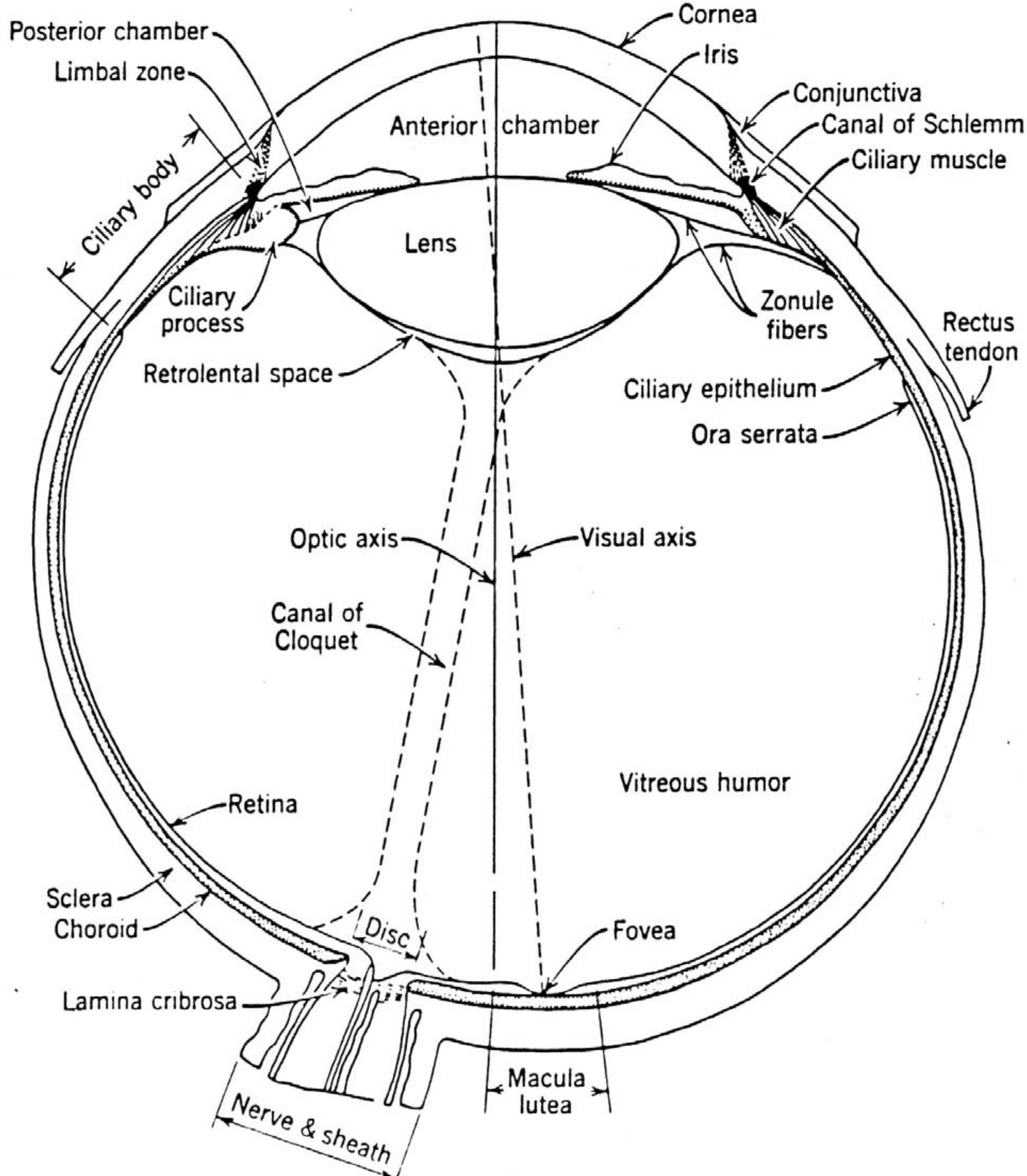
From Photons to Faces:

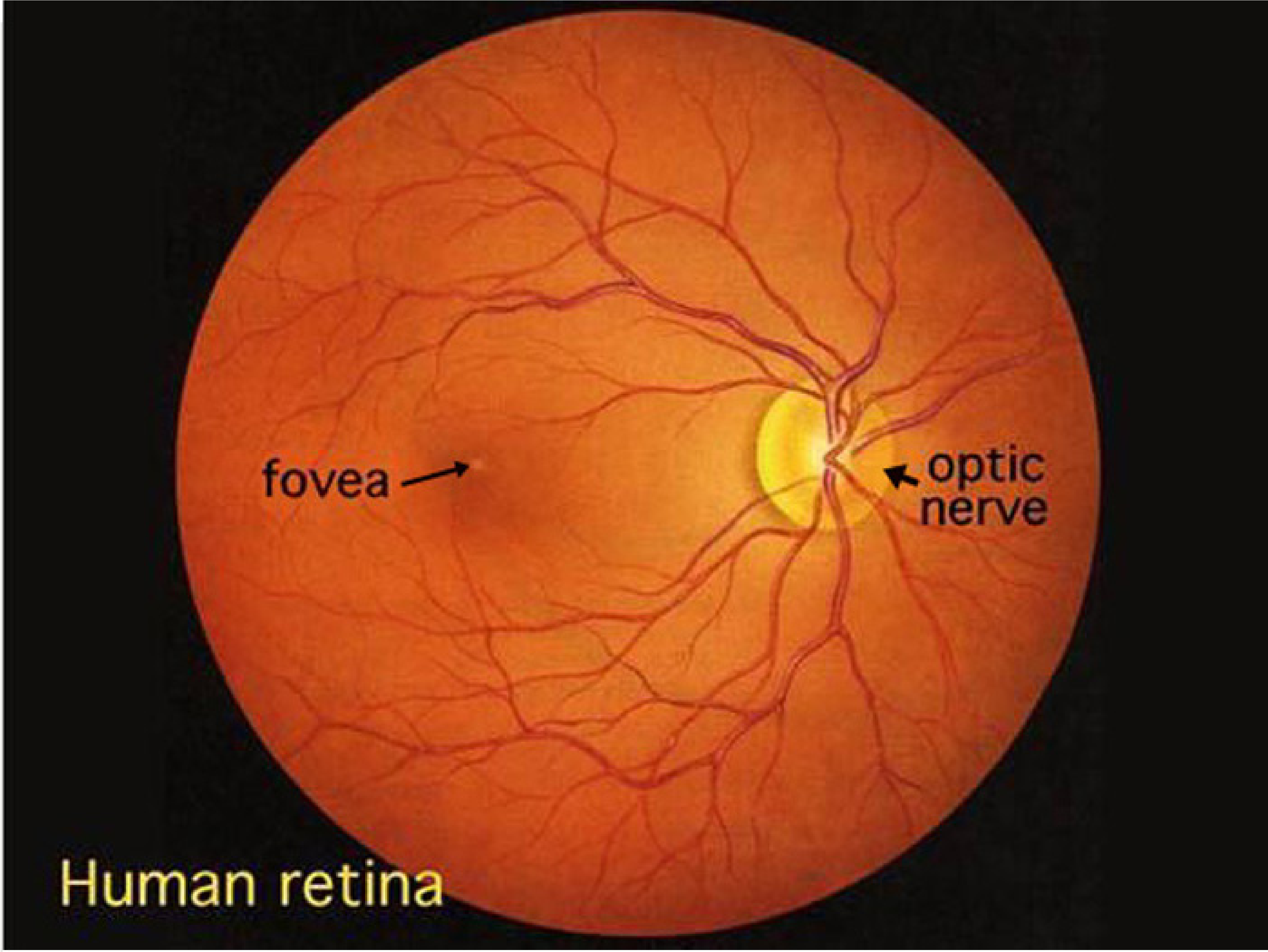
An Overview of the Primate Visual system

For Fei-Fei Li's Class

2008

Outer tunic
-cornea
-sclera
Middle tunic
-ciliary epithelium
-ligament (zonula)
-iris
-pupil
Inner tunic
-retina

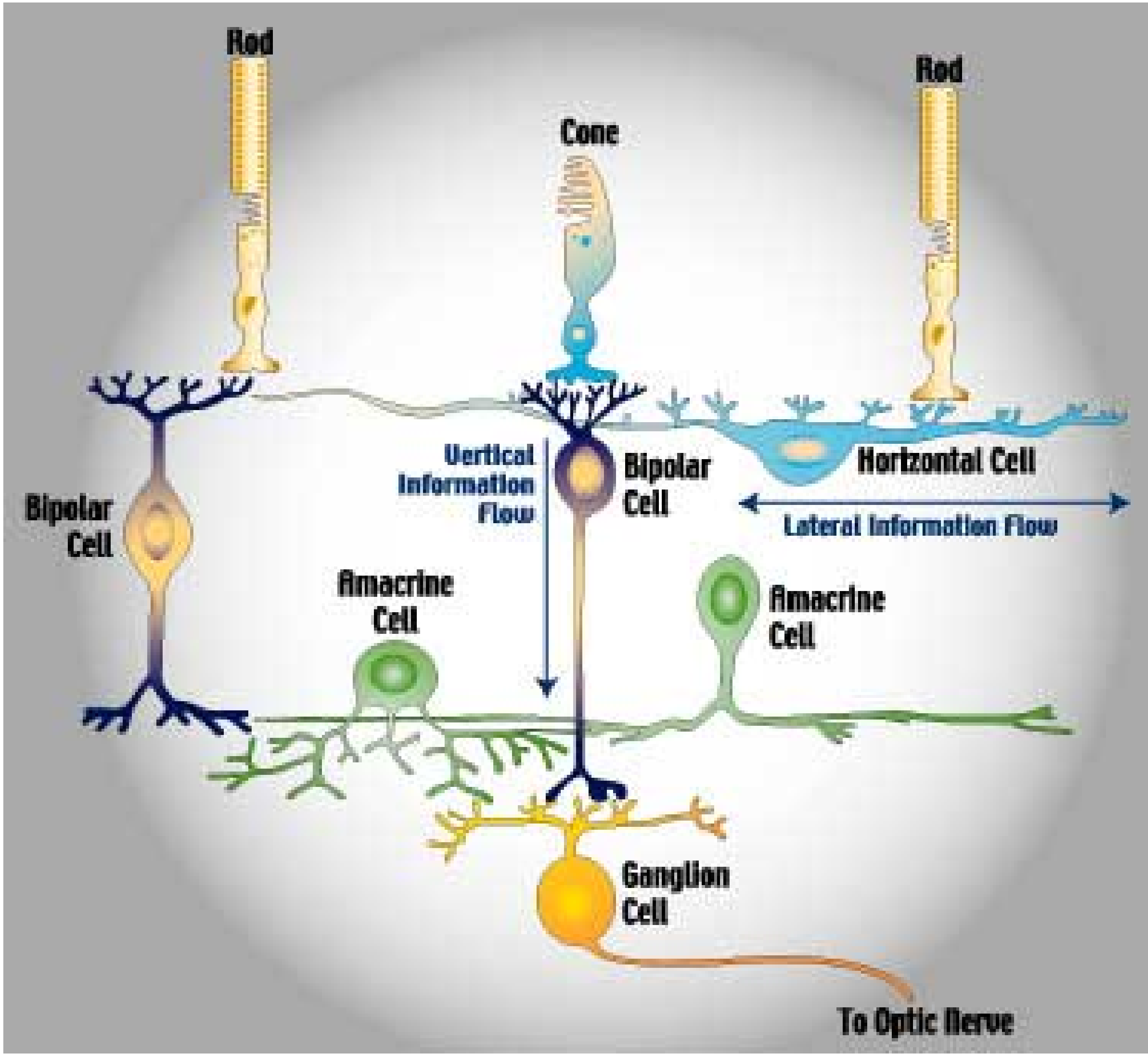



fovea
optic
nerve
Human retina

5 main classes of retinal cells

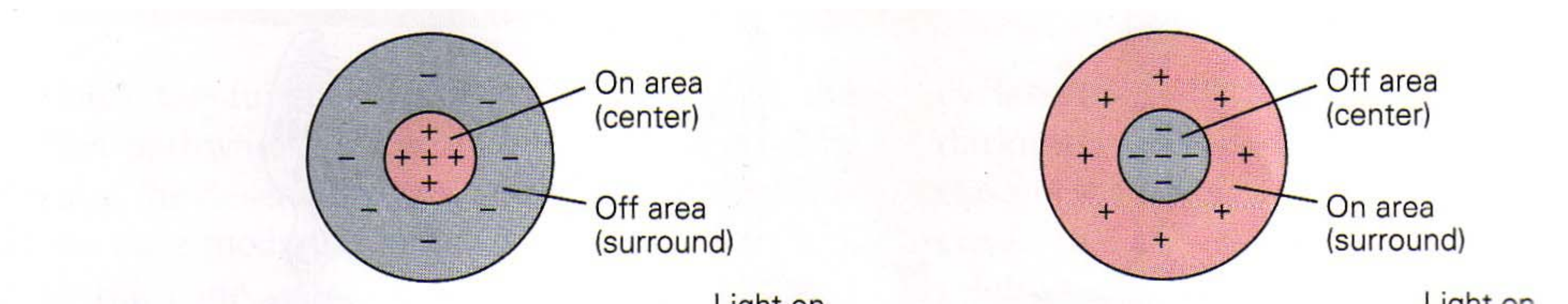
vertical:
-rods & cones
-bipolar cells (11)
-ganglion cells (20)

lateral:
-horizontal cells (4)
-amacrine cells (40)

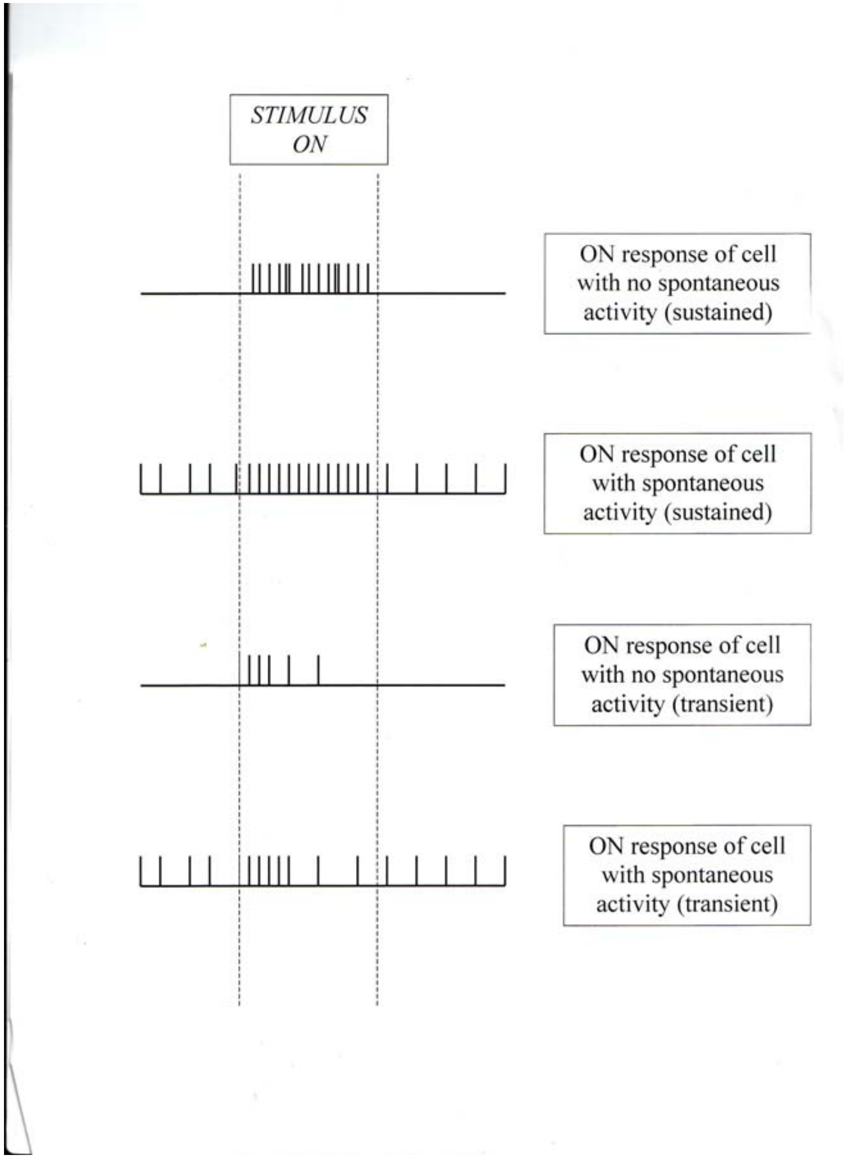


Receptive Fields

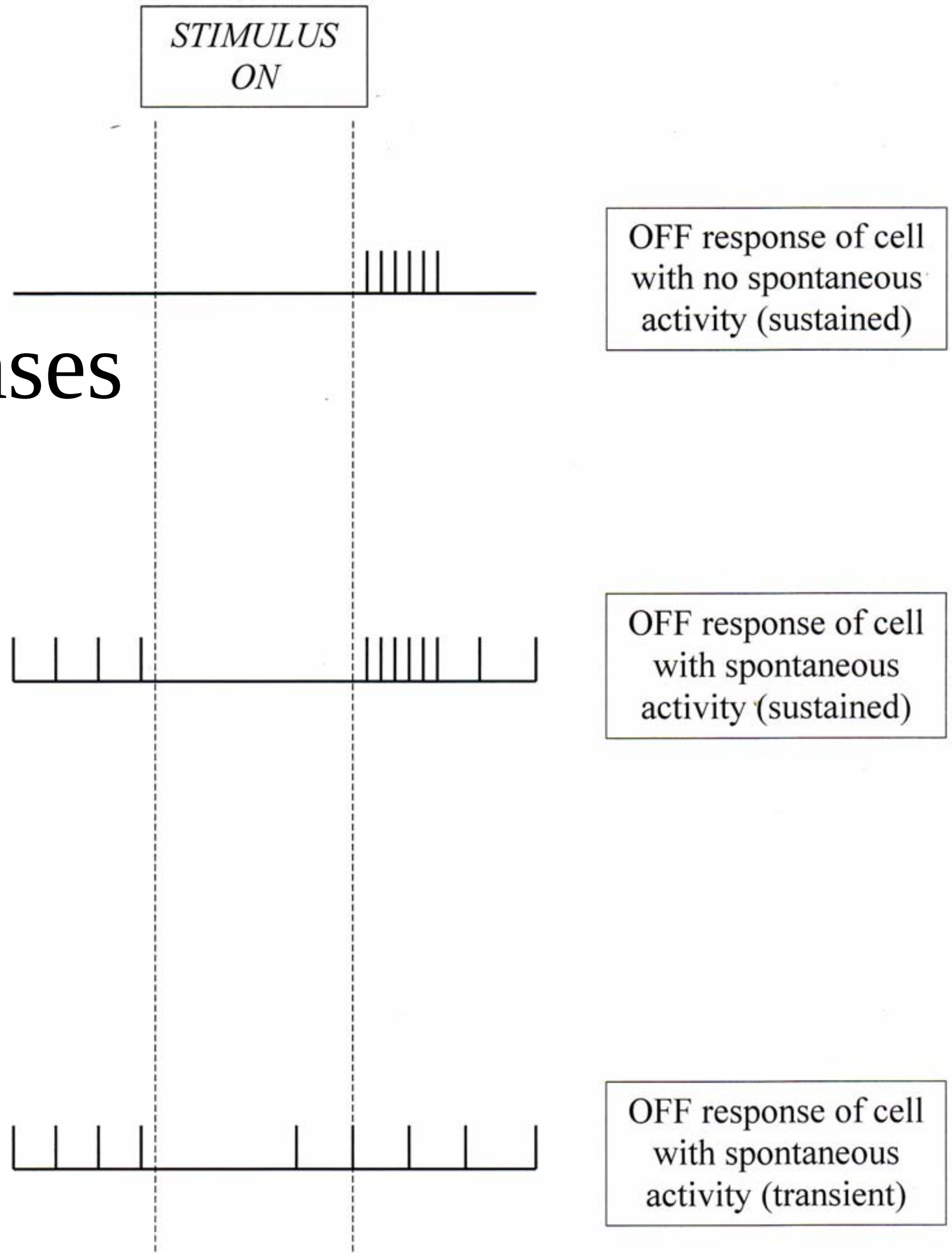
- All sensory neurons have RFs
- RF = part of the body whose stimulation will affect the activity of the cell (in retina, basilar membrane, skin, etc)
- Vary in size from a single hair to the entire skin ; from diameter of a rod to the entire visual field
- Retinal ganglion cells (and some others) have concentric RF with on-centers and off-surrounds or off centers and on surrounds



On Responses



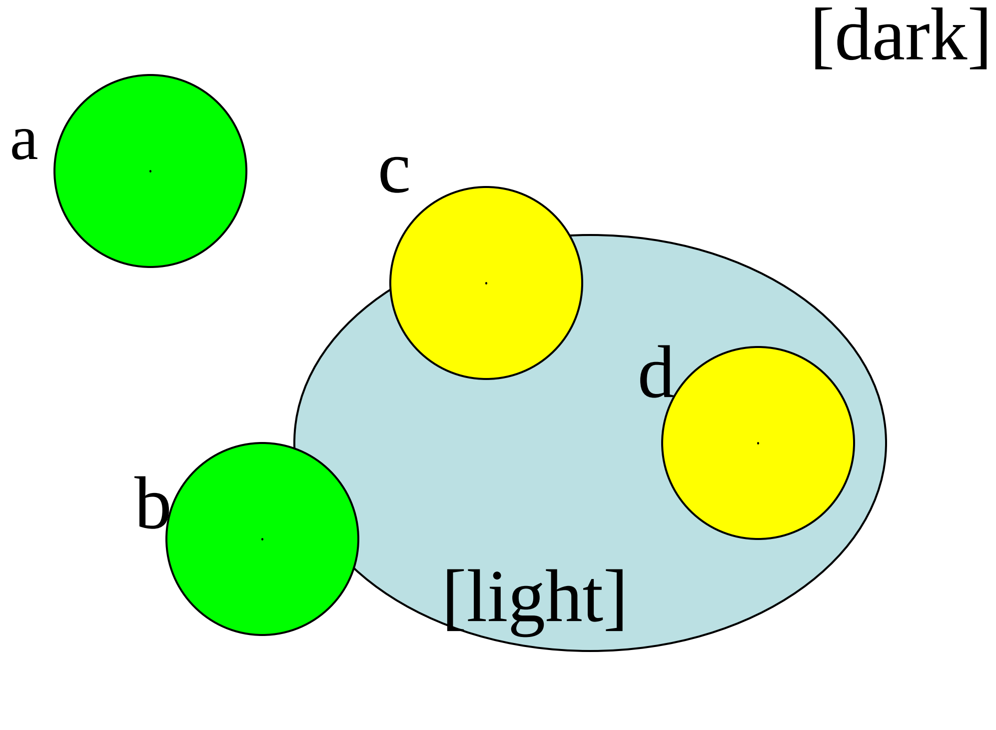
Off Responses



Suppose a-d were light detectors:

Rank their activation

d>c>b>a

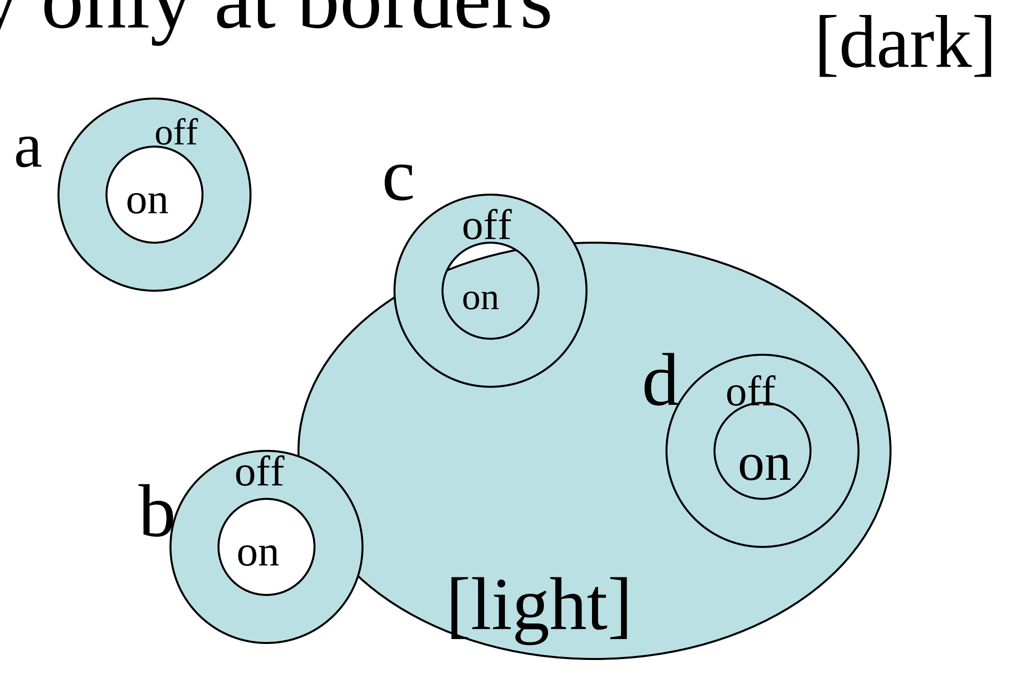


Suppose a-d were center on, surround off RFs

Rank their activation

c⇑, b⇓, a=d=0

activity only at borders



More generally,

- the nervous system is sensitive to change not steady state
    - over space : antagonistic on & off regions of RF in visual, somesthetic & auditory systems
        - On: specialized for detecting rapid onset
        - Off: specialized for detecting rapid offset
    - over time: most sensory cell have transisent responses
- what are some sensory cells that *are* sensitive to steady state?
    - Muscle sense organs: muscle spindles & golgi tendon organs
    - Interoceptive receptor: blood pressure

Where do the axons of retinal ganglion cells go?

In mammals the main areas are:

1. Dorsal lateral geniculate nucleus (in thalamus; aka:LGN, LGB, LGNd) -> striate cortex (V1)

   = geniculo-striate system

   [form, color, movement, space; css. vision}

2. Superior colliculus (optic tectum below primates; roof of midbrain) ->pulvinar (thalamus) ->extra-striate visual cortex

   = tectofugal system

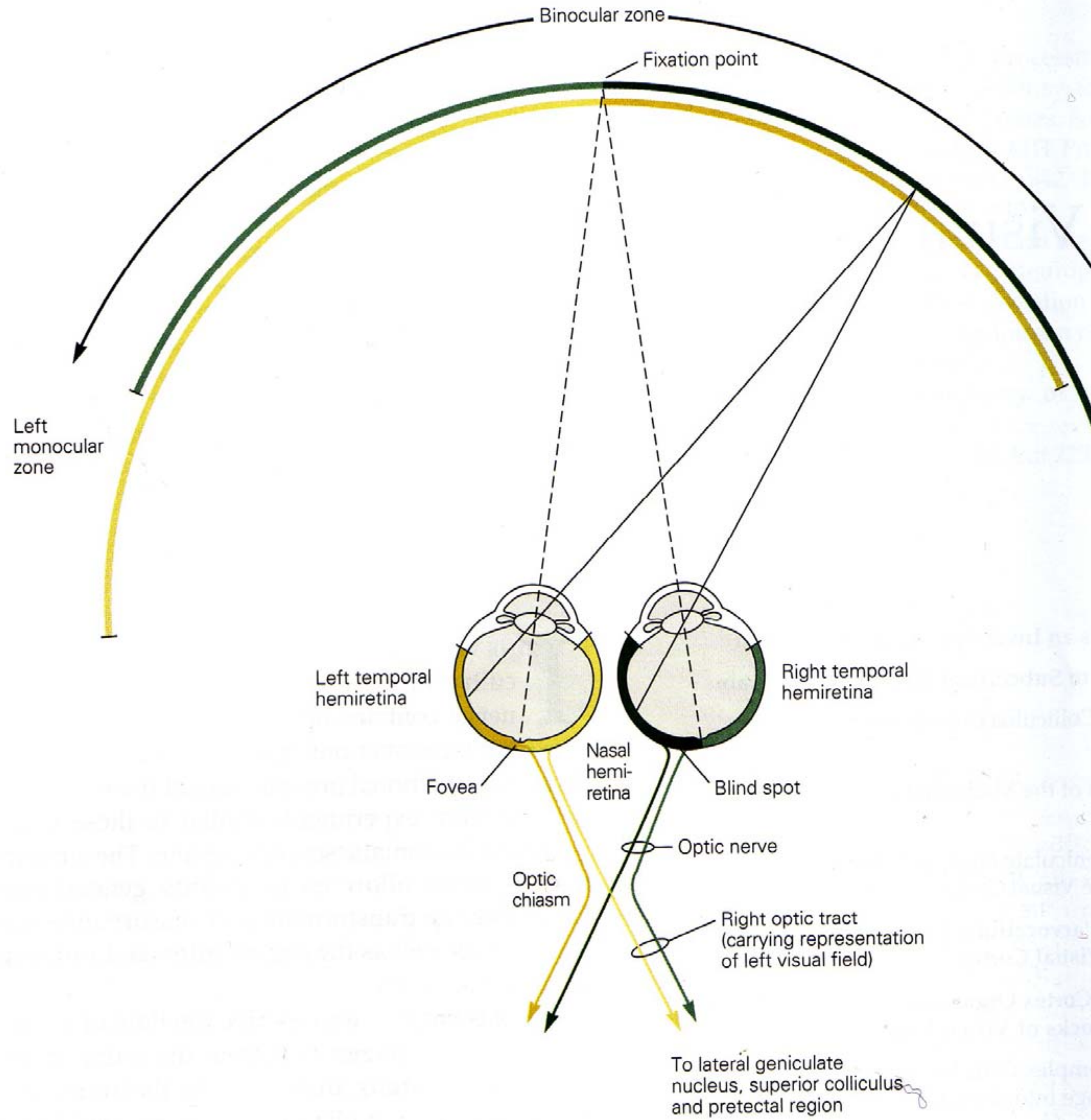
   [orientation of the eyes & head, eye movements; blindsight]

3. Pretectum [pupillary reflex]
4. Accessory optic system [stability of visual world +]
5. Suprachiasmatic nucleus of hypothalamus [circadian rhythms]

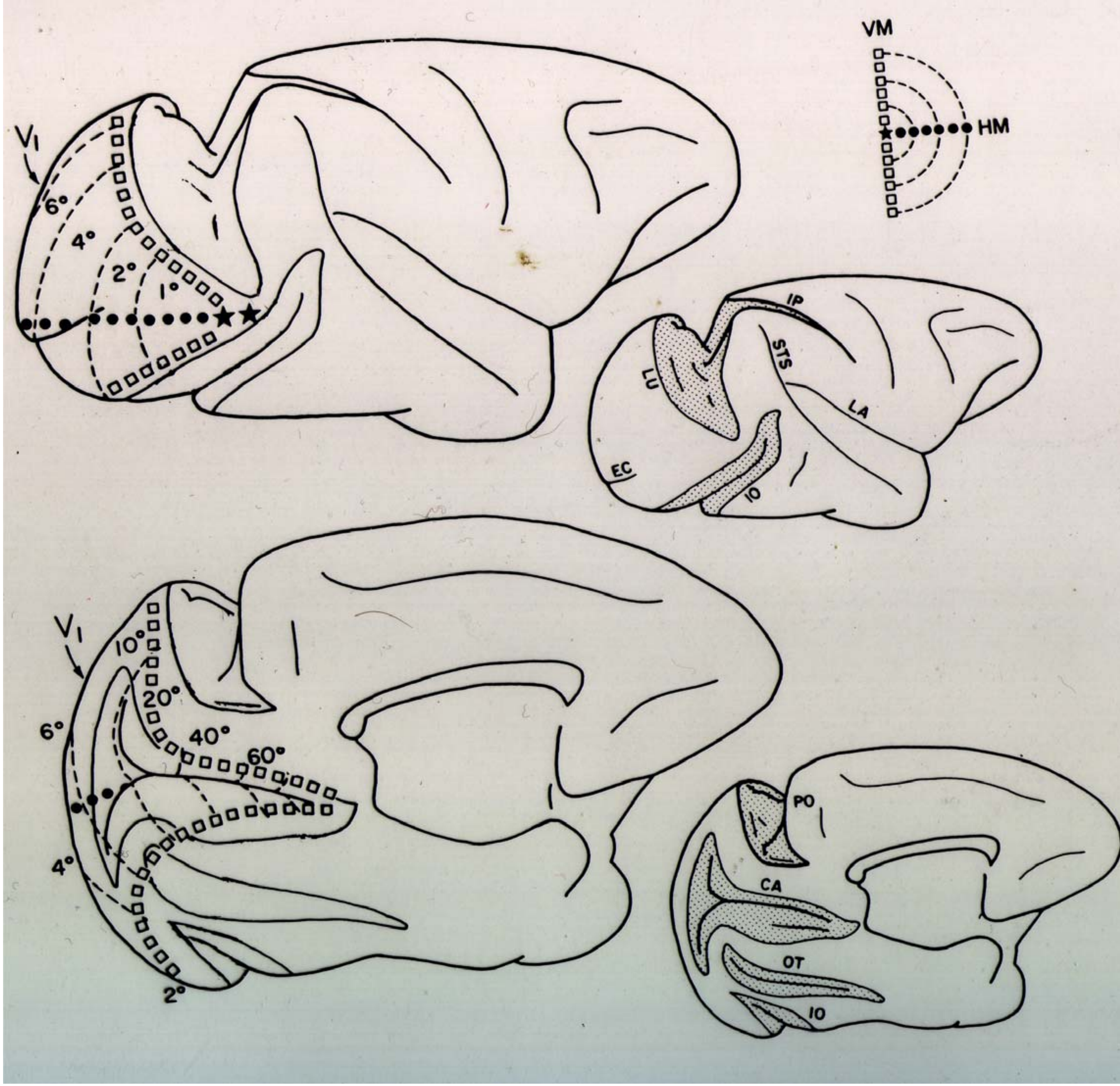
“partial decussation”
In primates, 1/2 the axons cross so that the right brain gets info about the left side and the left brain about the right side of space.

Amount of crossing depends on the frontality of the eyes
rat 1/10
horse 1/8
dog 1/4
cat 1/3

Advantages of frontal eyes? owls?
Tract & nerve?
Draw the effects of cutting left optic tract



Posterior sulci (grey) have been opened to show the buried cortex



Before Hubel and Wiesel:

light flash or even spot=> very little

?

need big computer?

After Hubel and Wiesel:

-Nobel, 1981

-neurophysiology & cognitive psychology never the same again

•*Their methods:*

-cat or monkey anesthetized and paralyzed (?)
-artificially respired, tracheotomy (?) -
-contact lens (??)
-hole in skull (?)
-metal wire , sharpened and insulated except tip
-moved via micromanipulator
-faces screen onto which stimuli are project
-listen to speaker (?)

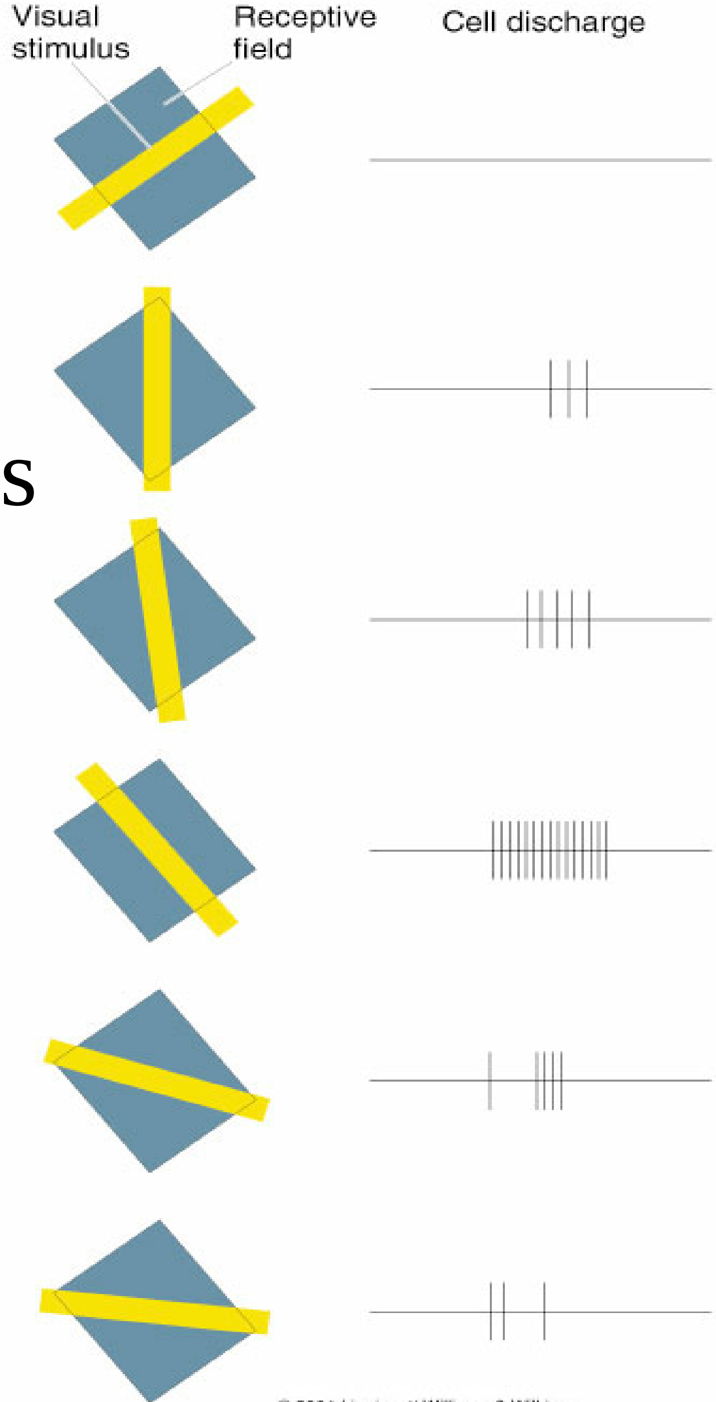
[today unanesthetized monkeys are more standard especially beyond striate cortex and computers are used to analyze responses}

=> simple and complex receptive fields

1. Simple RFs

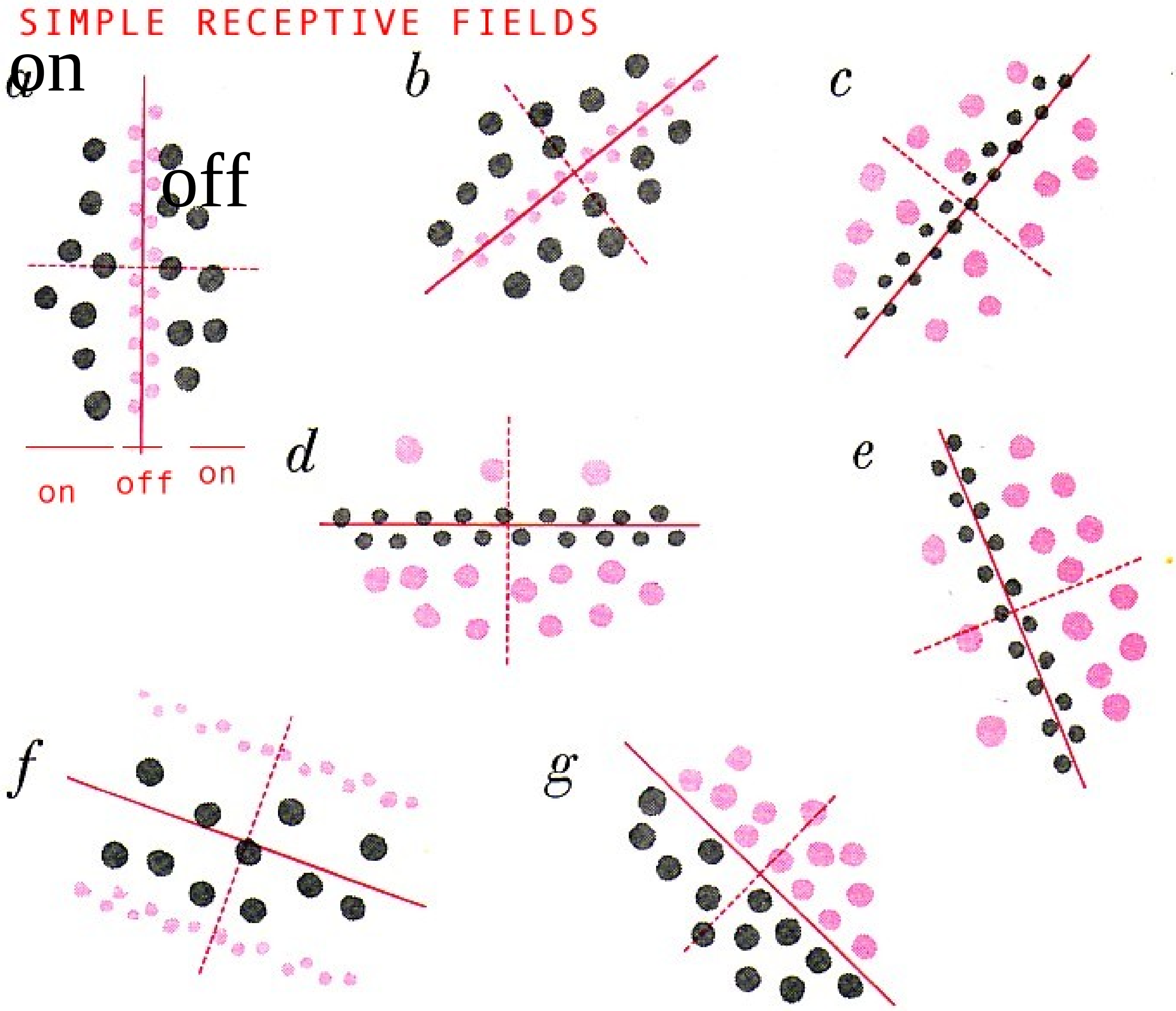
1. Rectangular (elongated) shape
2. Little or no response to diffuse light
3. Light slit, dark bar or edge best stimulus
4. Orientation critical
5. Width critical
6. On and off regions
7. May be sensitive to direction of movement
8. Shows summation

Orientation selectivity of striate simple receptive fields



on= grey

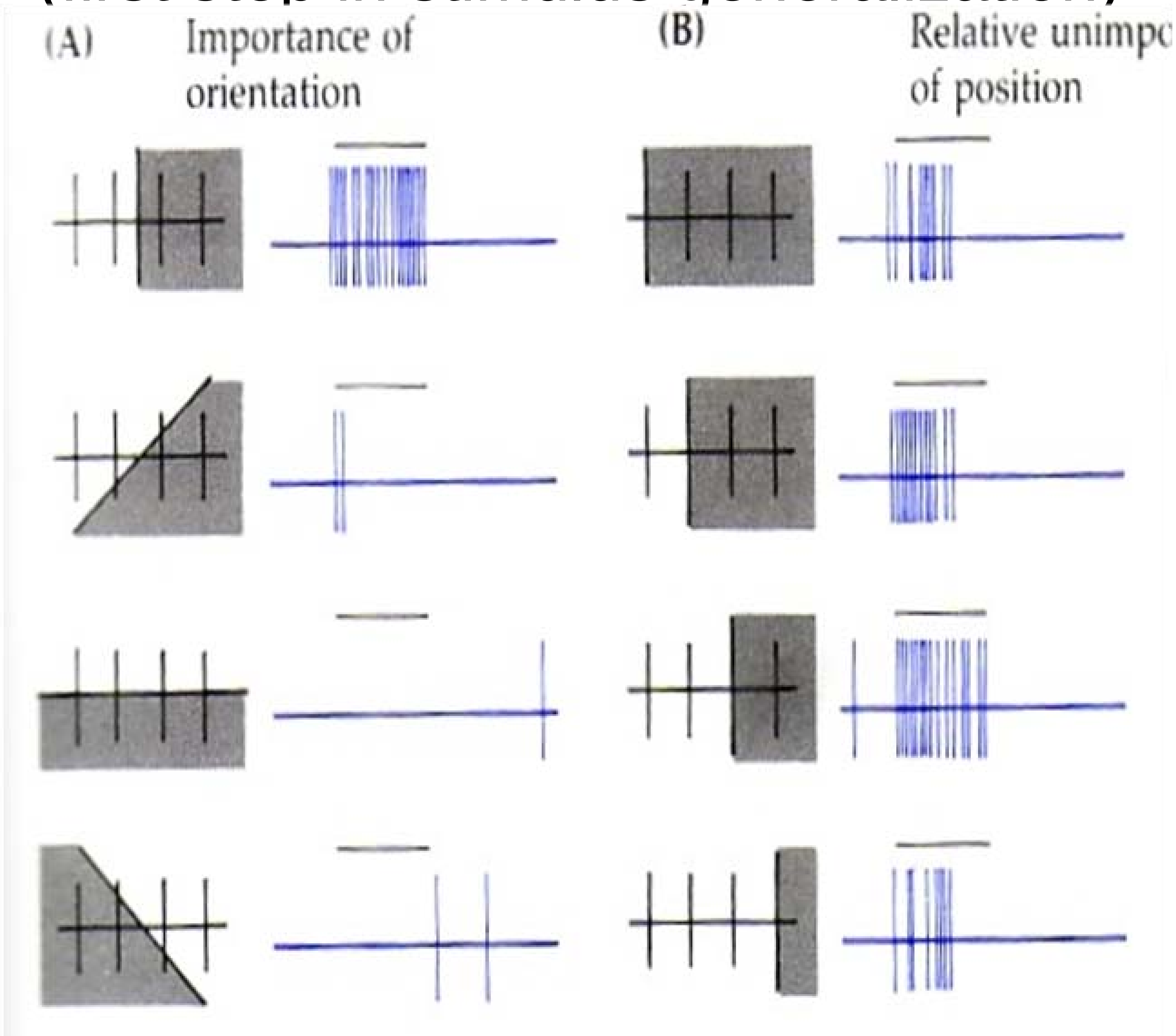
off=pink



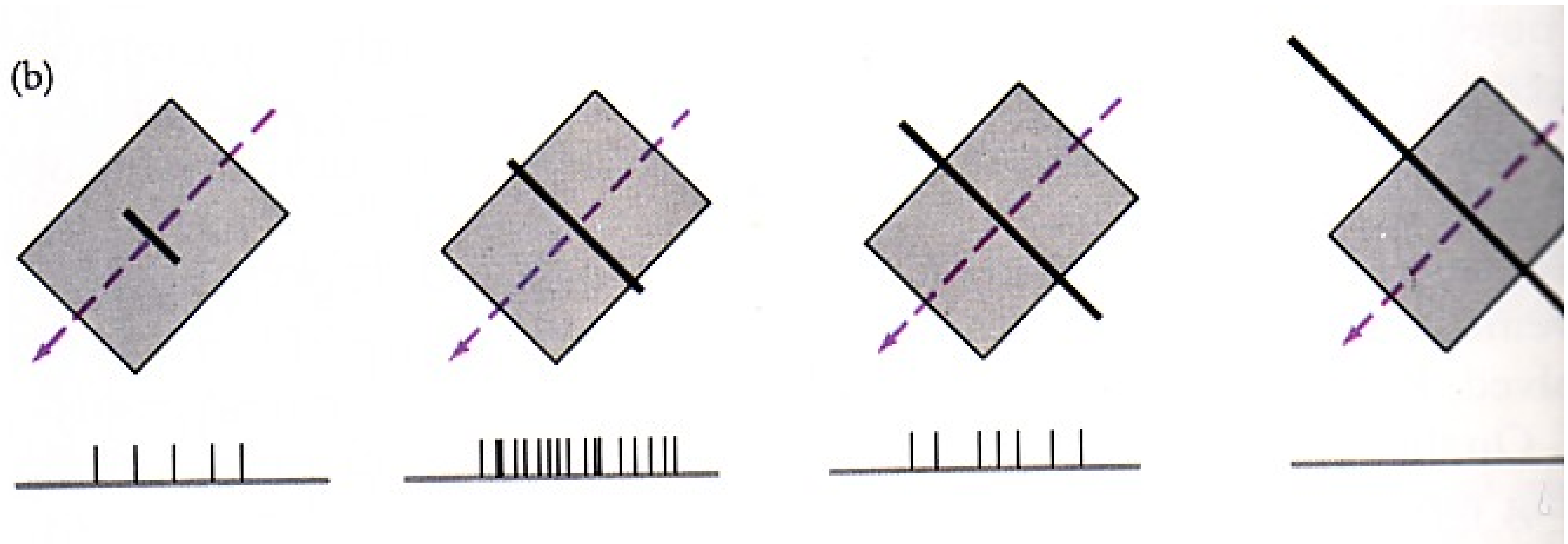
2. Complex RFs

1. Larger rf for given eccentricity
2. Again light slit, dark bar or edge best
3. Again orientation critical
4. Again width critical
5. Now exact position in the field not important
   [first step in perceptual constancy over retina}
6 No simple division into on & off areas
7. Usually more sensitive to direction of movement

Properties of Striate Complex Receptive Fields
(first step in stimulus generalization)



3. RF with hypercomplex or end stopped properties



An “end-stopped” complex cell or complex cell with “hypercomplex” properties . There are also end-stopped simple cells. Either may be end stopped on one or both sides.

Functions of Striate Cortex

1. Analyze shape in terms of line segments" …first step in pattern recognition…complex cells begin the second step: generalizing within the RF.
2. Bring together the two eyes. Most (85%) cells are binocular: they have RFs in both eyes. They show ocular dominance. RF usually differs in location in the two eyes: they are sensitive to retinal disparity

V1 cells are sensitive to:

- Location
- Light or dark
- Width of stimulus
- Length of stimulus (hypercomplex)
- Movement
- Depth<- disparity
- Color (in monkeys)

Are V1 cells feature detectors?

Could a striate cell detect a 45 deg redline?

If firing of a cell is less than maximal

It could be due to a change for example in

- Orientation
- Location
- Width of stimulus
- Length of stimulus (hypercomplex)
- Movement
- Depth
- Color
- *How does the system know?*

How to tell if the decline in firing is due to an orientation change

<table>
<tr><td>cell/ º</td><td>28 º</td><td>45º</td><td>63 º</td></tr>
<tr><td>1</td><td>|||||||</td><td>|||</td><td>|</td></tr>
<tr><td>2</td><td>|||</td><td>|||||||||</td><td>||</td></tr>
<tr><td>3</td><td>|</td><td>|||</td><td>|||||||</td></tr>
</table>

<table>
<tr><td></td><td>ORANGE</td><td>RED</td></tr>
<tr><td>1</td><td>||||||</td><td>||</td></tr>
<tr><td>2</td><td>||</td><td>||||||||</td></tr>
</table>

Thus to disambiguate the signal from a cell responsive to several parameters, the system must look at more than one neuron

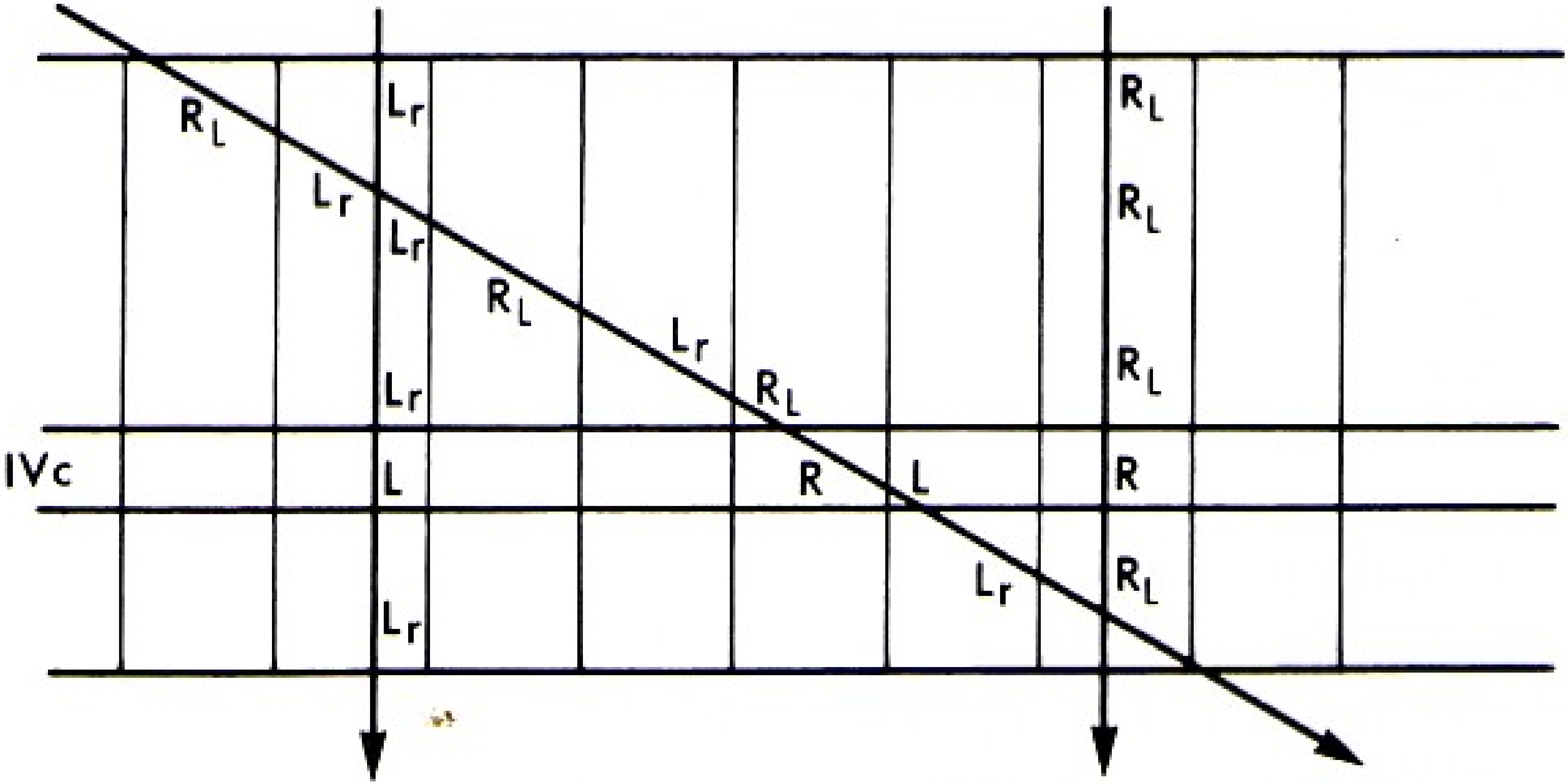
population coding =
ensemble coding =
coarse coding=
pattern of firing over neurons coding

most sensory coding is done in this fashion

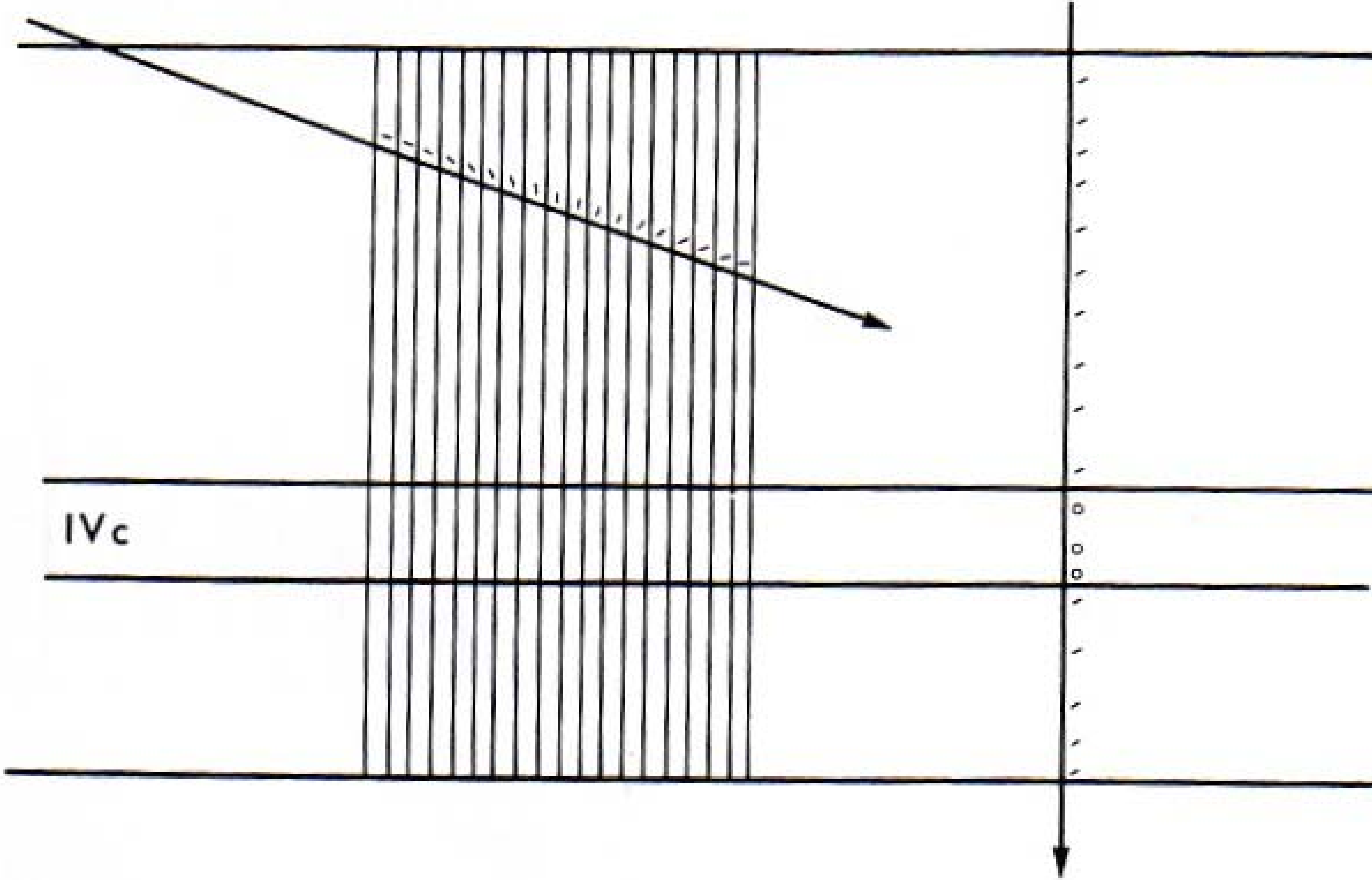
Functional Architecture

Cells with similar properties are not randomly distributed

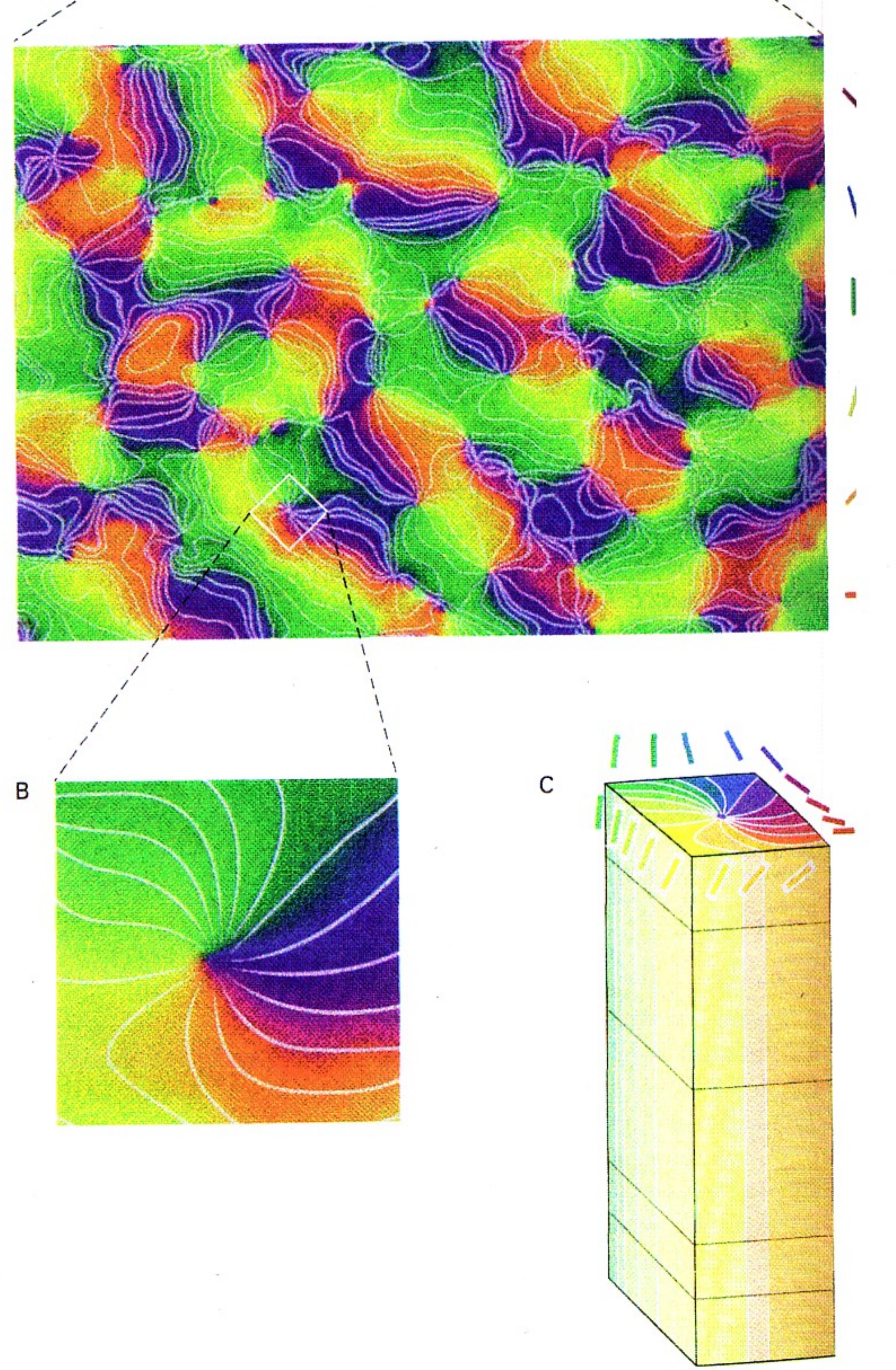
1. Retinotopic map
2. **Eye dominance columns**
3. **Orientation columns**
4. Ice cube => swirls
5. Blobs & swirls
6. Laminar organization of inputs and outputs
7. Horizontal connections



Section thru cortex showing ocular dominance columns (slabs)

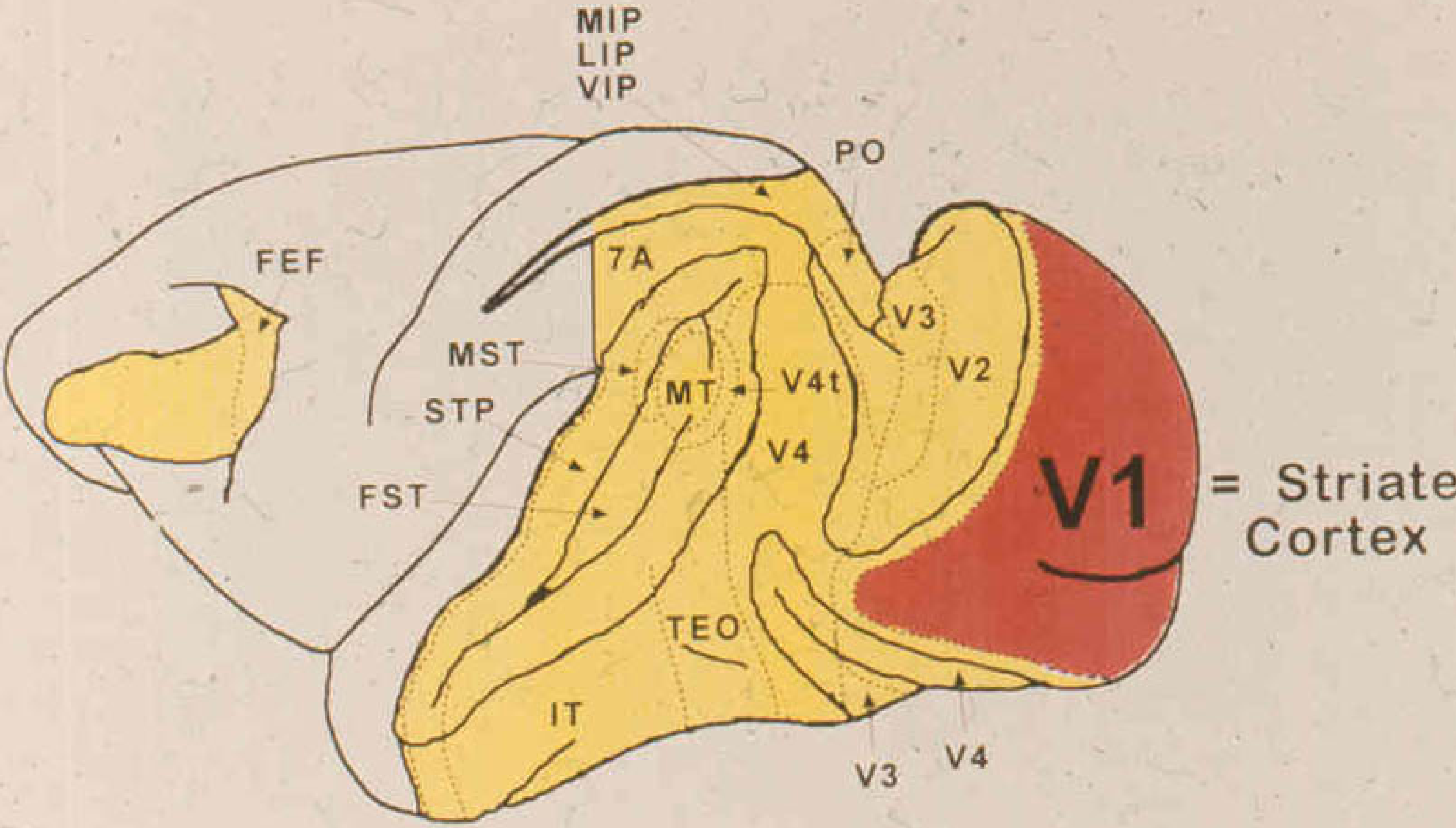

IVc

Orientation column are actually not orthogonal to o.d. columns as in the “ice cube” model. Rather they form spirals as shown by Blasdel with optical imaging



Striate cortex = visual cortex?

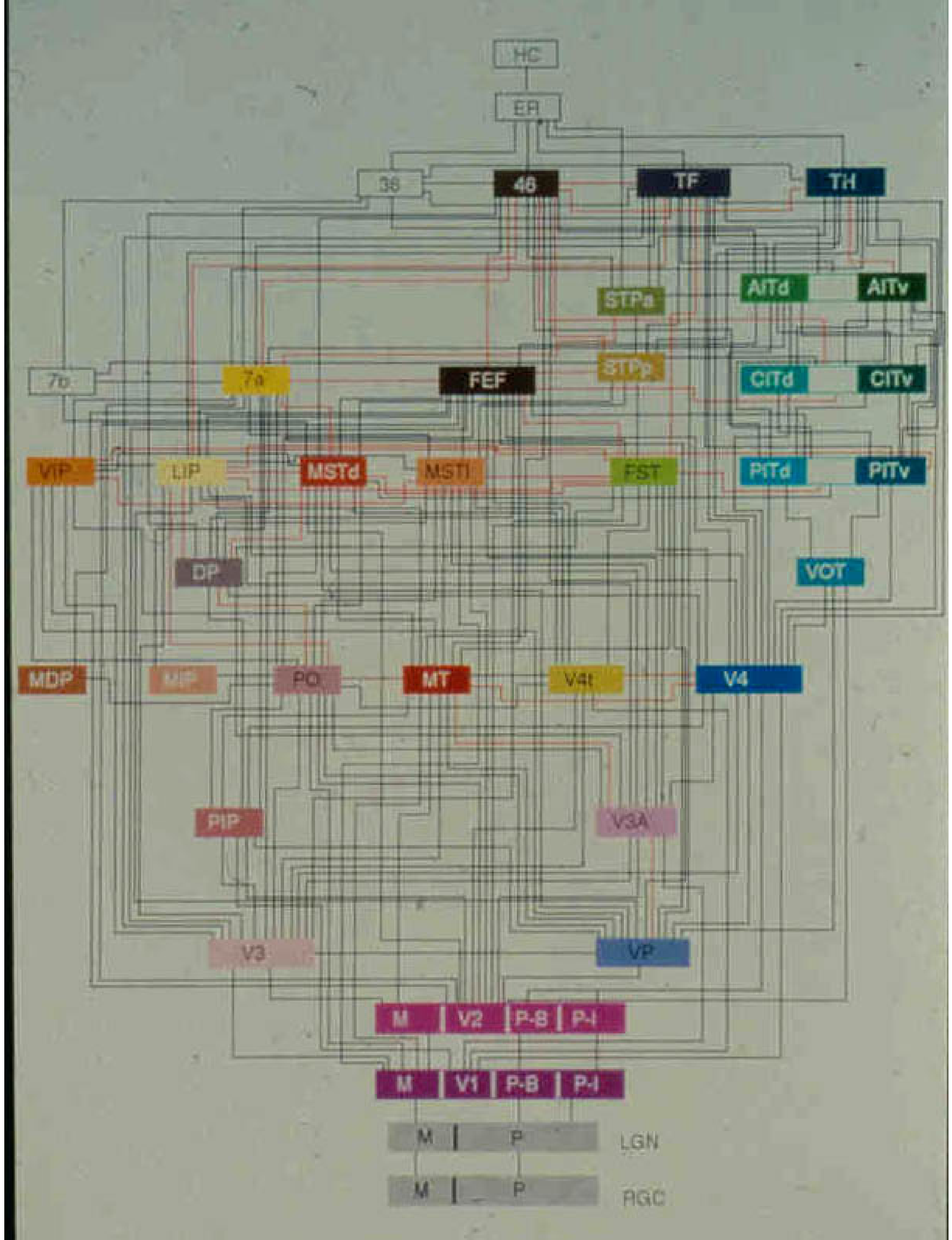
- Originally striate cortex was thought to be the only visual cortex and responsible for all of vision.
- By the 60's two other retinotopically organized visual areas were discovered (V2 & V3). [Talbot & Marshall; Hubel and Wiesel]
- By the 70's a multiplicity of cortical visual areas were discovered that now number over 40. [Allman and Kaas; Zeki]


MIP
LIP
VIP
PO
FEF
7A
V3
MST
V2
MT
V4t
STP
V4
V1
= Striate Cortex
FST
TEO
IT
V3
V4

CRITERION FOR A VISUAL AREA

1. Retinotopic organization
2. Distinctive inputs and outputs
3. Distinctive cyto- and myeloarchitecture
4. Distinctive neuronal response properties
5. Distinctive effects of lesions
6. Distinctive neurochemistry
7. Distinctive imaging activation

Fellemen &
Van Essen,1991

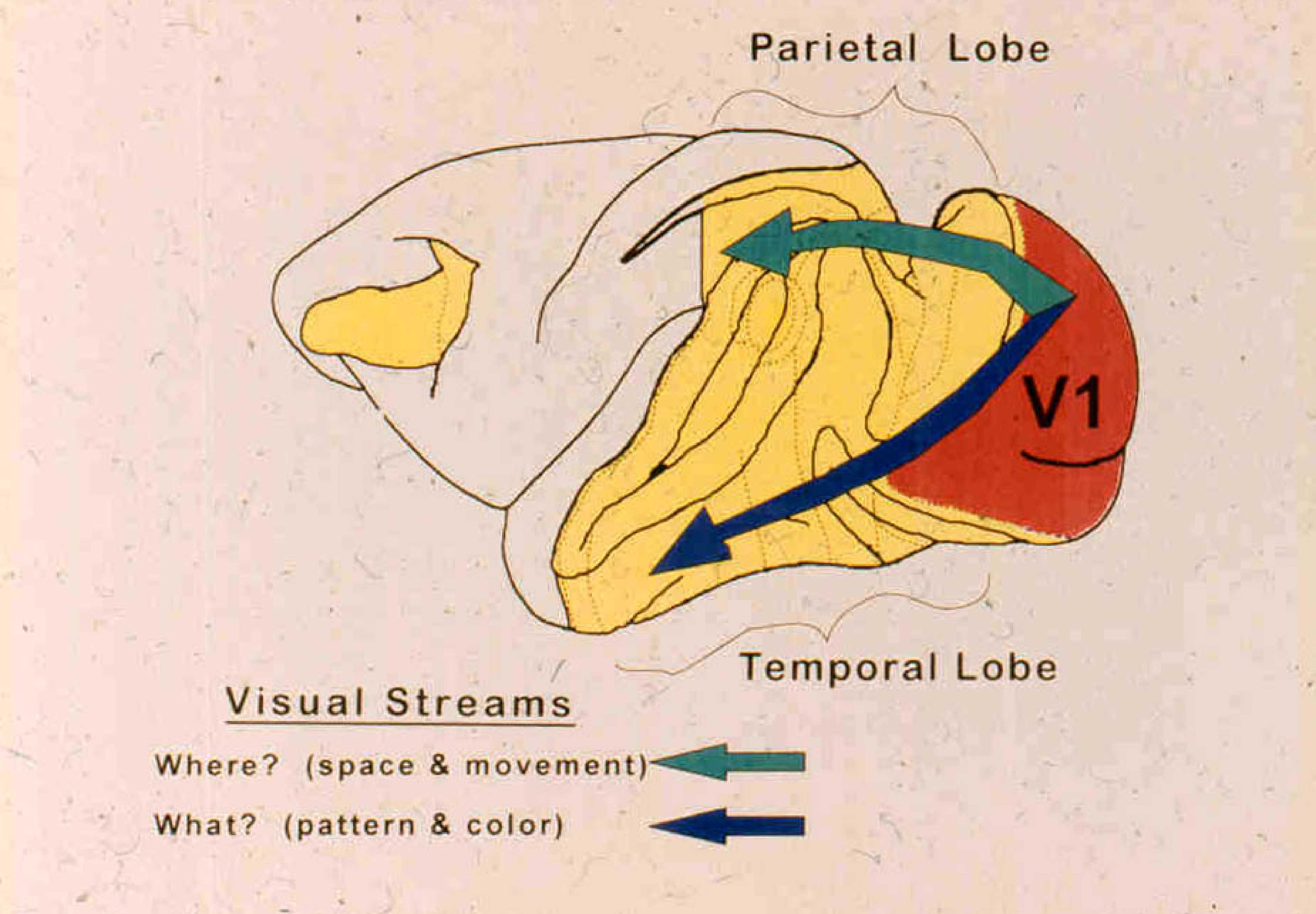


The Two Visual Streams

1. The VENTRAL or Occipito-temporal stream deals with “WHAT?” (or object recognition) functions

2. The DORSAL or Occipito-parietal stream deals with “WHERE?” (or spatial) functions

Originally proposed by Ungerleider and Mishkin, 1982

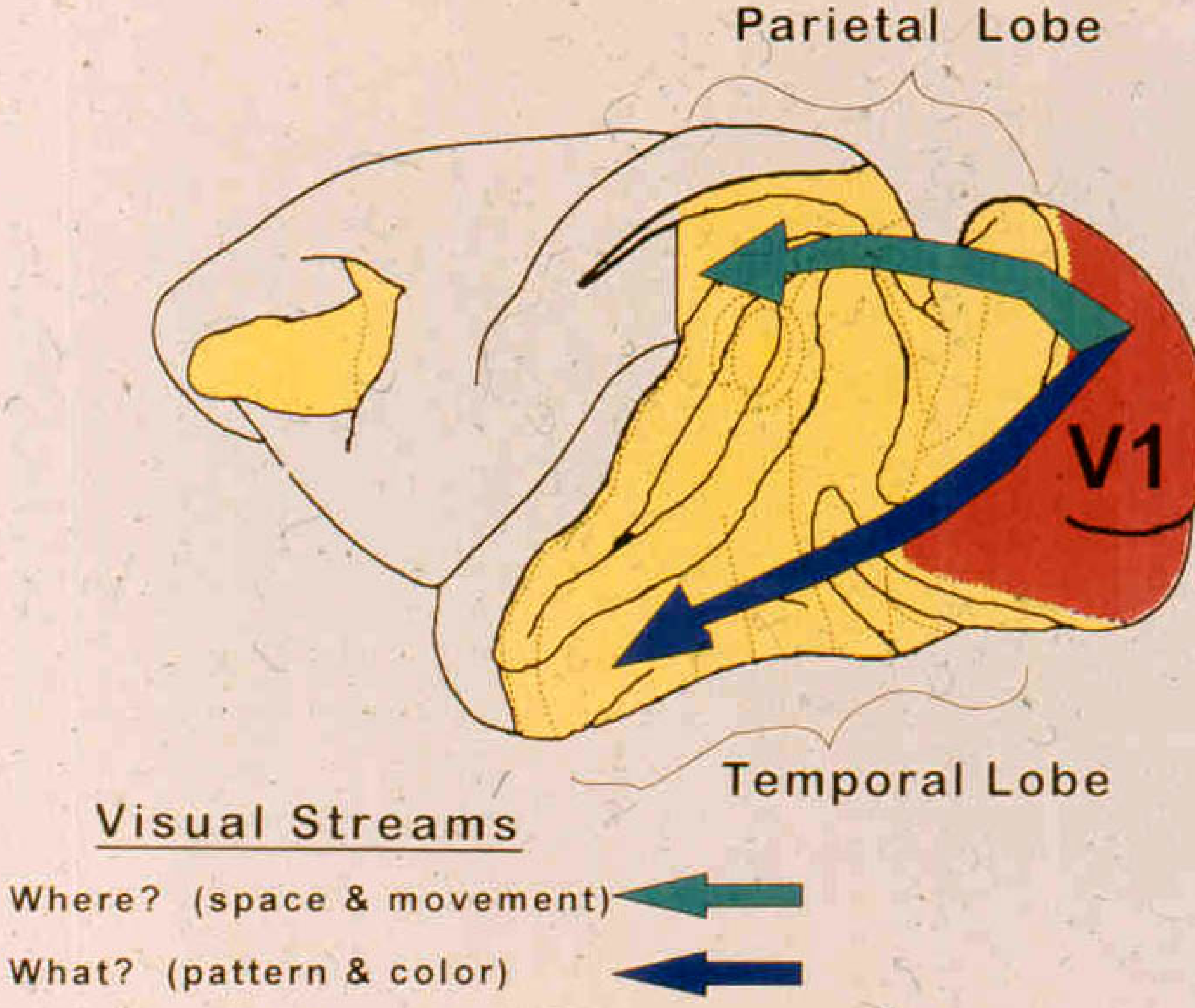

Parietal Lobe
V1
Temporal Lobe
Visual Streams
Where? (space & movement)
What? (pattern & color)

Evidence for Two Visual Streams

1. Study of Brain-injured Humans and Monkeys
("Neuropsychology")

2. Study of Single Neuron Properties in Awake Monkeys
("Neurophysiology")

3. Study of Metabolic Activity in Human Brain
("Neuroimaging")


Parietal Lobe
V1
Temporal Lobe
Visual Streams
Where? (space & movement)
What? (pattern & color)

Inferior Temporal Cortex Lesions

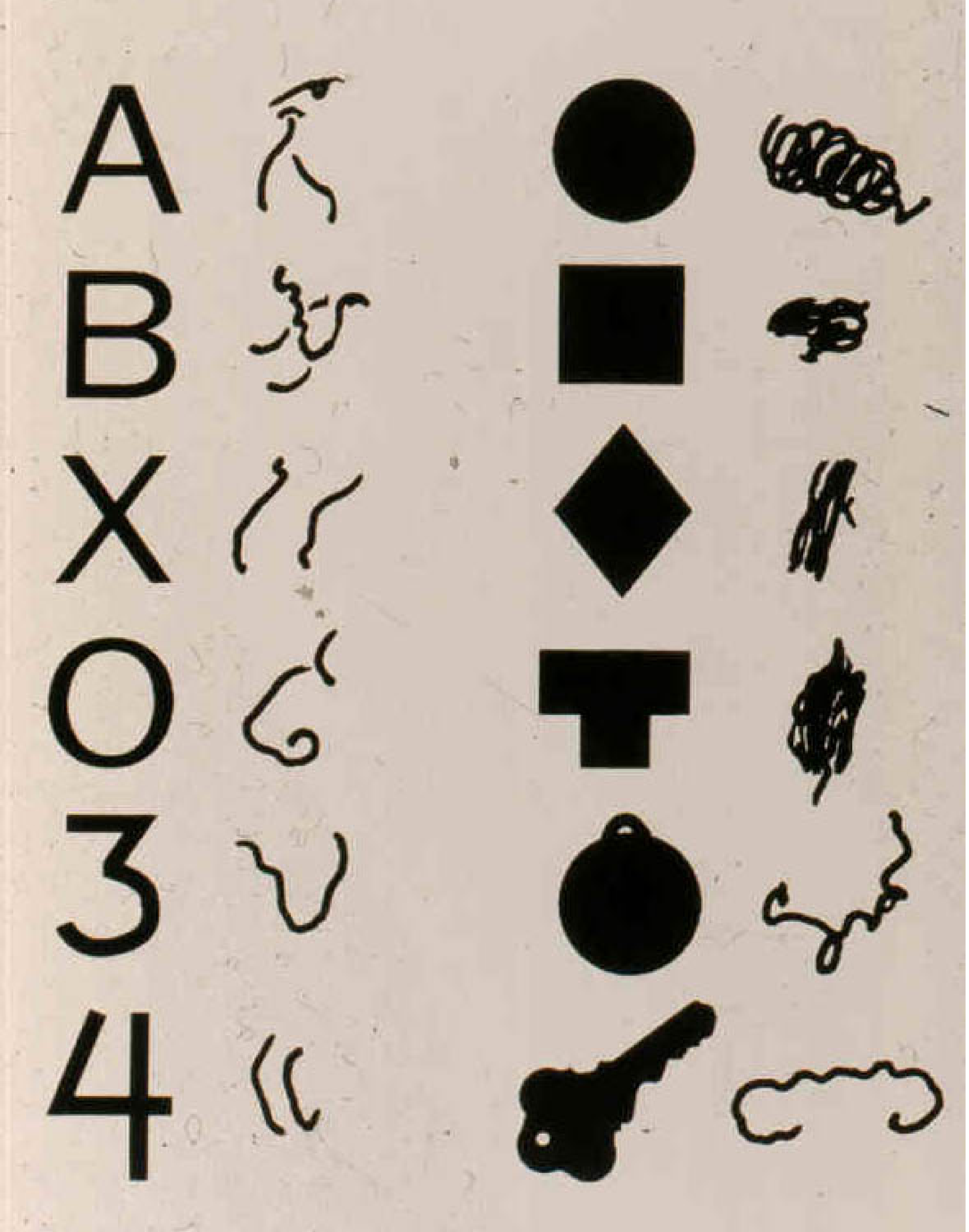
1. Produce Visual Agnosias : Impairments in Visual Object Recognition in the Absence of Loss in Basic Visual Functions

2. May Produce Specific Agnosias such as

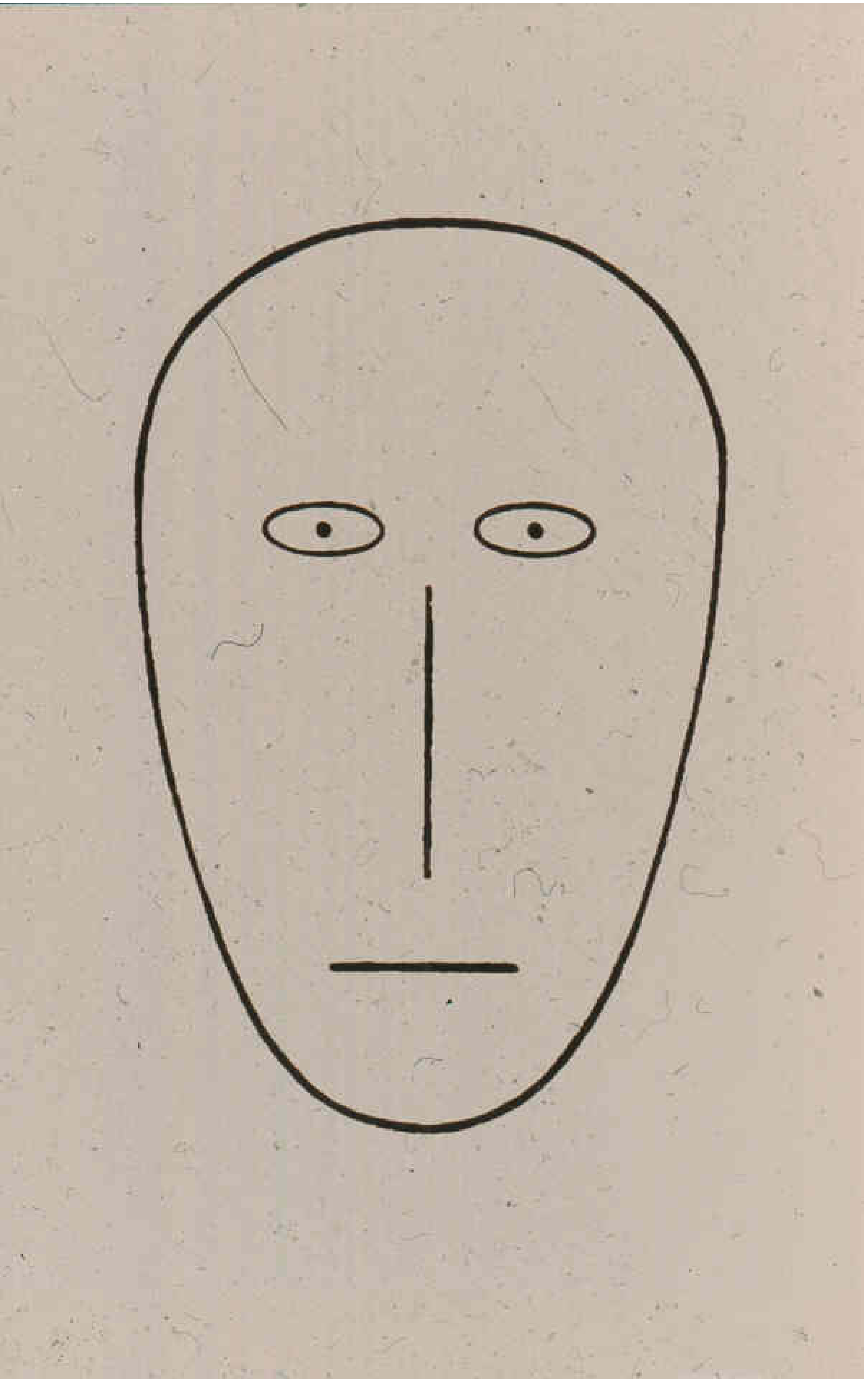
   -Prosopagnosia : Impaired Face recognition

   -Achromatopsia: Impaired Color Recognition

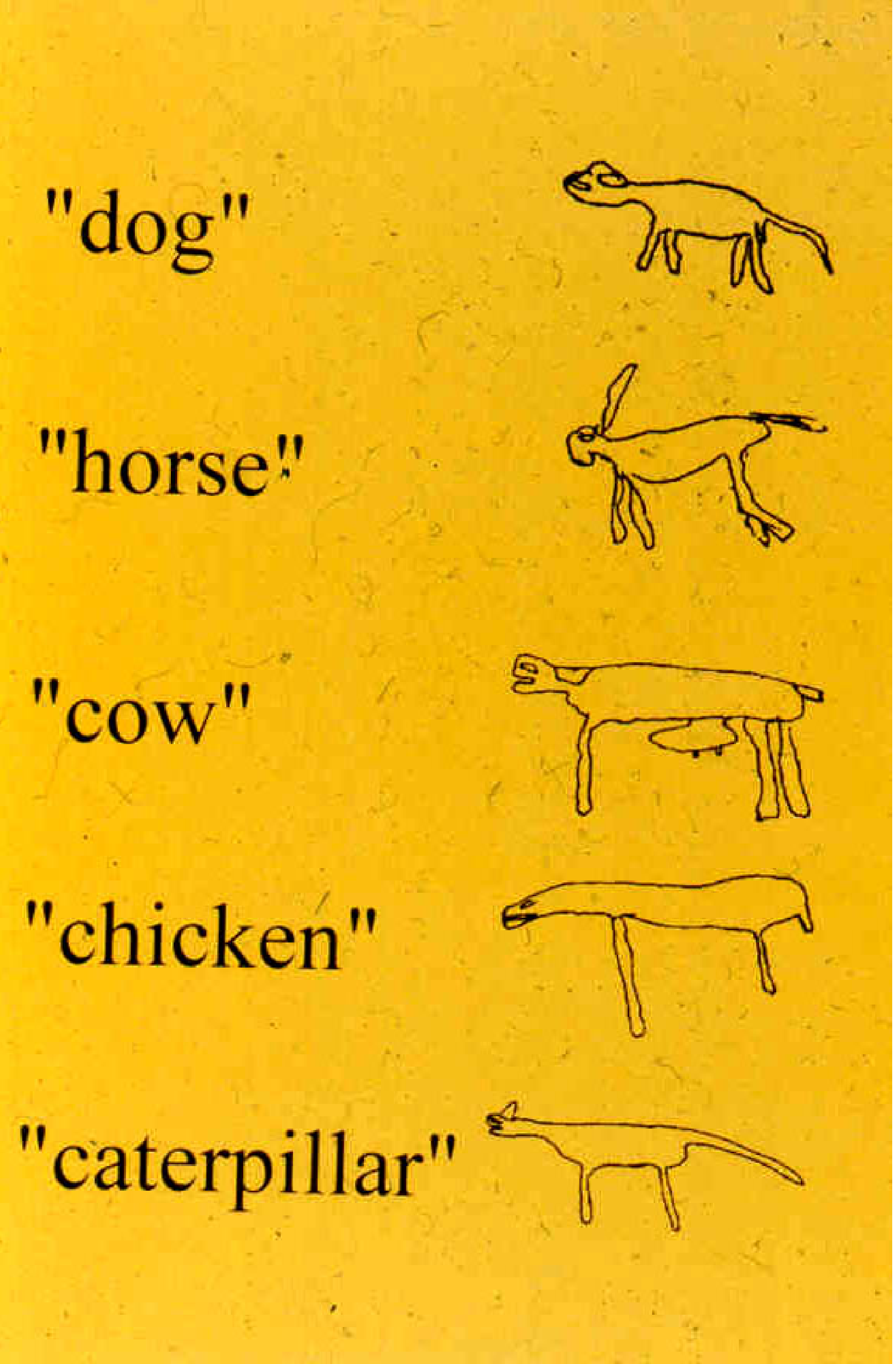
   -Category-Specific Agnosia such as Difficulty in Distinguishing Animate from Inanimate Objects



Copying by a
Patient suffering
From object agnosia



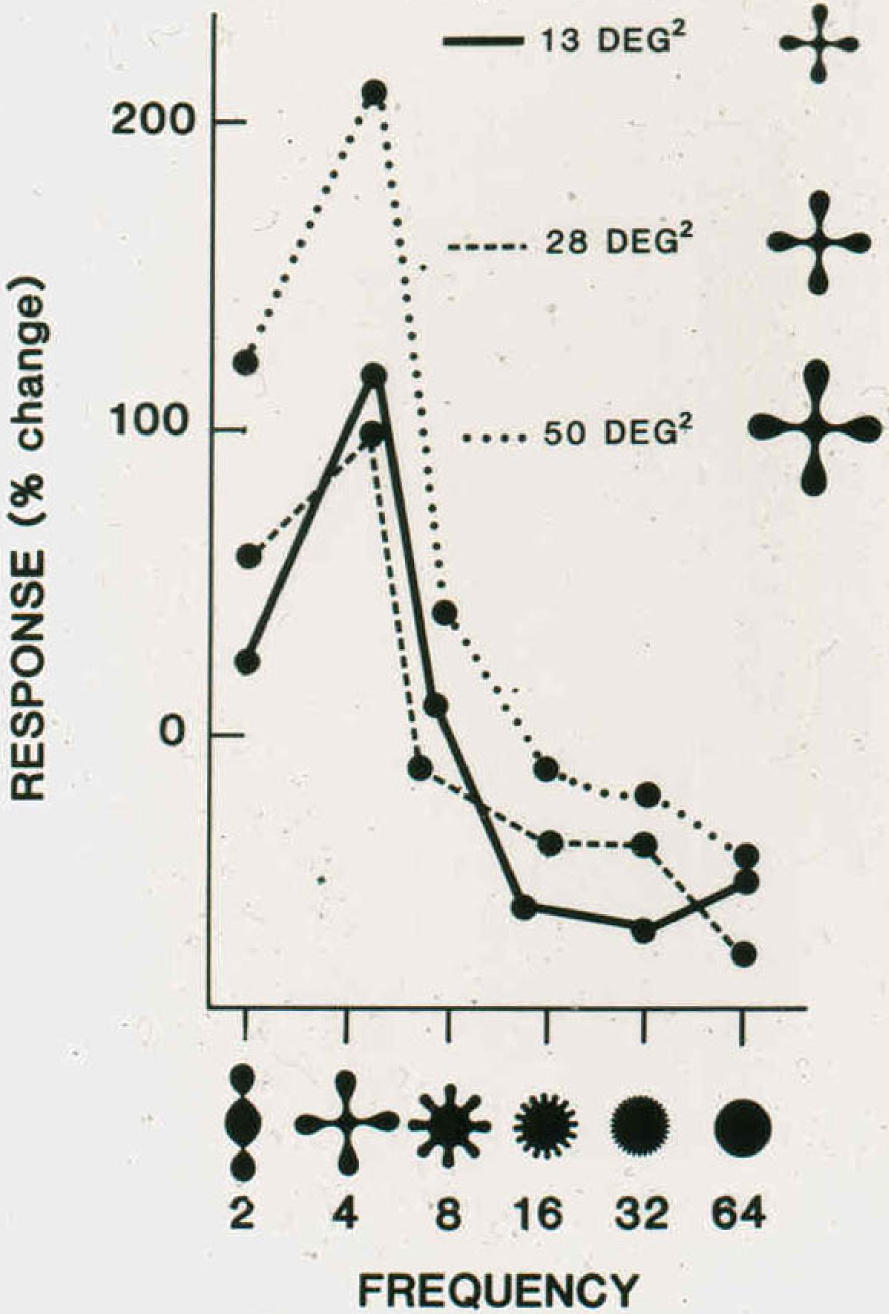
Described by a patient with prosopagnosia as "an apple with two worm holes, a folded over stem and a crease".



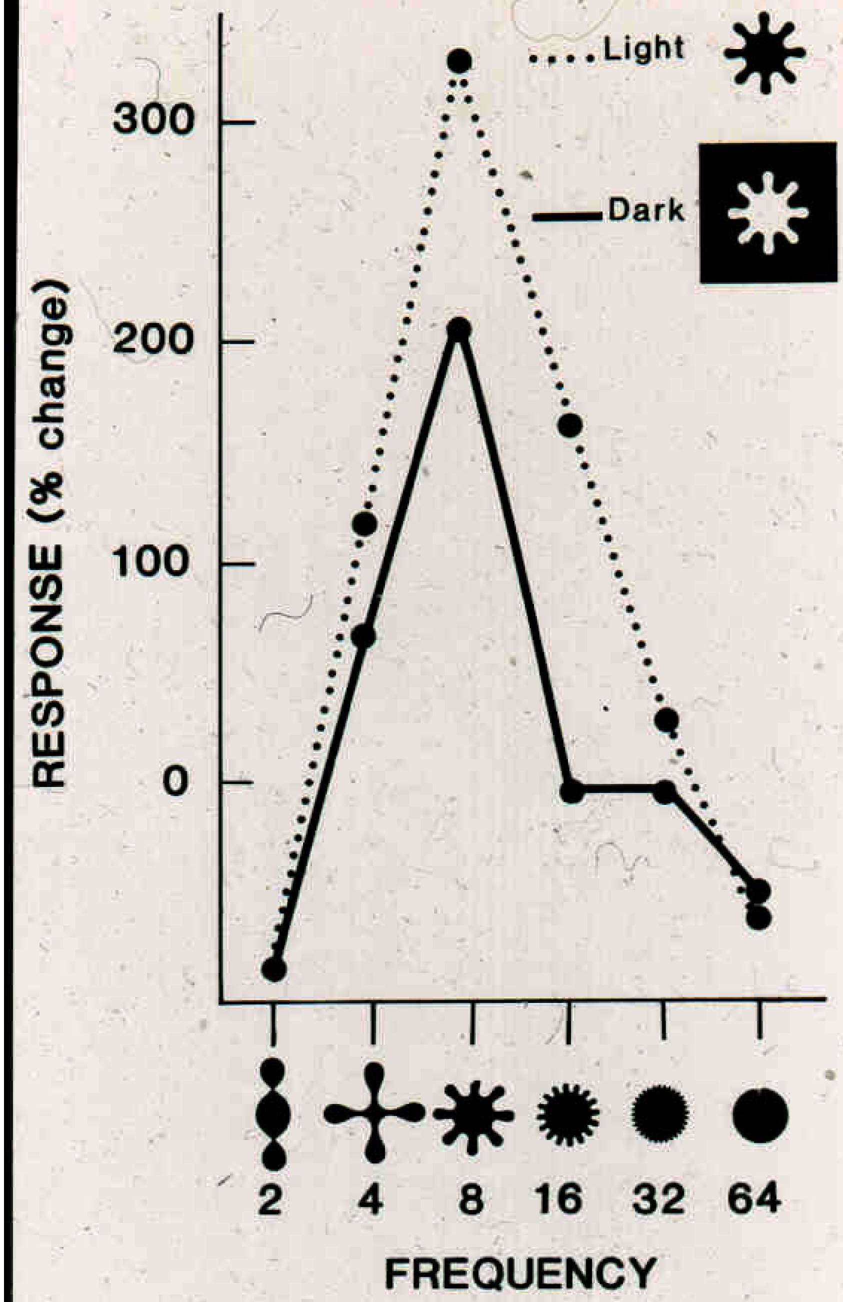
Drawing by a patient with agnosia for animate objects.

Inferior Temporal Neurons

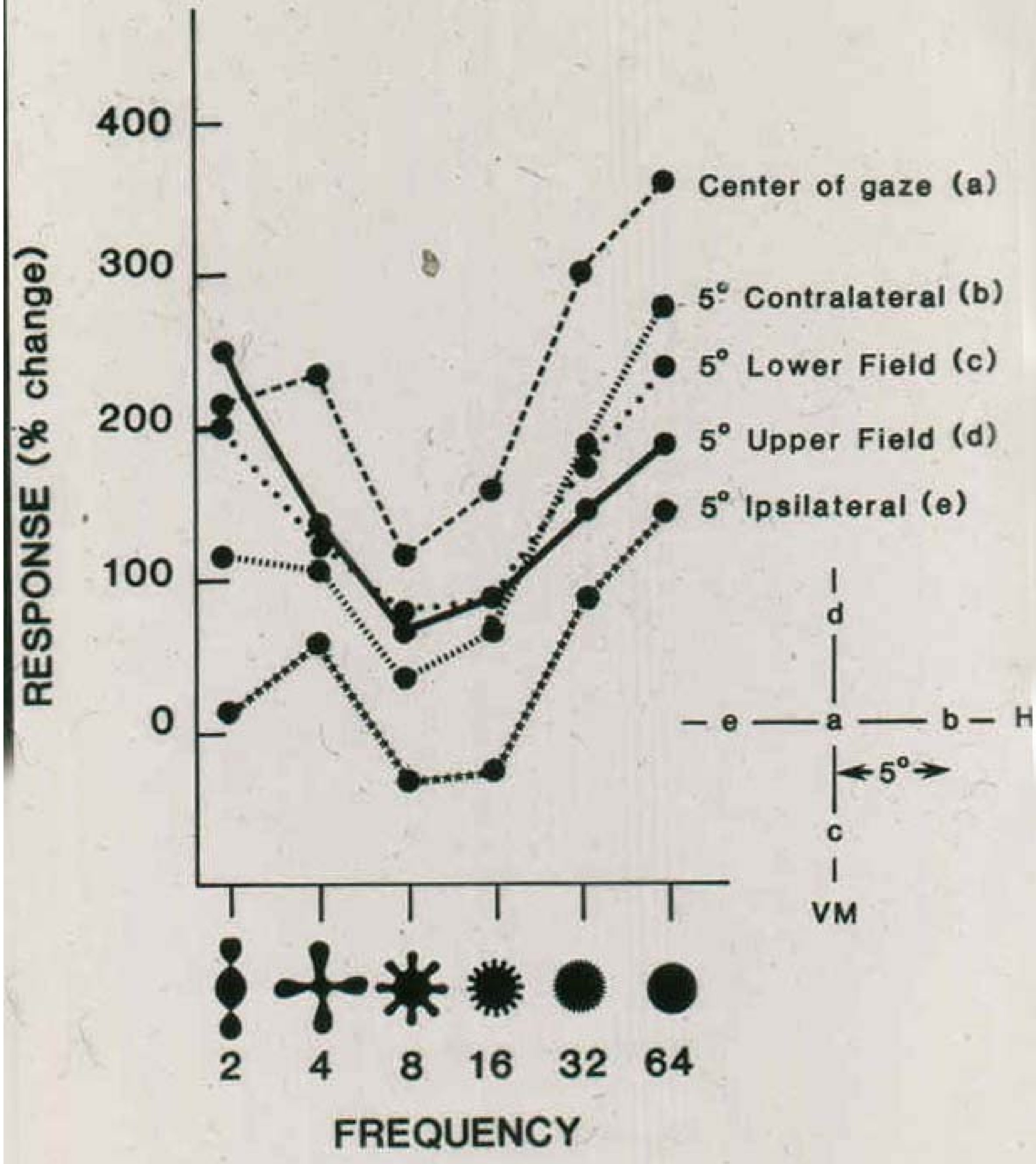
1. Respond Only to Visual Stimuli
2. Receptive fields are Large, Include the Fovea and are not Retinotopically Organized
3. Are Selective for Colors and Complex Shapes including Faces
4. Show Invariant Responses to Shape over Changes in Size, Contrast and Location
5. Are Affected by Attention, Short and Long term memory



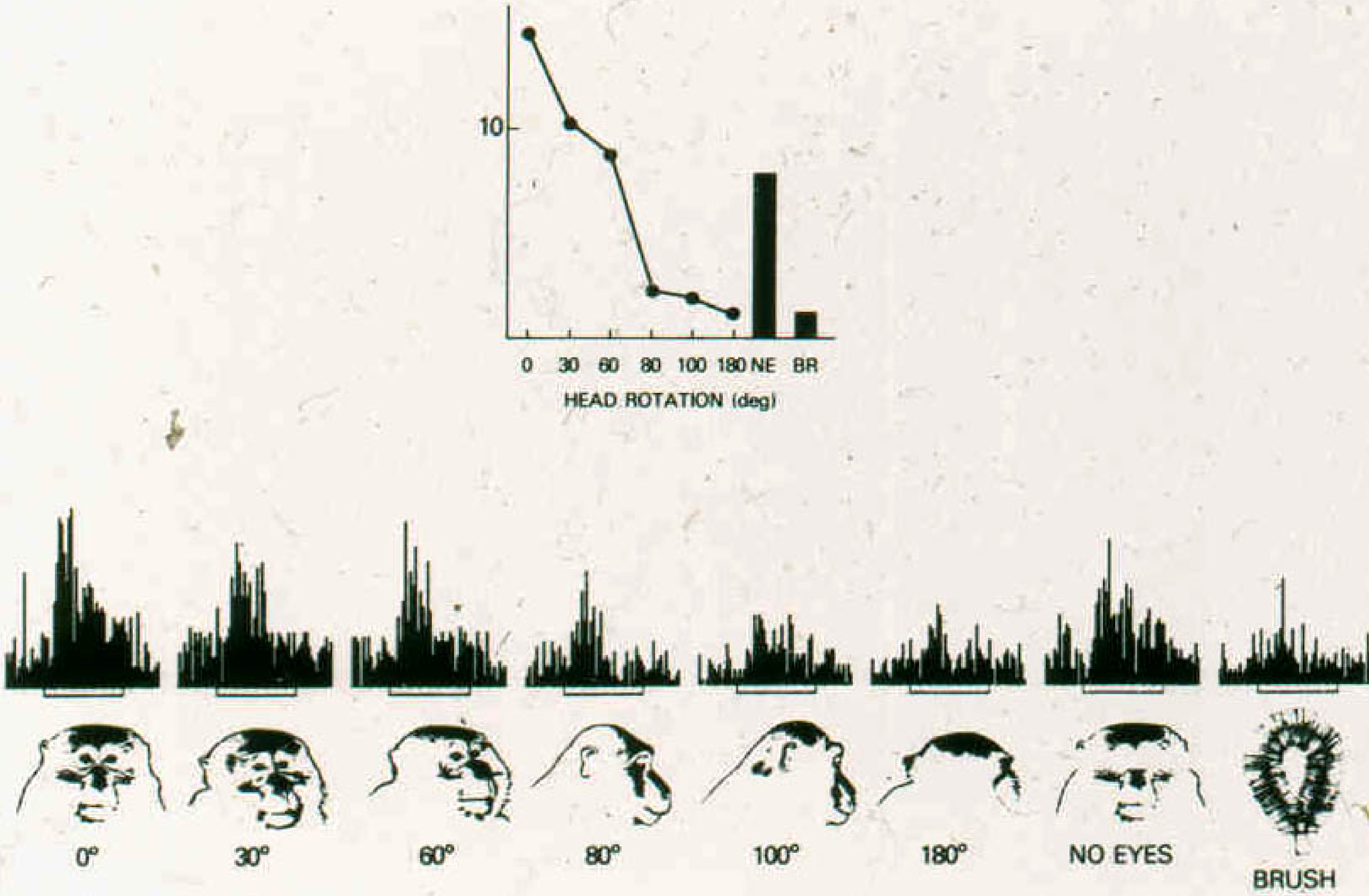
13 DEG²
28 DEG²
50 DEG²
200
100
0
RESPONSE (% change)
2
4
8
16
32
64
FREQUENCY

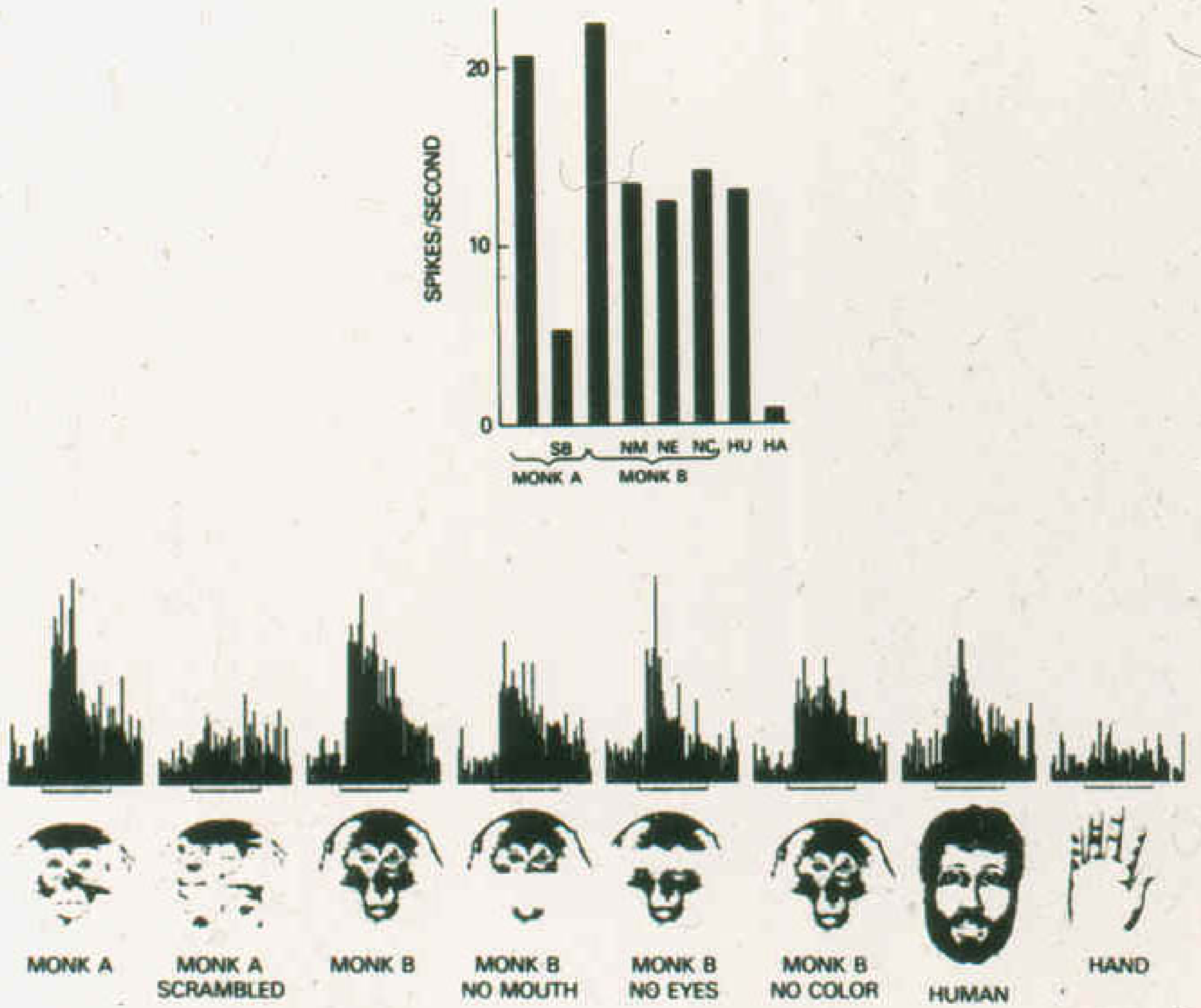


Light
Dark
300
200
100
0
RESPONSE (% change)
2
4
8
16
32
64
FREQUENCY

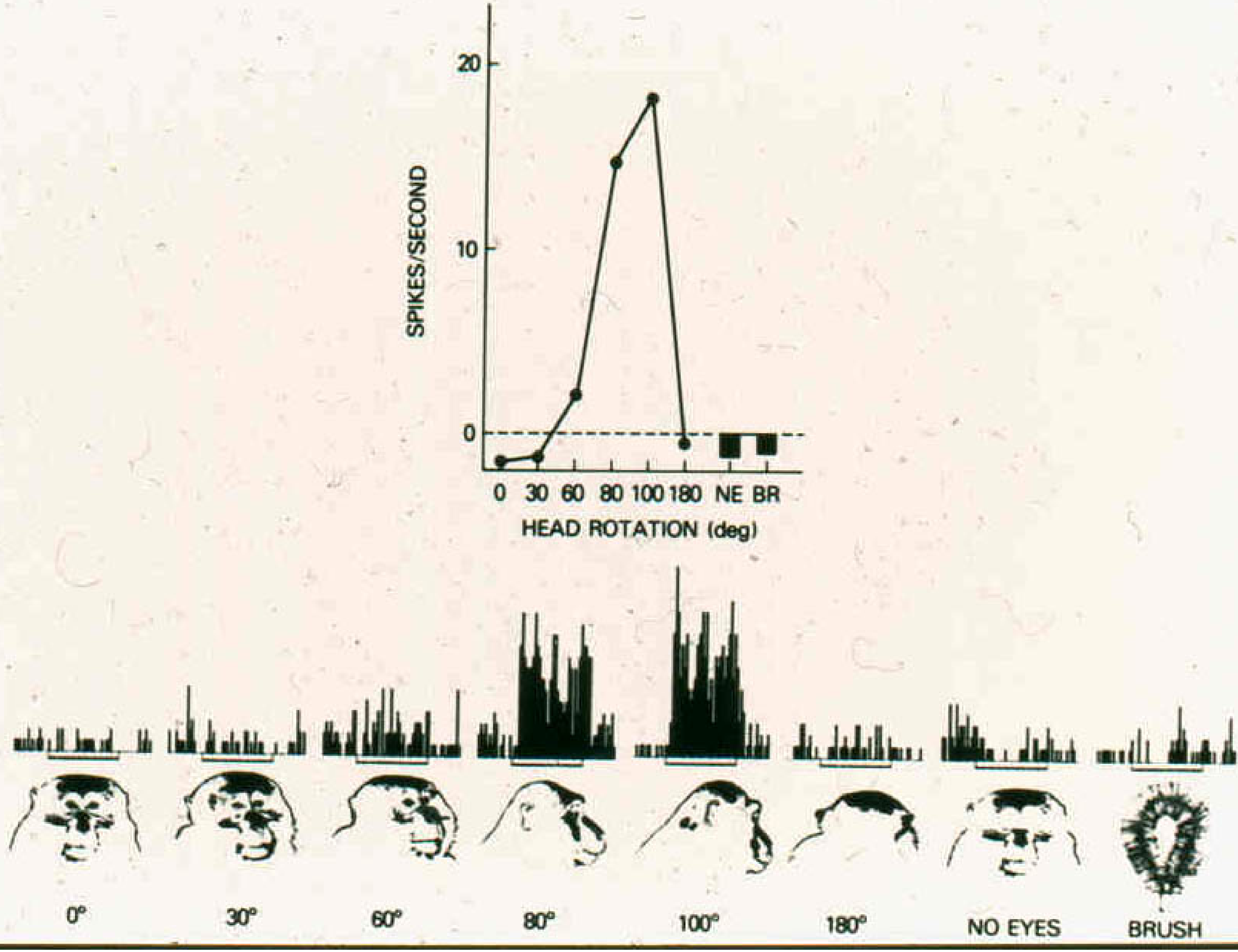


RESPONSE (% change)
400
300
200
100
0
Center of gaze (a)
5° Contralateral (b)
5° Lower Field (c)
5° Upper Field (d)
5° Ipsilateral (e)
d
e
a
b
H
5°
c
VM
2
4
8
16
32
64
FREQUENCY

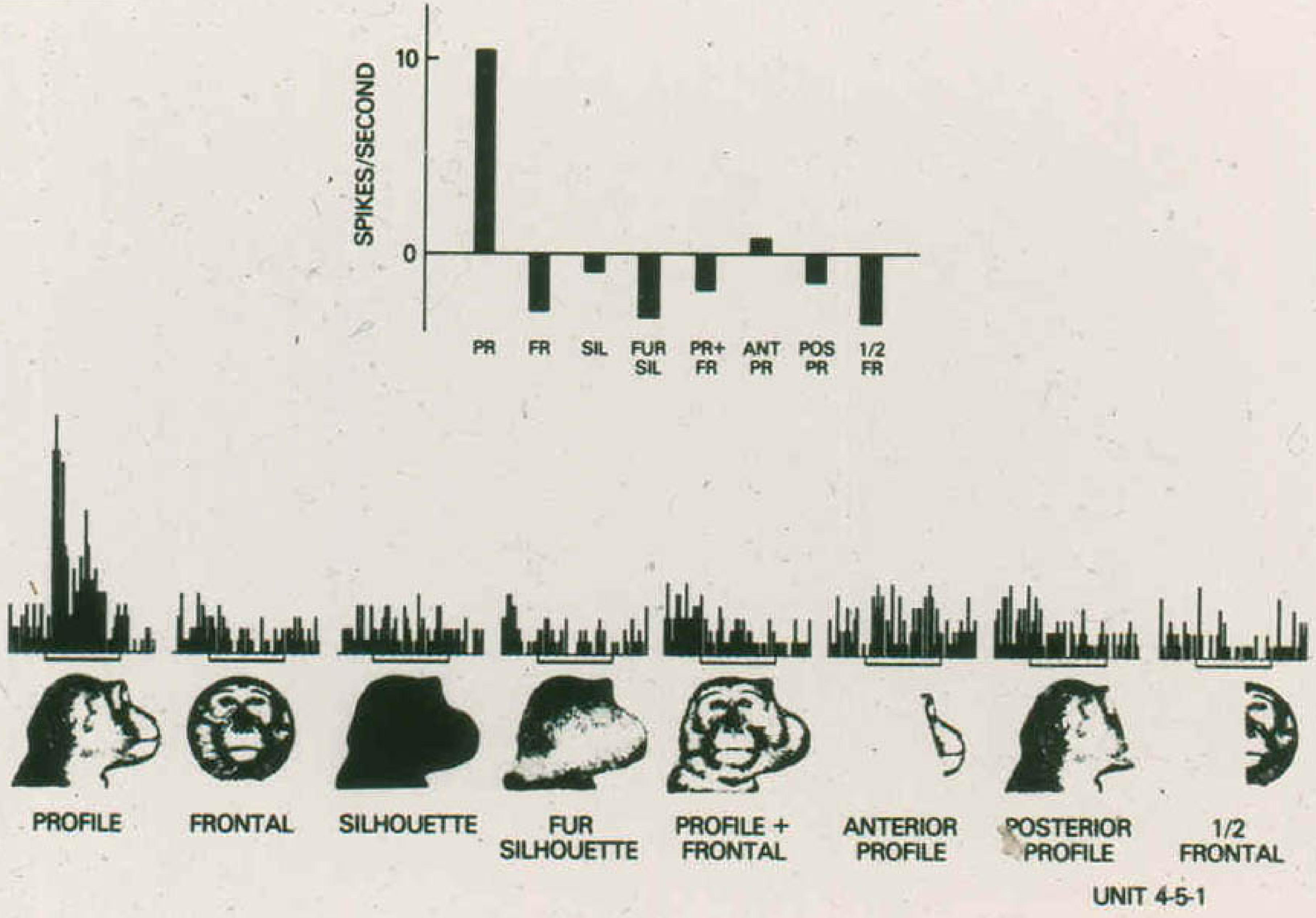

10
0
30
60
80
100
180
NE
BR
HEAD ROTATION (deg)
0°
30°
60°
80°
100°
180°
NO EYES
BRUSH



SPIKES/SECOND
0
10
20
SB
NM
NE
NC
HU
HA
MONK A
MONK B
MONK A
MONK A SCRAMBLED
MONK B
MONK B NO MOUTH
MONK B NO EYES
MONK B NO COLOR
HUMAN
HAND

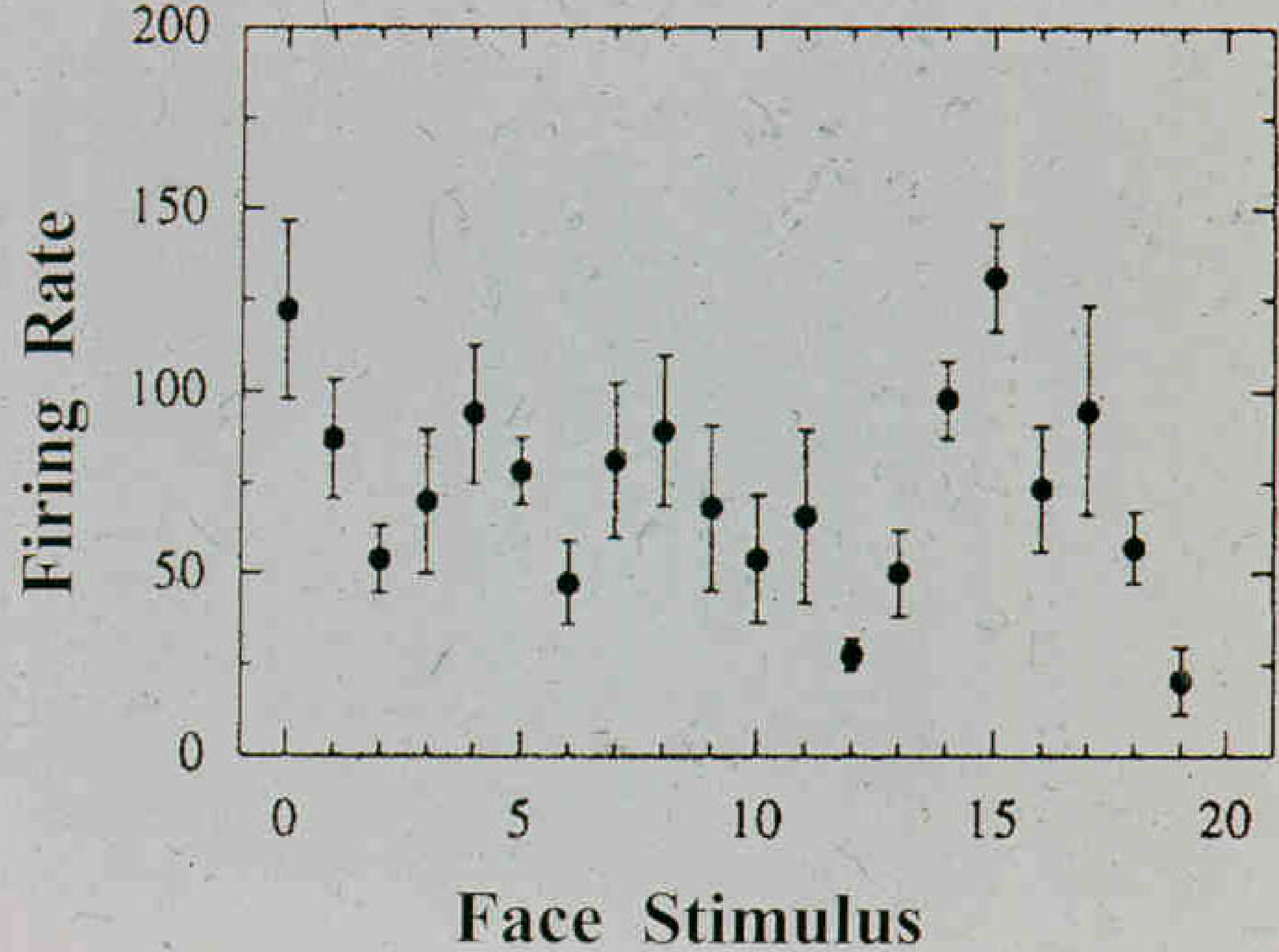


SPIKES/SECOND
20
10
0
0
30
60
80
100
180
NE
BR
HEAD ROTATION (deg)
0°
30°
60°
80°
100°
180°
NO EYES
BRUSH

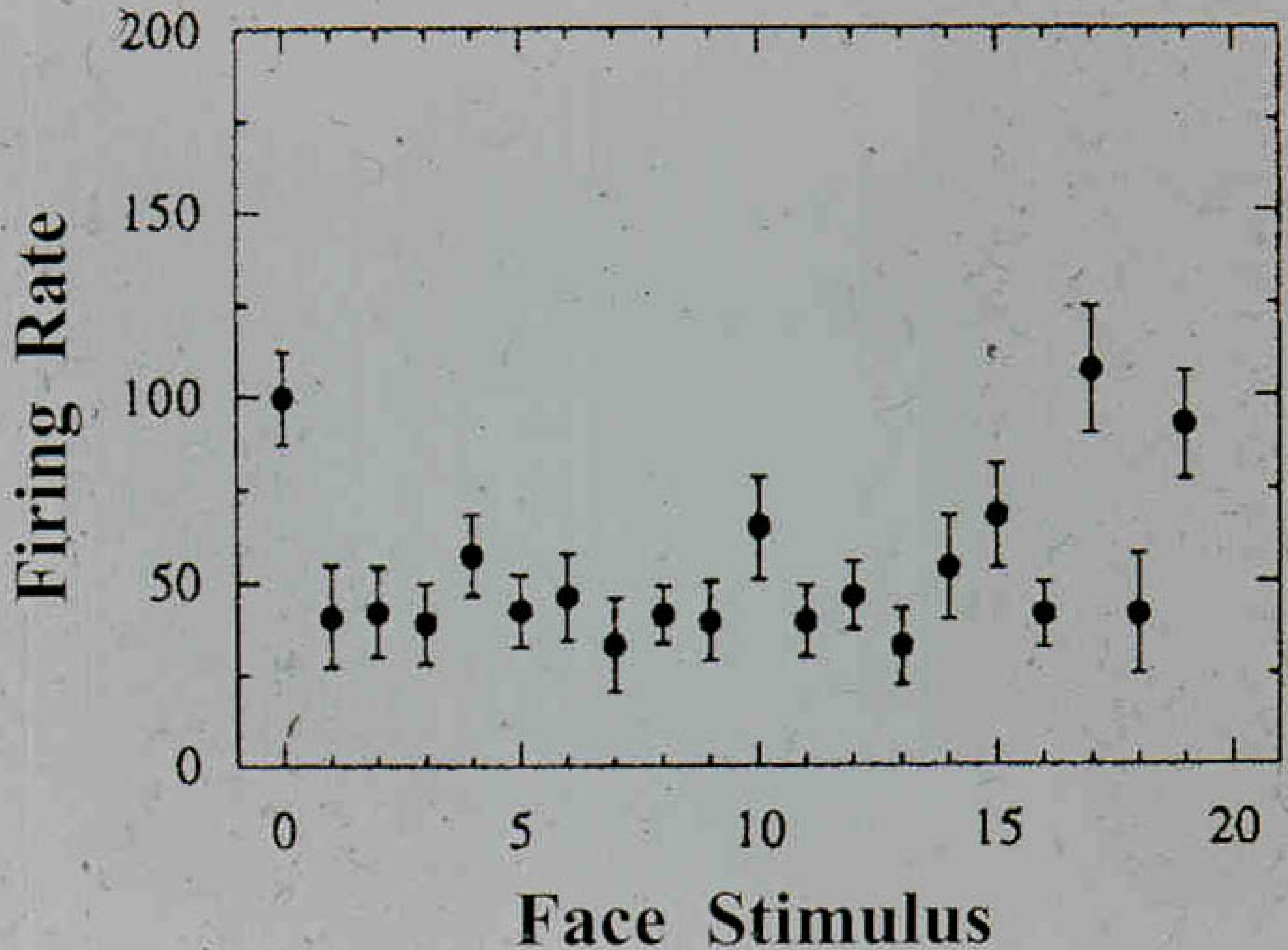

SPIKES/SECOND
10
0
PR
FR
SIL
FUR SIL
PR+ FR
ANT PR
POS PR
1/2 FR
PROFILE
FRONTAL
SILHOUETTE
FUR SILHOUETTE
PROFILE + FRONTAL
ANTERIOR PROFILE
POSTERIOR PROFILE
1/2 FRONTAL
UNIT 4-5-1

Are these face selective cells “grandmother cells”?

A “grandmother cell” is a cell that only responds to your grandmother or some other highly specific visual object or visual percept



(Abbott et al. 1996)



(Abbott et al, 1996)

- Faces appear to be coded by the pattern of activity across a set or ensemble of IT cells rather than by the firing of a dedicated “grandmother” cell

  = ensemble, pattern or coarse coding

- Other shapes are probably also coded by ensemble coding

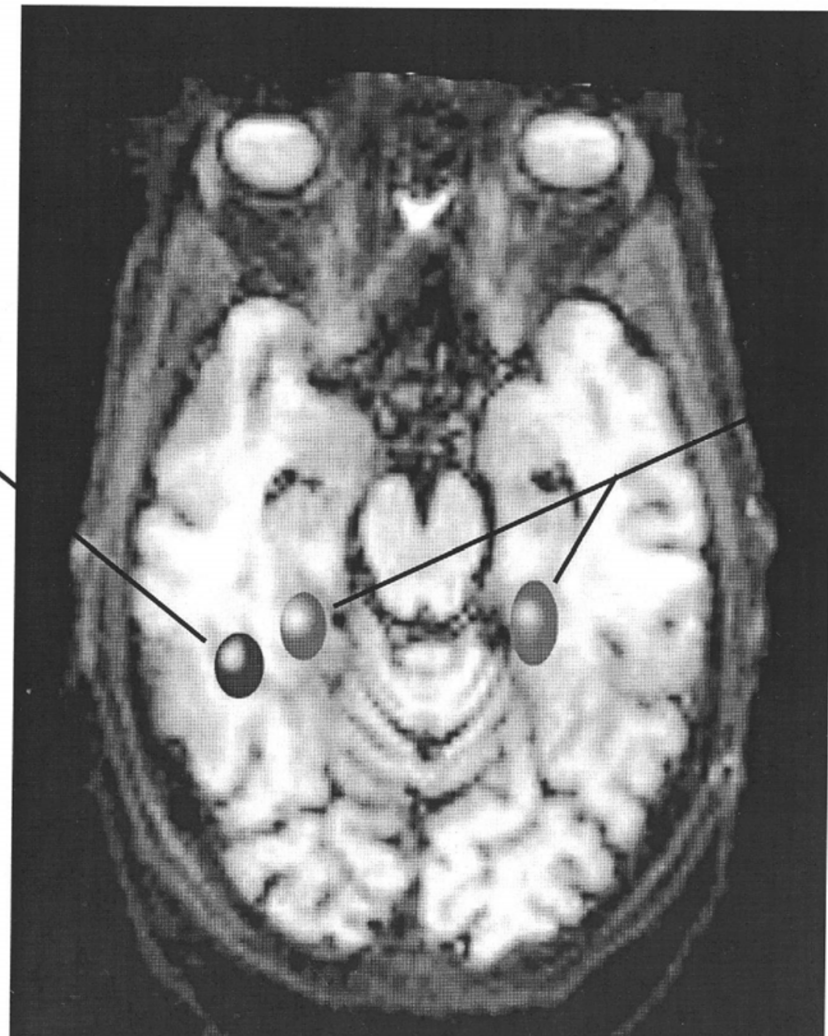
Click to add text

Regions of Interest

Fusiform Face Area (FFA)

- **responds to *faces***

(Kanwisher et al., 1997)



Parahippocampal Place Area (PPA)

- **responds to *houses* and places**

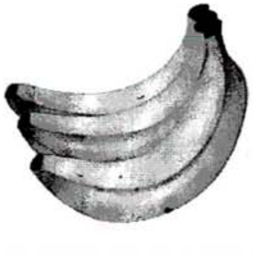
(Epstein & Kanwisher, 1998)

FFA responds more strongly to faces:

1.8 1.8 1.8 1.7 1.6 %MR Signal

than non-face control stimuli:

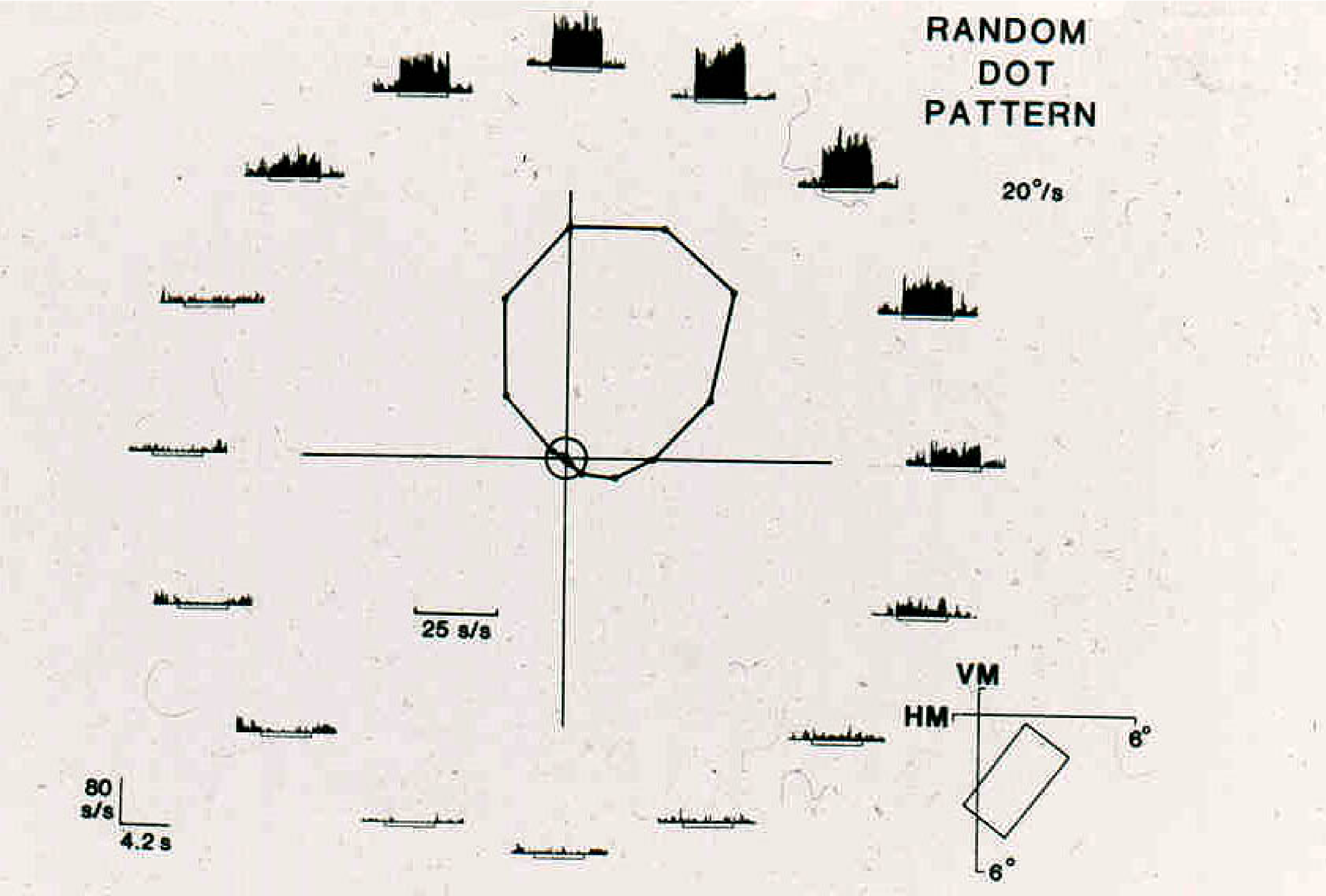
    

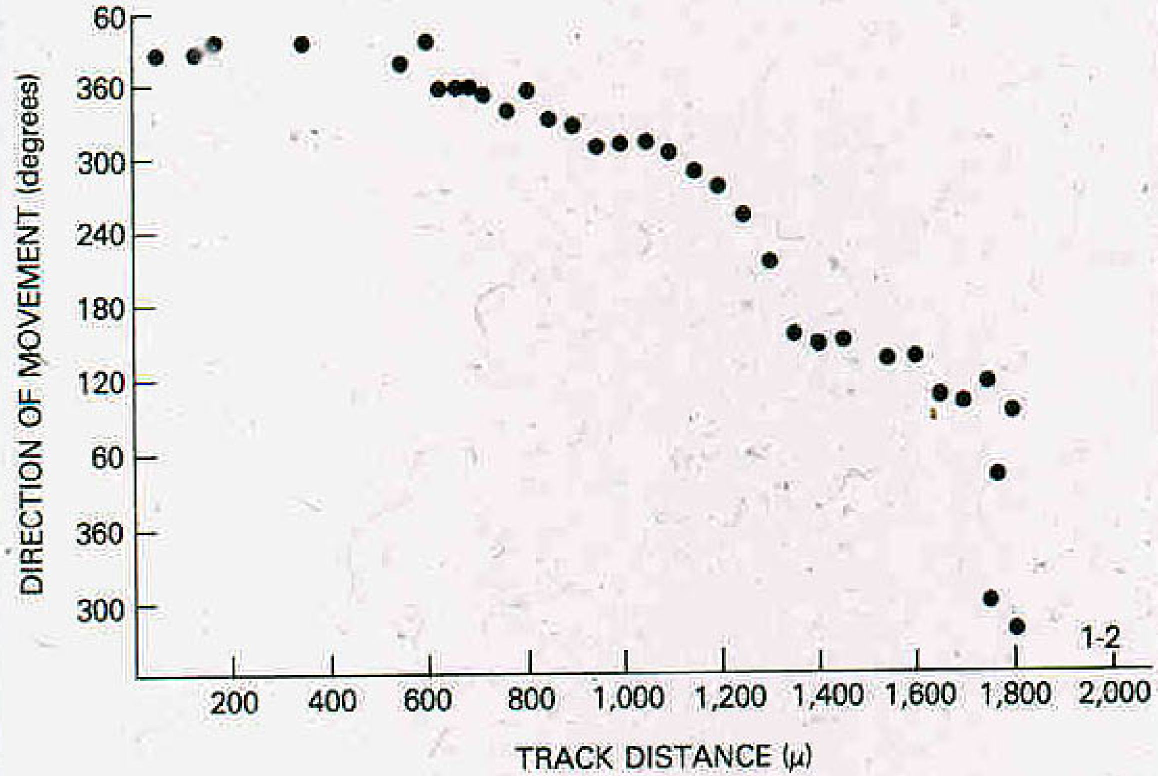
1.3 1.3 0.9 0.9 0.7 %MR Signa

MT neurons

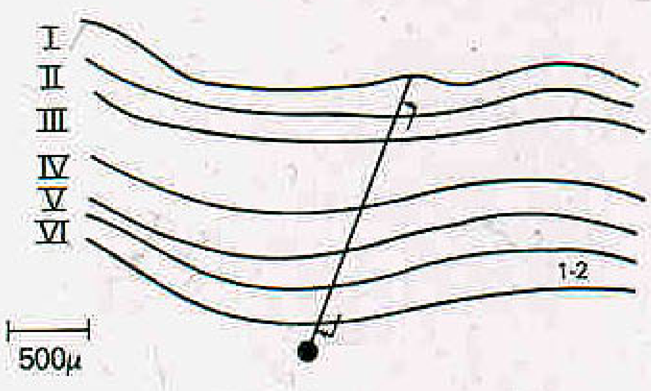
- selective for direction of movement
- selective for speed
- selective for retinal disparity
- relatively insensitive to shape
- insensitive to color

Direction tuning of a MT neuron (Albright, Desimone & Gross,1981)





DIRECTION OF MOVEMENT (degrees)
60
360
300
240
180
120
60
360
300
1-2
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
TRACK DISTANCE (μ)



I
II
III
IV
V
VI
1-2
500μ

What is the relation between neuronal activity and perception?

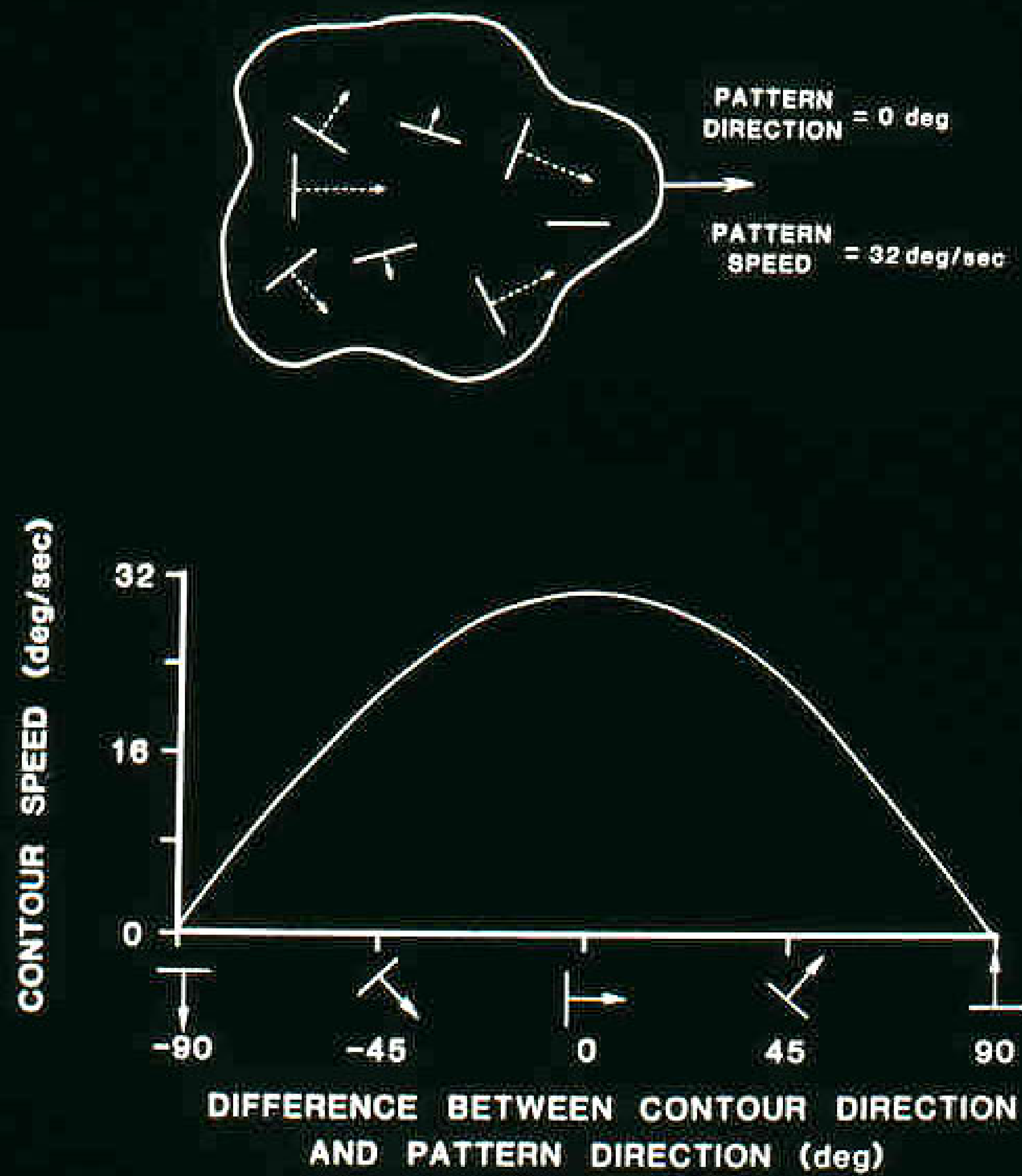
How would you determine if the activity of a cell coded “a beautiful man”

Newsome’s MT stimulation study

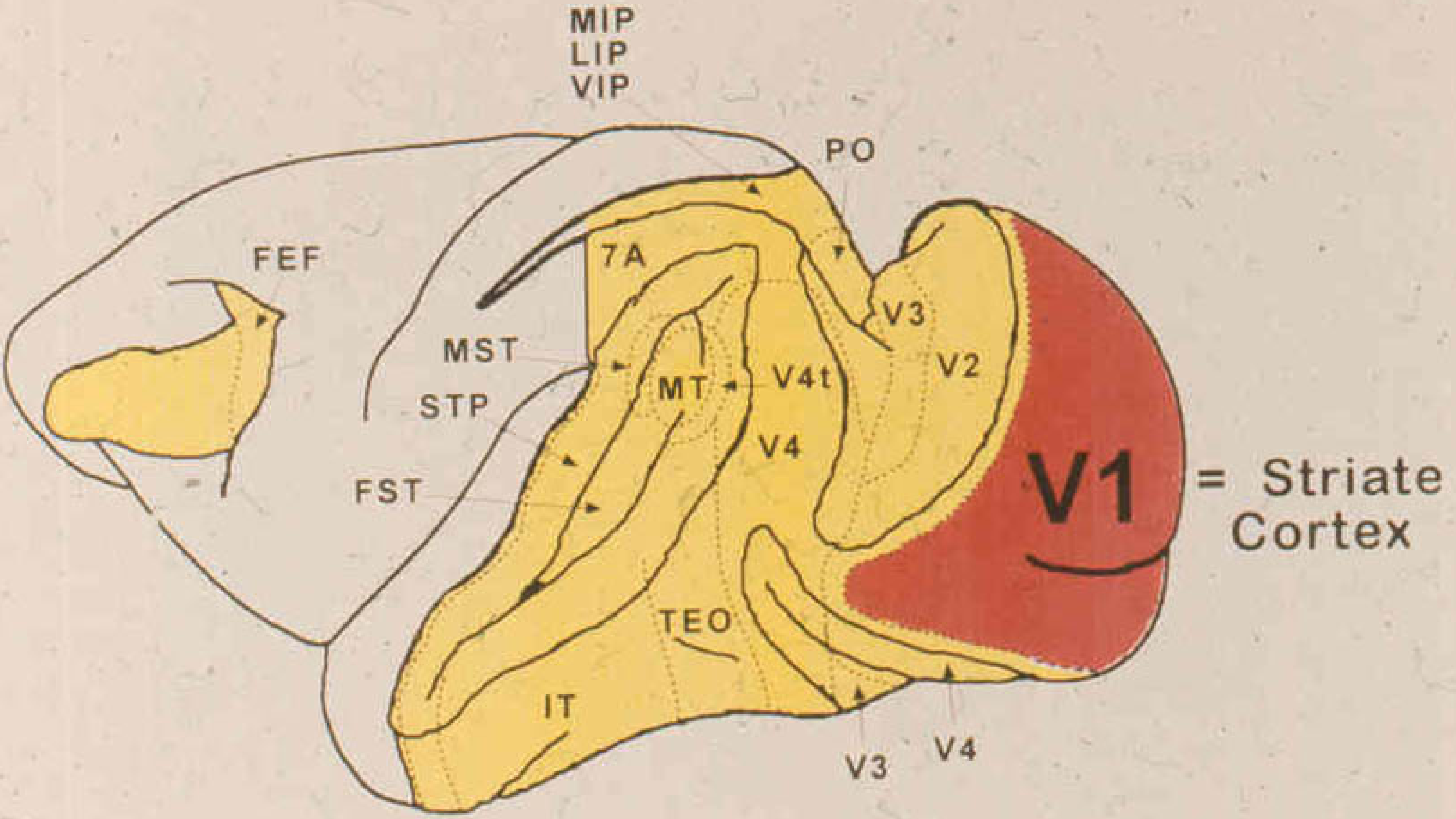
- present field of dots moving up or down
- train monkey to make an eye movement in the direction of moving dots
- Make task more difficult: 90% random;10% directional
- record in MT & find “up” column (correlation)
- electrically stimulate in “up” column when dots are moving down
- monkey makes upward eye movement : activating up cells => perception of up movement
- thus activating cells determines perception

Most MT cells, like V1 ones, are sensitive to the direction of movement of a contour.

Some MT neurons are sensitive to the direction of movement of a pattern or surface, thereby carrying the analysis of the visual stimulus a step beyond V1.


PATTERN DIRECTION = 0 deg
PATTERN SPEED = 32 deg/sec
CONTOUR SPEED (deg/sec)
32
16
0
-90
-45
0
45
90
DIFFERENCE BETWEEN CONTOUR DIRECTION AND PATTERN DIRECTION (deg)

Deficit in motion
Perception after
MT lesions


MIP
LIP
VIP
PO
FEF
7A
V3
MST
V4t
V2
MT
STP
V4
FST
V1
= Striate Cortex
TEO
IT
V3
V4

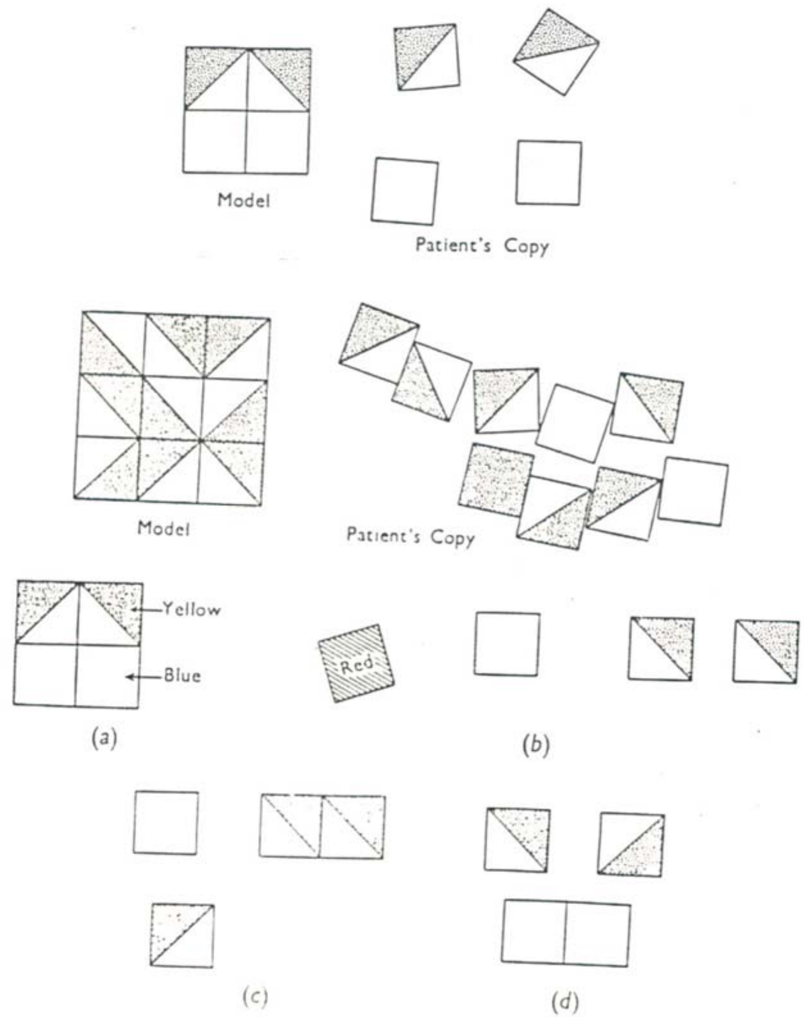
Posterior Parietal Lesions

1. Impair Visuo-Spatial Abilities

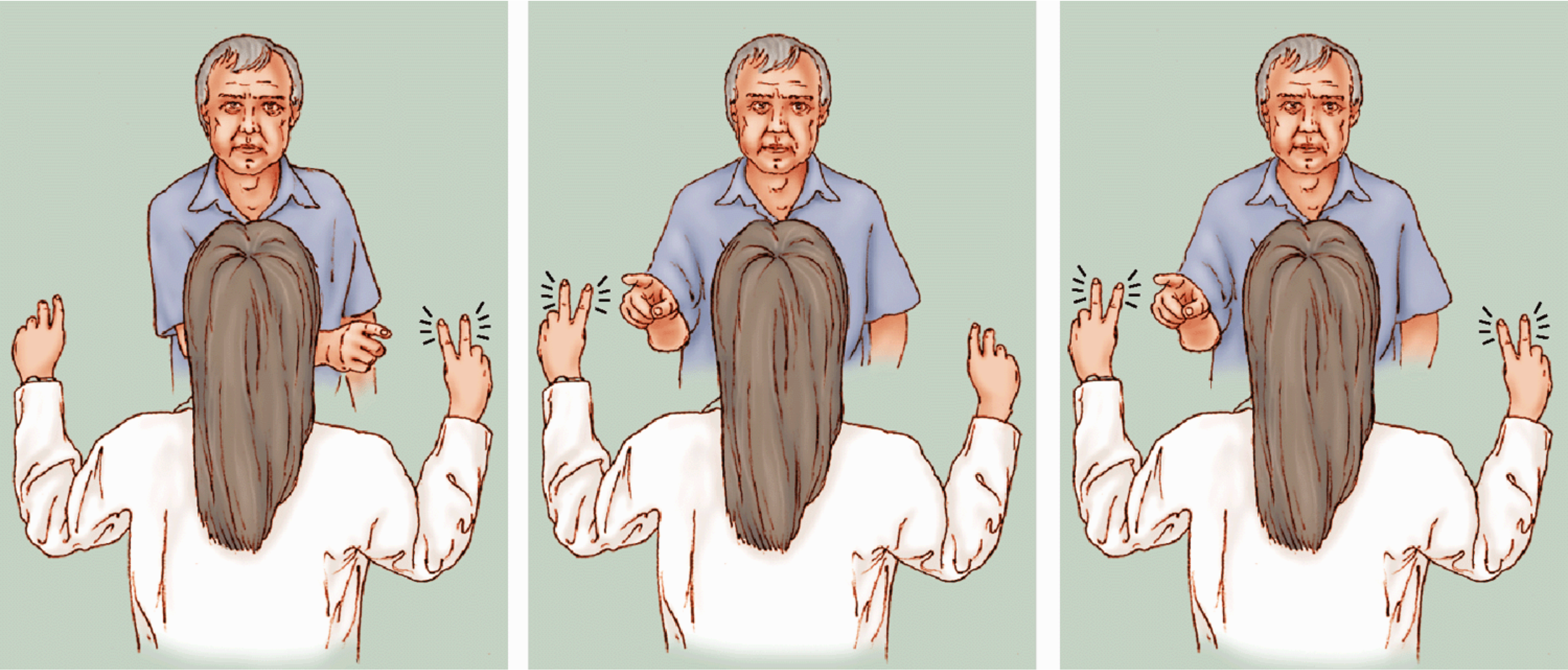
2. Produce Visual Neglect

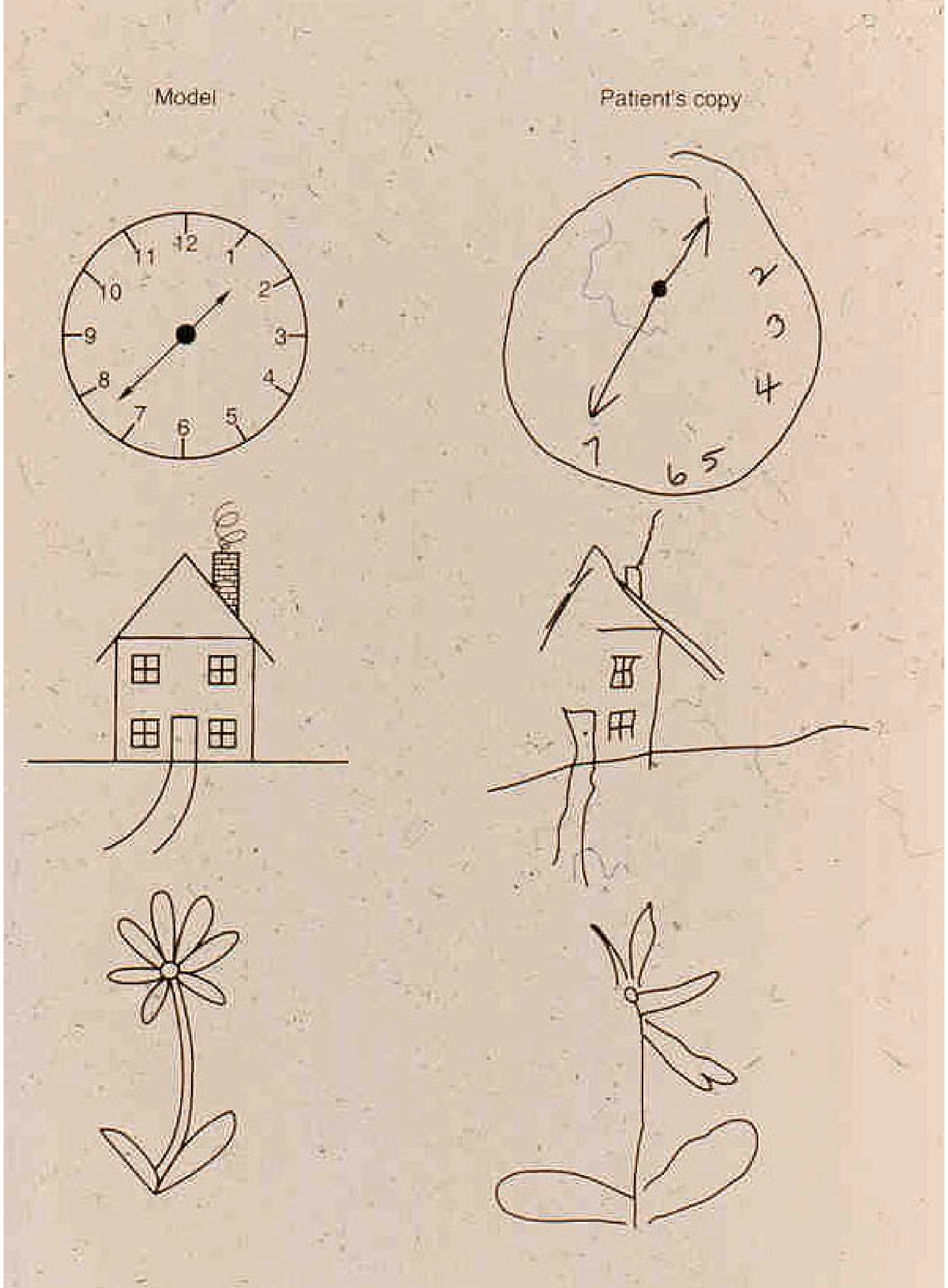
VISUAL - SPATIAL DEFICIT AFTER PARIETAL LOBE DAMAGE

Impairment in visuo-constructive abilities after posterior parietal lesions

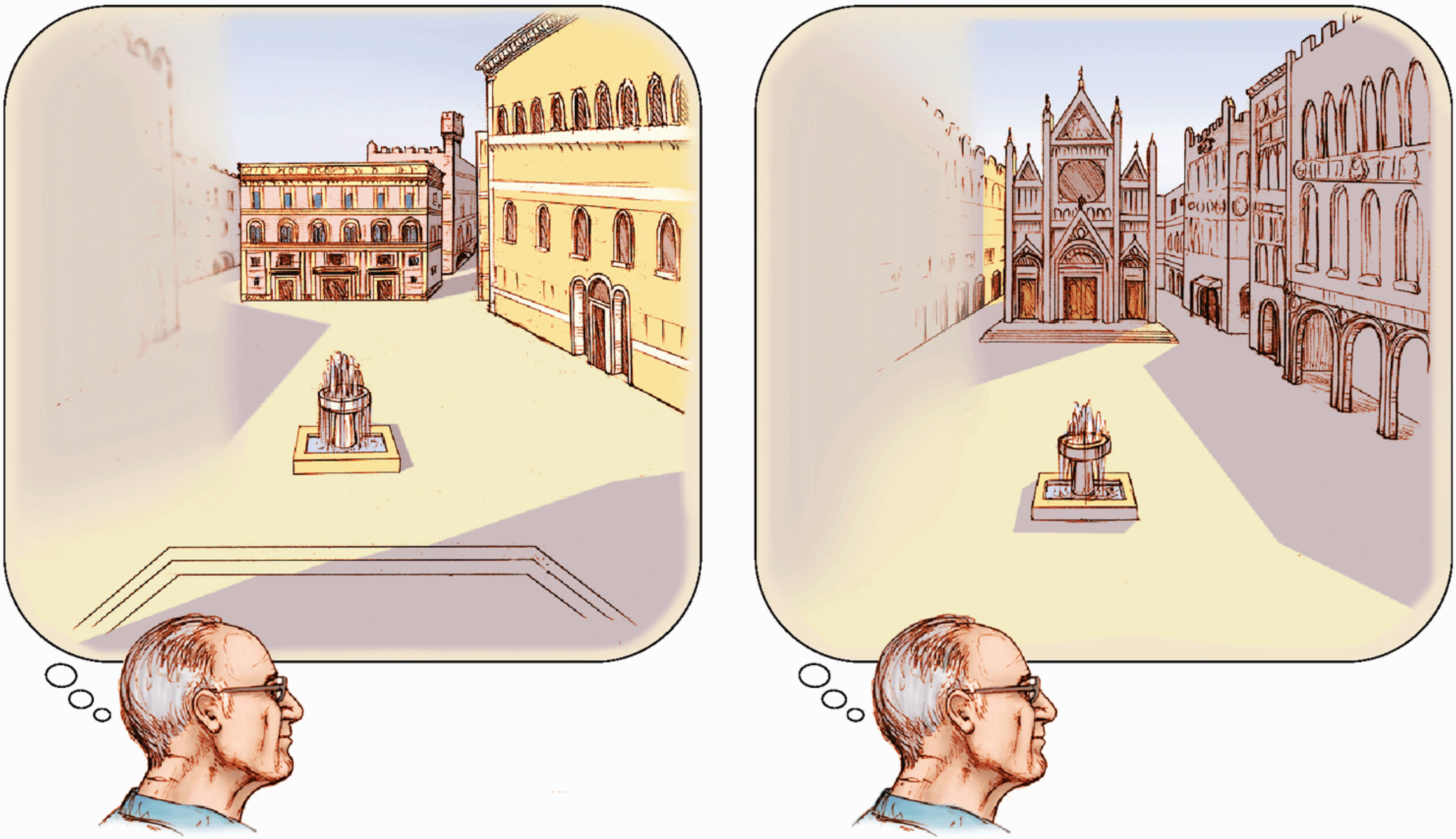


Visual "extinction" : an example of unilateral neglect after posterior parietal lesions





Neglect in the left half field after right posterior parietal lesions



Neglect in imaging or remembering the left half field after right posterior parietal lesions

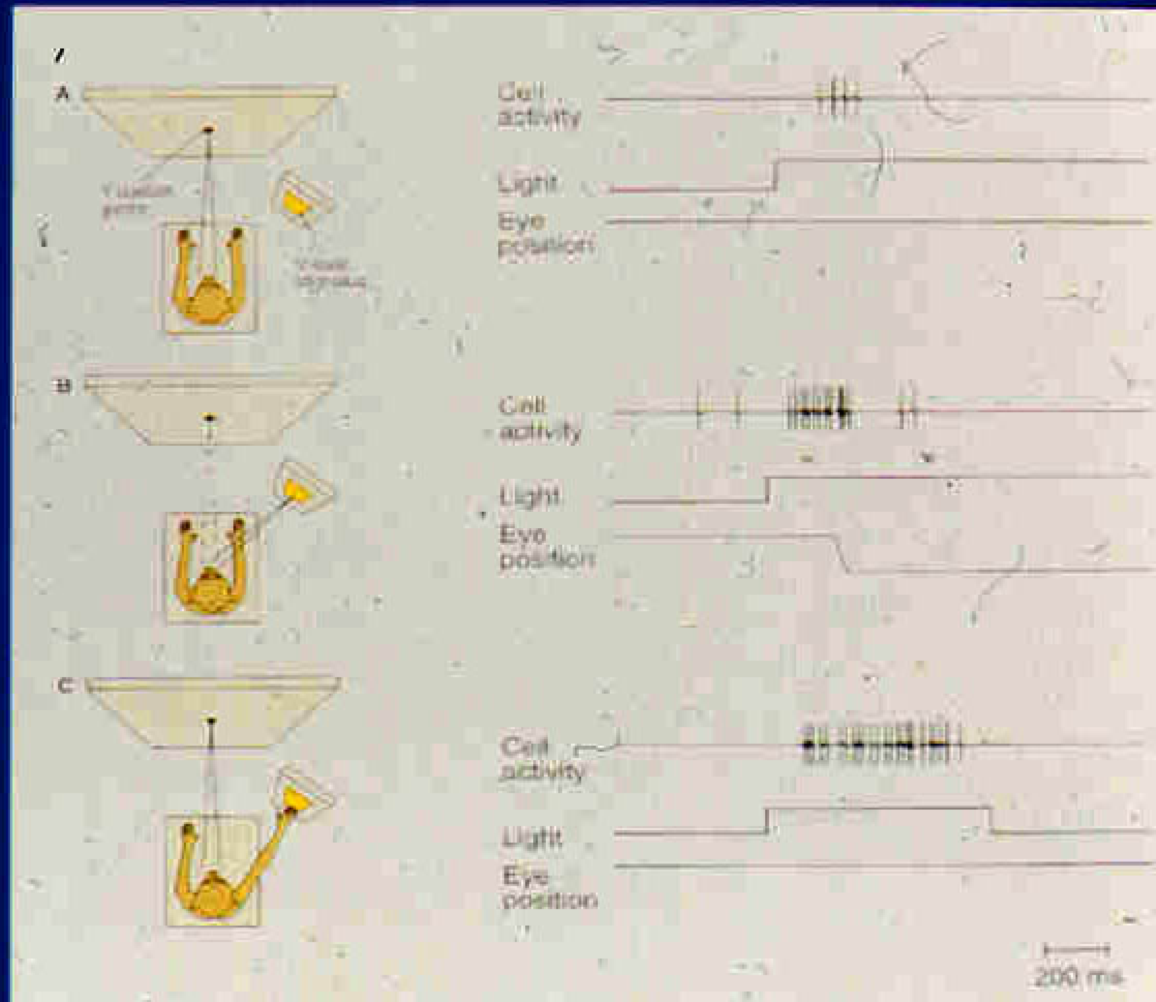
Adapted from Bisiach, E., and Luzzatti, C., Unilateral neglect of representational space, Cortex 14 (1978): 129–133.

Posterior Parietal Neurons
Respond More when the Animal is Attending to the Stimulus

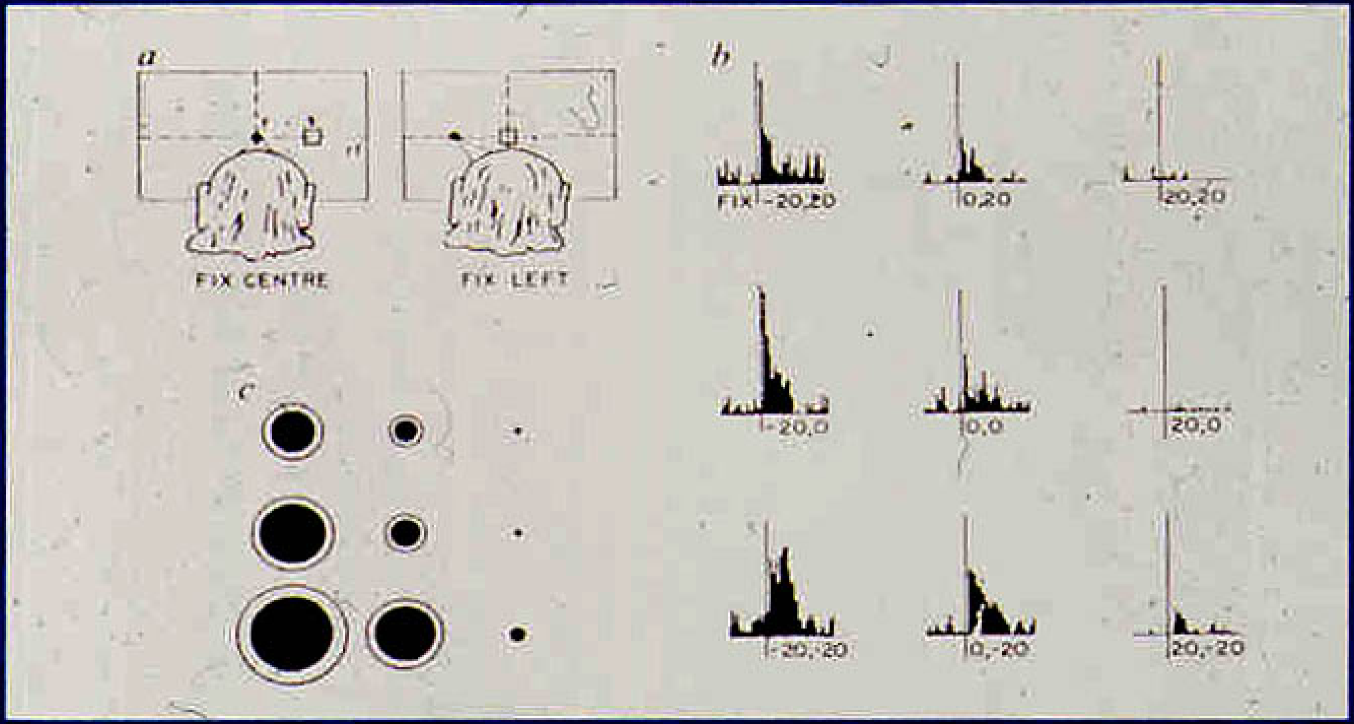
Passive stimulation →

Paying attention
prior to an eye movement →

Paying attention
prior to a hand movement →



Coding of Space by Posterior Parietal Neurons



These neurons have visual receptive fields whose response strength depends on the animal's angle of gaze. Therefore a set of such neurons can code spatial location independent of eye position

Some Caveats about the “Two Systems”

1. They are interconnected at every level.
2. Each is subdivided; 3 streams may be a better description: space,motion & recognition.
3. Even within a stream processing can be serial or parallel.
4. Continue into frontal lobes.
5. They converge in the frontal lobes, STP and entorhinal cortex.
6. Ventral stream carries spatial information (its receptive fields).
7. Ventral stream cells sensitive to movement and direction.
8. Dorsal stream carries information about shape as revealed by motor performance and AIP neurons.
9. Dorsal area MT sensitive to movement boundaries based on texture and color