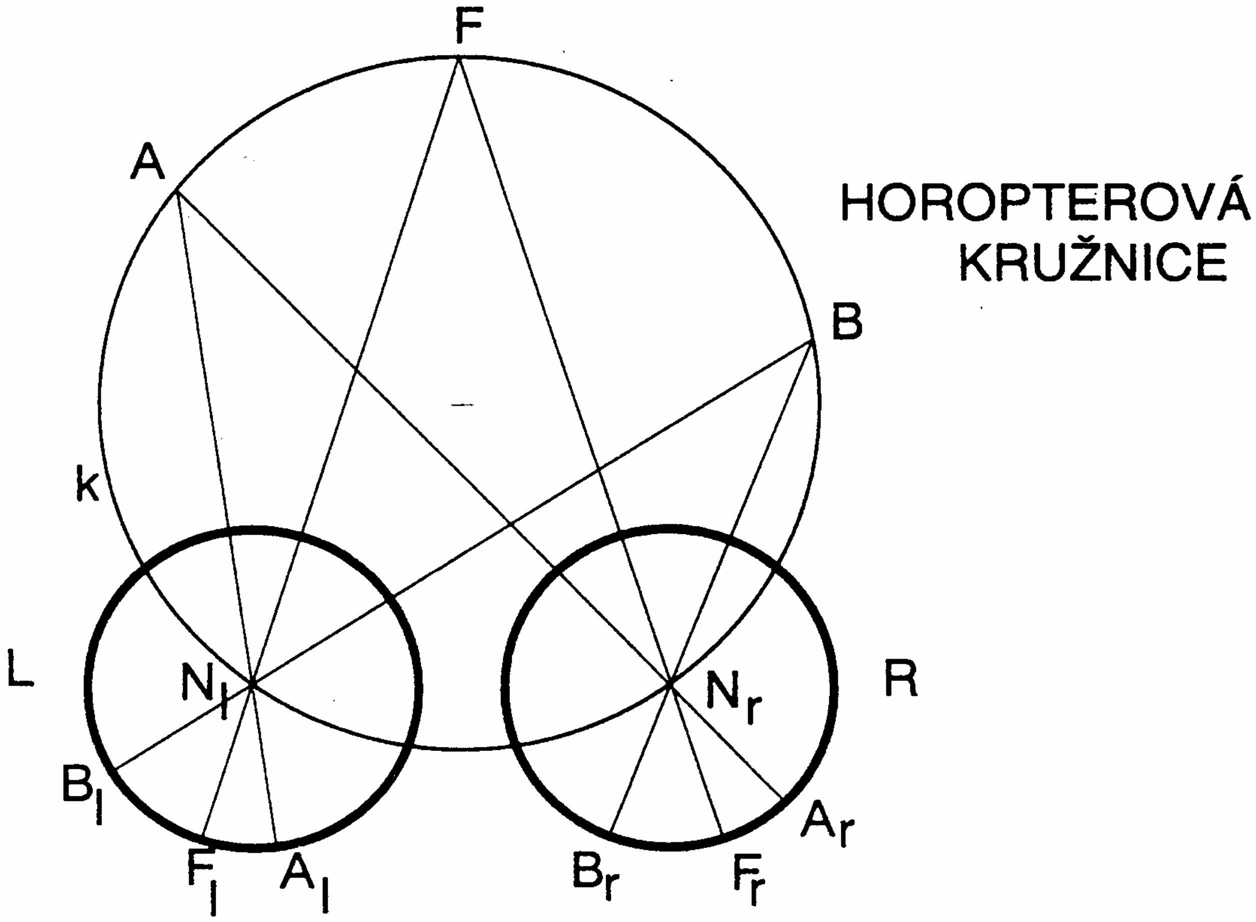
Vnímání prostoru

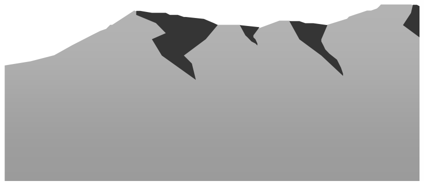
OBR. 57A

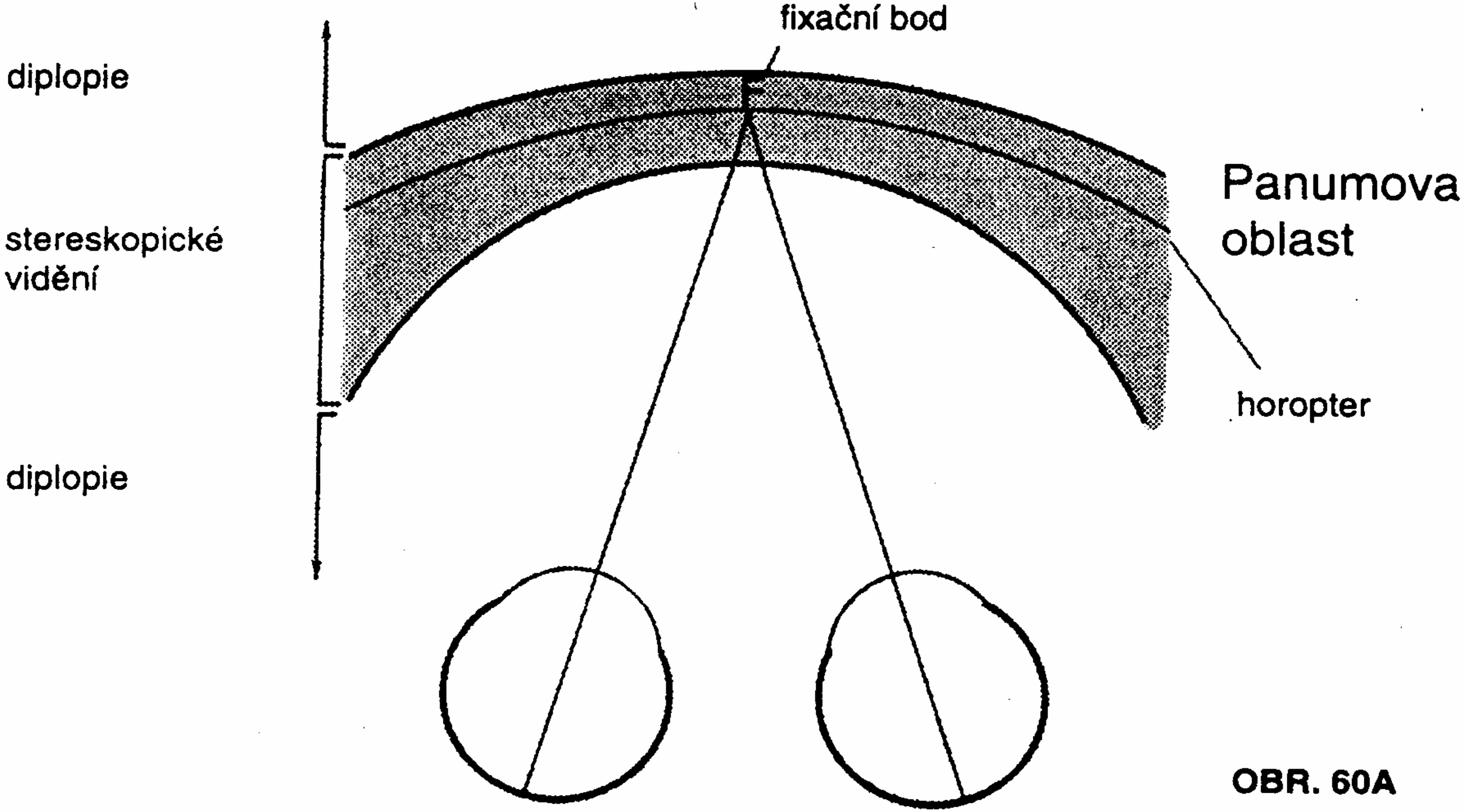
Sítnice pravého (R) a levého (L) oka. Body A a A' značí polohu identických míst. Černá skvrna znázorňuje centrální jamku.



OBR. 58A



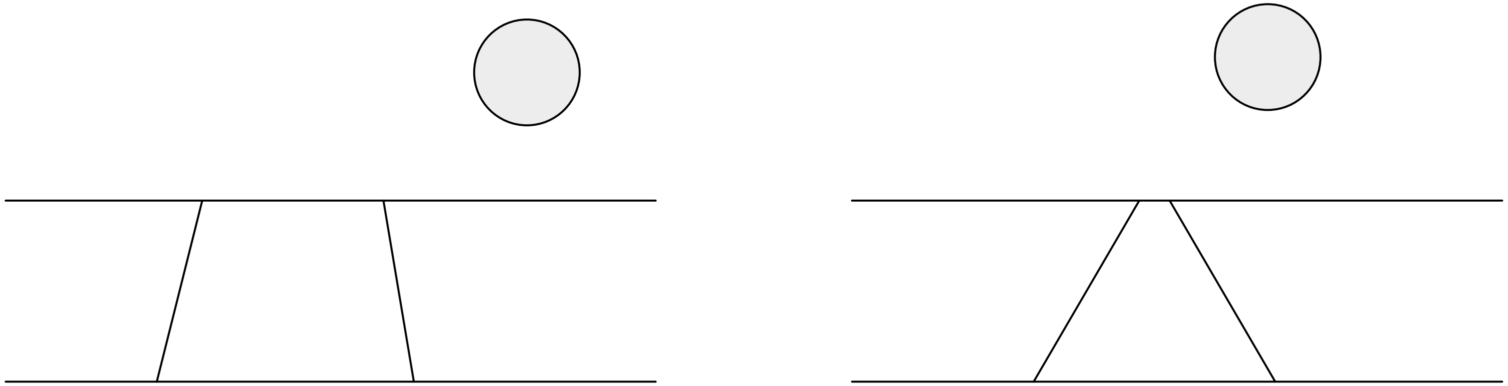


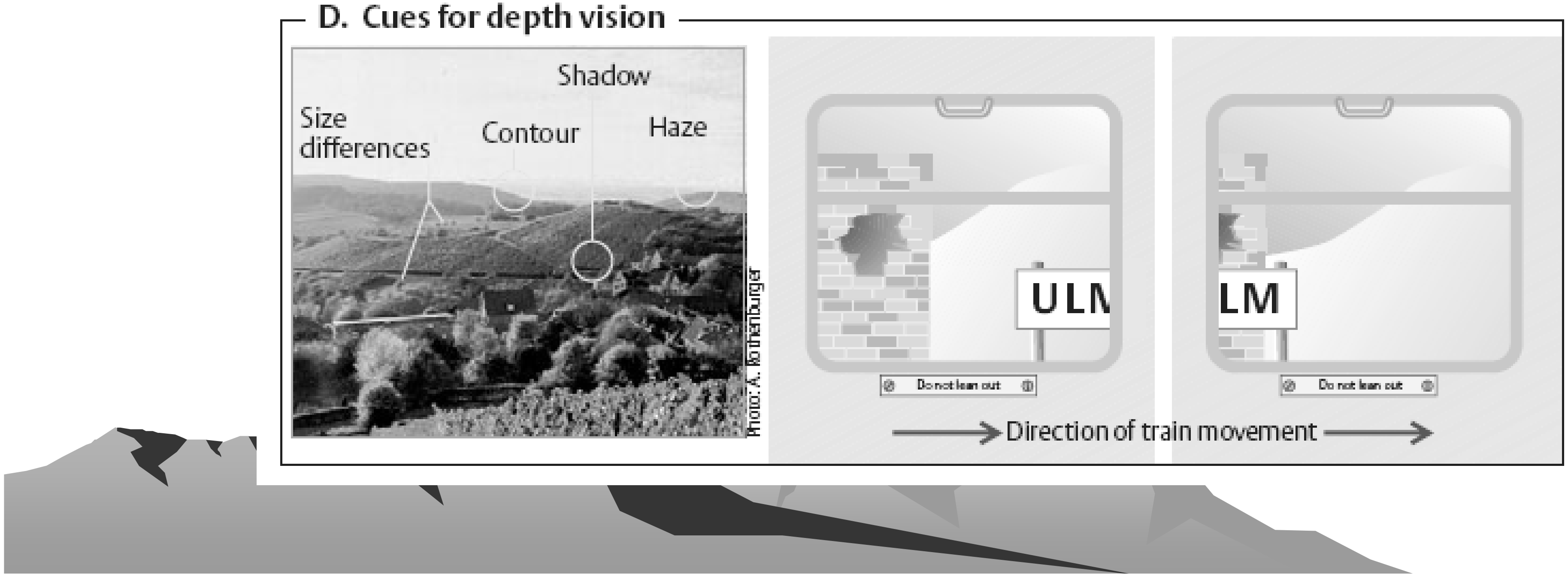

fixační bod
diplopie
stereskopické vidění
Panumova oblast
horopter
diplopie

OBR. 60A

- Binokulární neurony – fůze obrazů
- Sloupečky retinální disparace

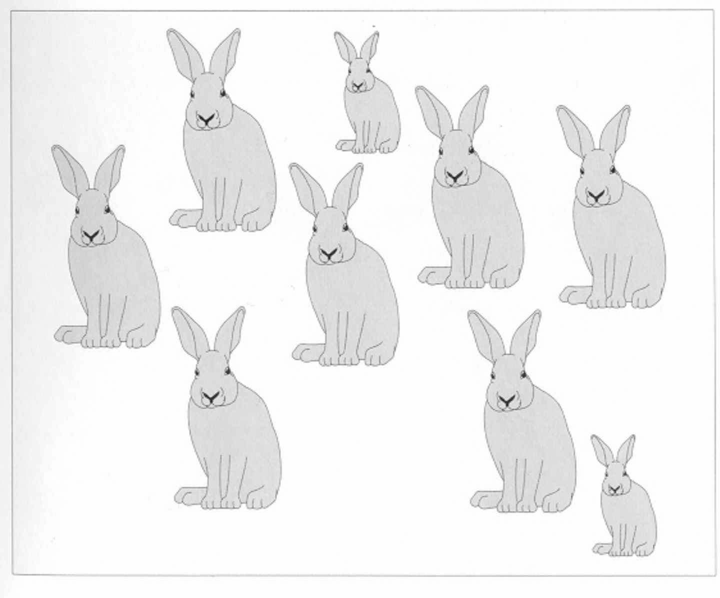
Další metody konstrukce prostoru.





D. Cues for depth vision

Jsou stejně malí, ale nevypadají…



Interpretace viděného rozeznávání objektů

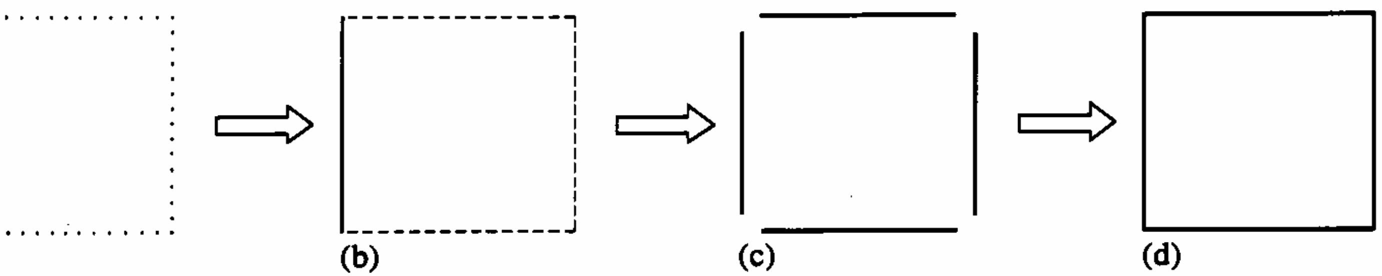


Figure 4.51 Descriptive advantages of visual grouping. See text for explanation.

Seskupování
Podle kontrastních
linií

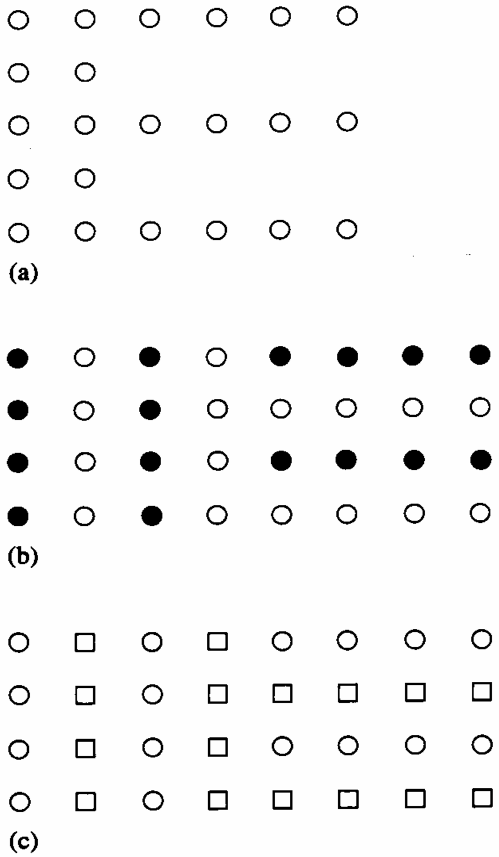
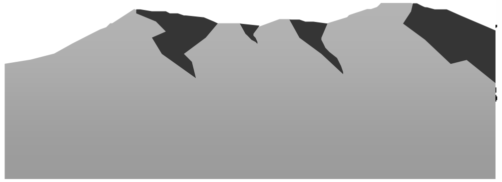
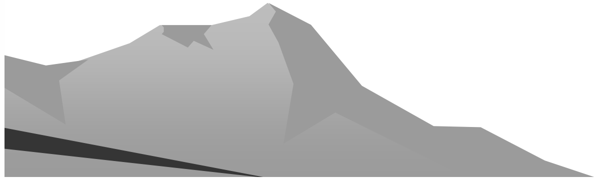


Figure 4.50 Examples of visual grouping: (a) Grouping by spacing. (b) Grouping by colour. (c) Grouping by shape.





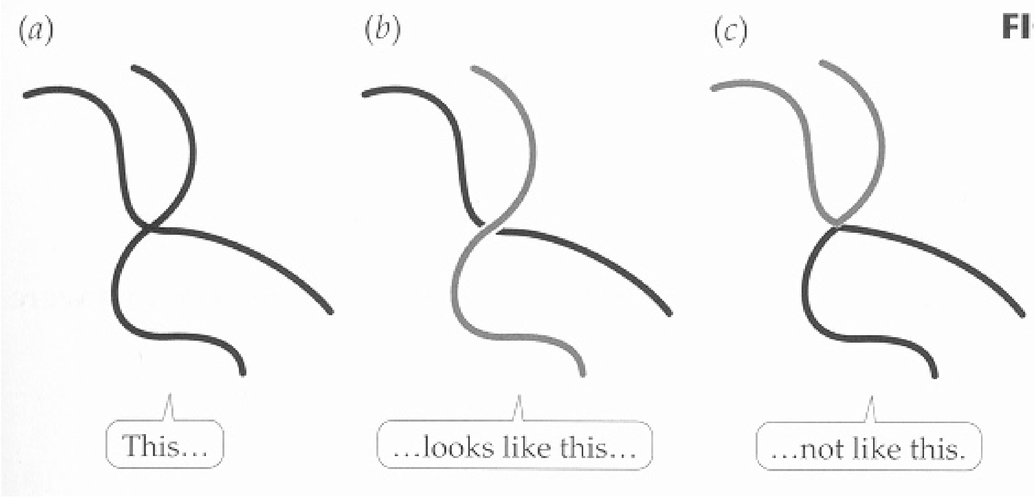
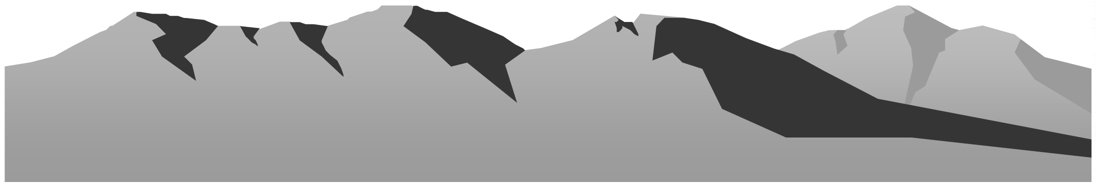
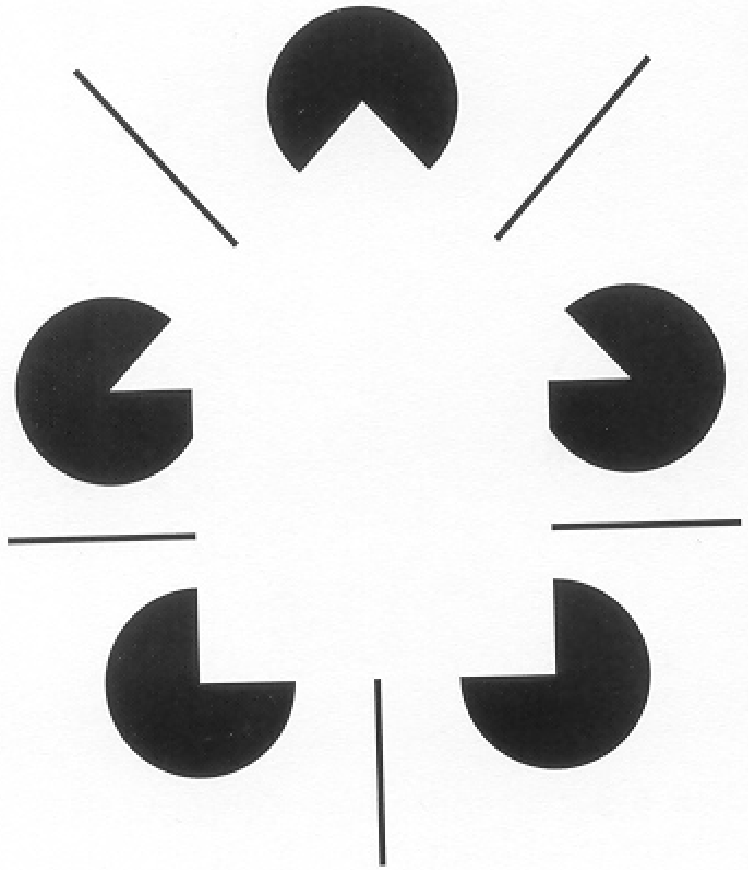


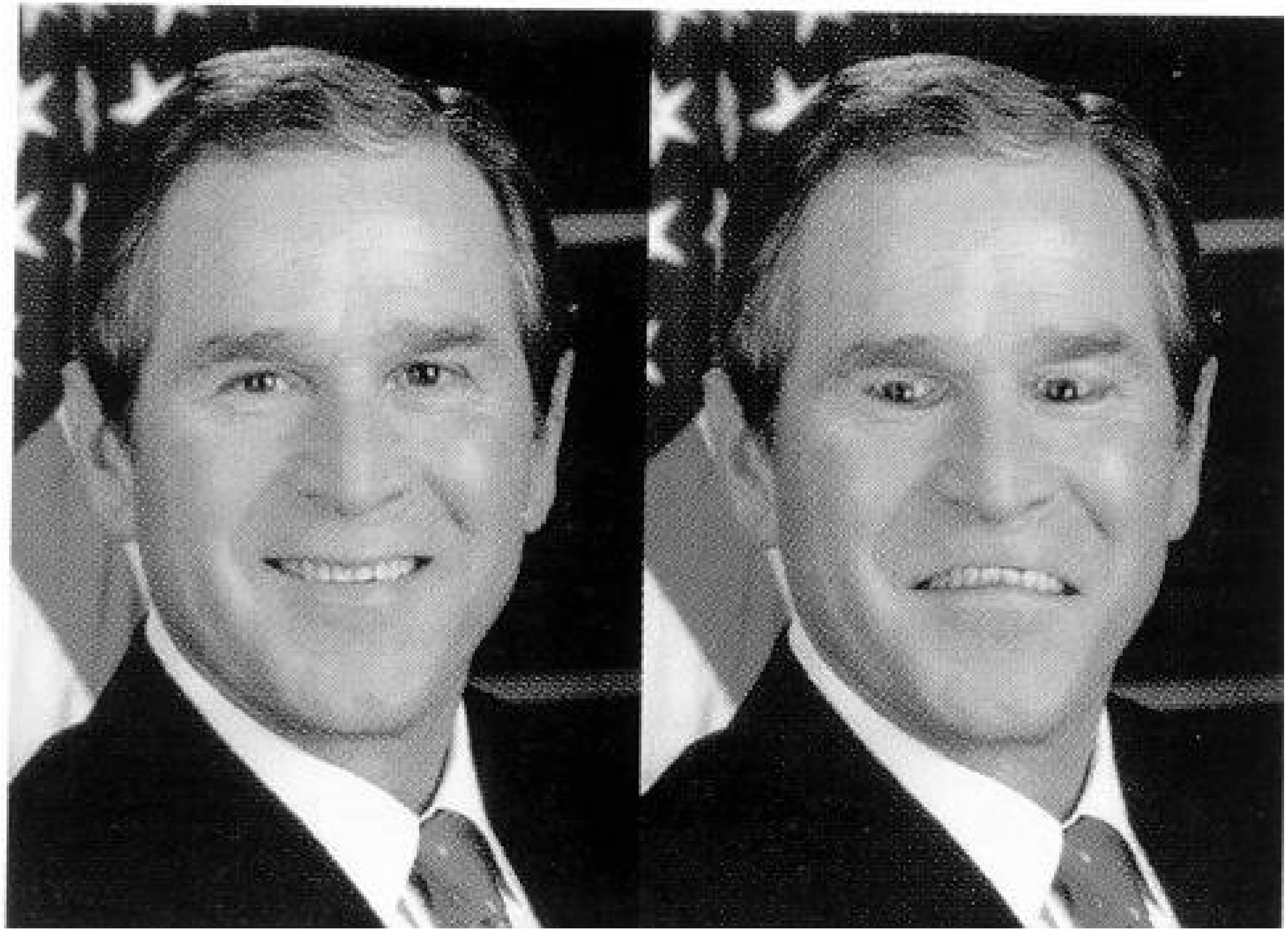
FIGURE 4.7 The Gestalt principle of good continuation.

Seskupování
Podle kontrastních
Linií
Hledání hran, kontur

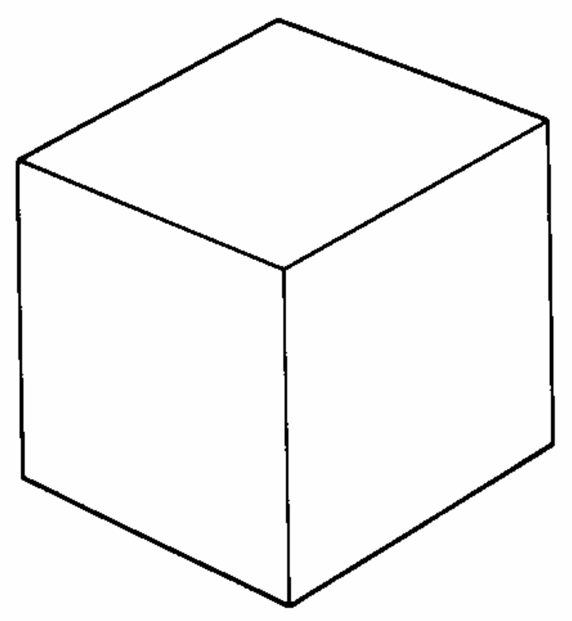


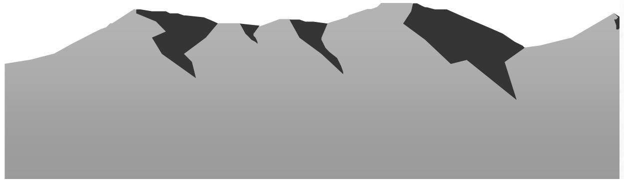


Orientace v prostoru nesmí být zásadní pro intepretaci



Zkušenost – rozeznáme tvar i z různých úhlů





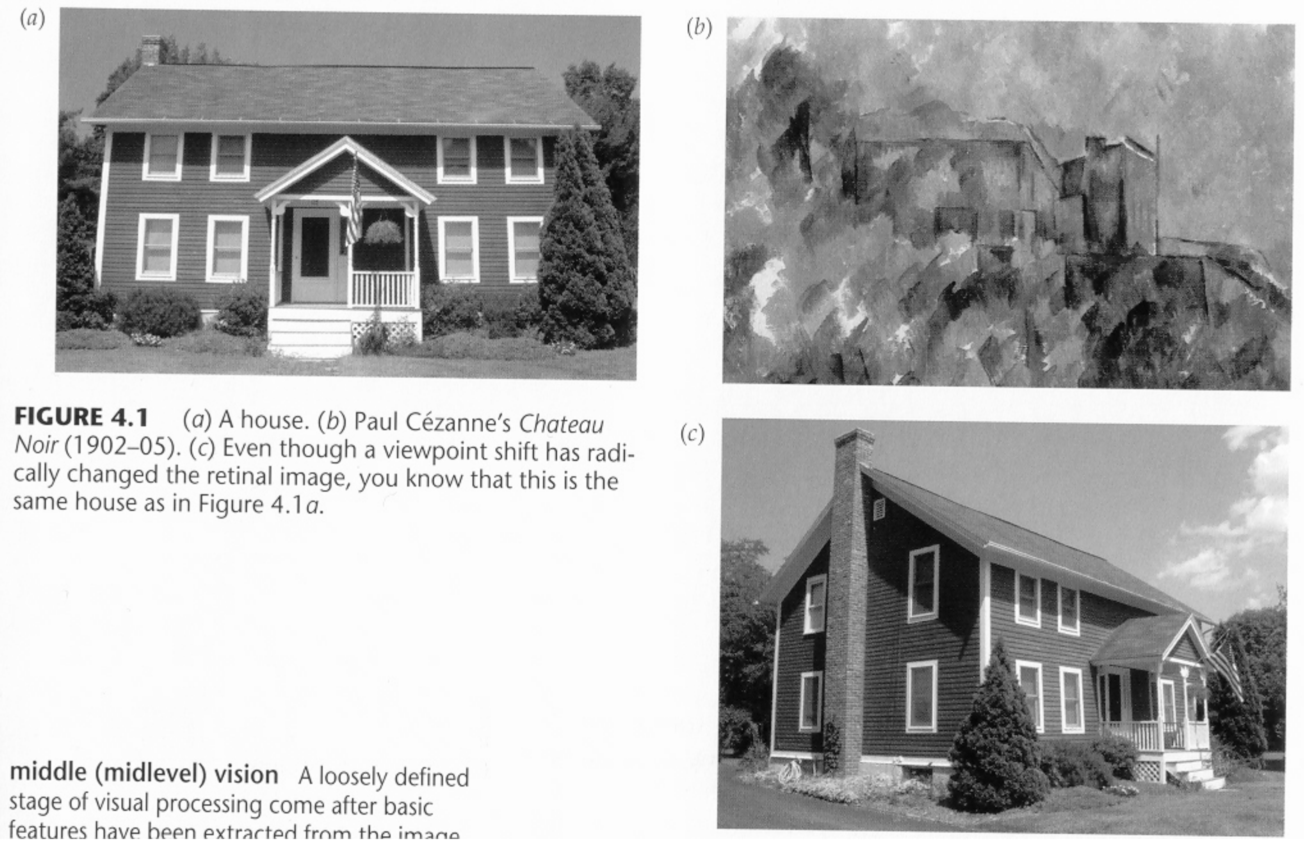


FIGURE 4.1 (*a*) A house. (*b*) Paul Cézanne's *Chateau Noir* (1902–05). (*c*) Even though a viewpoint shift has radically changed the retinal image, you know that this is the same house as in Figure 4.1*a*.

middle (midlevel) vision A loosely defined stage of visual processing come after basic features have been extracted from the image

Iluze 1

Iluze 2

Iluze 3

Zdánlivý pohyb

Analýza biologického pohybu

Jak je pohyb důležitý

Únava analyzátoru pohybu

Psychofyziologie

- Poznávací procesy
  - Asociační korové oblasti
    - Parasensorické
    - Prefrontální
    - Paralimbická

Parasensorické

- Unimodální – sekundární korové oblasti jednotlivých smyslů. Léze vedou k agnosiím.
  - Zrakové:
    - Pro kresby
    - Prosopagnosie – pro tváře
    - Pro pohyb
    - Pro hloubku prostoru

Parasensorické

- Unimodální – sekundární korové oblasti jednotlivých smyslů. Léze vedou k agnosiím.
  - Sluchové:
    - Čistá slovní hluchota, ale mluvení, čtení, psaní ano
    - Pro neverbální zvuky

Parasensorické

- Unimodální – sekundární korové oblasti jednotlivých smyslů. Léze vedou k agnosiím.
  - Somatosensorické:
    - Astereognosie – neschopnost poznat hmatem

Parasensorické

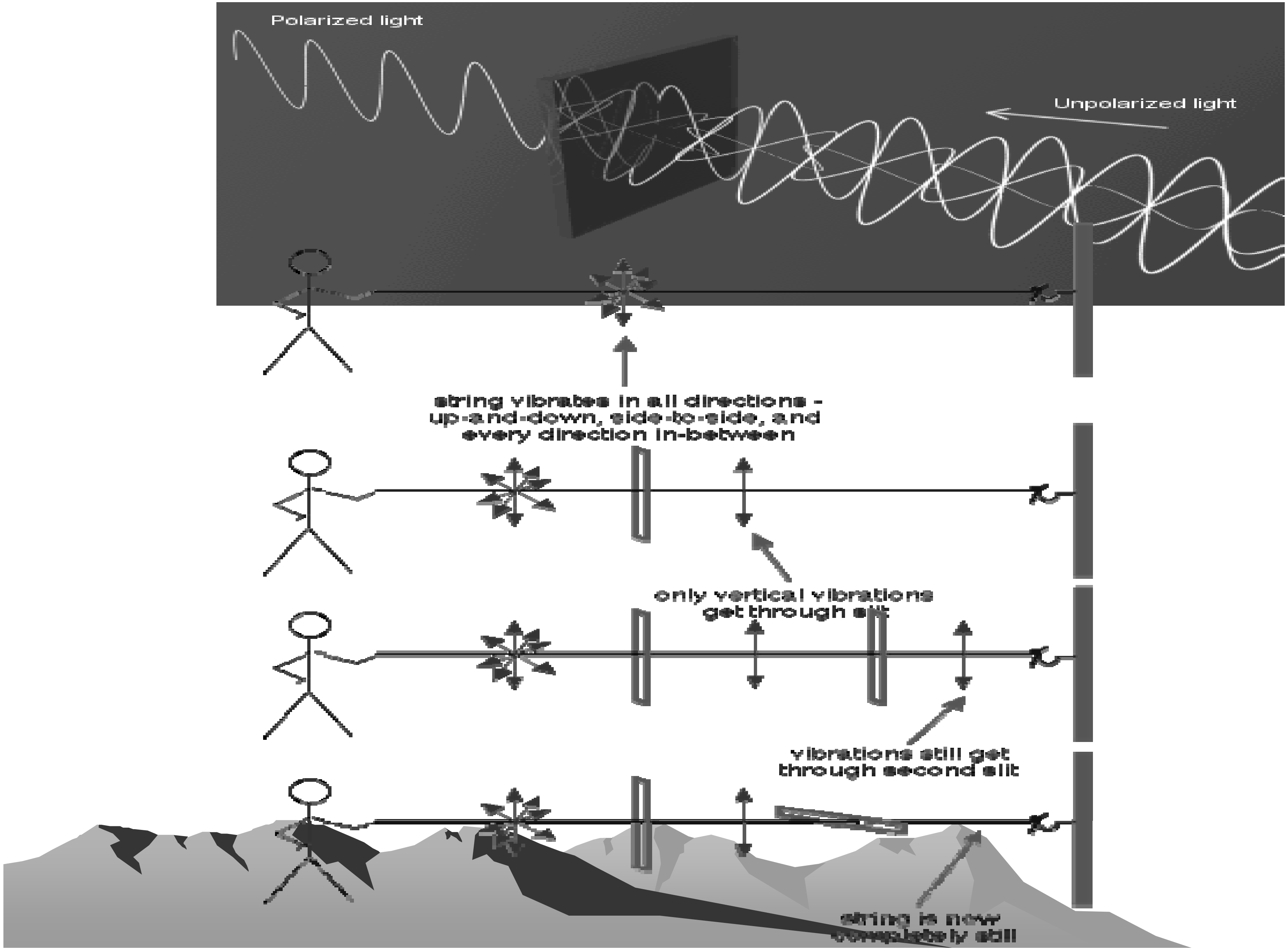
- Polymodální
  - Hemineglect syndrom: ignorace vizuálních, somatosensorických, sluchových podnětů z jedné poloviny těla

Schopnost pravé hemisféry sdělovat a vnímat emocionální komponentu řeči.

Aprosodie- neschopnost: motorická, sensorická.

- deaf abstract thinking - téma

Polarizované světlo – mám nové články!!



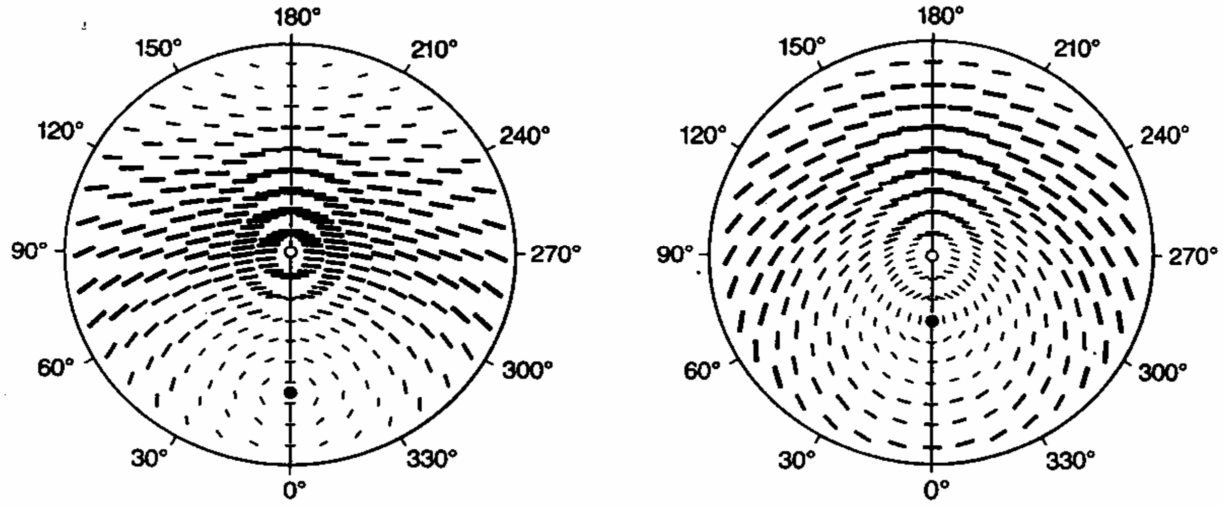


Fig. 3. Two-dimensional representations of the celestial E-vector pattern (the pattern of polarized light) depicted for two different elevations of the sun (filled circle): 25° in left figure, 60° in right figure. The orientation and size of each black bar mark the angle and degree (percentage) of polarization, respectively. The open circle indicates the zenith. The solar meridian (the line from the zenith down to the horizon) and the anti-solar meridian represent the symmetry plane of the celestial E-vector pattern. From Wehner (1994a).

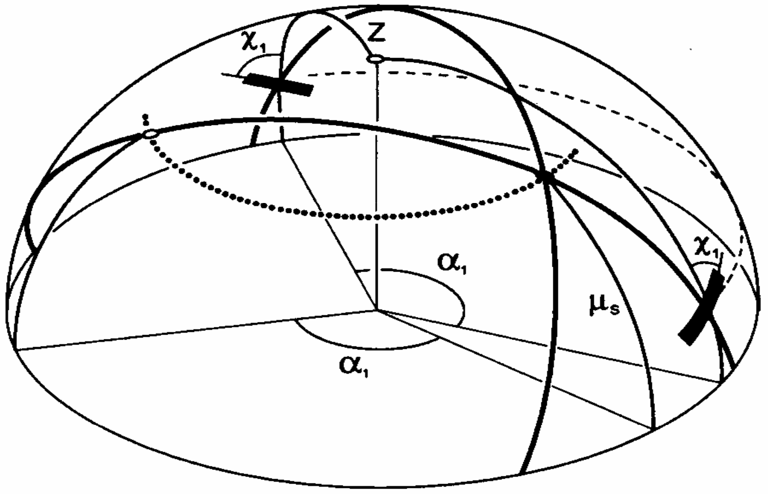
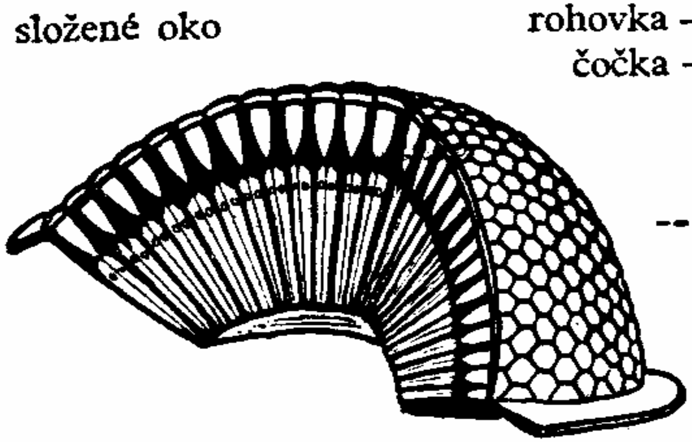
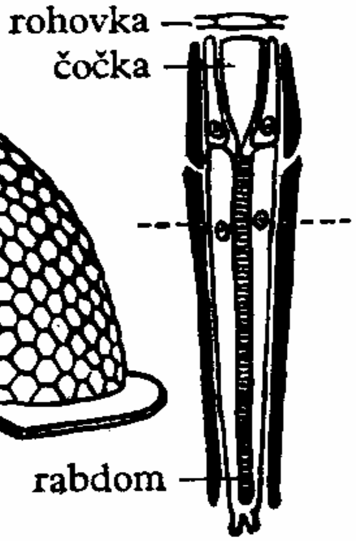
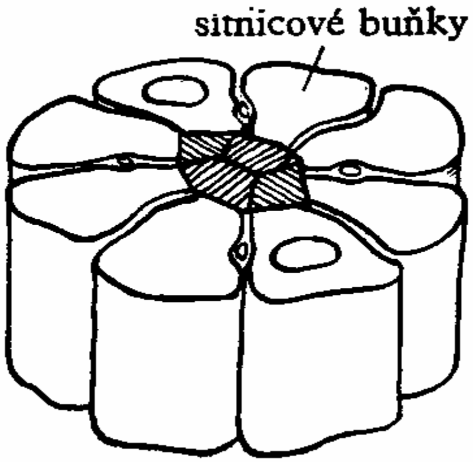


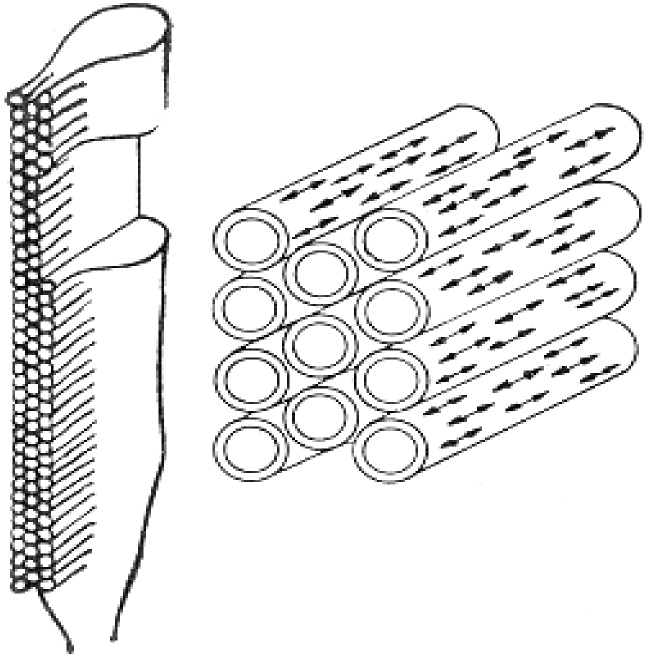
Fig. 4. Three-dimensional constructions required to infer the position of the sun – and hence the azimuthal position of the solar meridian – from at least two patches of polarized light in the sky. The black bars indicate the orientation of the E-vectors (χ) at two points in the sky. The following directives would yield an all-inclusive solution of the problem: First, determine the E-vector orientation at two points in the sky (a task not discussed here); then construct the great circles (heavy black arcs) running at right angles through the E-vectors; finally determine the position of the sun (filled circle) as the point of intersection of the two great circles. With one E-vector alone, the position of the sun cannot be determined unambiguously. If the elevation of the sun (μ_s) were known at a particular time of day, two intersection points of the great circle inclined orthogonally to χ_1 and the parallel of altitude defined by μ_s could be determined. These intersection points define the correct position of the sun (filled circle), as well as a fictive position (open circle), which is separated by the azimuthal difference α_1 from the correct one. The insect's E-vector compass does not operate this way, but is based on a set of simpler rules (see text and Fig. 5). Modified from Wehner (1981).



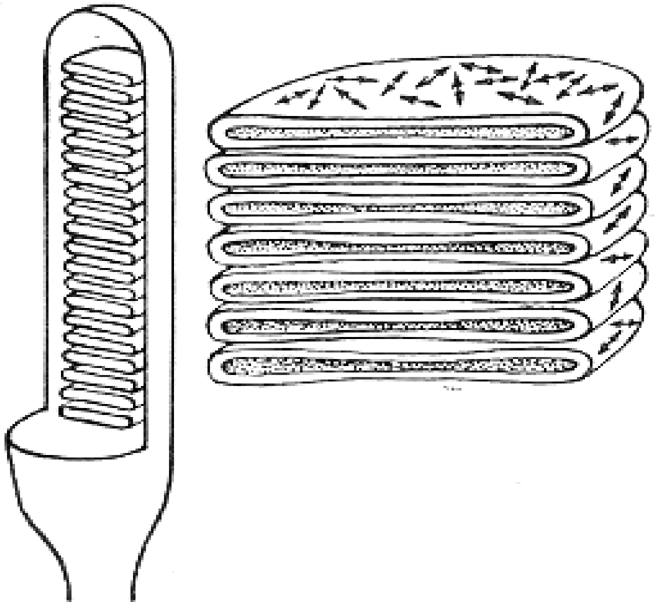




Složené oko hmyzu se skládá z mnoha omatidií, oddělených od sebe pigmentem. Každé omatidium má vlastní rohovku, čočku a sítnicovou tyčinku (rabdom) tvořenou osmi sítnicovými buňkami, jež přecházejí v nerv.



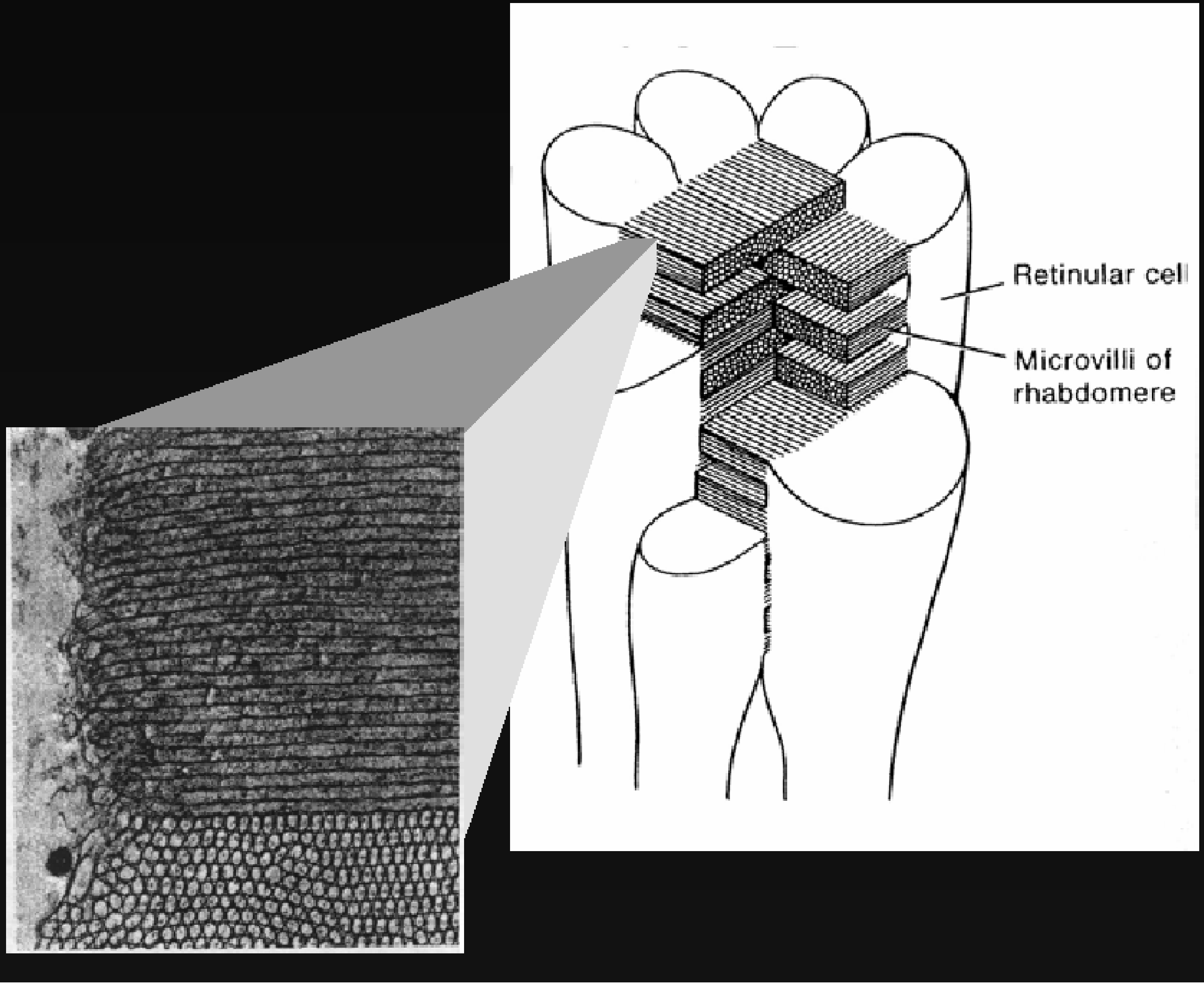
sítnicová buňka hmyzu



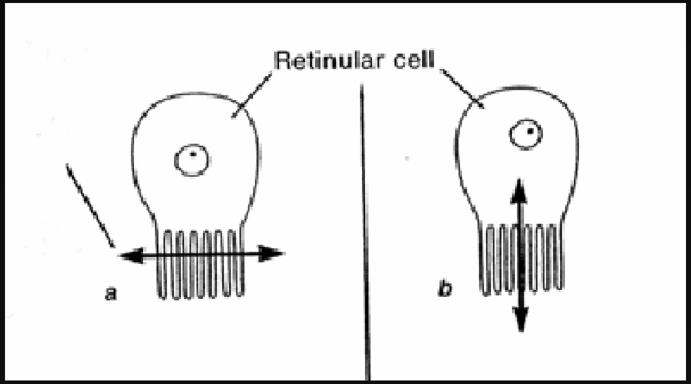
zraková tyčinka obratlovců

Molekuly světločivého pigmentu (radopsinu) jsou v tyčince hmyzího oka uspořádány jedním směrem, kdežto v tyčince oka obratlovce jsou neuspořádané. Vysvětluje to rozdíl ve schopnostech obou očí rozlišovat rovinu polarizovaného světla.

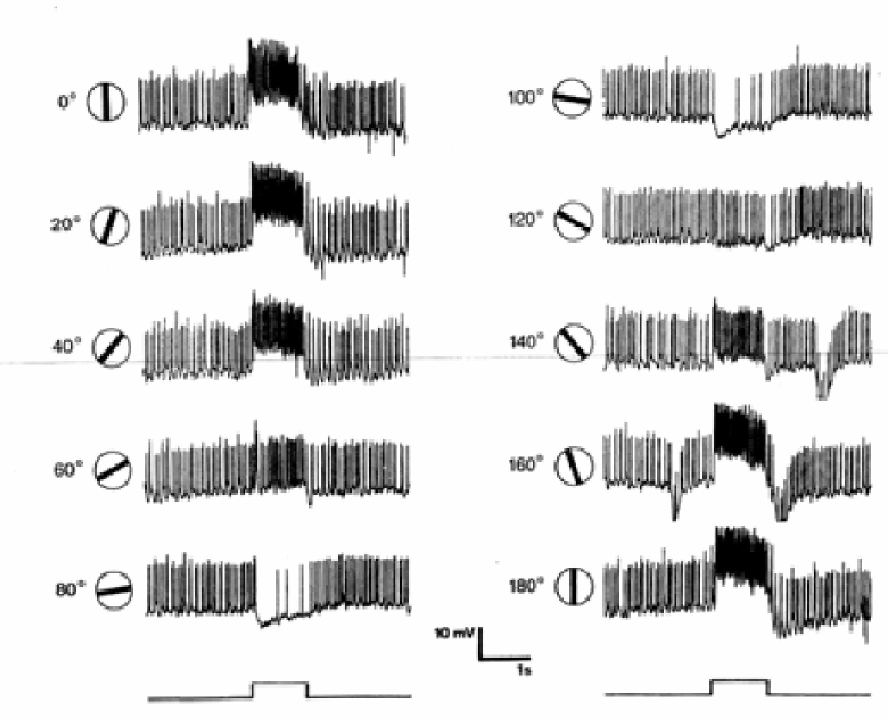
Organization of retinular cells allows for detection of polarized light



Arthropod visual neurons can be sensitive to specific planes of polarized light



Cricket



(Wehner 1989)