3

Spatial Vision: From Spots to Stripes

Chapter 3 Spatial Vision: From Spots to Stripes

- Visual Acuity: Oh Say, Can You See?
- Retinal Ganglion Cells and Stripes
- The Lateral Geniculate Nucleus
- The Striate Cortex
- Receptive Fields in Striate Cortex
- Columns and Hypercolumns
- Selective Adaptation: The Psychologist's Electrode
- The Development of Spatial Vision

Visual Acuity: Oh Say, Can You See?

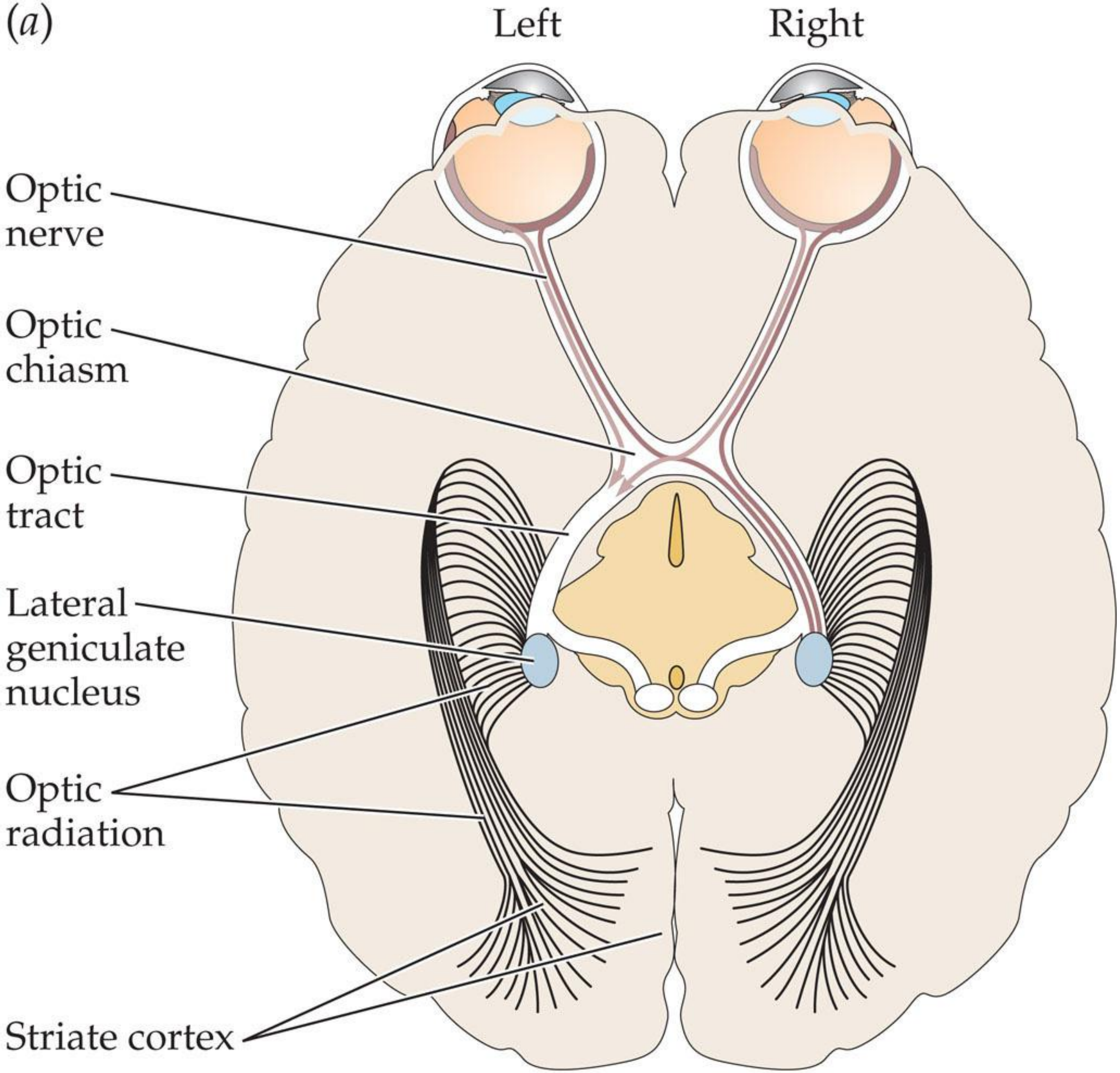
The King said, "I haven't sent the two Messengers, either. They're both gone to the town. Just look along the road, and tell me if you can see either of them."

"I see nobody on the road," said Alice.

"I only wish I had such eyes," the King remarked in a fretful tone. "To be able to see Nobody! And at that distance, too!"

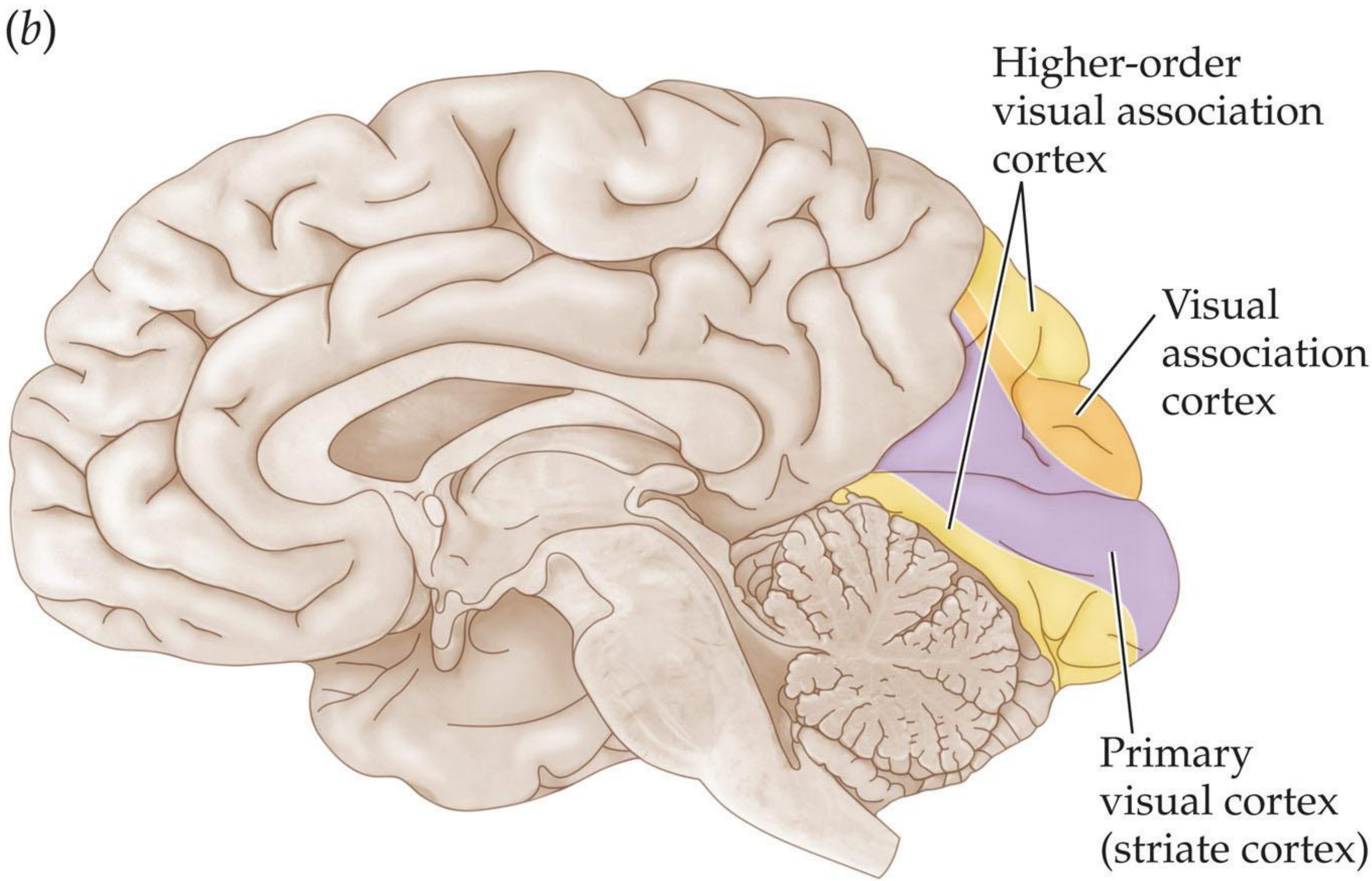
Lewis Carroll, *Through the Looking Glass*

Figure 3.1 Cortical visual pathways (Part 1)



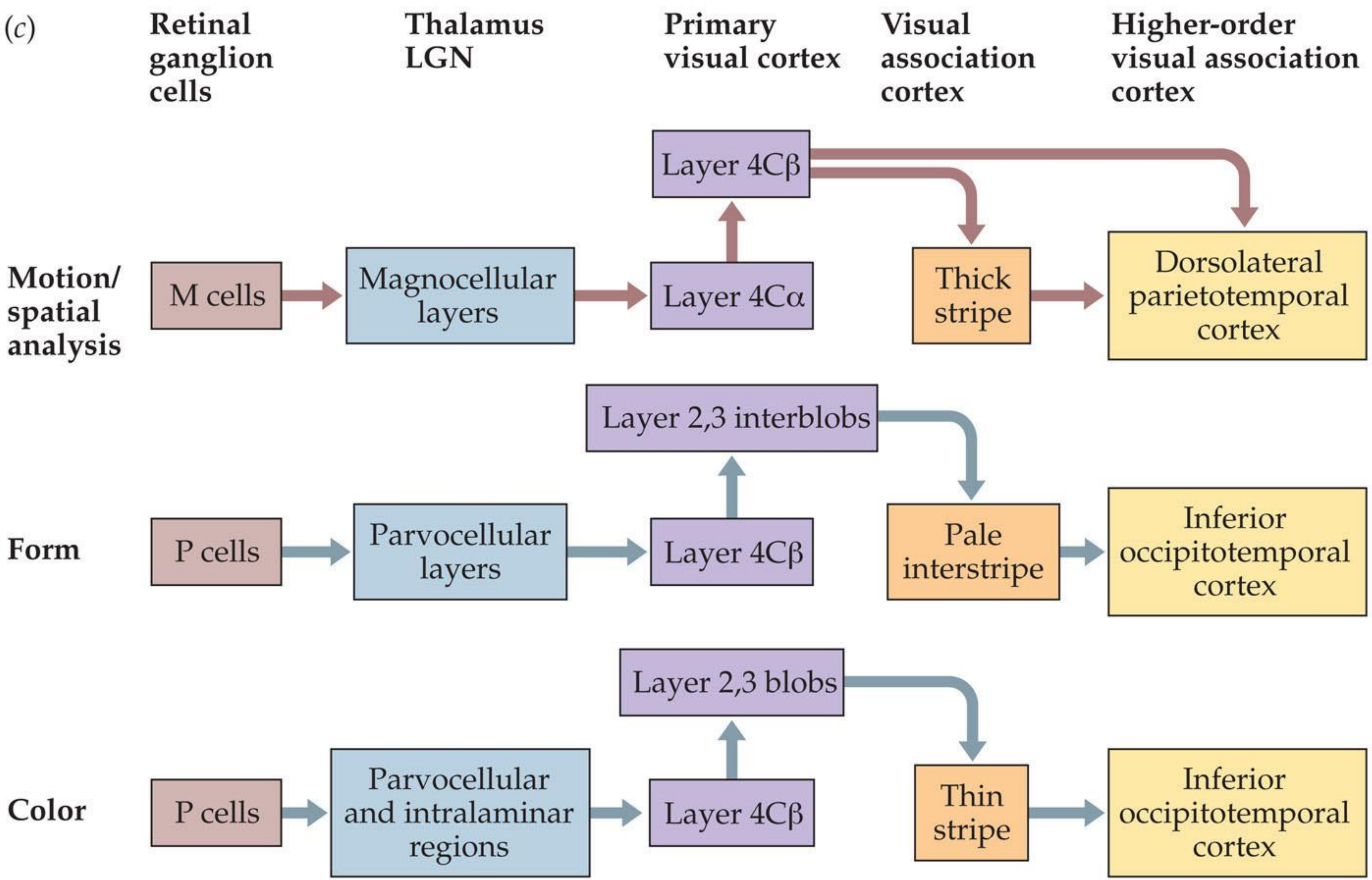
SENSATION & PERCEPTION 4e, Figure 3.1 (Part 1)

Figure 3.1 Cortical visual pathways (Part 2)



SENSATION & PERCEPTION 4e, Figure 3.1 (Part 2)

Figure 3.1 Cortical visual pathways (Part 3)



SENSATION & PERCEPTION 4e, **Figure 3.1 (Part 3)**

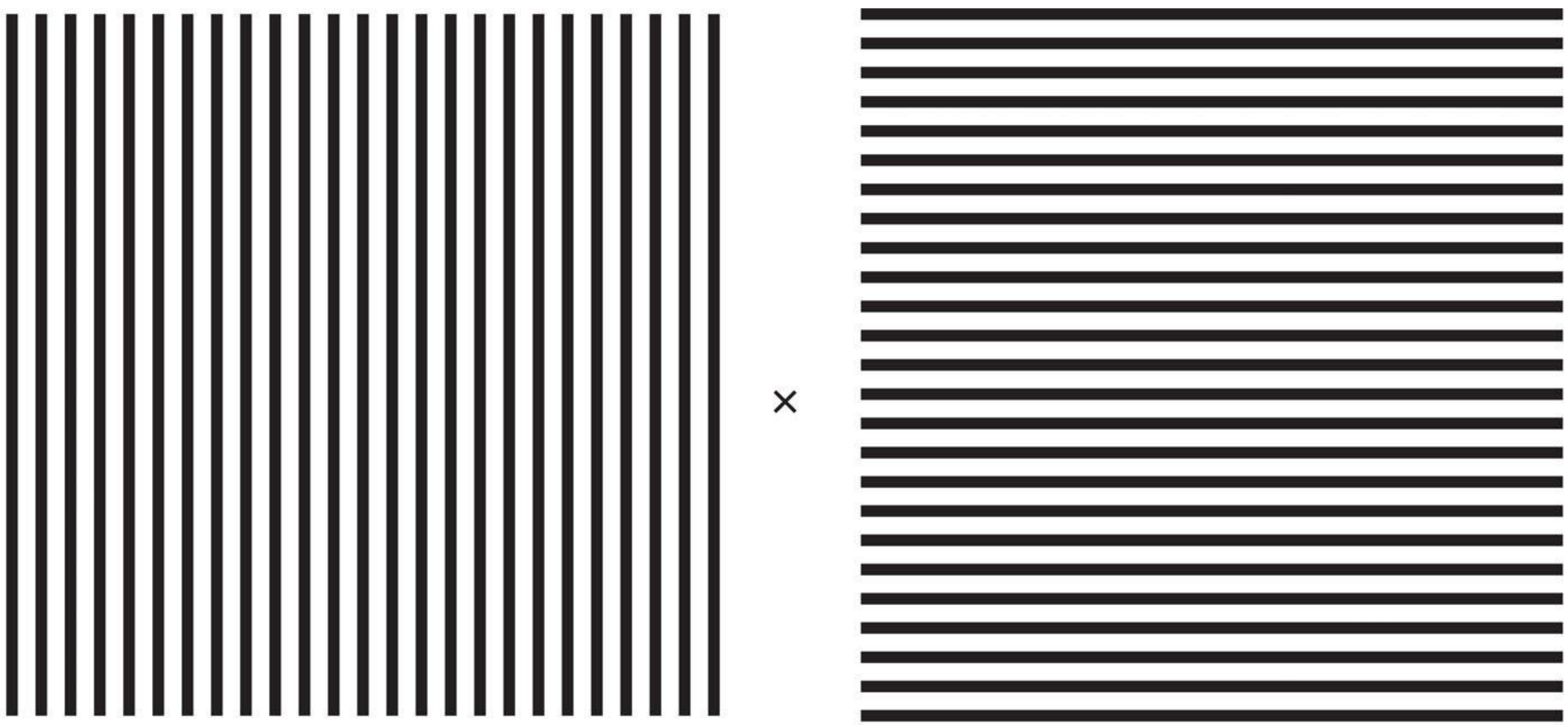
Visual Acuity: Oh Say, Can You See?

What is the path of image processing from the eyeball to the brain?

- Eye (vertical path)
  - Photoreceptors
  - Bipolar cells
  - Retinal ganglion cells
- Lateral geniculate nucleus
- Striate cortex

Visual Acuity: Oh Say, Can You See?

Acuity: The smallest spatial detail that can be resolved.

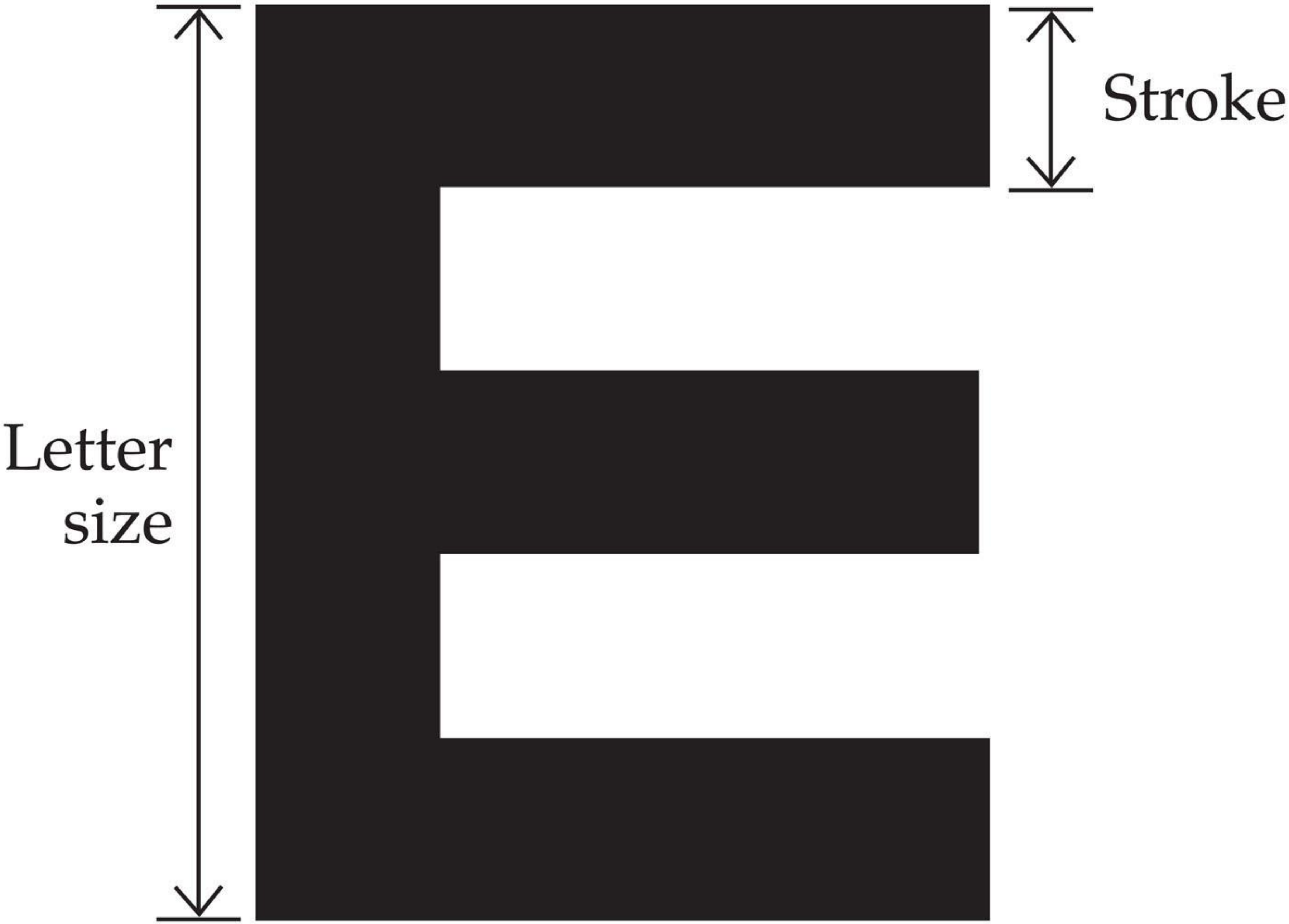


***SENSATION & PERCEPTION 4e*, Figure 3.2**

The Snellen *E* test

- Herman Snellen invented this method for designating visual acuity in 1862.
- Notice that the strokes on the E form a small grating pattern.

Figure 3.5 A Snellen *E*



SENSATION & PERCEPTION 4e, Figure 3.5

Visual Acuity: Oh Say, Can You See?

There are several ways to measure visual acuity.

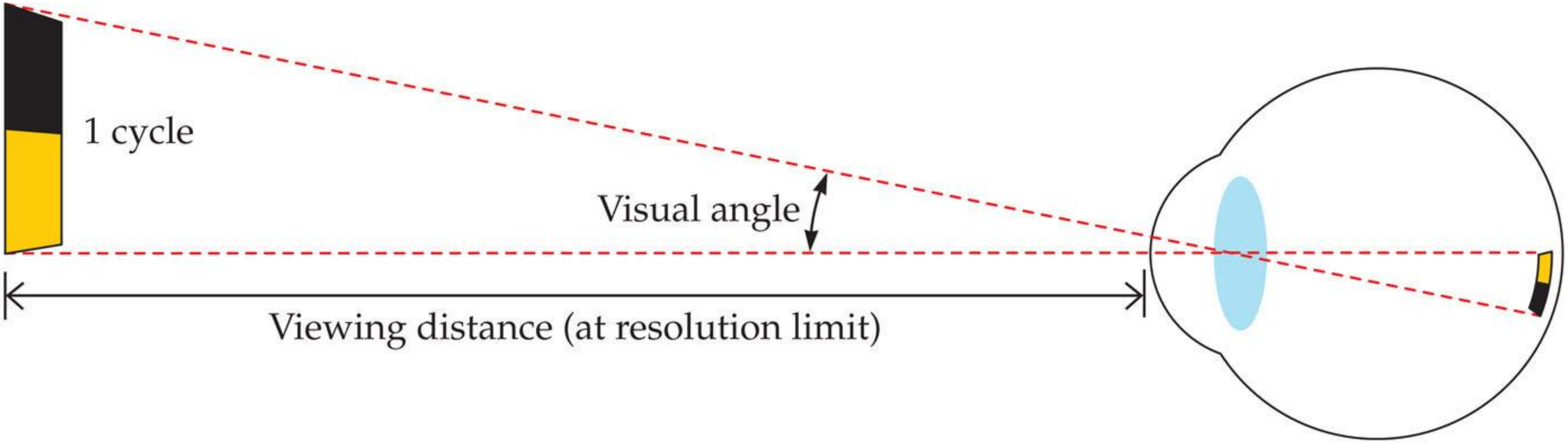
- Eye doctors use distance to characterize visual acuity, as in “20/20 vision.”
  - Your distance/Normal vision distance

Visual Acuity: Oh Say, Can You See?

Vision scientists: Smallest visual angle of a cycle of grating

- The smaller the visual angle at which you can identify a cycle of a grating, the better your vision

Figure 3.3 Visual angle



SENSATION & PERCEPTION 4e, Figure 3.3

Visual Acuity: Oh Say, Can You See?

Types of Visual Acuity

- Minimum visual acuity: The smallest object that one can detect.
- Minimum resolvable acuity: The smallest angular separation between neighboring objects that one can resolve.
- Minimum recognizable acuity: The angular size of the smallest feature that one can recognize.
- Minimum discriminable acuity: The angular size of the smallest change in a feature we can discriminate.

TABLE 3.1

Summary of the different forms of acuity and their limits

Type of acuity	Measured	Acuity (degree)
Minimum visible	Detection of a feature	0.00014
Minimum resolvable	Resolution of two features	0.017
Minimum recognizable	Identification of a feature	0.017
Minimum discriminable	Discrimination of a change in a feature	0.00024

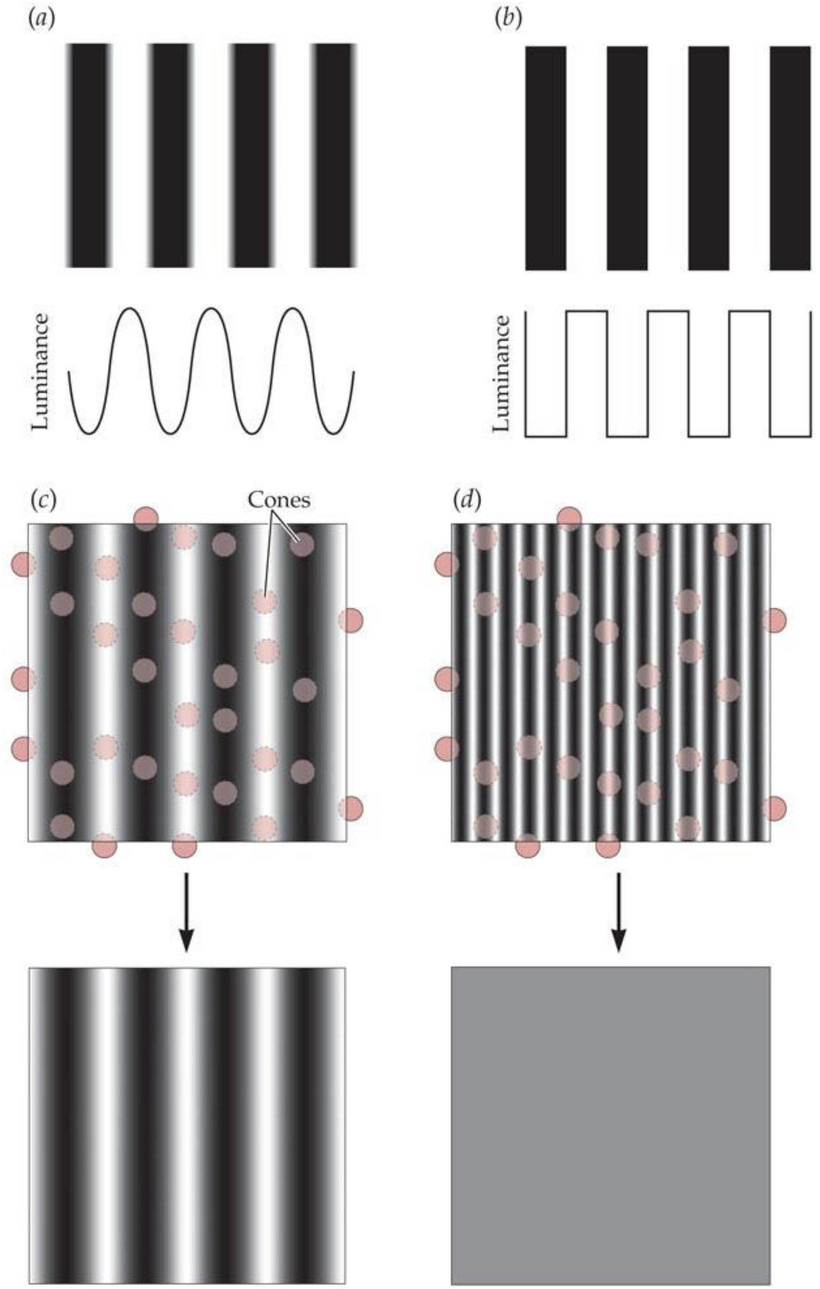
SENSATION & PERCEPTION 4e, Table 3.1

Visual Acuity: Oh Say, Can You See?

Why does an oriented grating appear to be gray if you are far enough away?

- This striped pattern is a “sine wave grating.”
- The visual system “samples” the grating discretely.

Figure 3.4 A square wave grating and a sine wave grating



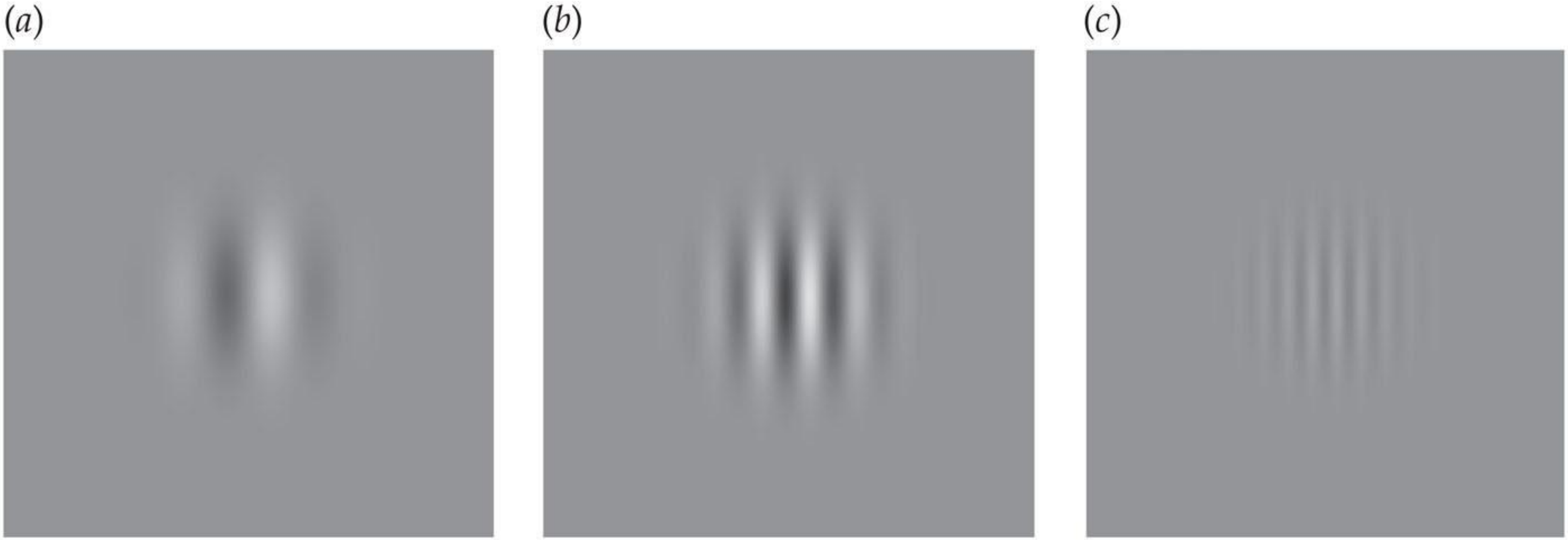
SENSATION & PERCEPTION 4e, Figure 3.4

Visual Acuity: Oh Say, Can You See?

Spatial frequency: Cycles of a grating per unit of visual angle (in degrees).

- Another way to think of spatial frequency is as the number of times a pattern repeats per unit area.
- In Figure 3.6, (*a*) has a low spatial frequency, (*b*) has a medium spatial frequency, and (*c*) has a high spatial frequency.

Figure 3.6 Sine wave gratings illustrating low (*a*), medium (*b*), and high (*c*) spatial frequencies



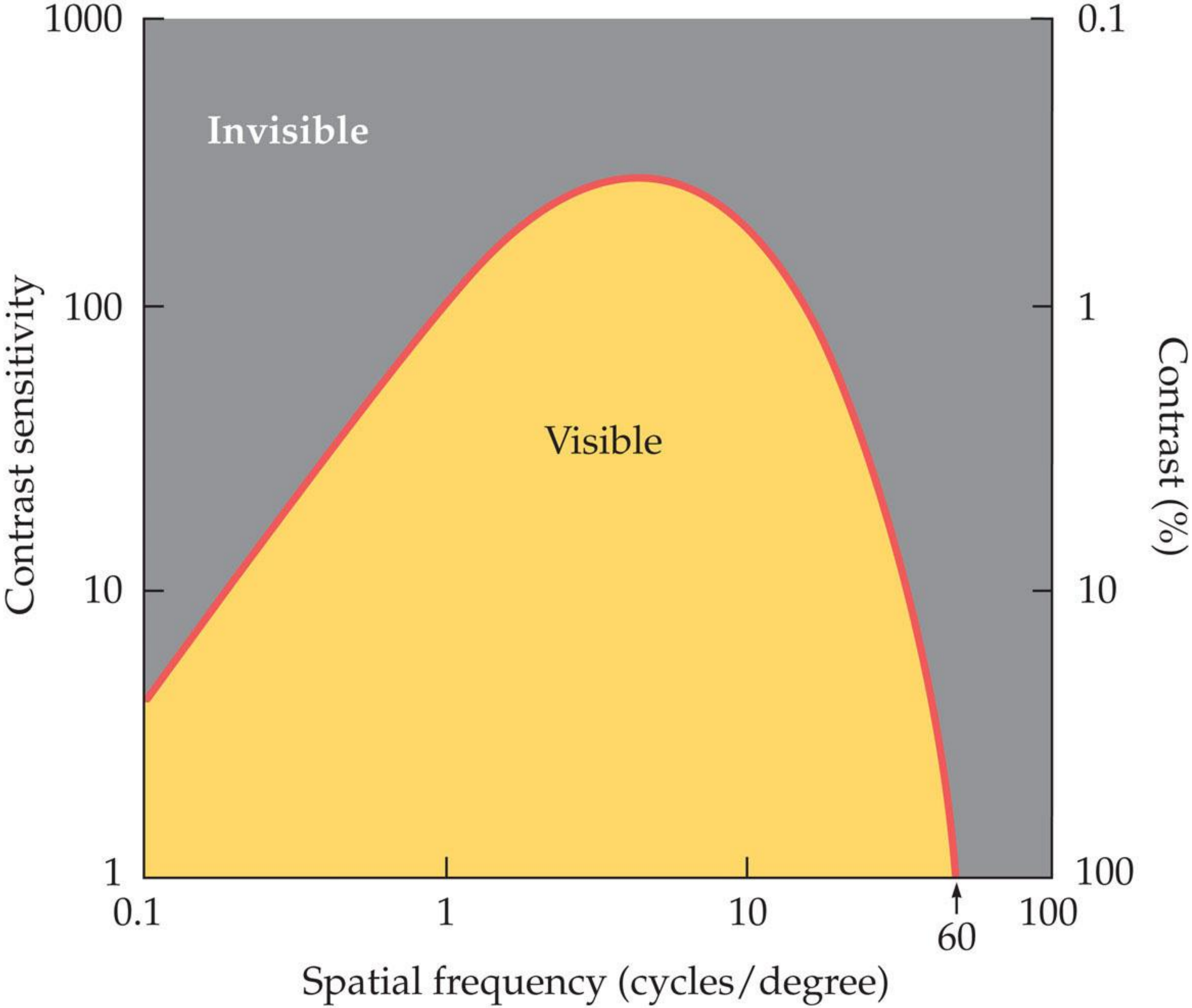
SENSATION & PERCEPTION 4e, Figure 3.6

Visual Acuity: Oh Say, Can You See?

Visibility of a pattern as a function of spatial frequency and contrast

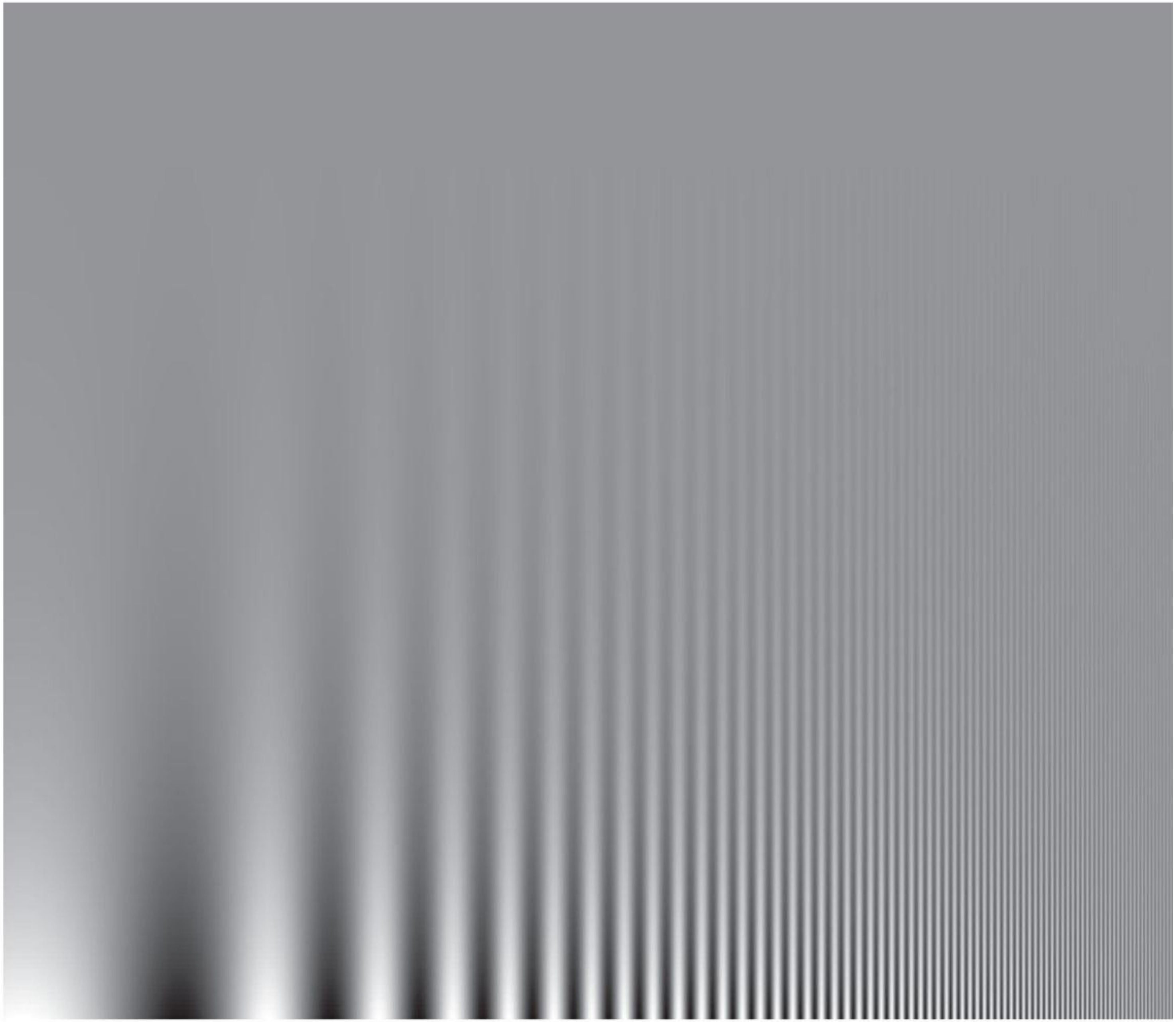
- Figure 3.7 shows the contrast sensitivity function for a person with normal vision.
- Figure 3.8 shows a pictorial representation of the same data.

Figure 3.7 The contrast sensitivity function: the window of visibility



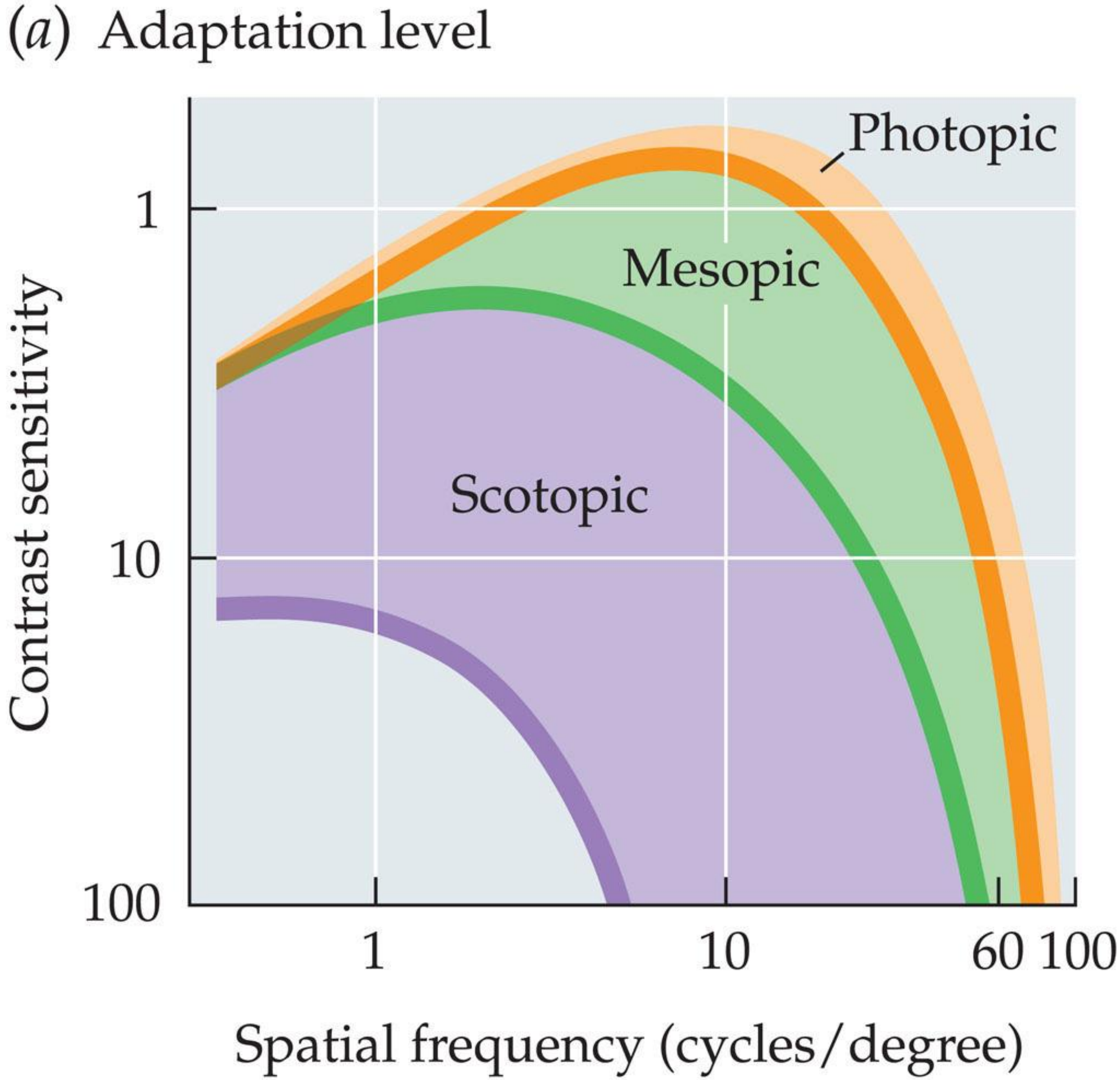
SENSATION & PERCEPTION 4e, Figure 3.7

Figure 3.8 A grating modulated by contrast and by spatial frequency



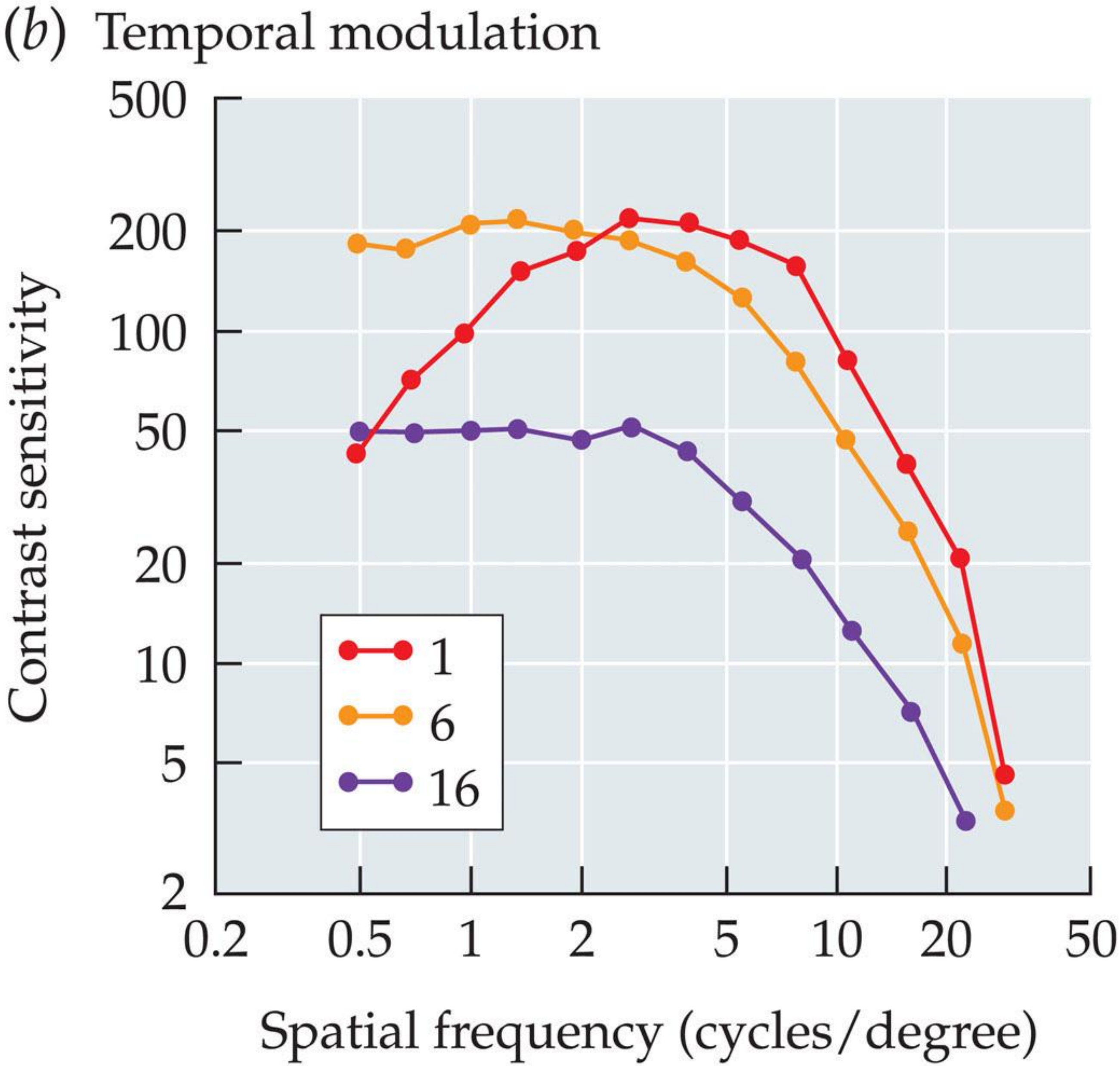
SENSATION & PERCEPTION 4e, Figure 3.8

Figure 3.9 The shape and height of the contrast sensitivity function is influenced by a wide variety of factors (Part 1)



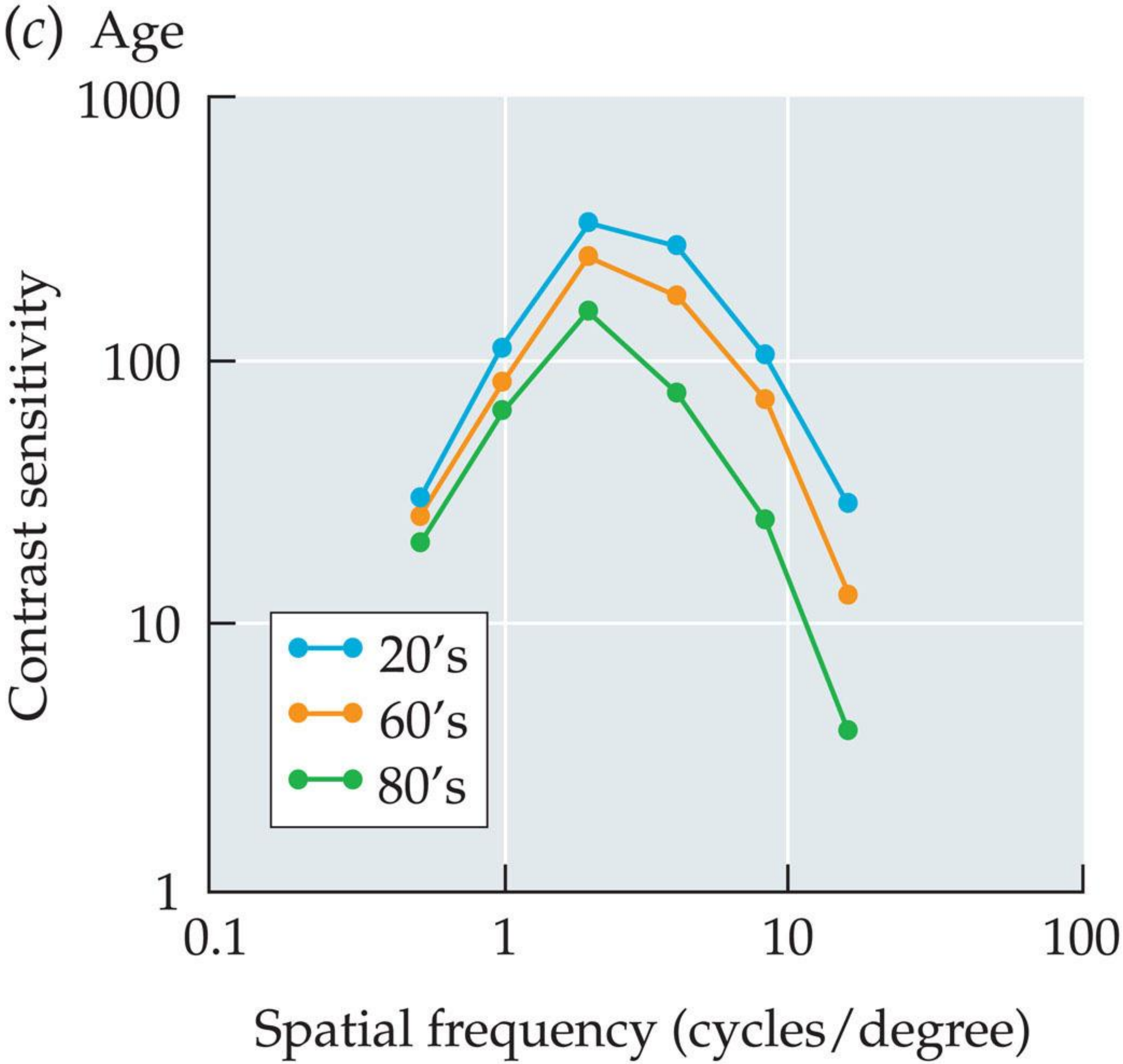
SENSATION & PERCEPTION 4e, Figure 3.9 (Part 1)

Figure 3.9 The shape and height of the contrast sensitivity function is influenced by a wide variety of factors (Part 2)



SENSATION & PERCEPTION 4e, **Figure 3.9 (Part 2)**

Figure 3.9 The shape and height of the contrast sensitivity function is influenced by a wide variety of factors (Part 3)



SENSATION & PERCEPTION 4e, Figure 3.9 (Part 3)

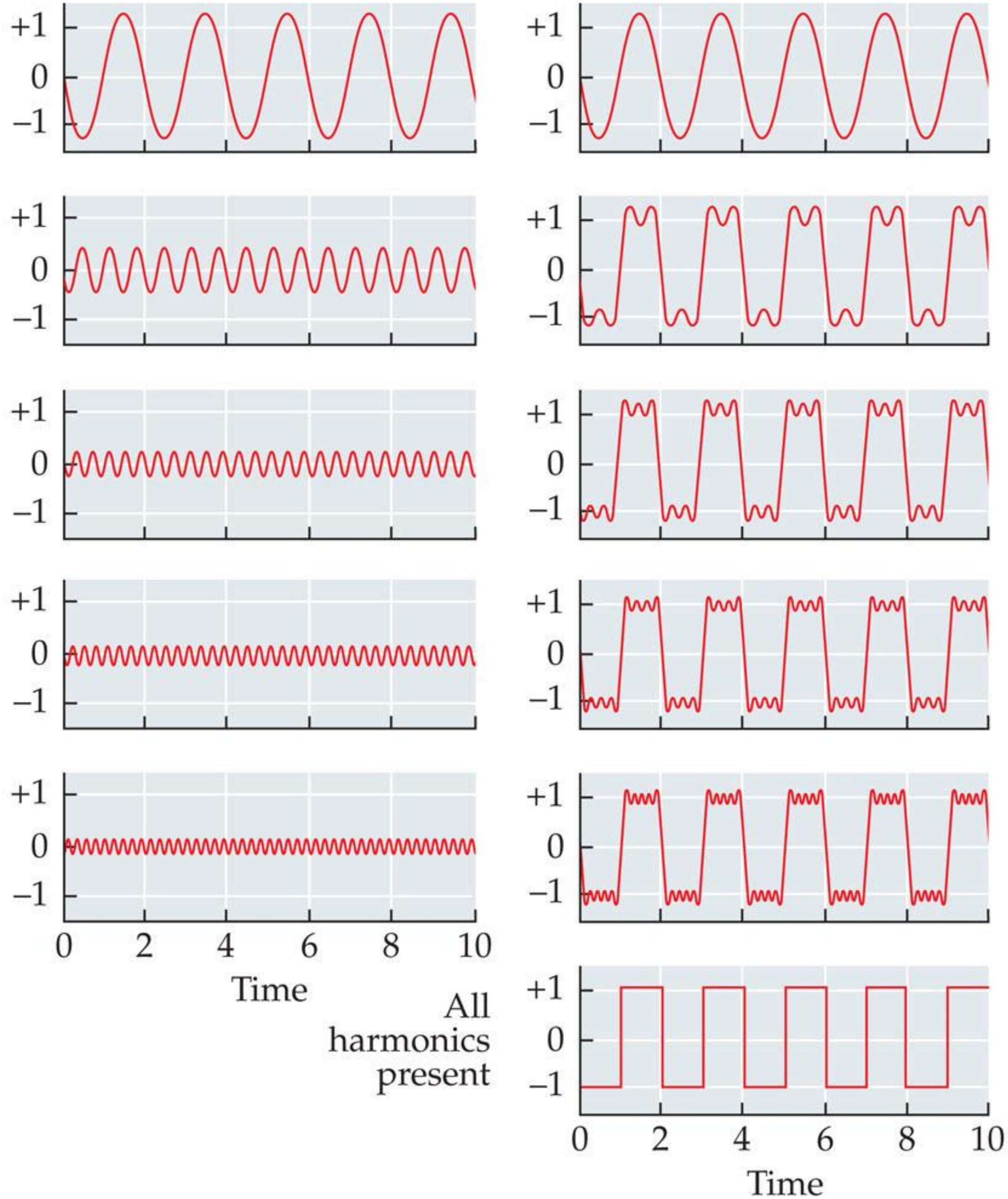
Why sine gratings?

- Patterns of stripes with fuzzy boundaries are quite common.
  - Trees in a forest, books on a bookshelf, pencils in a cup
- The edge of any object produces a single stripe, often blurred by a shadow, in the retinal image.

Why sine gratings? (*continued*)

- The visual system breaks down images into a vast number of components; each is a sine wave grating with a particular spatial frequency.
    - This is called “Fourier analysis,” which is also how our perceptual systems deal with sound waves.

Figure 3.10 Fourier analysis



SENSATION & PERCEPTION 4e, Figure 3.10

Retinal Ganglion Cells and Stripes

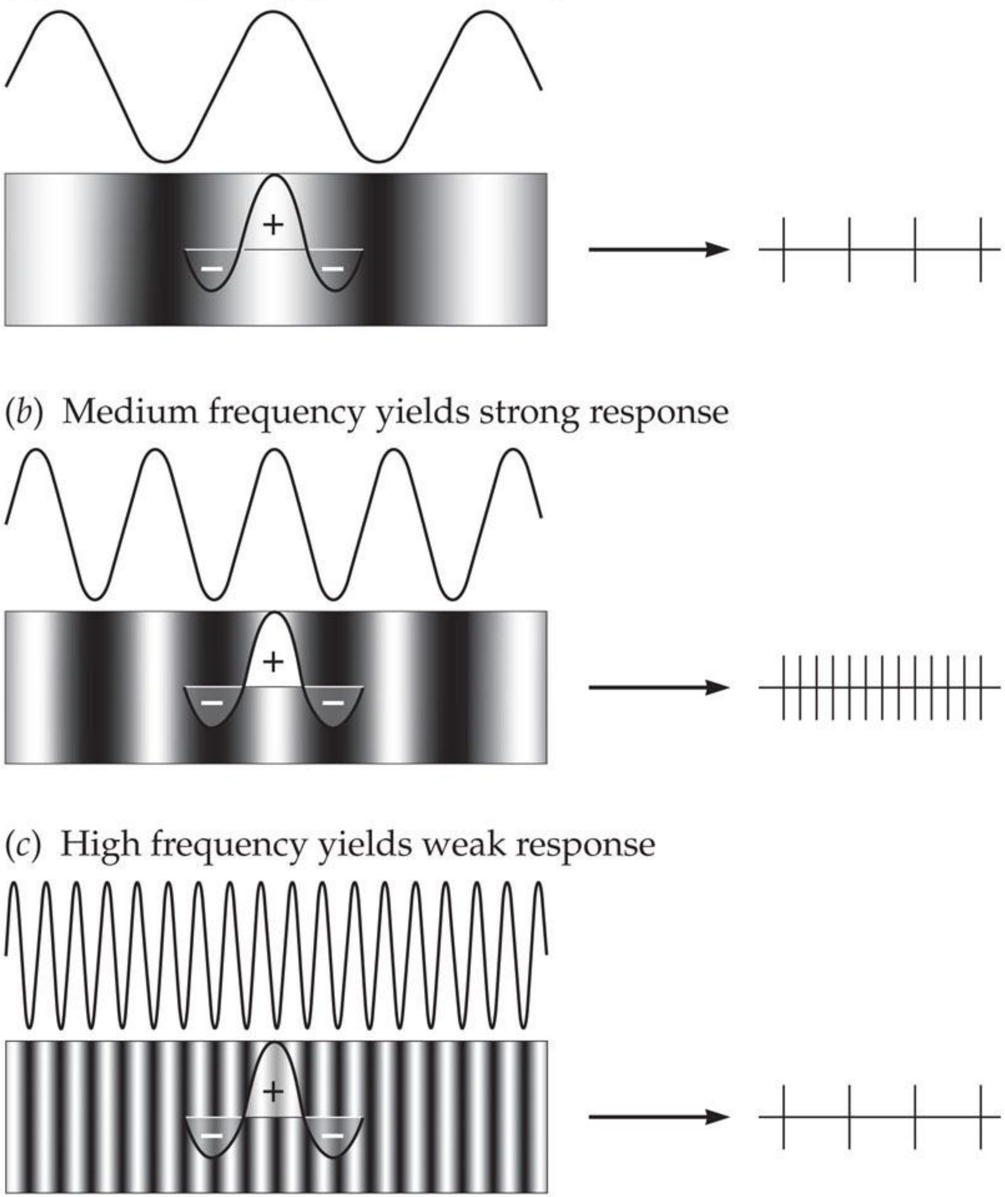
How do the center-surround receptive fields respond to sine wave patterns with different spatial frequencies?

Figure 3.11 The response of an ON-center retinal ganglion cell to gratings of different spatial frequencies

(*a*) Low frequency yields weak response

(*b*) Medium frequency yields strong response

(*c*) High frequency yields weak response



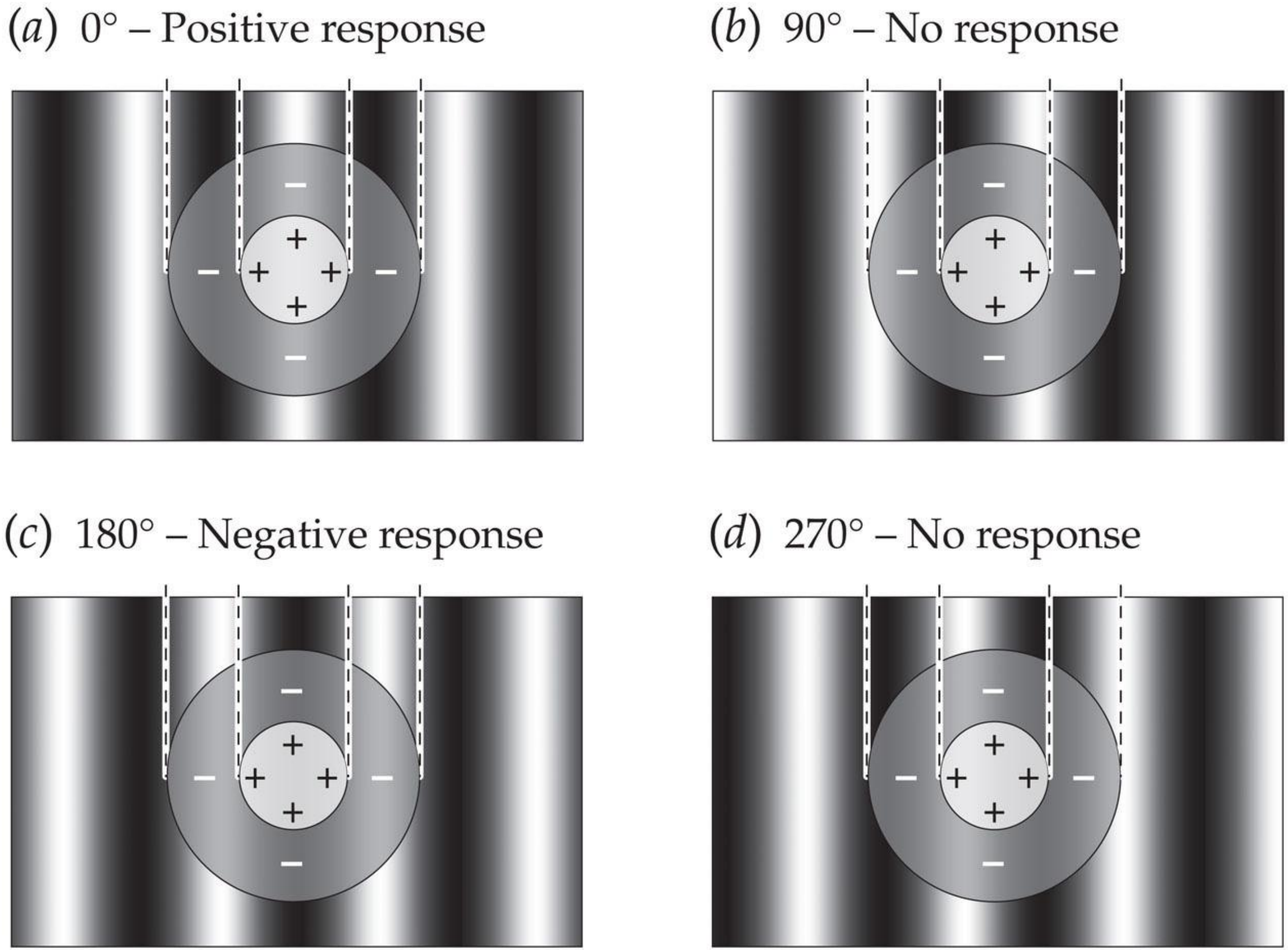
SENSATION & PERCEPTION 4e, Figure 3.11

Retinal Ganglion Cells and Stripes

Not only is the spatial frequency important, but so is the phase.

- Phase: The phase of a grating refers to its position within a receptive field.

Figure 3.12 The response of a ganglion cell to a grating depends on the phase of the grating



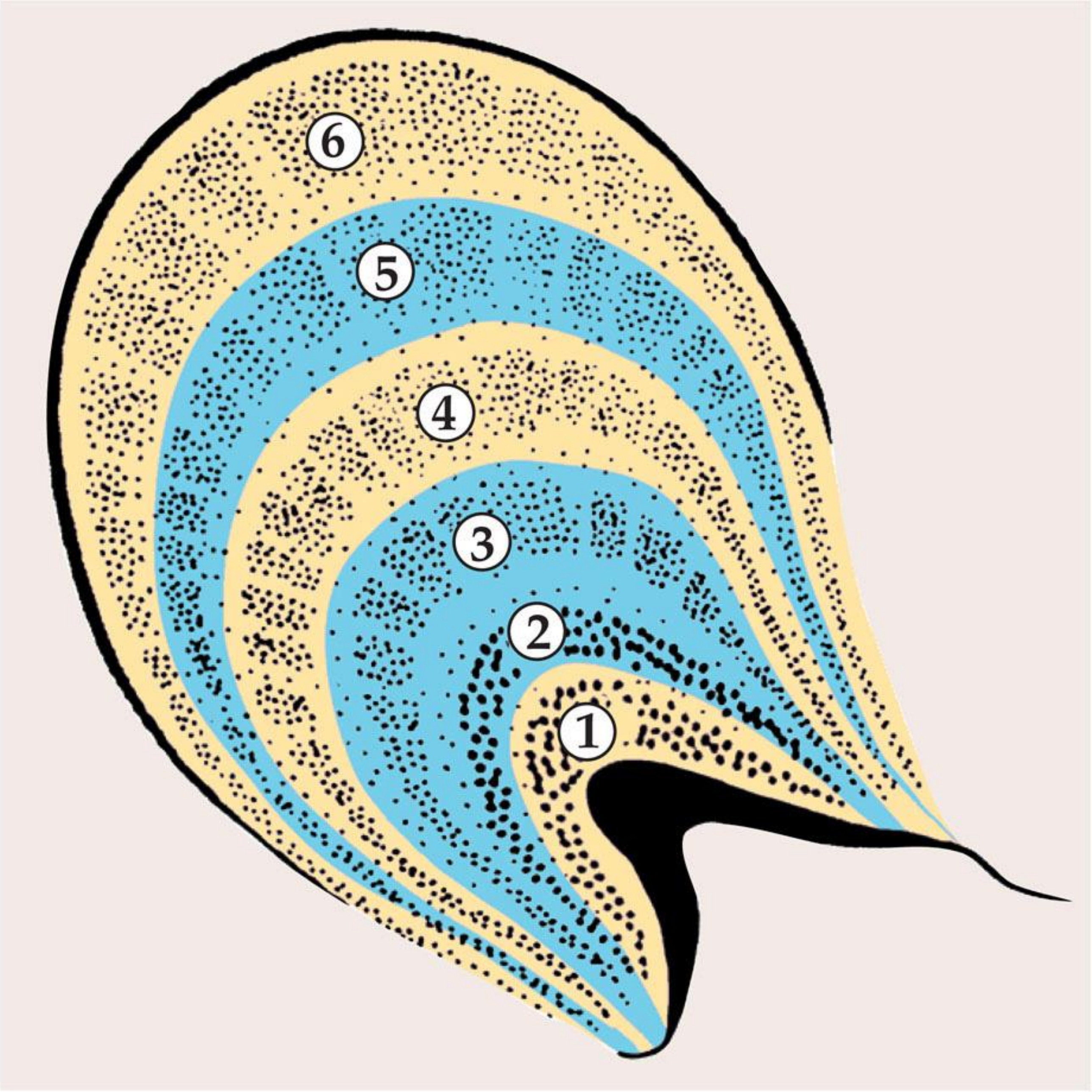
SENSATION & PERCEPTION 4e, **Figure 3.12**

The Lateral Geniculate Nucleus

We have two lateral geniculate nuclei (LGNs). Axons of retinal ganglion cells synapse there.

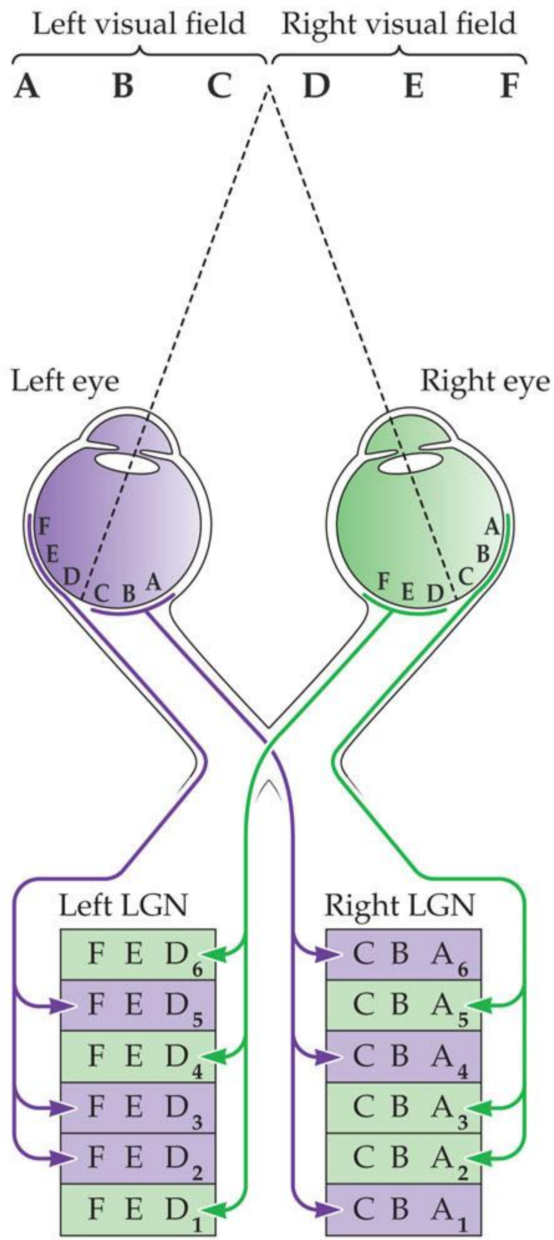
- Ipsilateral: Referring to the same side of the body (or brain).
- Contralateral: Referring to the opposite side of the body (or brain).

Figure 3.13 The primate lateral geniculate nucleus



SENSATION & PERCEPTION 4e, Figure 3.13

Figure 3.14 Input from the right visual field is mapped in an orderly fashion onto the different layers of the left LGN, and input from the left visual field is mapped to the right LGN



SENSATION & PERCEPTION 4e, Figure 3.14

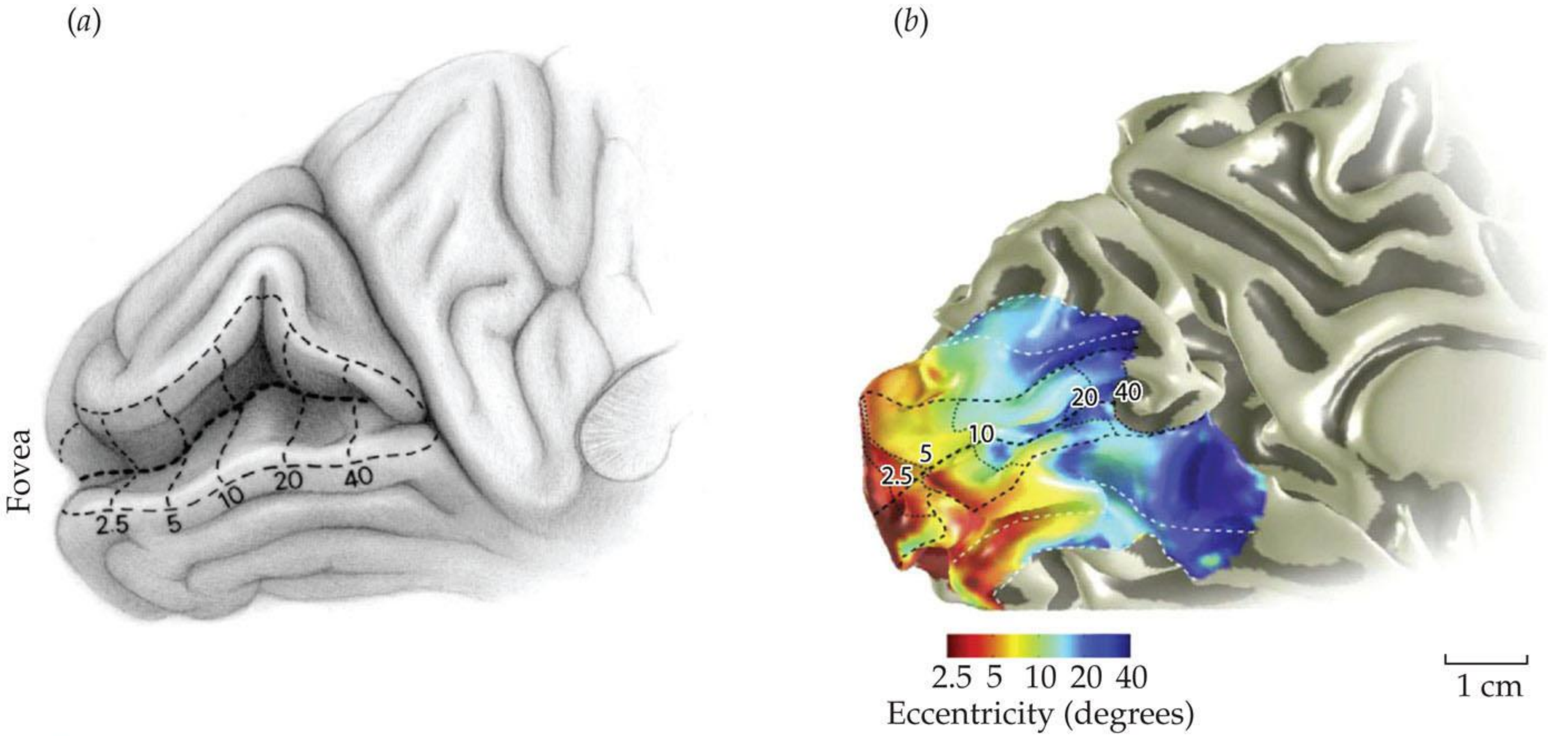
Types of cells in the LGN

- Magnocellular: Large cells, bottom two layers. Receive input from M ganglion cells. Respond best to large, fast-moving objects.
- Parvocellular: Smaller cells, top four layers. Receive input from P ganglion cells. Respond best to fine spatial details of stationary objects.
- Koniocellular: Very small cells in between the manocellular and parvocellular sections. We are still not entirely sure what these cells do.

The topography of the human cortex

- Much of our early information about cortical layout came from animals and humans with cortical lesions.
- Now, we can map human cortex using MRI and fMRI—safe, noninvasive imaging techniques.
  - MRI reveals the structure of the brain.
  - fMRI reveals brain activity through blood oxygen level–dependent (BOLD) signals.

Figure 3.17 Mapping the visual field onto the cortex



SENSATION & PERCEPTION 4e, Figure 3.17

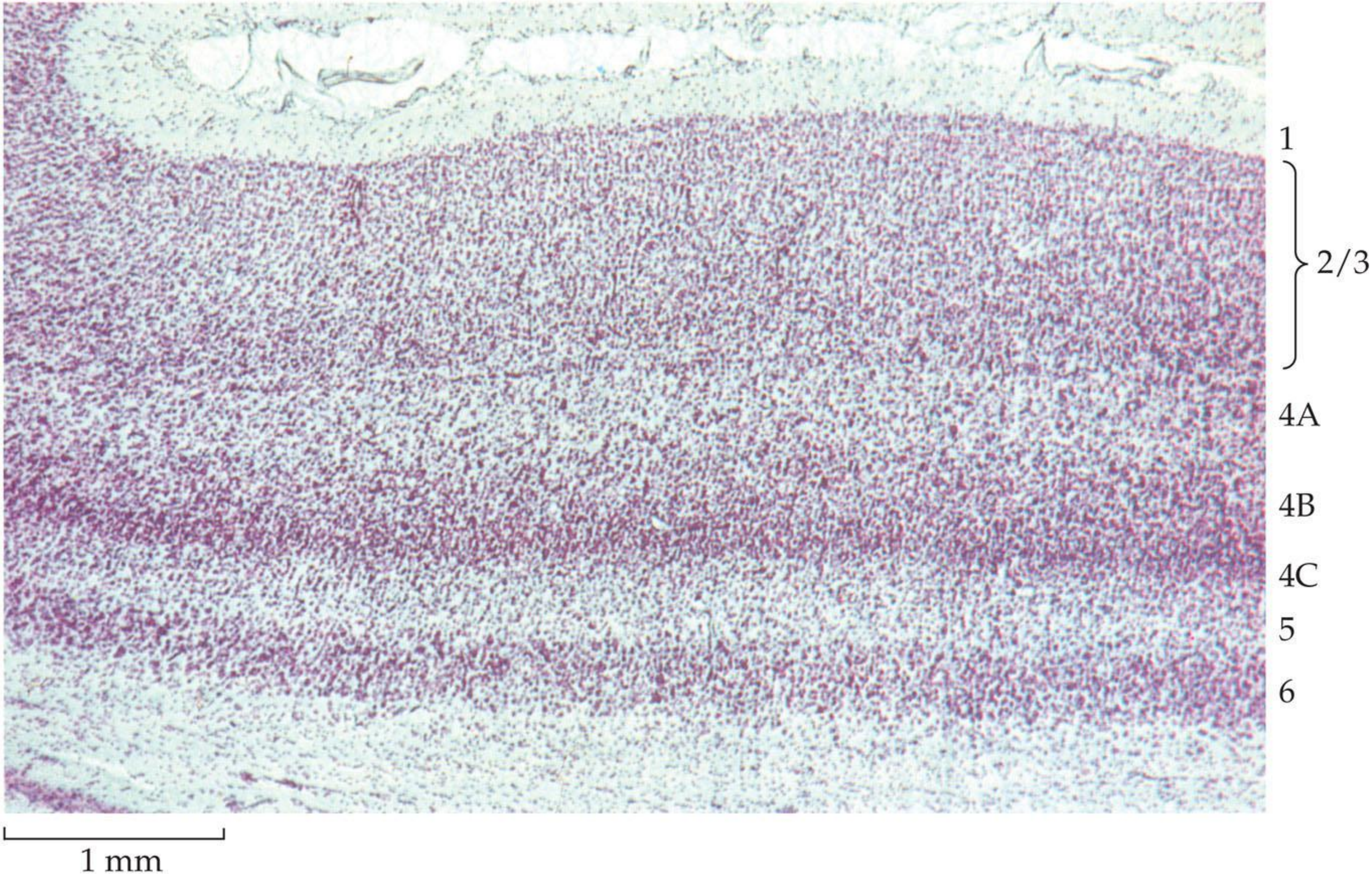
The Striate Cortex

Striate cortex: Also known as primary visual cortex, area 17, or V1.

A major transformation of visual information takes place in striate cortex.

- Circular receptive fields found in retina and LGN are replaced with elongated “stripe” receptive fields in cortex.
- It has about 200 million cells!

Figure 3.15 Striate cortex

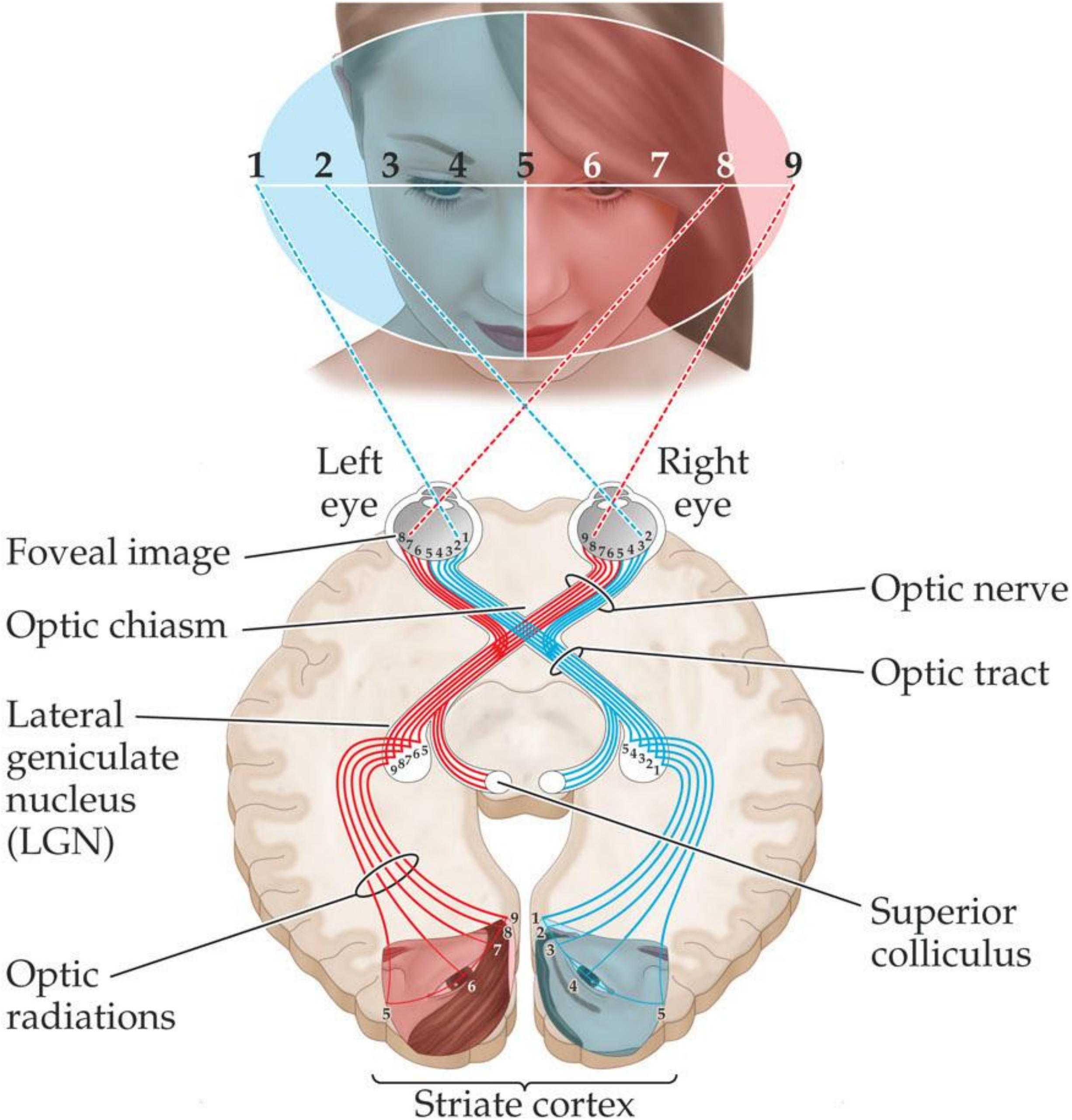


SENSATION & PERCEPTION 4e, Figure 3.15

Two important features of striate cortex

1. Topographical mapping
2. Cortical magnification
   - Dramatic scaling of information from different parts of visual field
   - Proportionally much more cortex devoted to processing the fovea than to processing the periphery

Figure 3.16 The mapping of objects in space onto the visual cortex



SENSATION & PERCEPTION 4e, Figure 3.16

The Striate Cortex

Visual acuity declines in an orderly fashion with eccentricity—distance from the fovea

***SENSATION & PERCEPTION 4e*, Figure 3.19**

The Striate Cortex

One consequence of cortical magnification is that images in the periphery have much lower resolution than images at fixation.

This can lead to *visual crowding*: the deleterious effect of clutter on peripheral object detection.

- Stimuli that can be seen in isolation in peripheral vision become hard to discern when other stimuli are nearby.
- This is a major bottleneck for visual processing.
  - When we can’t see an object due to crowding, we have to move our eyes to look directly at it with our high acuity foveal receptive fields.

Figure 3.20 Visual crowding

SENSATION & PERCEPTION 4e, Figure 3.20

Receptive Fields in Striate Cortex

Cells in striate cortex respond best to bars of light rather than to spots of light.

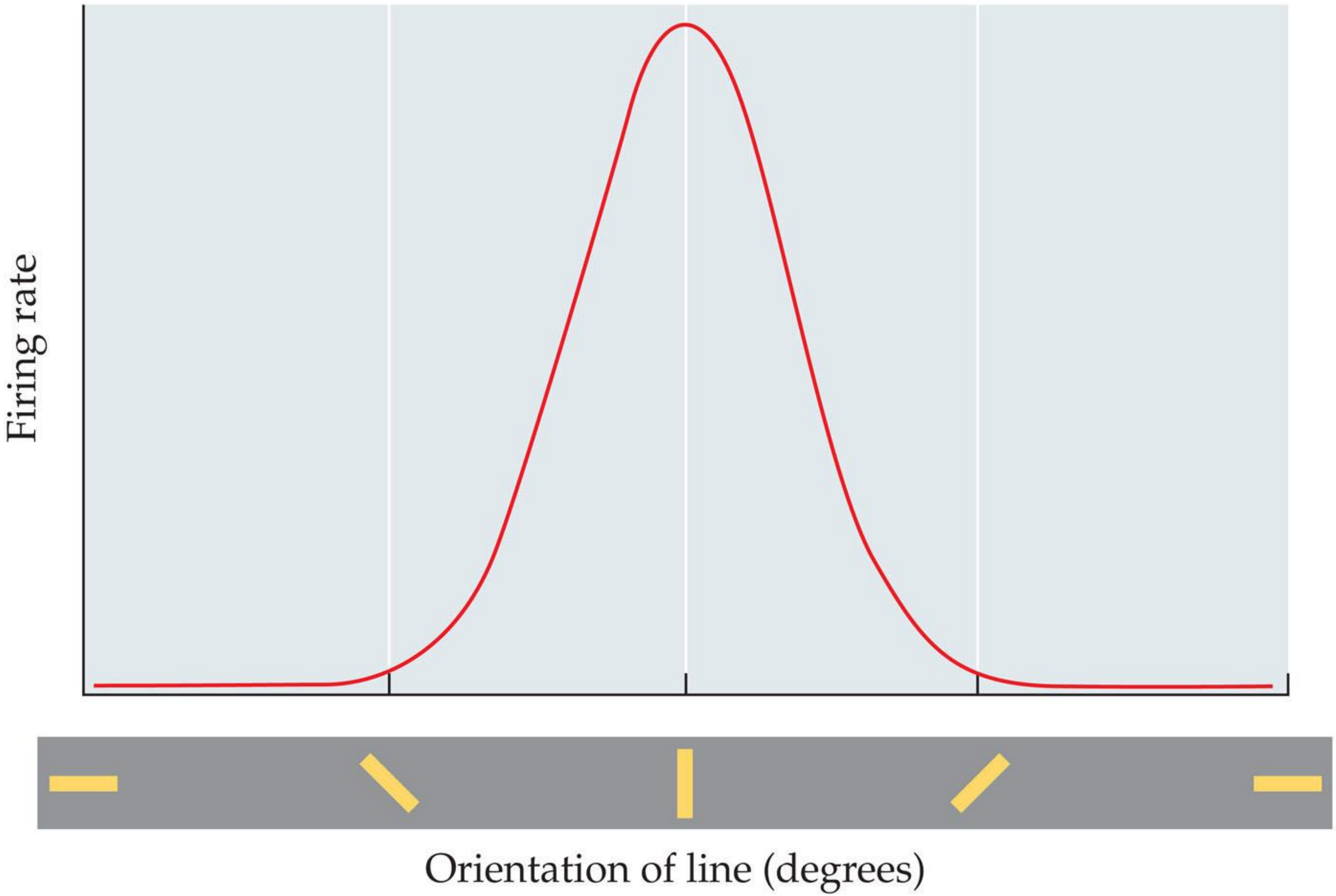
- Some cells prefer bars of light, some prefer bars of dark (simple cells).
- Some cells respond to both bars of light and dark (complex cells).

Receptive Fields in Striate Cortex

Orientation tuning

- Tendency of neurons in striate cortex to respond most to bars of certain orientations
- Response rate falls off with angular difference of bar from preferred orientation

Figure 3.21 Orientation tuning function of a cortical cell



SENSATION & PERCEPTION 4e, **Figure 3.21**

Receptive Fields in Striate Cortex

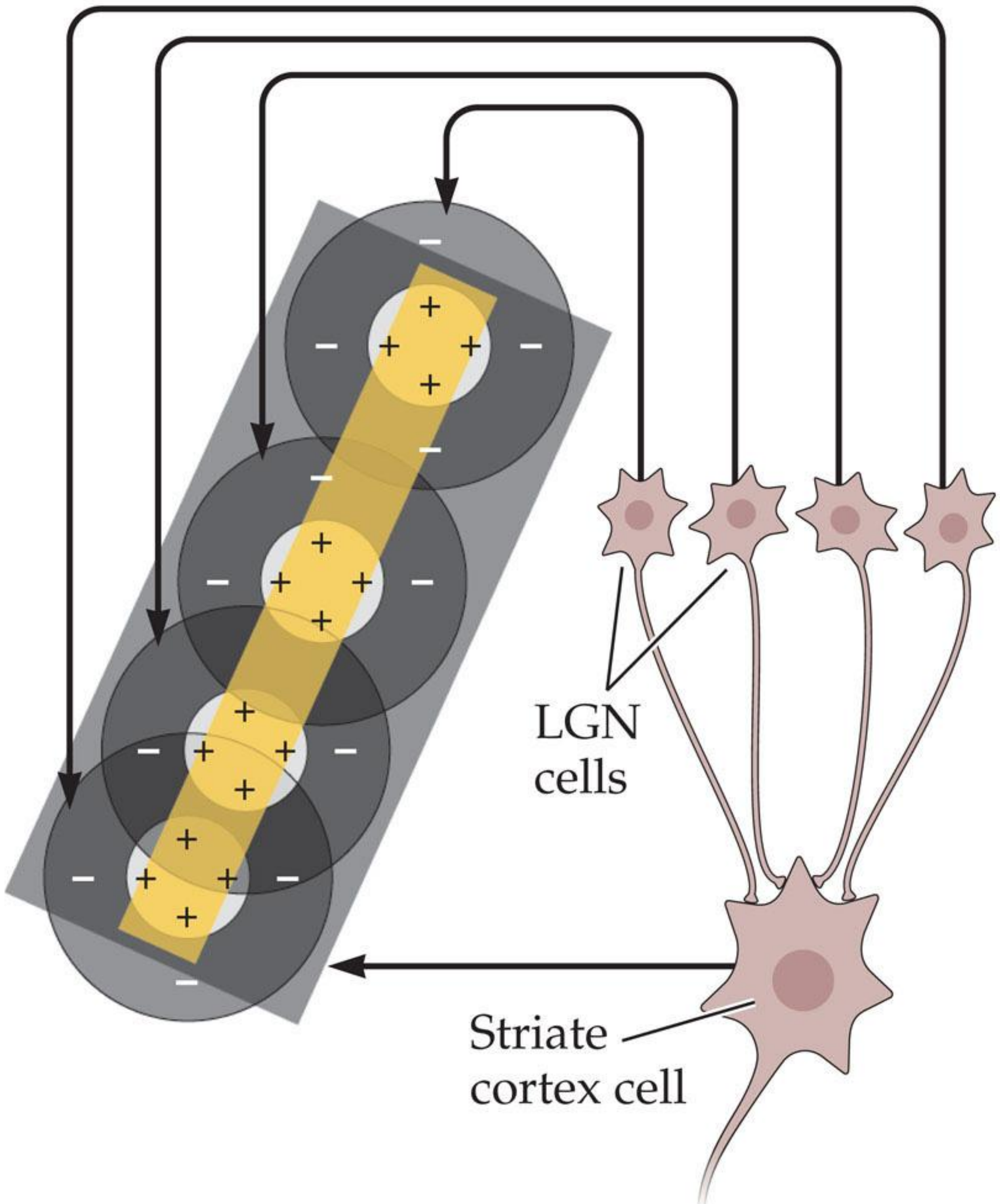
How are the circular receptive fields in the LGN transformed into the elongated receptive fields in striate cortex?

- Hubel and Wiesel: Very simple scheme to accomplish this transformation
  - A cortical neuron that responds to oriented bars of light might receive input from several retinal ganglion cells.

Receptive Fields in Striate Cortex

- If you string several retinal ganglion cells together, they can form an oriented bar.
- A cell that is tuned to any orientation you want could be created in cortex by connecting it up with the appropriate retinal ganglion cells.

Figure 3.22 Hubel and Wiesel's model of how striate cortex cells get their orientation tuning



SENSATION & PERCEPTION 4e, **Figure 3.22**

Receptive Fields in Striate Cortex

Many cortical cells respond especially well to

- Moving lines
- Bars
- Edges
- Gratings
  - Striate cortex cells respond to gratings of a certain frequency and orientation.
- Certain motion directions

Receptive Fields in Striate Cortex

Since striate cortical cells respond to such specific stimulus characteristics, they function like a *filter* for the portion of the image that excites the cell.

Receptive Fields in Striate Cortex

Each LGN cell responds to one eye or the other, never to both.

Each striate cortex cell can respond to input from both eyes.

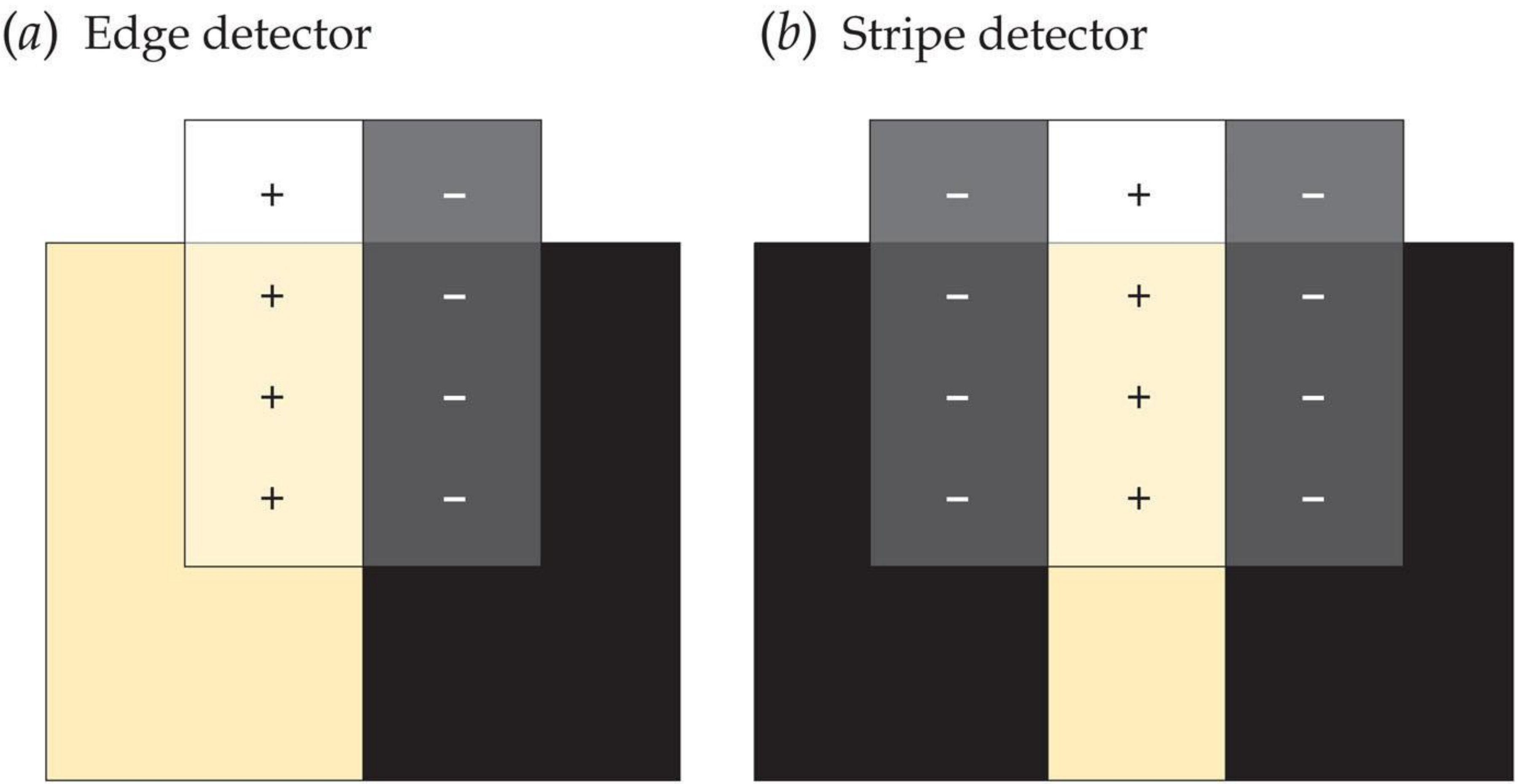
- By the time information gets to primary visual cortex, inputs from both eyes have been combined.
- Cortical neurons tend to have a *preferred* eye, however. They tend to respond more vigorously to input from one eye or the other.

Receptive Fields in Striate Cortex

Simple cells versus complex cells

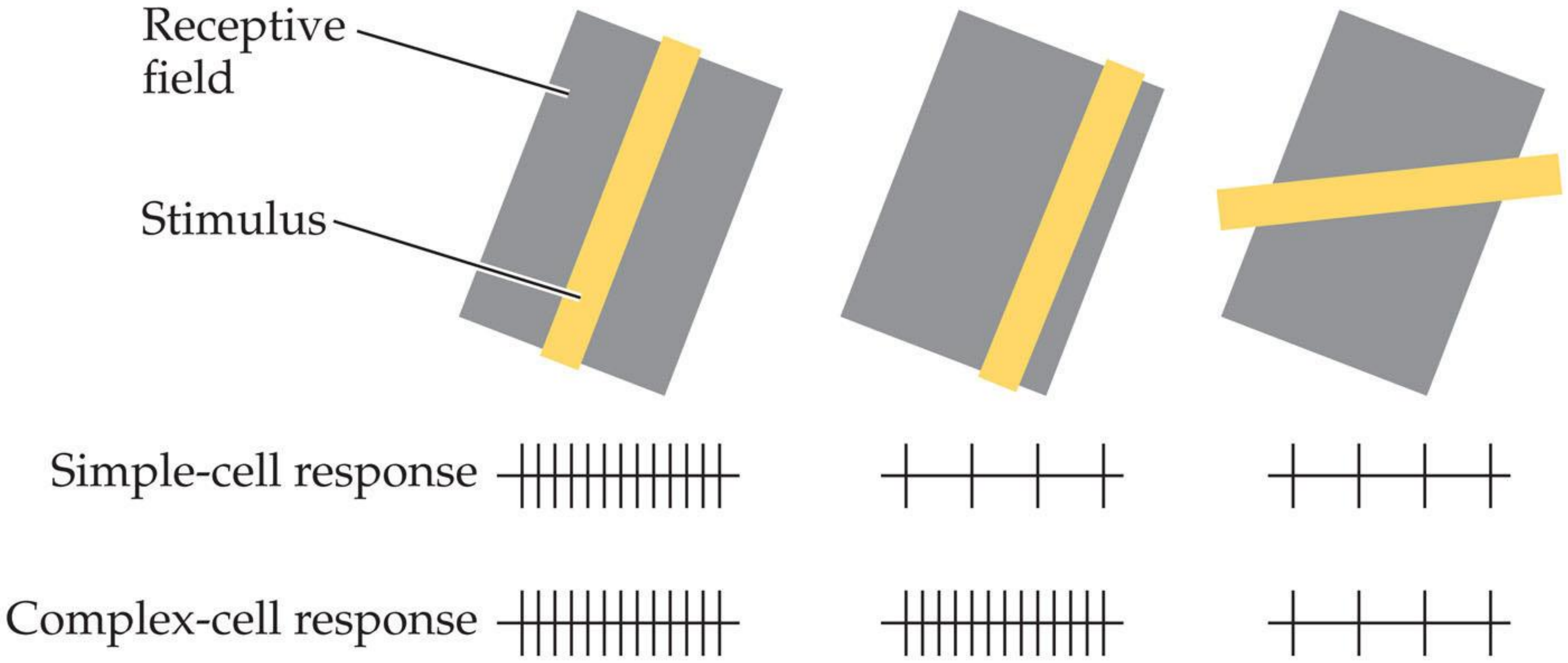
- Can you imagine how you would wire together retinal ganglion cells so that their receptive fields would combine to create these cortical cells?

Figure 3.23 Two flavors of simple cells: (*a*) an edge detector and (*b*) a stripe detector



SENSATION & PERCEPTION 4e, Figure 3.23

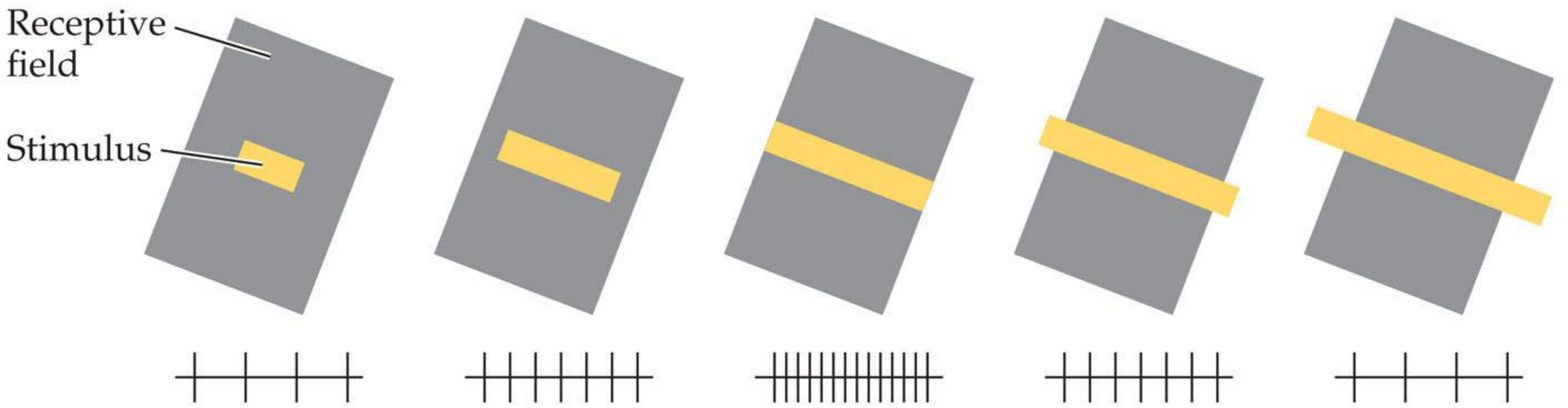
Figure 3.24 A simple cell and a complex cell might both be tuned to the same orientation and stripe width but respond differently



SENSATION & PERCEPTION 4e, Figure 3.24

Receptive Fields in Striate Cortex

End stopping: Some cells prefer bars of light of a certain length.



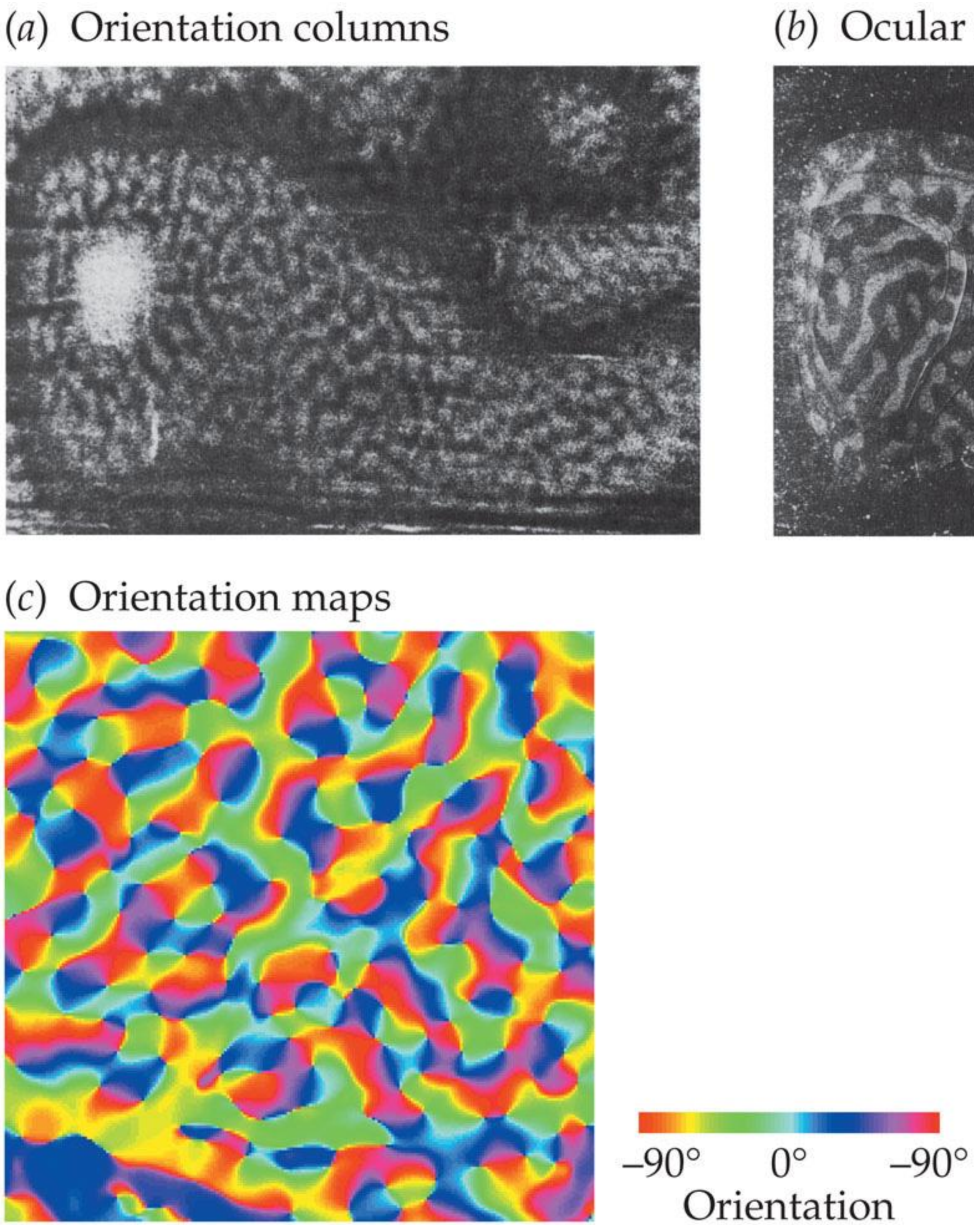
SENSATION & PERCEPTION 4e, Figure 3.25

Columns and Hypercolumns

Column: A vertical arrangement of neurons.

- Within each column, all neurons have the same orientation tuning.
- Hubel and Wiesel: Found systematic, progressive change in preferred orientation as they moved laterally along the cortex; all orientations were encountered within a distance of about 0.5 mm.

Figure 3.26 Orientation (*a*) and ocular dominance (*b*) columns of the striate cortex, revealed by staining. (*c*) Optical imaging of the orientation maps in monkey cortex



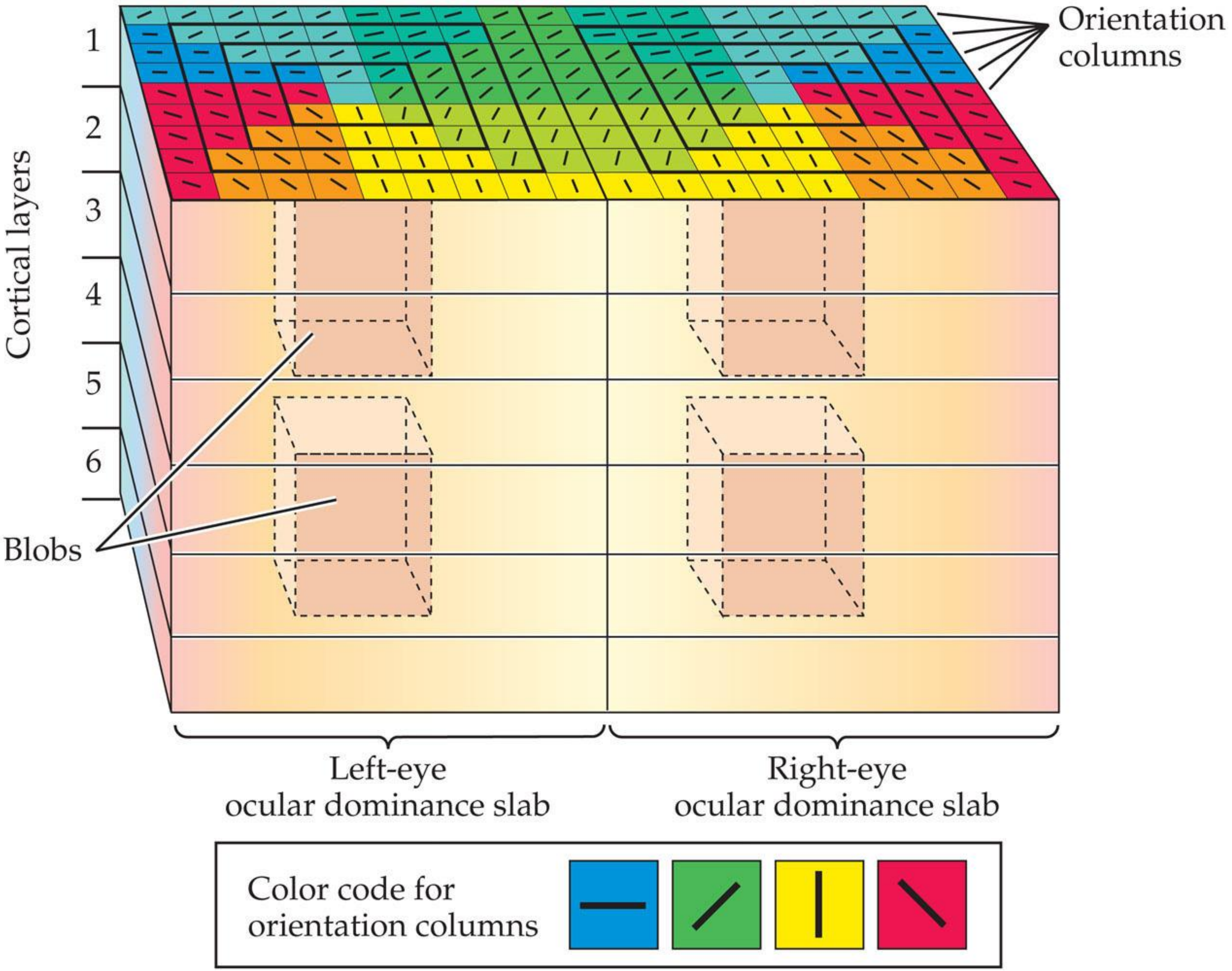
SENSATION & PERCEPTION 4e, Figure 3.26

Columns and Hypercolumns

Hypercolumn: A 1-mm block of striate cortex containing “all the machinery necessary to look after everything the visual cortex is responsible for, in a certain small part of the visual world” (Hubel, 1982).

- Each hypercolumn contains cells responding to every possible orientation (0–180 degrees), with one set preferring input from the left eye and one set preferring input from the right eye.

Figure 3.27 Model of a hypercolumn



Columns and Hypercolumns

Each column has a particular orientation preference which is indicated on the top of each column (and color-coded).

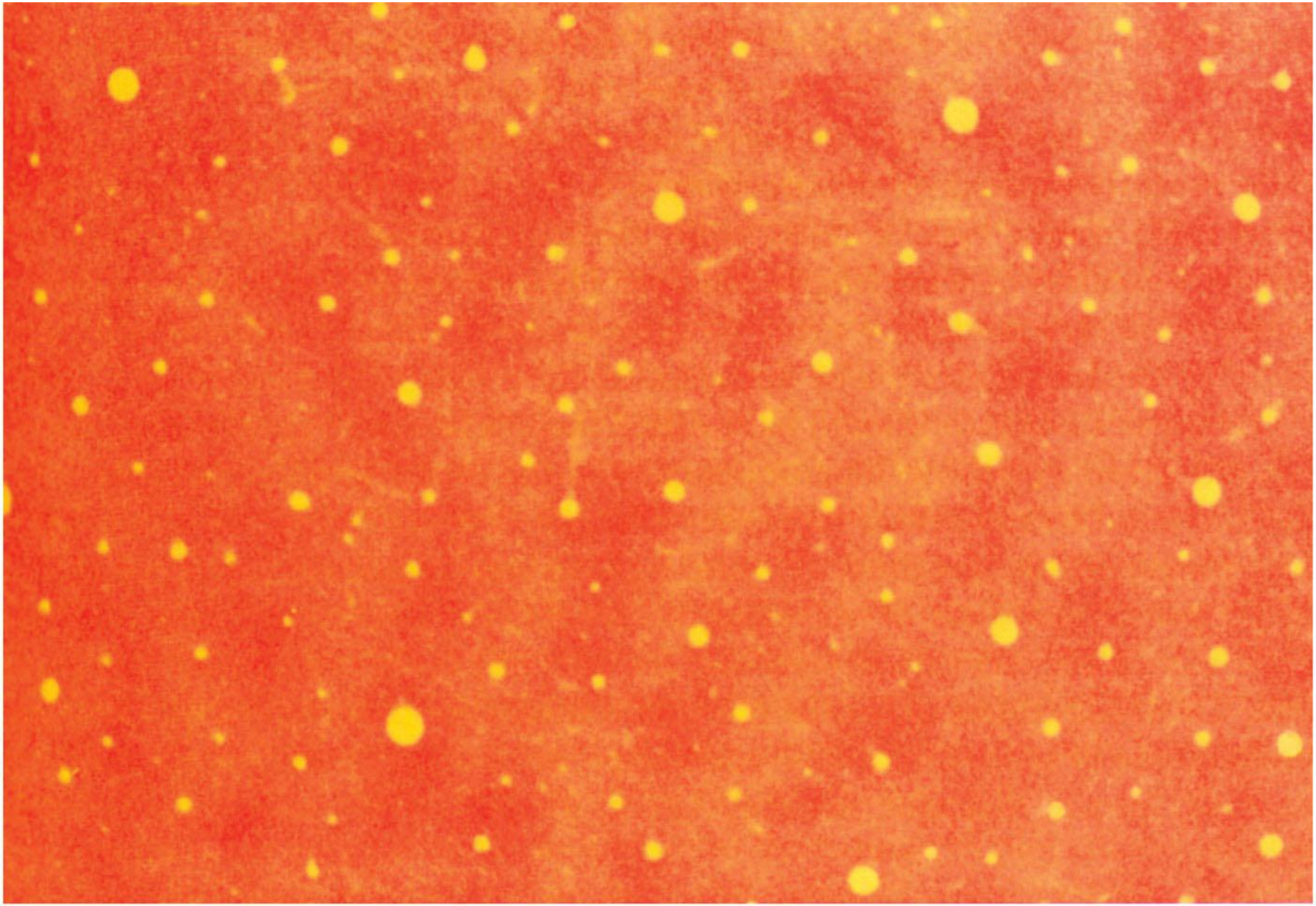
Adjacent groups of columns have a particular ocular dominance—a preference for input from one eye or the other—as indicated at the bottom of the figure.

Blobs are indicated as cubes embedded in the hypercolumn.

Columns and Hypercolumns

Regular array of “CO blobs” in systematic columnar arrangement (discovered by using cytochrome oxidase staining technique)

Figure 3.28 Cytochrome oxidase (CO) blobs



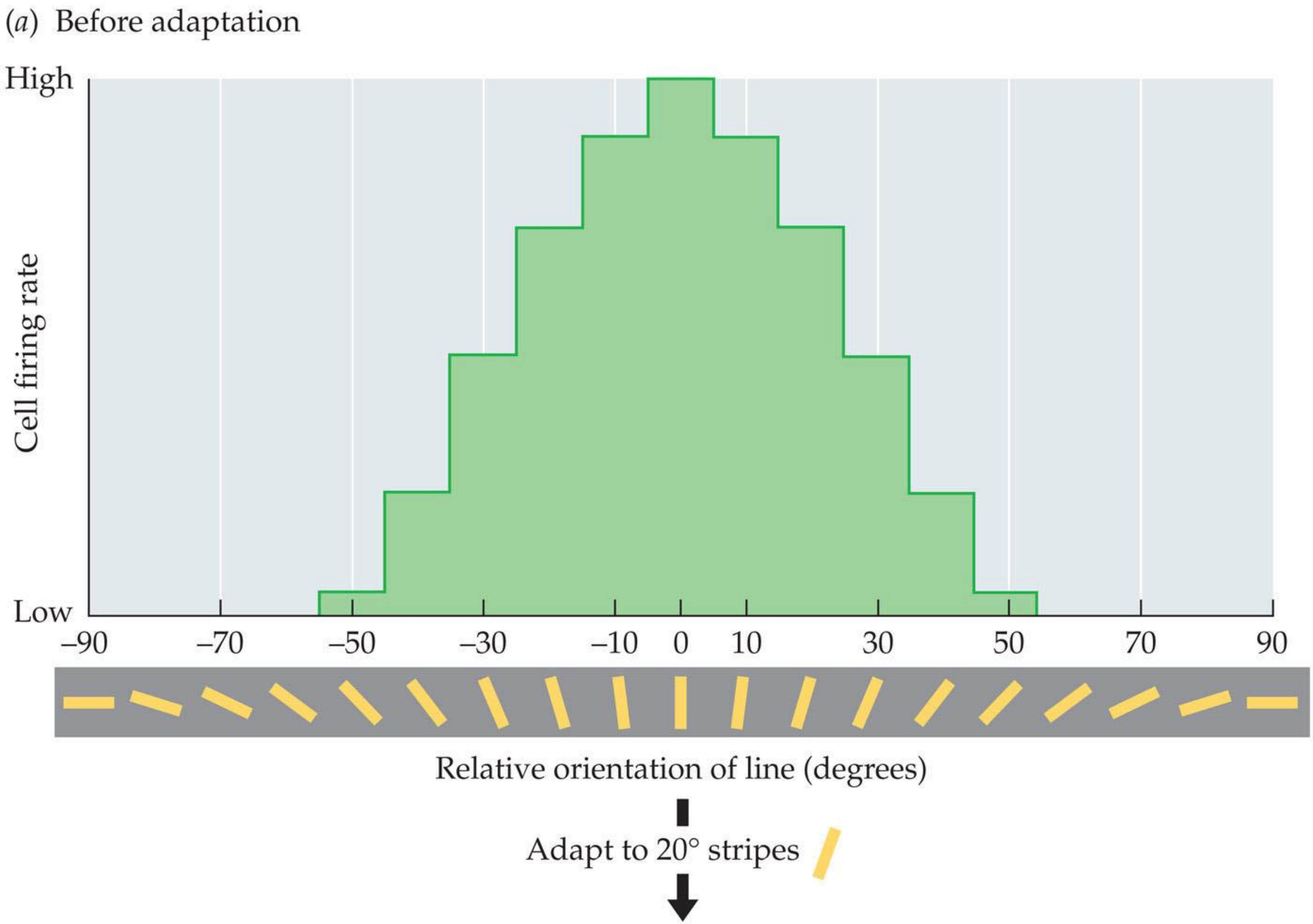
SENSATION & PERCEPTION 4e, Figure 3.28

Selective Adaptation: The Psychologist's Electrode

Adaptation: A reduction in response caused by prior or continuing stimulation.

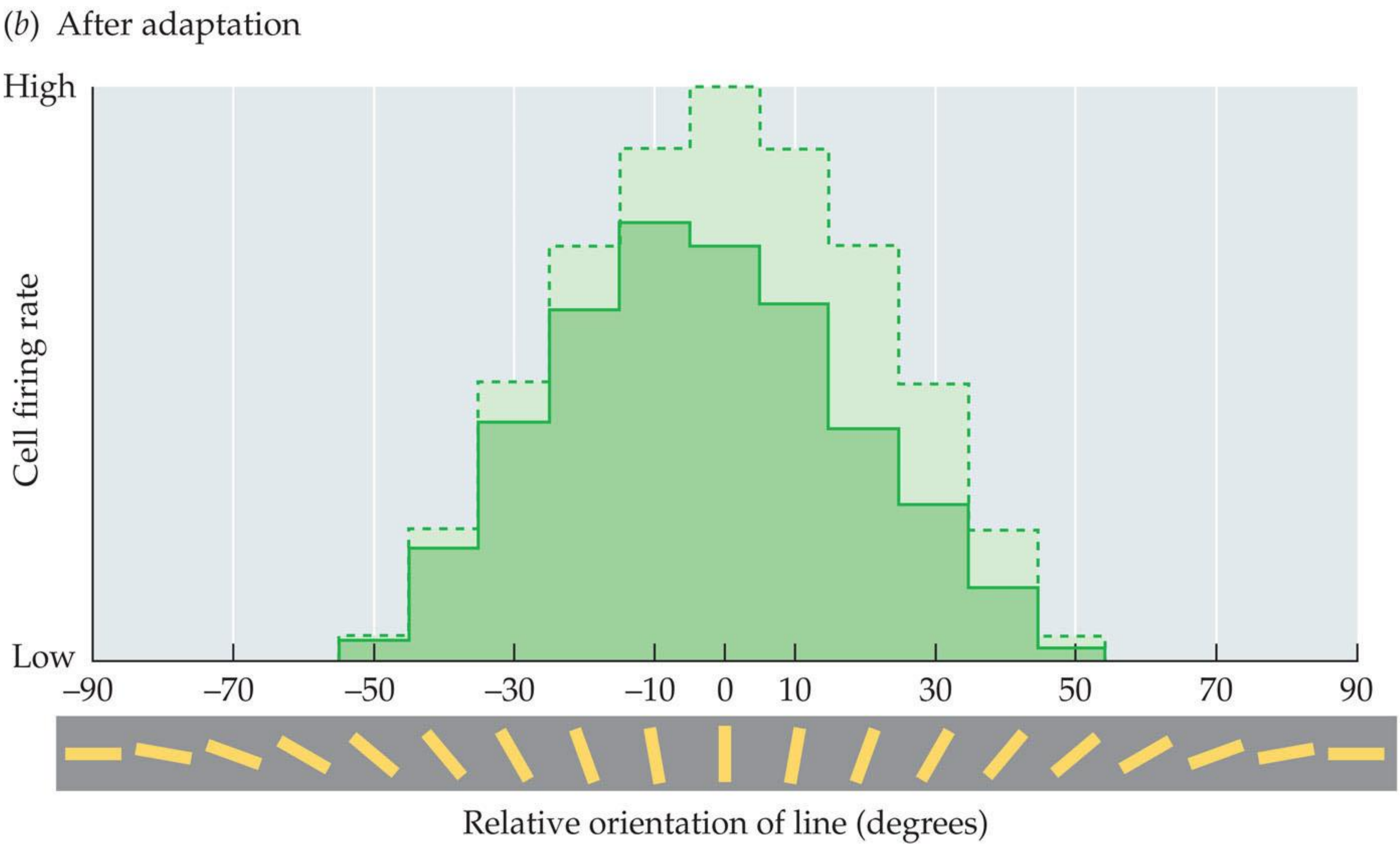
- An important method for deactivating groups of neurons without surgery
- If presented with a stimulus for an extended period of time, the brain adapts to it and stops responding.
- This fact can be exploited to selectively "knock out" groups of neurons for a short period.

Figure 3.29 The psychologist's electrode (Part 1)



SENSATION & PERCEPTION 4e, Figure 3.29 (Part 1)

Figure 3.29 The psychologist's electrode (Part 2)

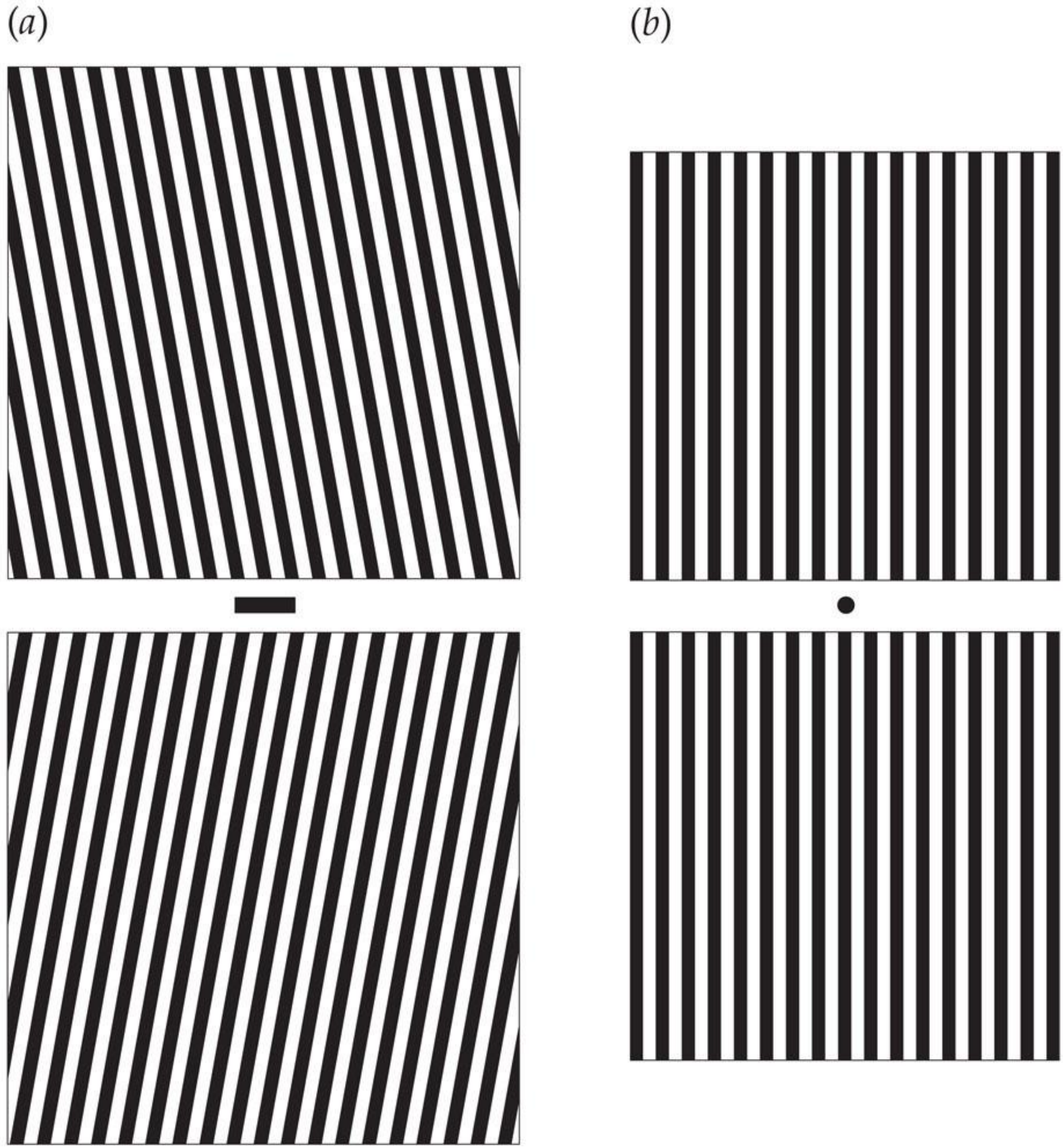


SENSATION & PERCEPTION 4e, Figure 3.29 (Part 2)

Selective Adaptation: The Psychologist's Electrode

This demonstration will allow you to experience selective adaptation for yourself.

Figure 3.30 Stimuli for demonstrating selective adaptation



SENSATION & PERCEPTION 4e, Figure 3.30

Selective Adaptation: The Psychologist's Electrode

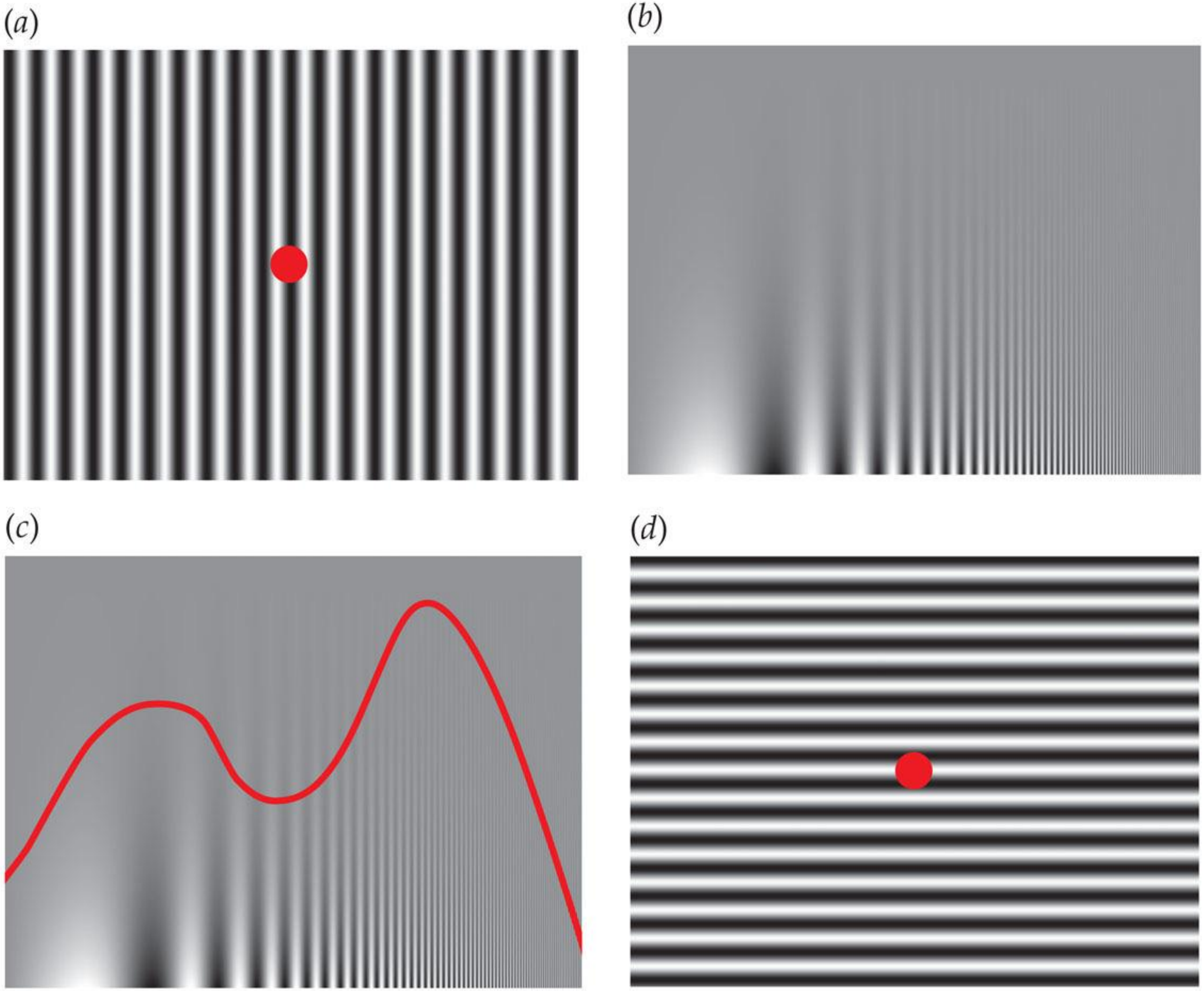
Tilt aftereffect: The perceptual illusion of tilt, produced by adapting to a pattern of a given orientation.

- Supports the idea that the human visual system contains individual neurons selective for different orientations

Selective Adaptation: The Psychologist's Electrode

Selective adaptation for spatial frequency: Evidence that human visual system contains neurons selective for spatial frequency.

Figure 3.31 A demonstration of adaptation that is specific to spatial frequency



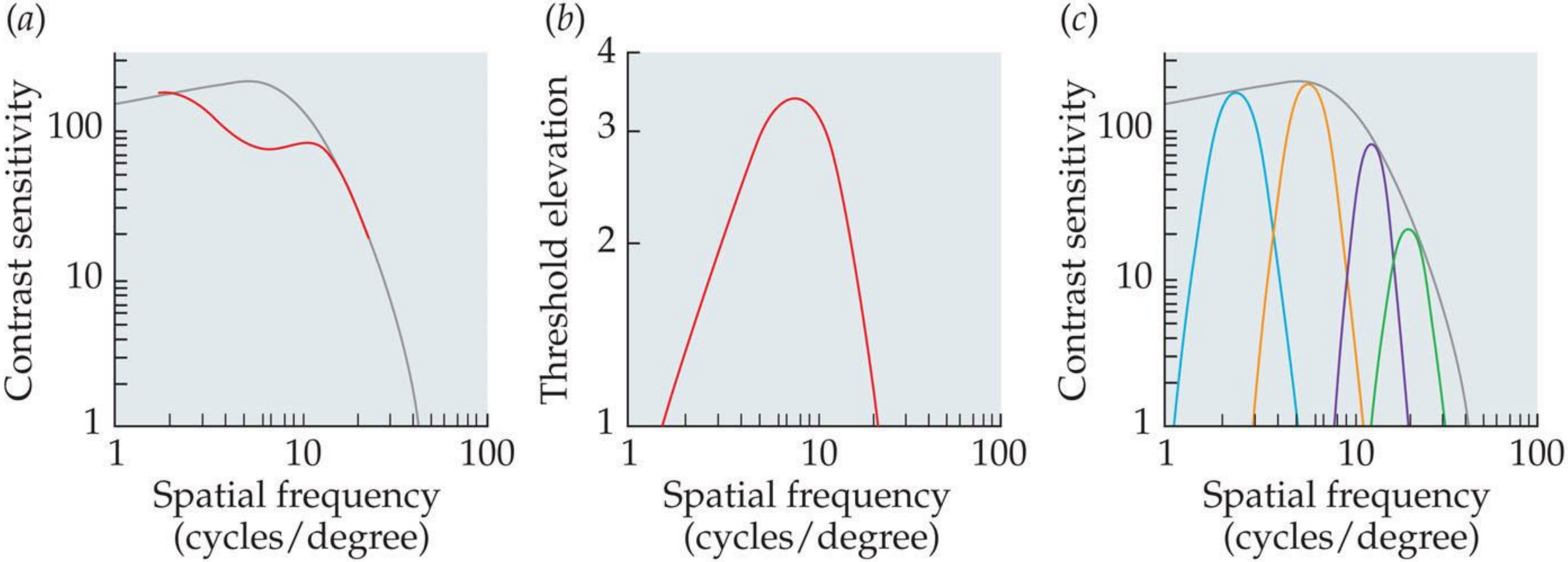
SENSATION & PERCEPTION 4e, Figure 3.31

Selective Adaptation: The Psychologist's Electrode

Adaptation experiments provide strong evidence that orientation and spatial frequency are coded separately by neurons in the human visual system.

- Cats and monkeys: Neurons in striate cortex, not in retina or LGN
- Humans operate the same way as cats and monkeys with respect to selective adaptation.

Figure 3.32 Spatial-frequency adaptation



SENSATION & PERCEPTION 4e, Figure 3.32

Selective Adaptation: The Psychologist's Electrode

(a) Shows selective adaptation to a frequency of 7 cycles/degree

- There is a dip in the contrast sensitivity function at that spatial frequency.

(*b*) Shows how the threshold changed at the adapted frequency

(*c*) Shows where the contrast sensitivity function comes from

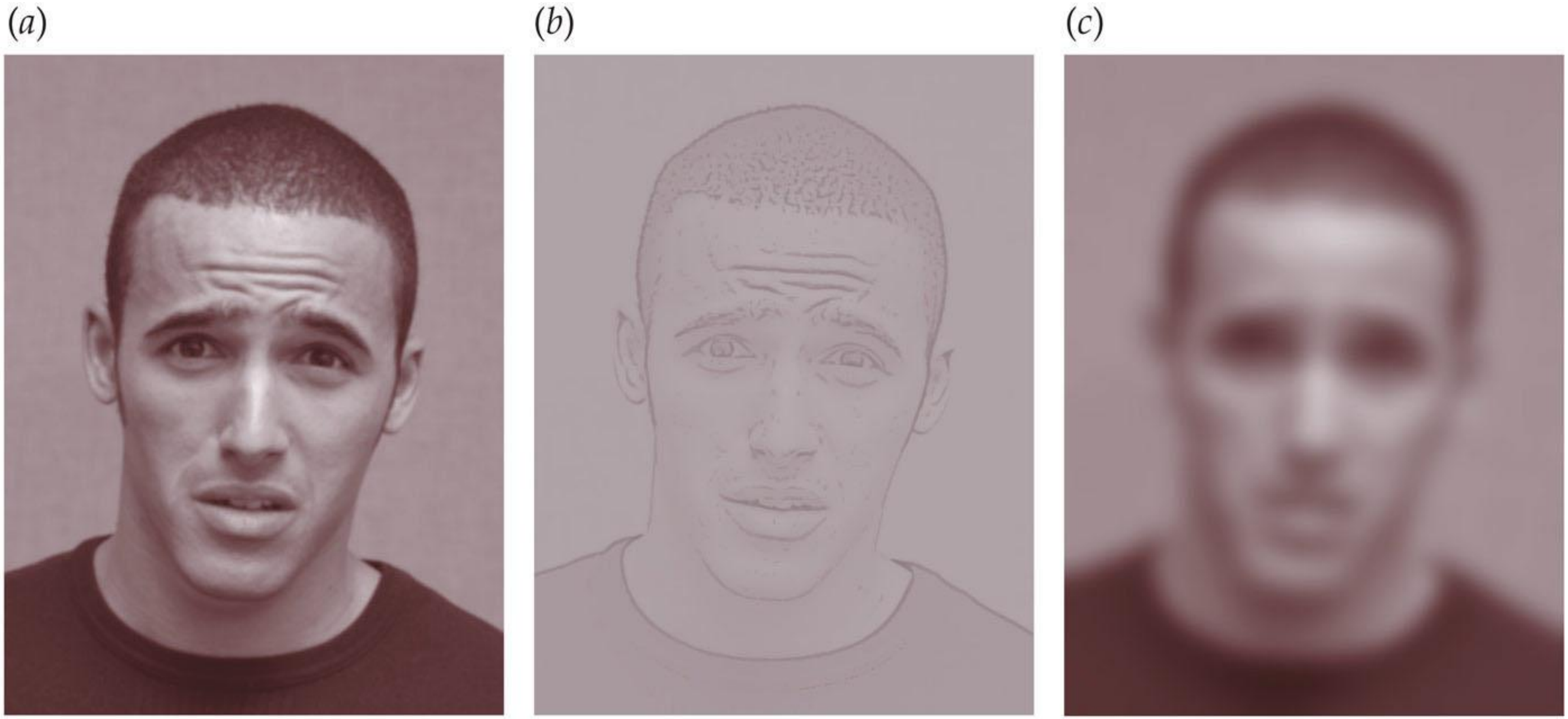
Selective Adaptation: The Psychologist's Electrode

Human vision is coded in spatial-frequency channels.

- Spatial-frequency channel: A pattern analyzer, implemented by an ensemble of cortical neurons, in which each set of neurons is tuned to a limited range of spatial frequencies.

Why would the visual system use spatial-frequency filters to analyze images?

Figure 3.34 A complete image (*a*) and reconstructions: with the low spatial frequencies removed, (*b*), and with the high spatial frequencies removed (*c*)



SENSATION & PERCEPTION 4e, Figure 3.34

Selective Adaptation: The Psychologist's Electrode

If it is hard to tell who this famous person is, try squinting or defocusing the projector.

Figure 3.35 Who is hidden behind the high-spatial-frequency mask in this image?

SENSATION & PERCEPTION 4e, **Figure 3.35**

How can you study the vision of infants who can’t yet speak?

- Infants prefer to look at more complex stimuli.
- The forced-choice preferential-looking paradigm
- Visual evoked potentials
  - VEPs are electrical signals from the brain that are evoked by visual stimuli.

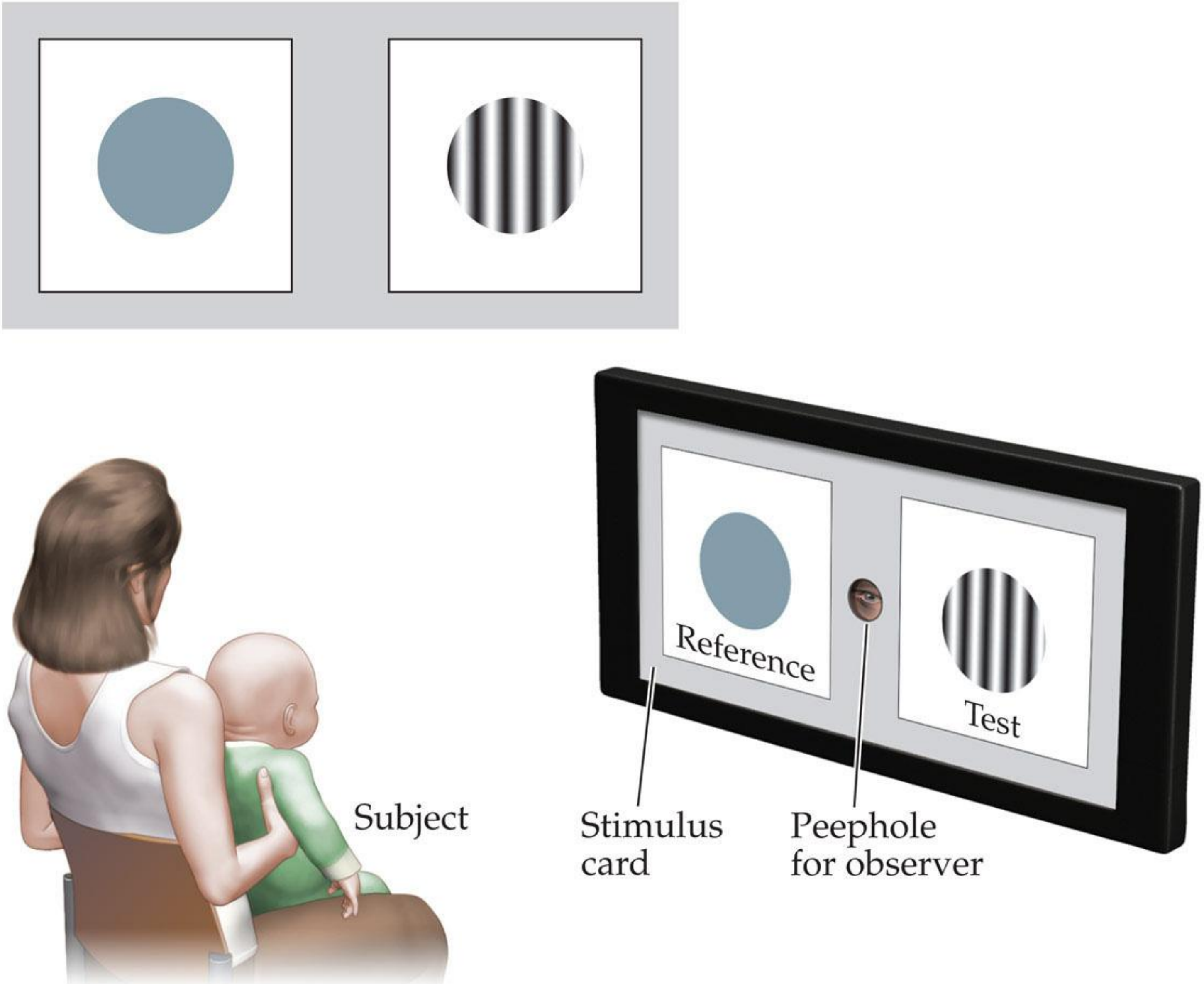
The Development of Spatial Vision

Young children are not very sensitive to high spatial frequencies.

- Visual system is still developing.
  - Cones and rods are still developing and taking final shape.
  - Retinal ganglion cells are still migrating and growing connections with the fovea.
  - The fovea itself has not fully developed until about 4 years of age.

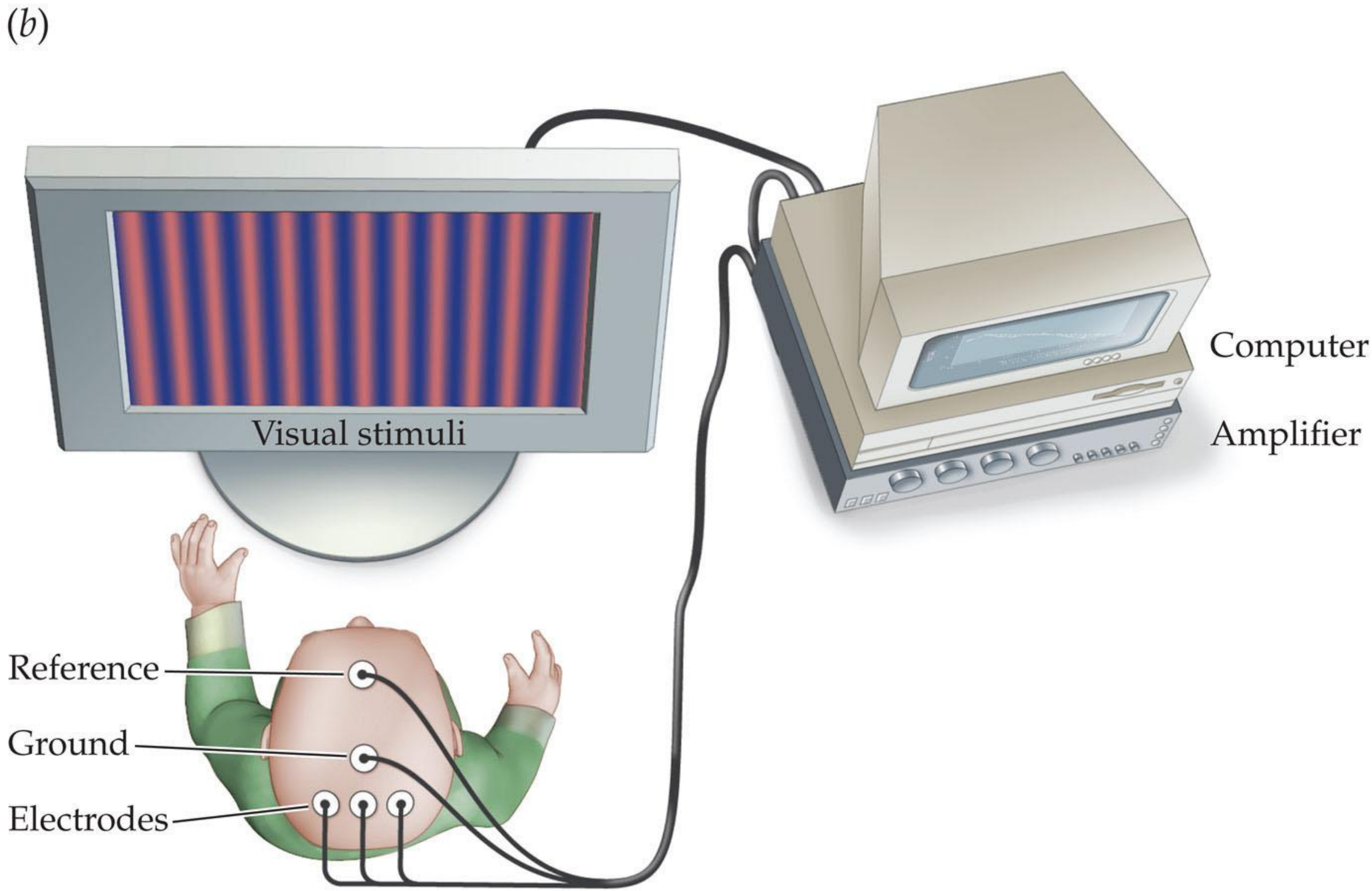
Figure 3.36 Assessing vision in infants (Part 1)

(*a*) Stimulus card



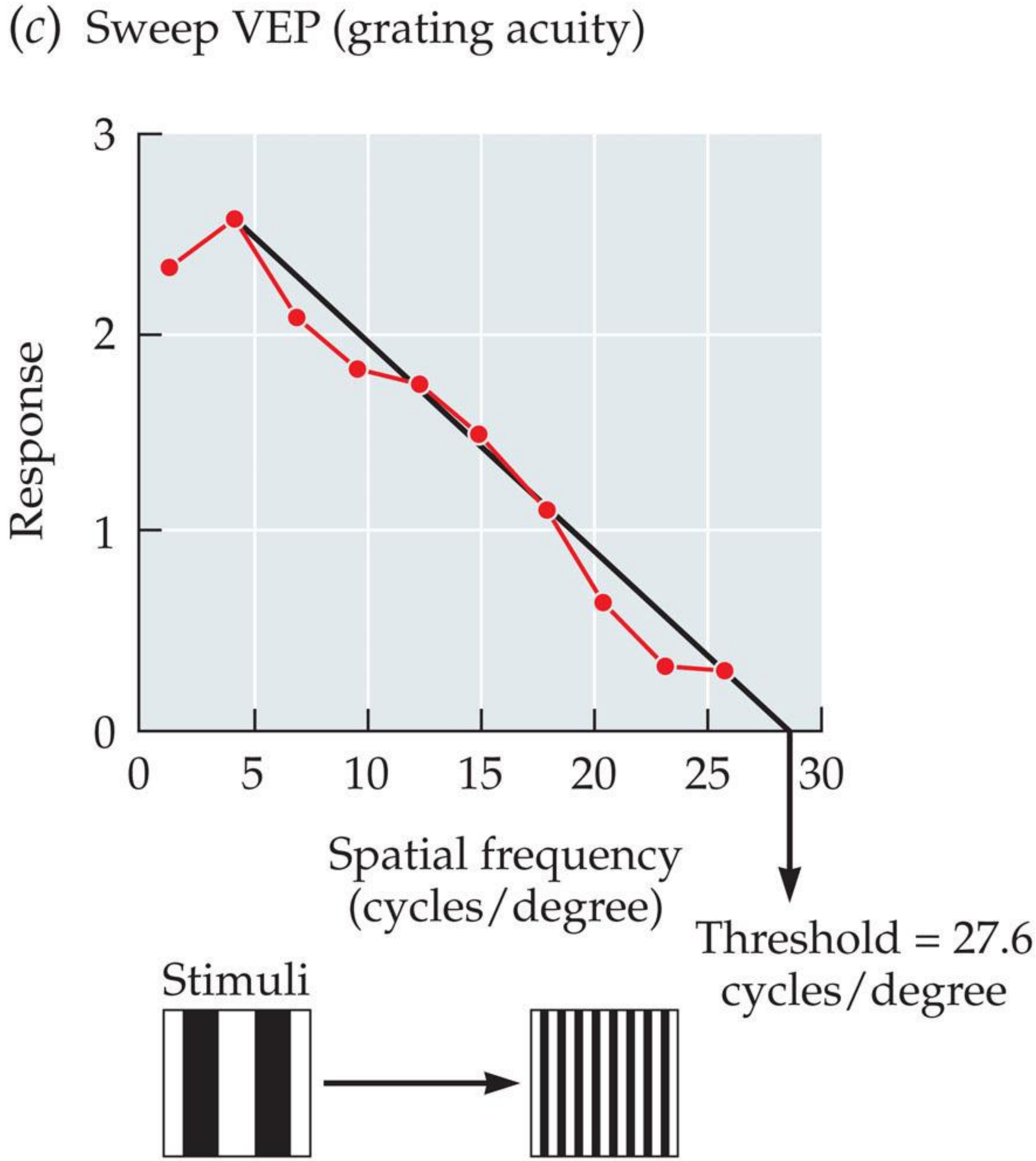
***SENSATION & PERCEPTION 4e*, Figure 3.36 (Part 1)**

Figure 3.36 Assessing vision in infants (Part 2)



SENSATION & PERCEPTION 4e, Figure 3.36 (Part 2)

Figure 3.36 Assessing vision in infants (Part 3)



SENSATION & PERCEPTION 4e, Figure 3.36 (Part 3)

Sensation & Perception in Everyday Life: The Girl Who Almost Couldn't See Stripes

Story of Jane: Abnormal early visual experience resulting in possibly permanent consequences

- Jane had a severe cataract in her left eye.

Sensation & Perception in Everyday Life: The Girl Who Almost Couldn’t See Stripes

Monocular vision from deprivation can cause massive changes in cortical physiology, resulting in devastating and permanent loss of spatial vision.

- Amblyopia: Reduced spatial vision in an otherwise healthy eye.
- Strabismus: A misalignment of the two eyes.
- Anisometropia: A condition in which the two eyes have different refractive errors.

Sensation & Perception in Everyday Life: The Girl Who Almost Couldn’t See Stripes

Cataracts and strabismus can lead to serious problems, but early detection and care can prevent such problems!

- There appears to be a critical period of about 4–5 years early in life during which problems can be corrected.

Sensation & Perception in Everyday Life: The Girl Who Almost Couldn't See Stripes

- If input from one eye is limited (due to cataract, amblyopia, or strabismus), then the neurons that were meant to process that eye may get reassigned to process the other eye instead.
- If corrected early enough, this process can be reversed.