6

Space Perception and Binocular Vision

- Monocular Cues to Three-Dimensional Space
- Binocular Vision and Stereopsis
- Combining Depth Cues
- Development of Binocular Vision and Stereopsis

Realism: The external world exists.

Positivists: The world depends on the evidence of the senses; it could be a hallucination!

- This is an interesting philosophical position, but for the purposes of this course, let’s just assume the world exists.

Euclidian geometry: Parallel lines remain parallel as they are extended in space.

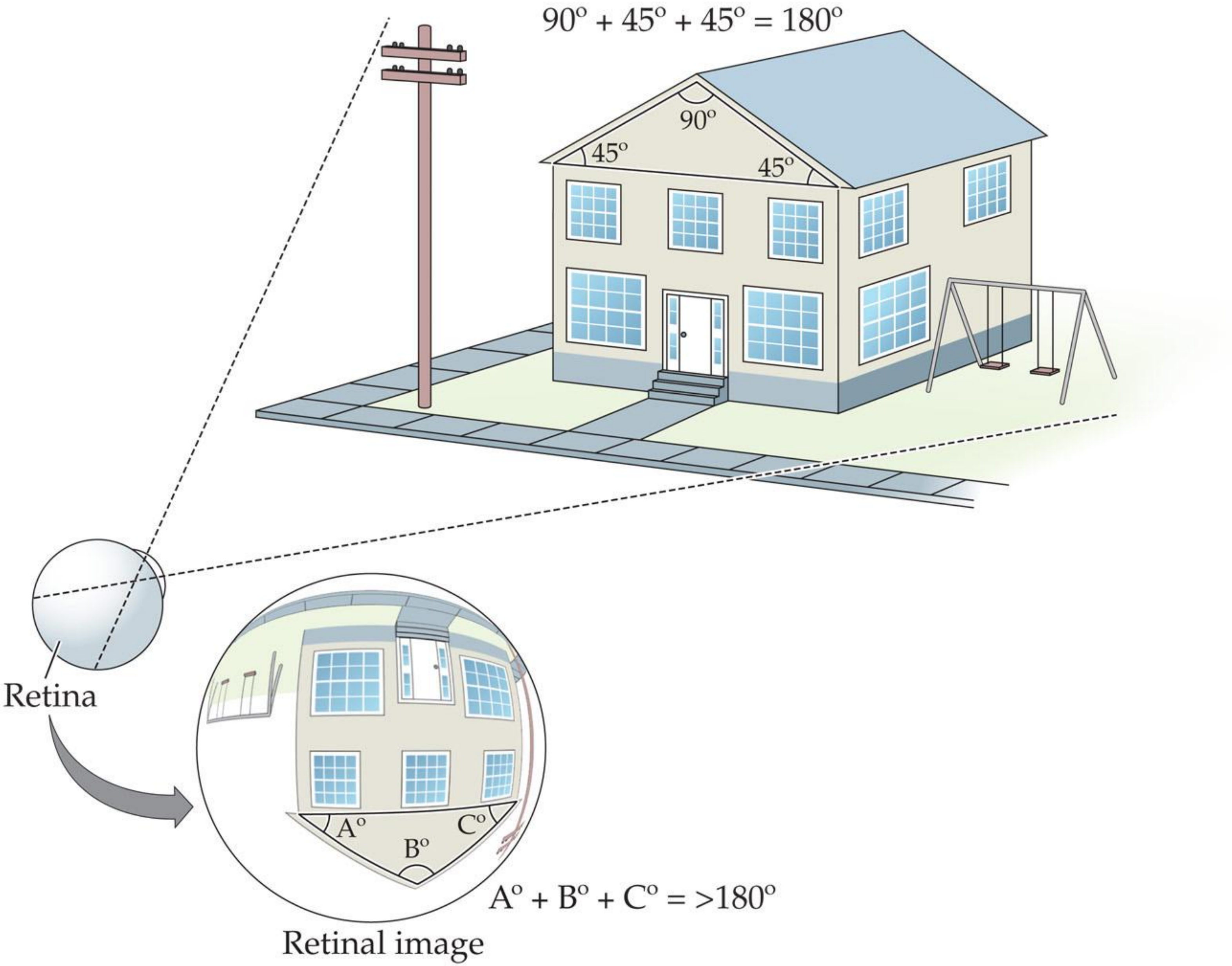
- Objects maintain the same size and shape as they move around in space.
- Internal angles of a triangle always add up to 180 degrees, etc.

Introduction

Notice that images projected onto the retina are non-Euclidean!

- Therefore, our brains work with non-Euclidean geometry all the time, even though we are not aware of it.

Figure 6.1 The Euclidean geometry of the three-dimensional world turns into something quite different on the curved, two-dimensional retina



SENSATION & PERCEPTION 4e, Figure 6.1

Introduction

Probability summation: The increased probability of detecting a stimulus from having two or more samples.

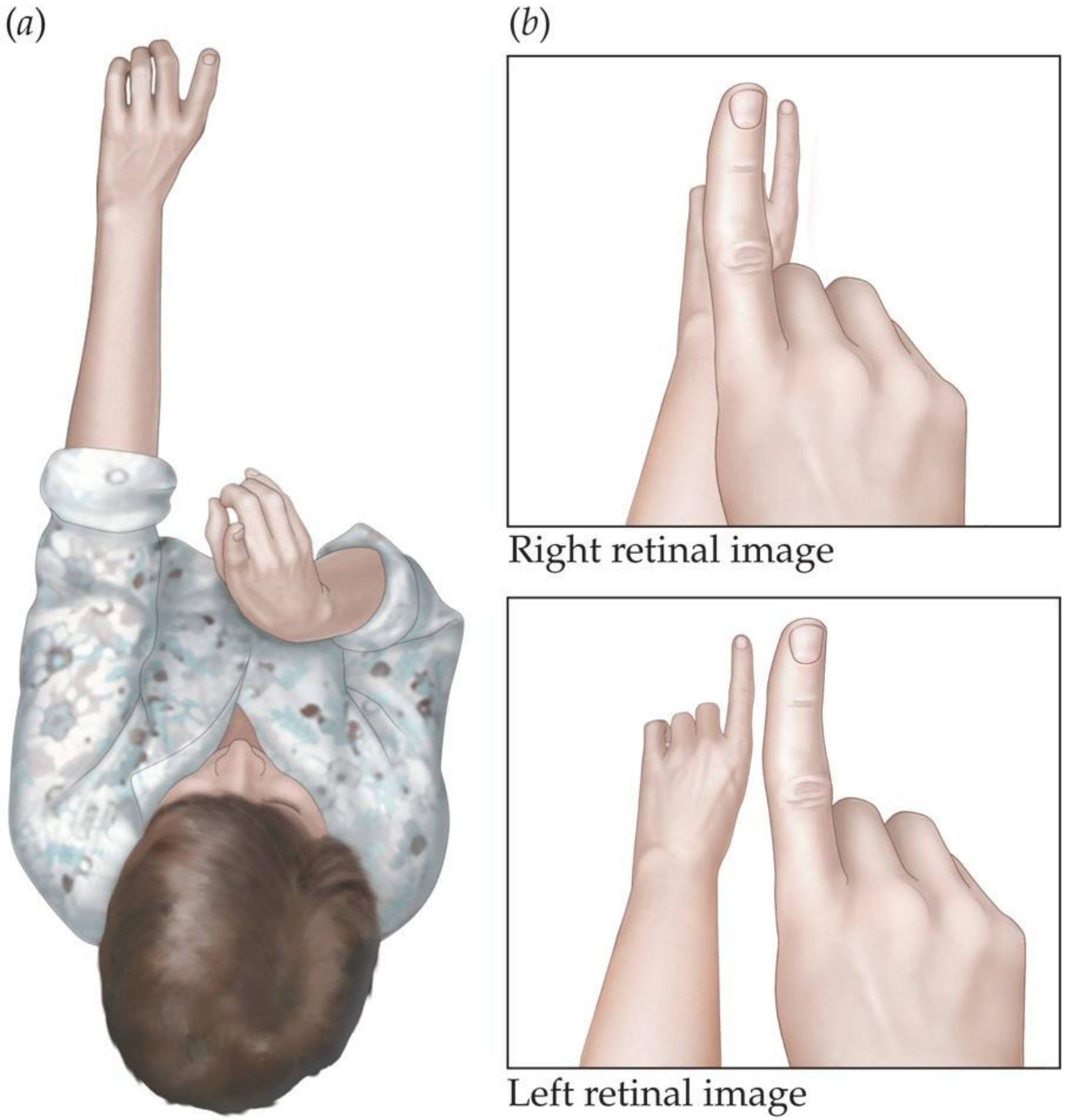
- One of the advantages of having two eyes that face forward.

Introduction

Binocular summation: The combination (or "summation") of signals from each eye in ways that make performance on many tasks better with both eyes than with either eye alone.

The two retinal images of a three-dimensional world are not the same!

Figure 6.2 The two retinal images of a three-dimensional world are not the same



SENSATION & PERCEPTION 4e, Figure 6.2

Binocular disparity: The differences between the two retinal images of the same scene.

- Disparity is the basis for stereopsis, a vivid perception of the three-dimensionality of the world that is not available with monocular vision.

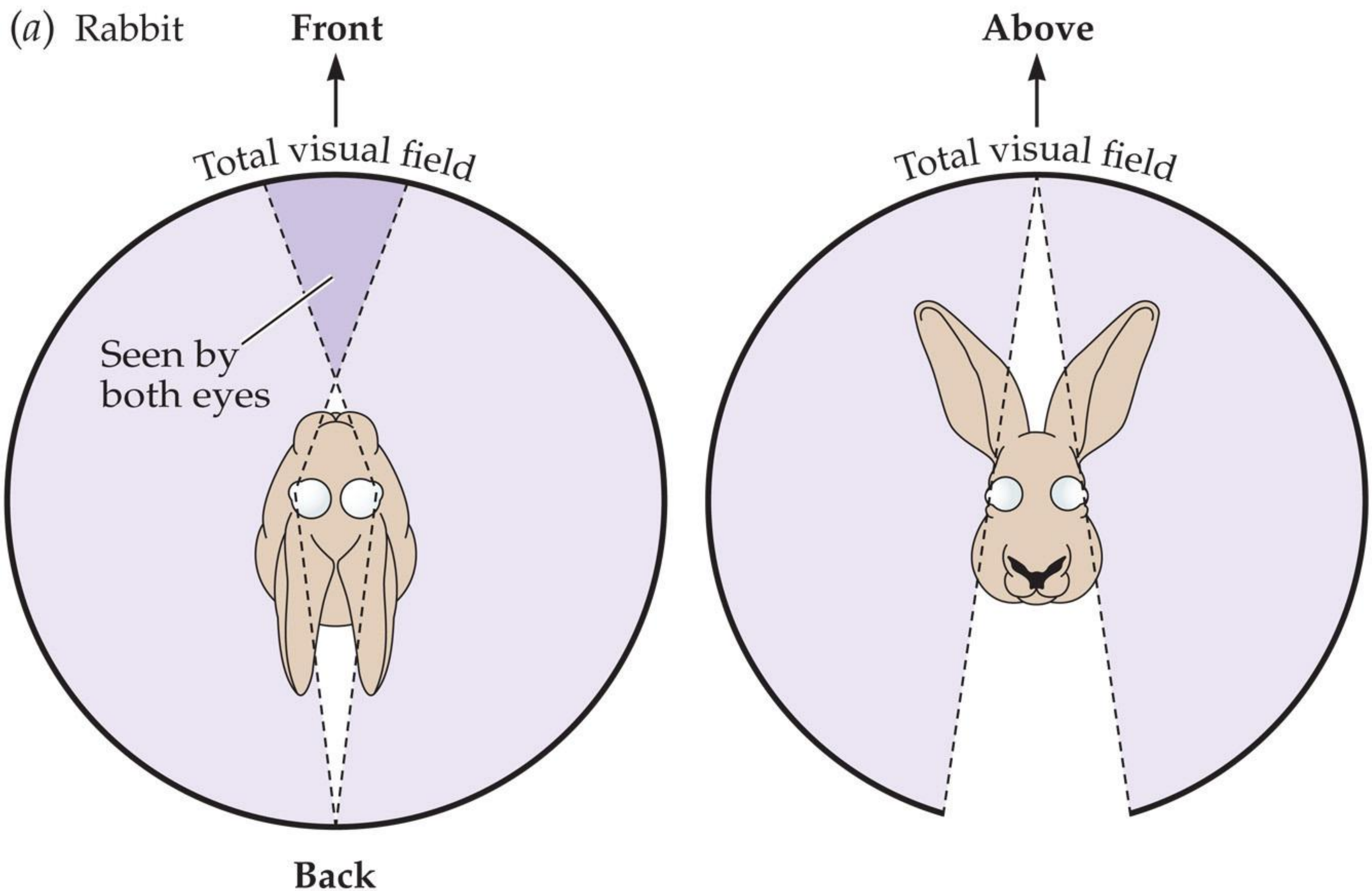
Introduction

Depth cue: Information about the third dimension (depth) of visual space.

Monocular depth cue: A depth cue that is available even when the world is viewed with one eye alone.

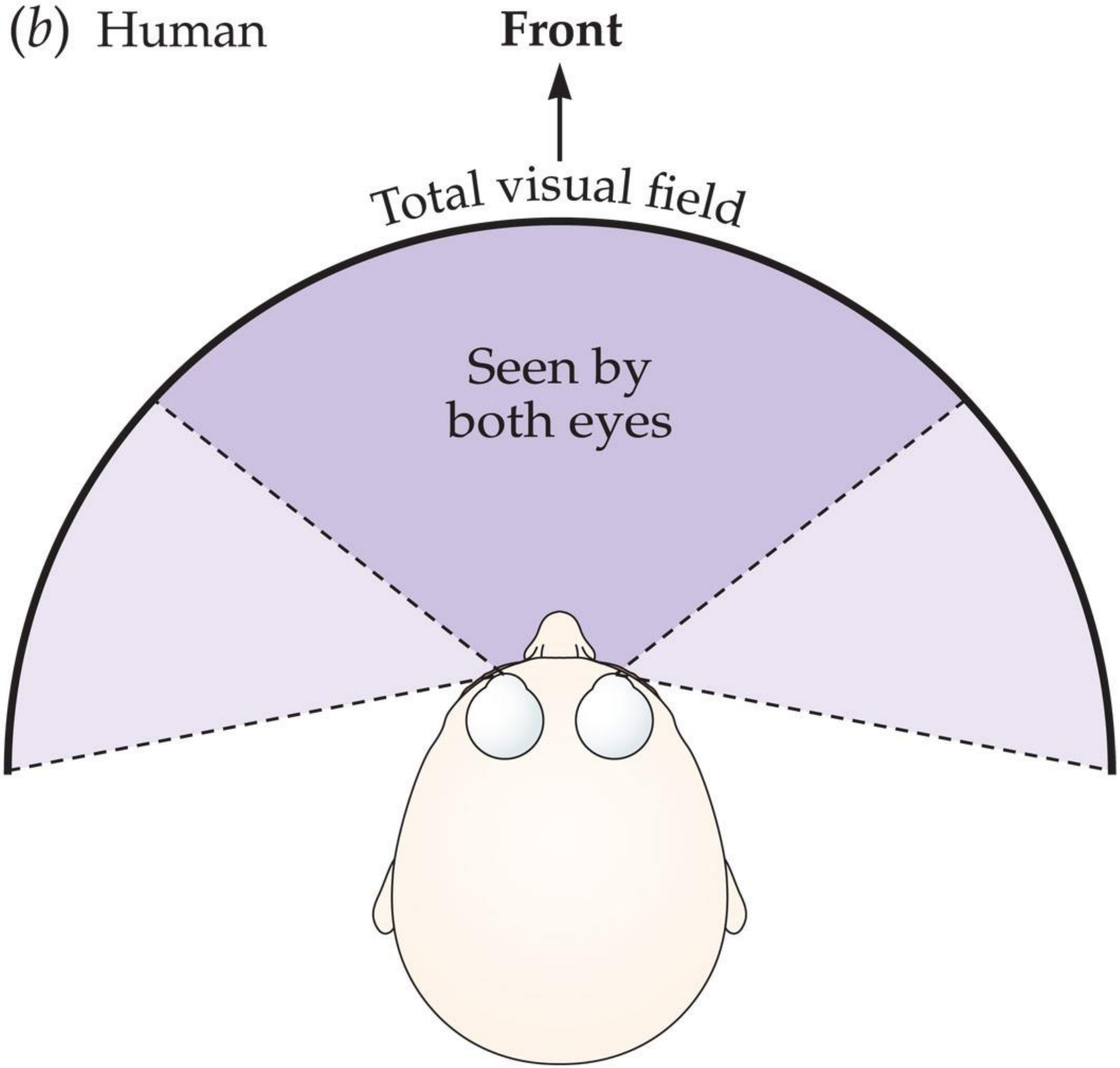
Binocular depth cue: A depth cue that relies on information from both eyes.

Figure 6.3 Comparing rabbit and human visual fields (Part 1)



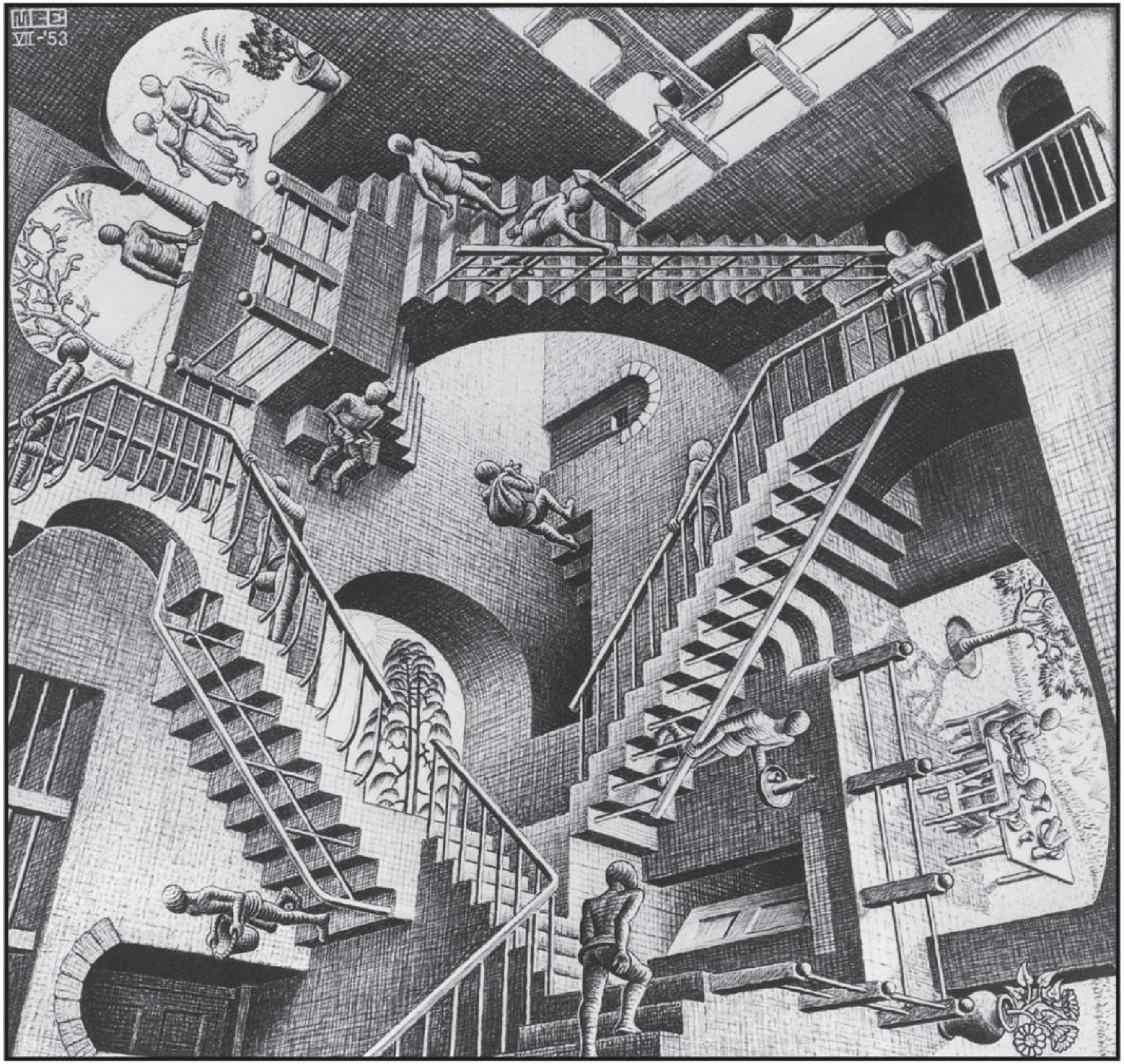
SENSATION & PERCEPTION 4e, Figure 6.3 (Part 1)

Figure 6.3 Comparing rabbit and human visual fields (Part 2)



SENSATION & PERCEPTION 4e, Figure 6.3 (Part 2)

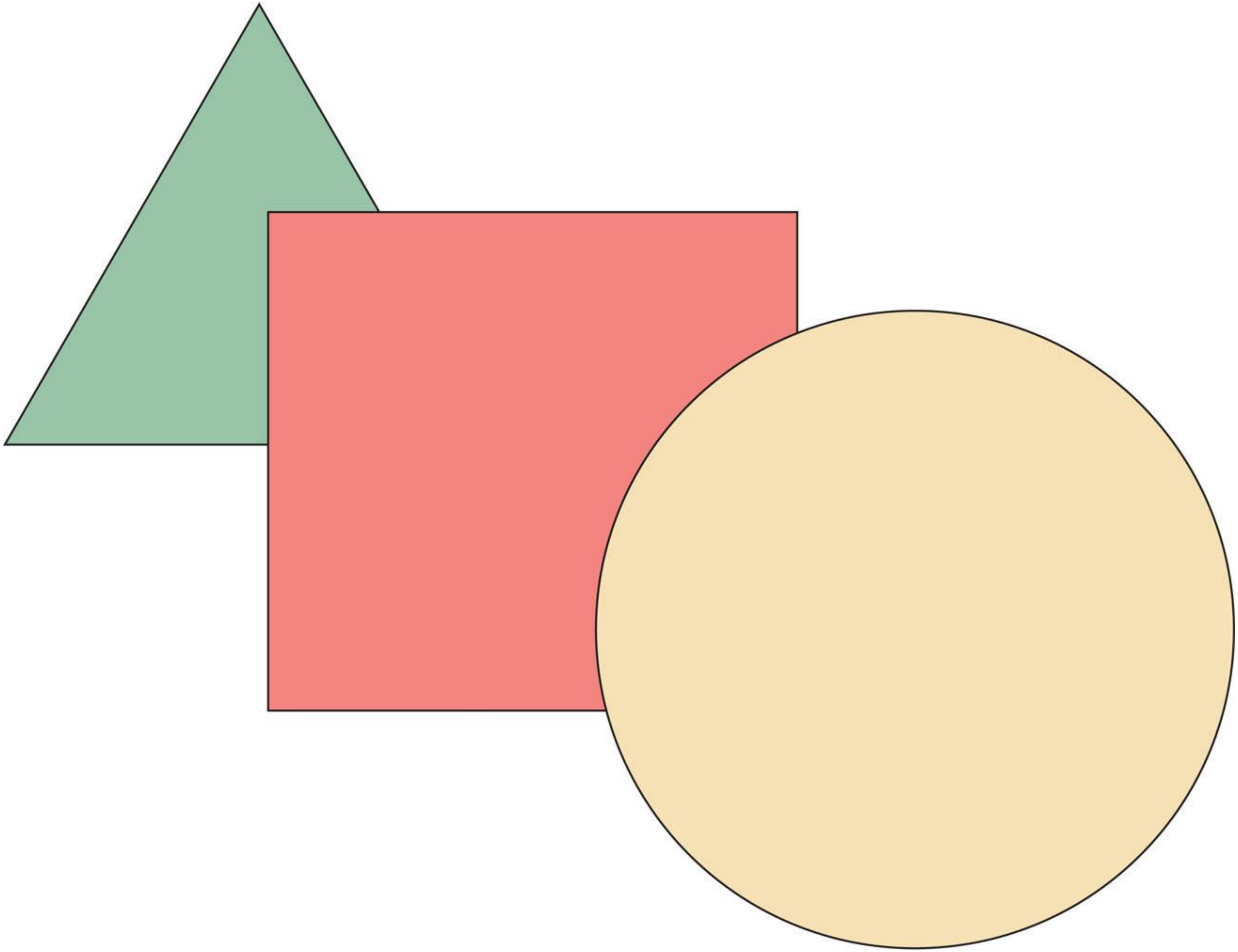
Figure 6.4 M. C. Escher, *Relativity*, 1953



***SENSATION & PERCEPTION 4e*, Figure 6.4**

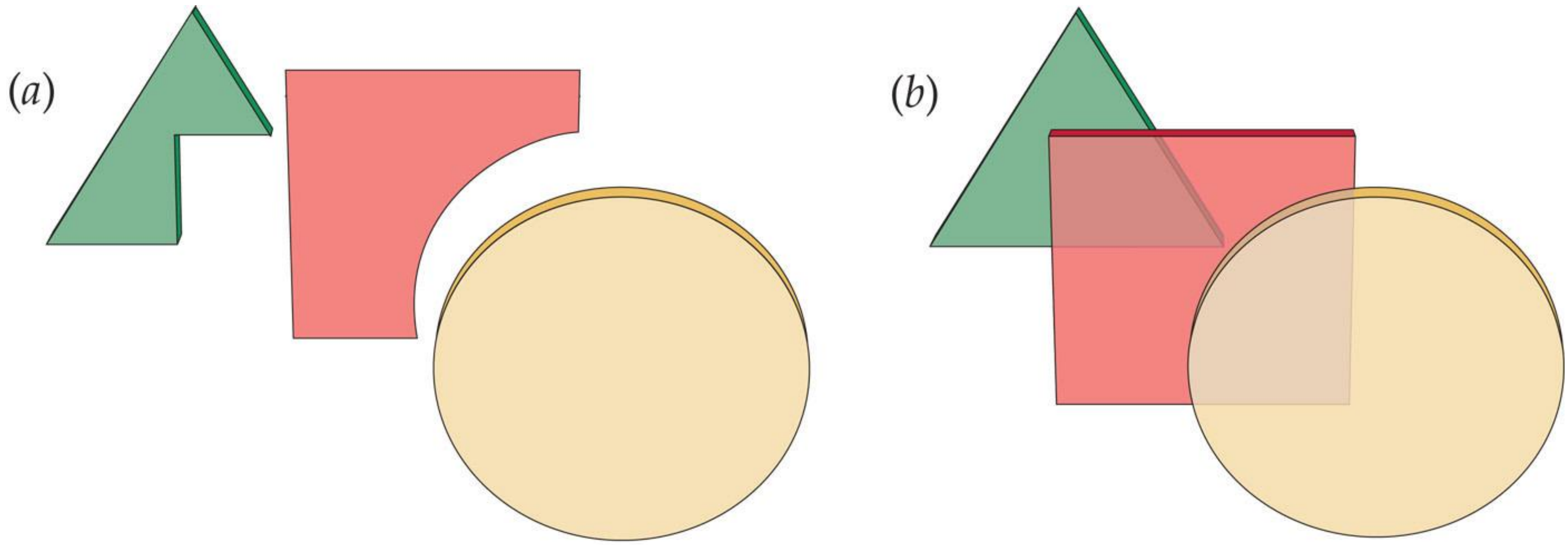
Occlusion: A cue to relative depth order in which, for example, one object partially obstructs the view of another object.

Figure 6.5 Occlusion makes it easy to infer relative position in depth



SENSATION & PERCEPTION 4e, Figure 6.5

Figure 6.6 Figure 6.5 could be an “accidental” view of the pieces shown here in (*a*). It is much more likely, however, that it is a generic view of circle, square, and triangle, as shown in (*b*)



SENSATION & PERCEPTION 4e, Figure 6.6

Metrical depth cue: A depth cue that provides quantitative information about distance in the third dimension.

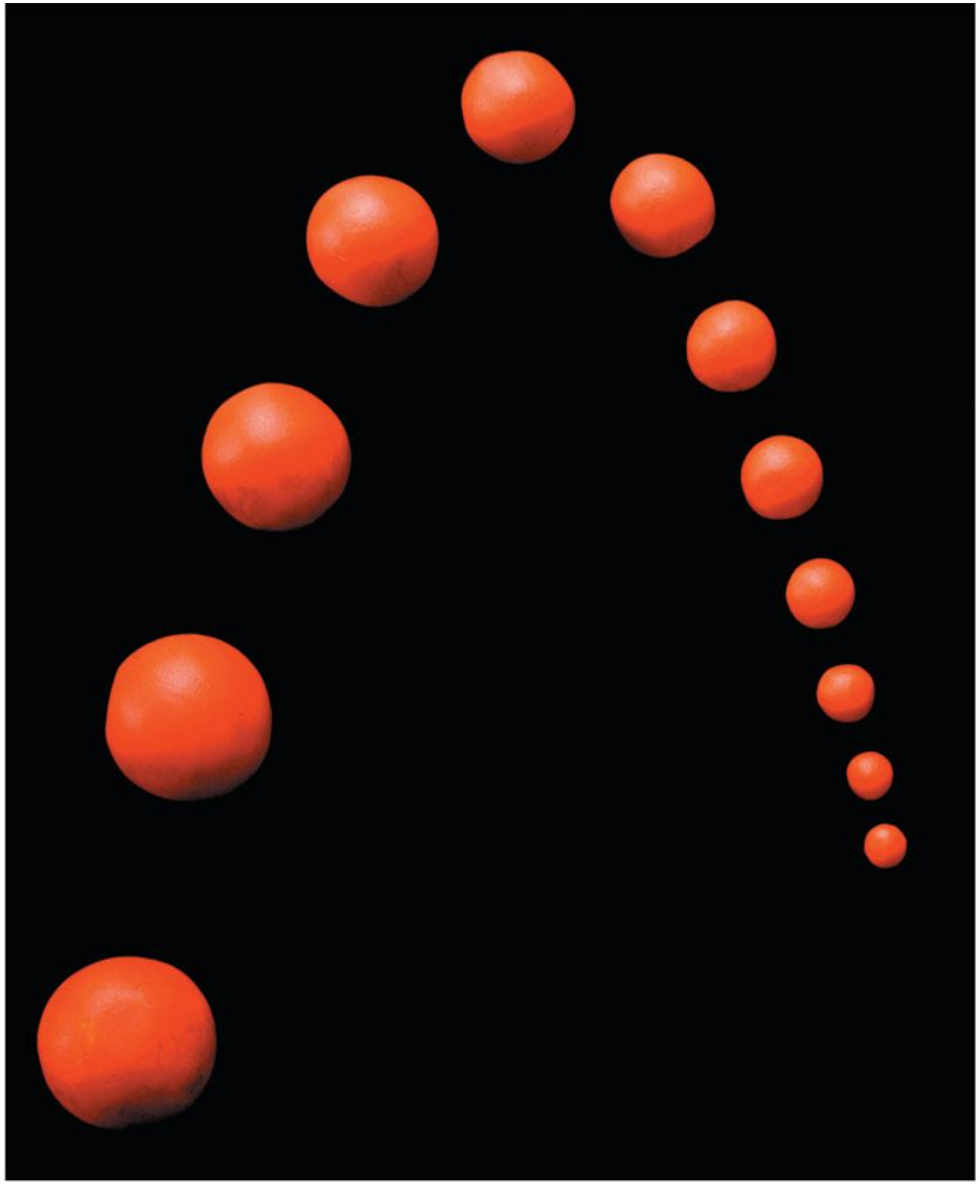
Nonmetrical depth cue: A depth cue that provides information about the depth order (relative depth) but not depth magnitude.

Monocular Cues to Three-Dimensional Space

Relative size: A comparison of size between items without knowing the absolute size of either one.

- All things being equal, we assume that smaller objects are farther away from us than larger objects.

Figure 6.7 This is a photograph of a collection of Plasticine balls that are resting on the same surface at the same distance from the camera



SENSATION & PERCEPTION 4e, Figure 6.7

Monocular Cues to Three-Dimensional Space

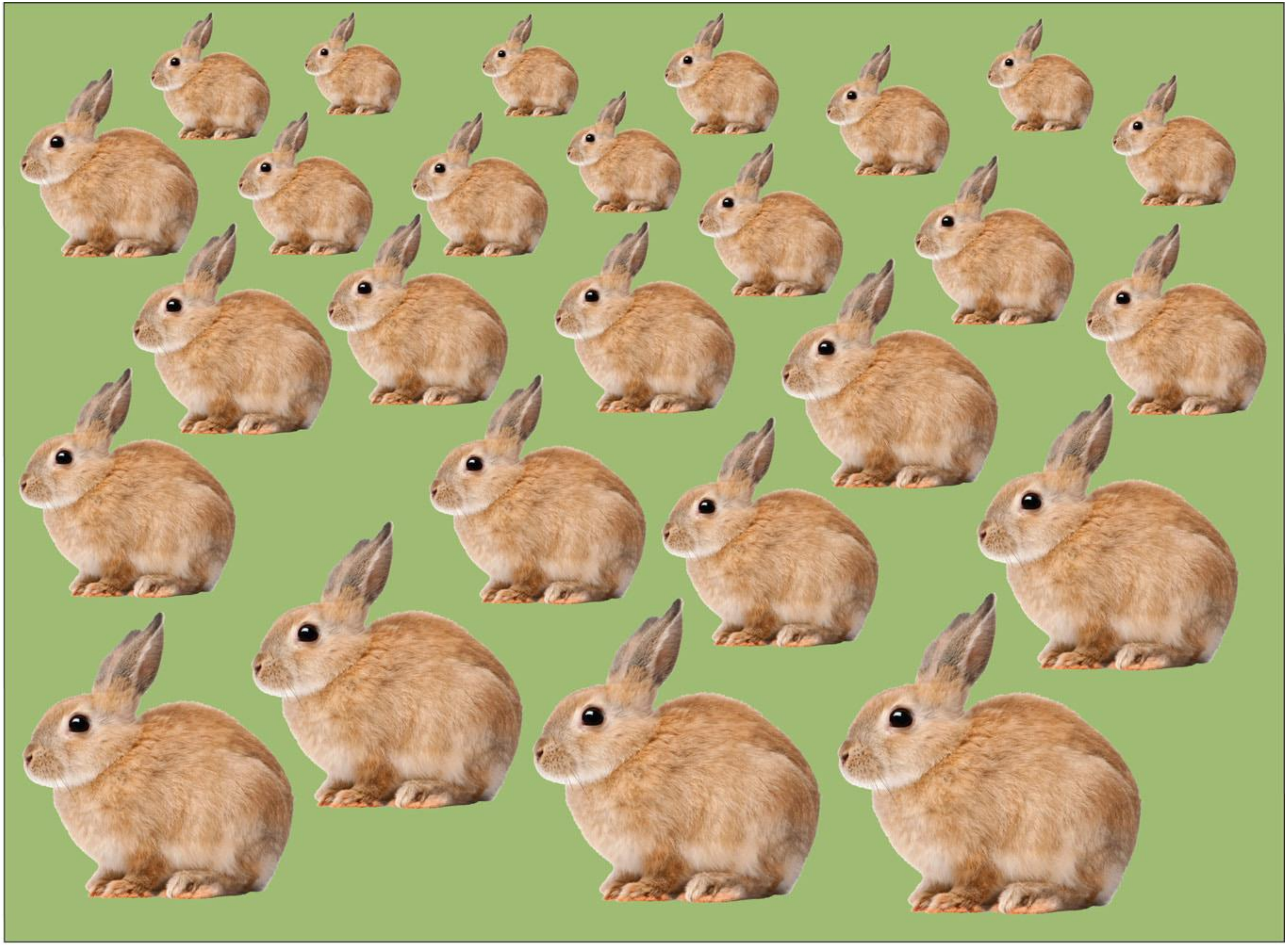
Relative height: For objects touching the ground, those higher in the visual field appear to be farther away. In the sky above the horizon, objects lower in the visual field appear to be farther away.

Monocular Cues to Three-Dimensional Space

Texture gradient: A depth cue based on the geometric fact that items of the same size form smaller, closer spaced images the farther away they get.

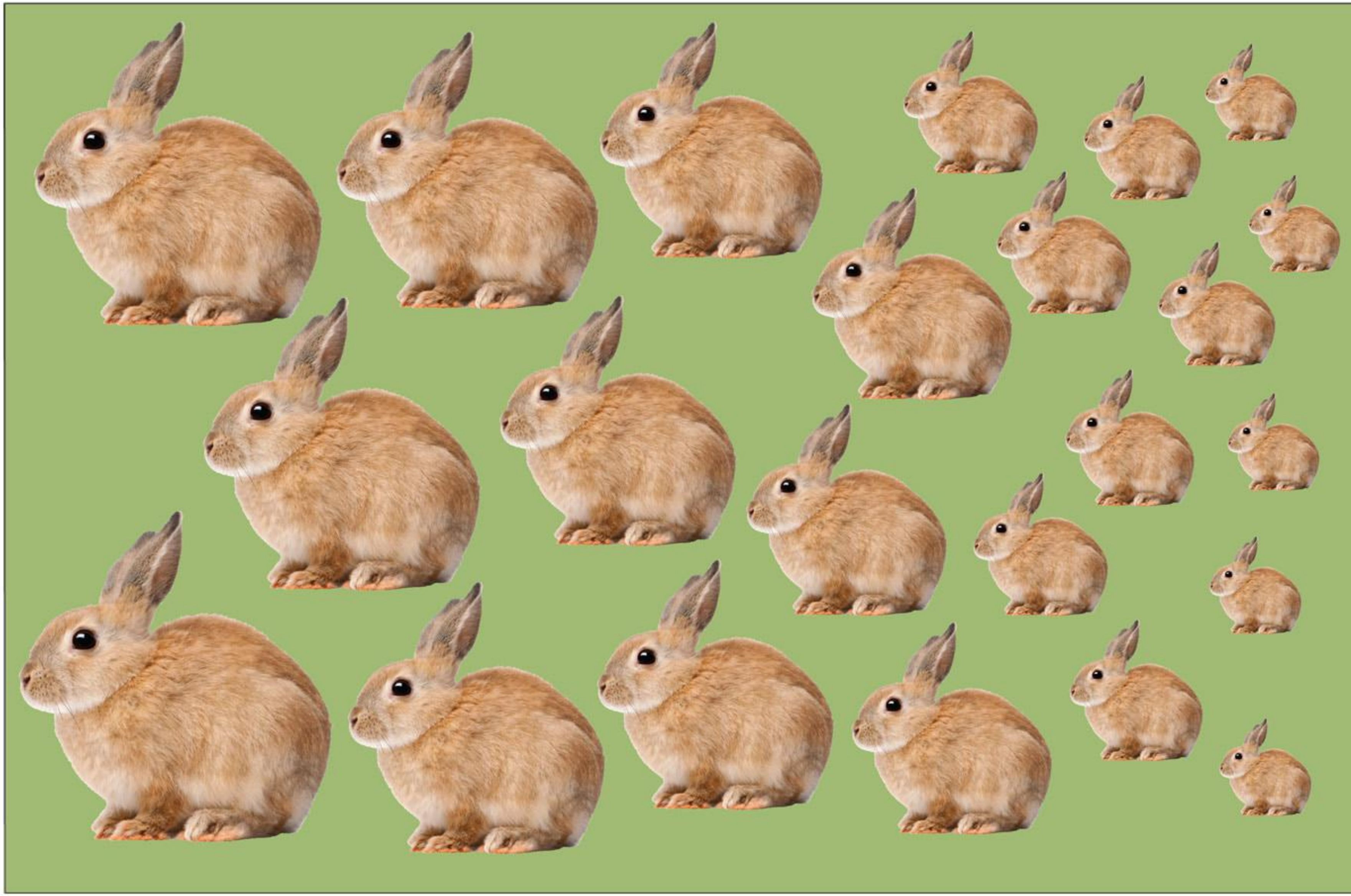
- Texture gradients result from a combination of the cues of relative size and relative height.

Figure 6.8 This rabbit texture gradient shows that the size cue is more effective when size changes systematically



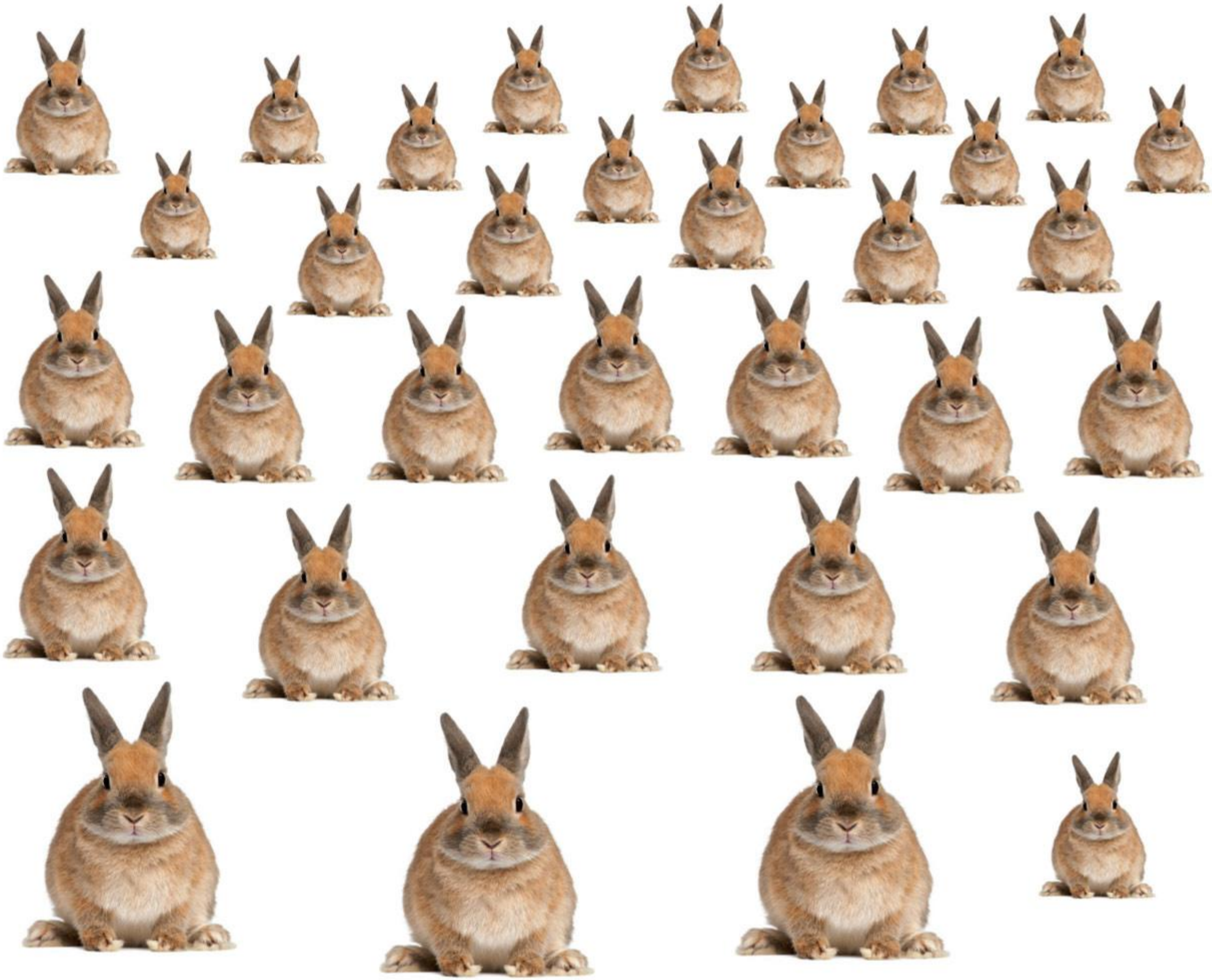
SENSATION & PERCEPTION 4e, **Figure 6.8**

Figure 6.9 Organized differently, this illustration of the same rabbits as those shown in Figure 6.8 does not produce the same sense of depth



SENSATION & PERCEPTION 4e, Figure 6.9

Figure 6.11 The rabbit image at the top far left is the same size as the one at the bottom far right



Monocular Cues to Three-Dimensional Space

Familiar size: A cue based on knowledge of the typical size of objects.

- When you know the typical size of an object, you can guess how far away it is based on how small or large it appears.
- The cue of familiar size often works in conjunction with the cue of relative size.

Figure 6.12 The cue of familiar size

SENSATION & PERCEPTION 4e, Figure 6.12

Monocular Cues to Three-Dimensional Space

Relative size and relative height both provide some metrical information.

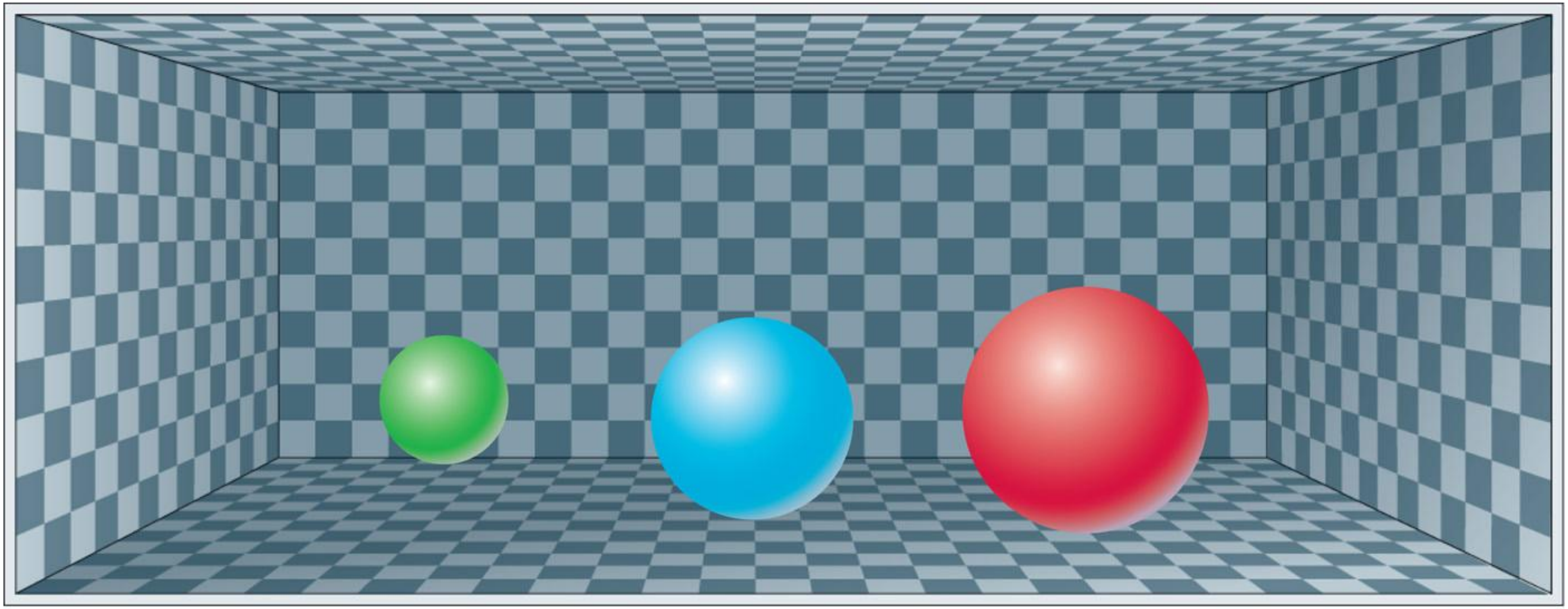
- Relative metrical depth cue: A depth cue that could specify, for example, that object A is twice as far away as object B without providing information about the absolute distance to either A or B.

Monocular Cues to Three-Dimensional Space

Familiar size can provide precise metrical information if your visual system knows the actual size of the object and the visual angle it takes up on the retina.

- Absolute metrical depth cue: A depth cue that provides quantifiable information about distance in the third dimension.

Figure 6.13 The metrical cues of relative size and height can give the visual system more information than a nonmetrical cue like occlusion can



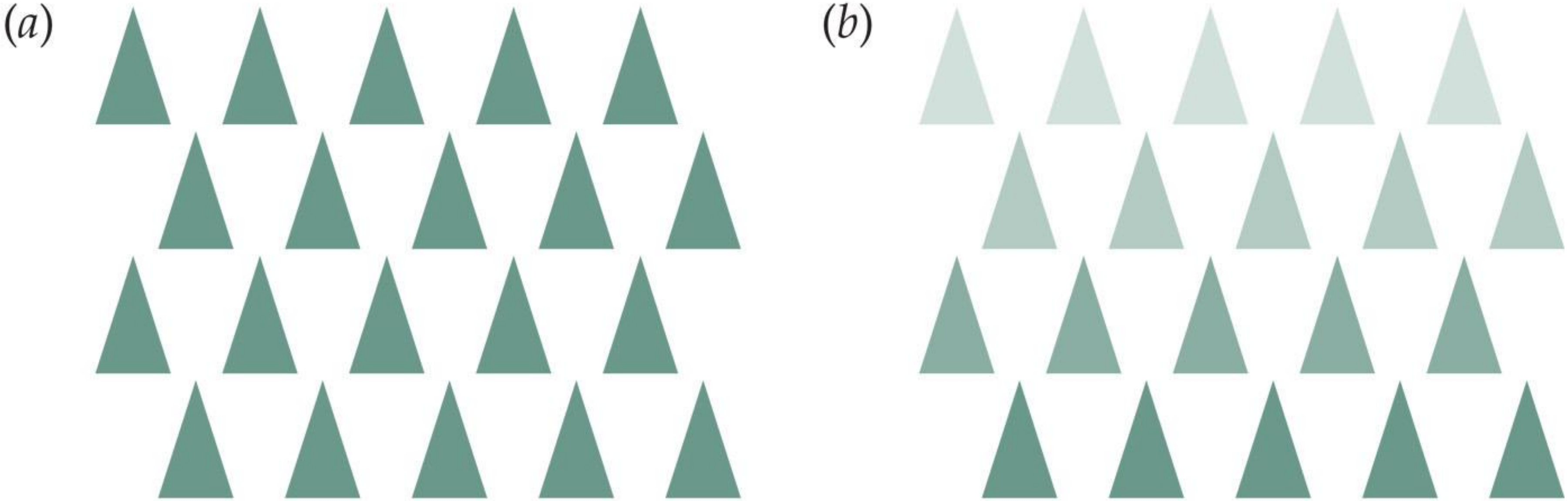
SENSATION & PERCEPTION 4e, Figure 6.13

Monocular Cues to Three-Dimensional Space

Aerial perspective: A depth cue based on the implicit understanding that light is scattered by the atmosphere.

- More light is scattered when we look through more atmosphere.
- Thus, more distant objects appear fainter, bluer, and less distinct.

Figure 6.14 The triangles seem to recede into depth more in (*b*) than in (*a*)



SENSATION & PERCEPTION 4e, Figure 6.14

Figure 6.15 A real-world example of aerial perspective

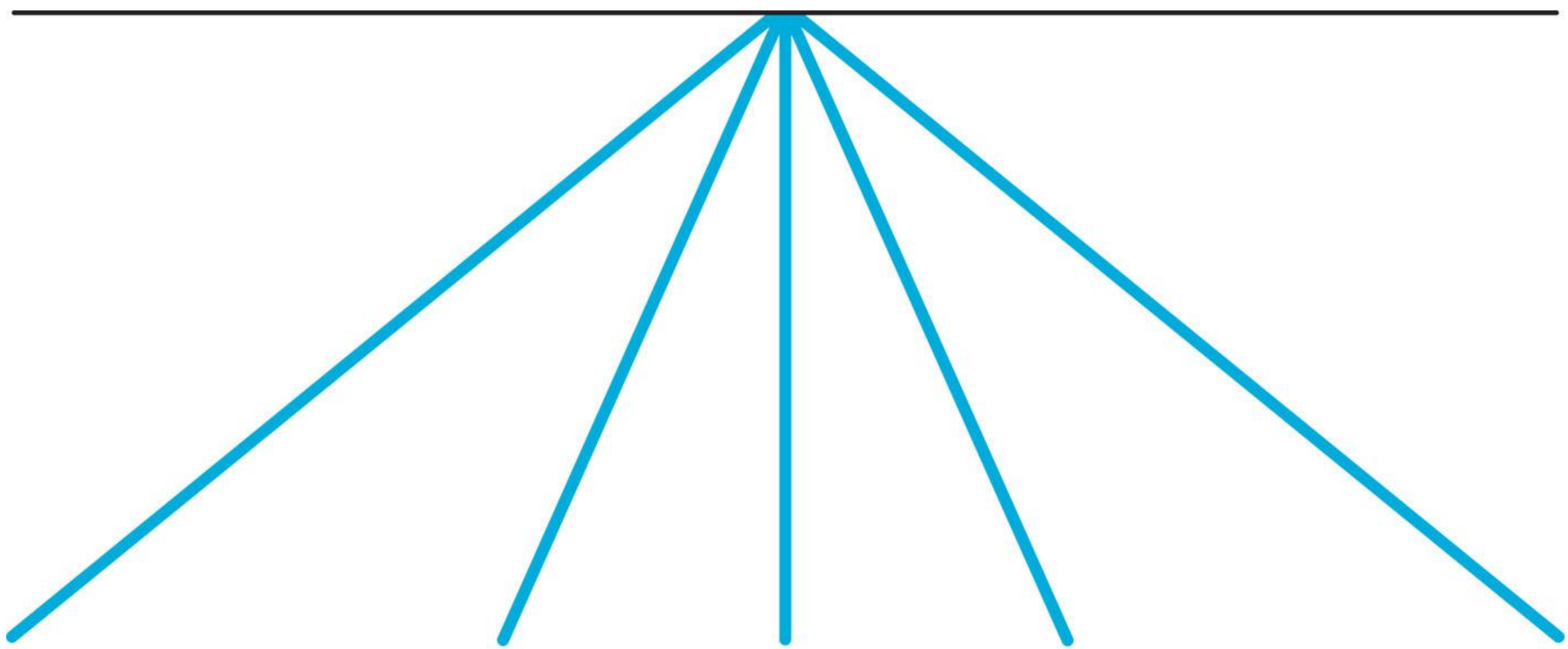
SENSATION & PERCEPTION 4e, Figure 6.15

Monocular Cues to Three-Dimensional Space

Linear perspective: Lines that are parallel in the three-dimensional world will appear to converge in a two-dimensional image as they extend into the distance.

Vanishing point: The apparent point at which parallel lines receding in depth converge.

Figure 6.16 Linear perspective



SENSATION & PERCEPTION 4e, Figure 6.16

Figure 6.17 *Architectural View* by Francesco di Giorgio Martini (1477), a very clear example of linear perspective

SENSATION & PERCEPTION 4e, Figure 6.17

Monocular Cues to Three-Dimensional Space

Pictorial depth cue: A cue to distance or depth used by artists to depict three-dimensional depth in two-dimensional pictures.

Anamorphosis (or anamorphic projection): Use of the rules of linear perspective to create a two-dimensional image so distorted that it looks correct only when viewed from a special angle or with a mirror that counters the distortion.

Figure 6.19 In 1533, Hans Holbein painted the double portrait in (*a*) with an odd object (*b*) at the feet of the two men

(*a*)

(*b*)

SENSATION & PERCEPTION 4e, Figure 6.19

Figure 6.20 Modern-day anamorphic art

(a)

(b)

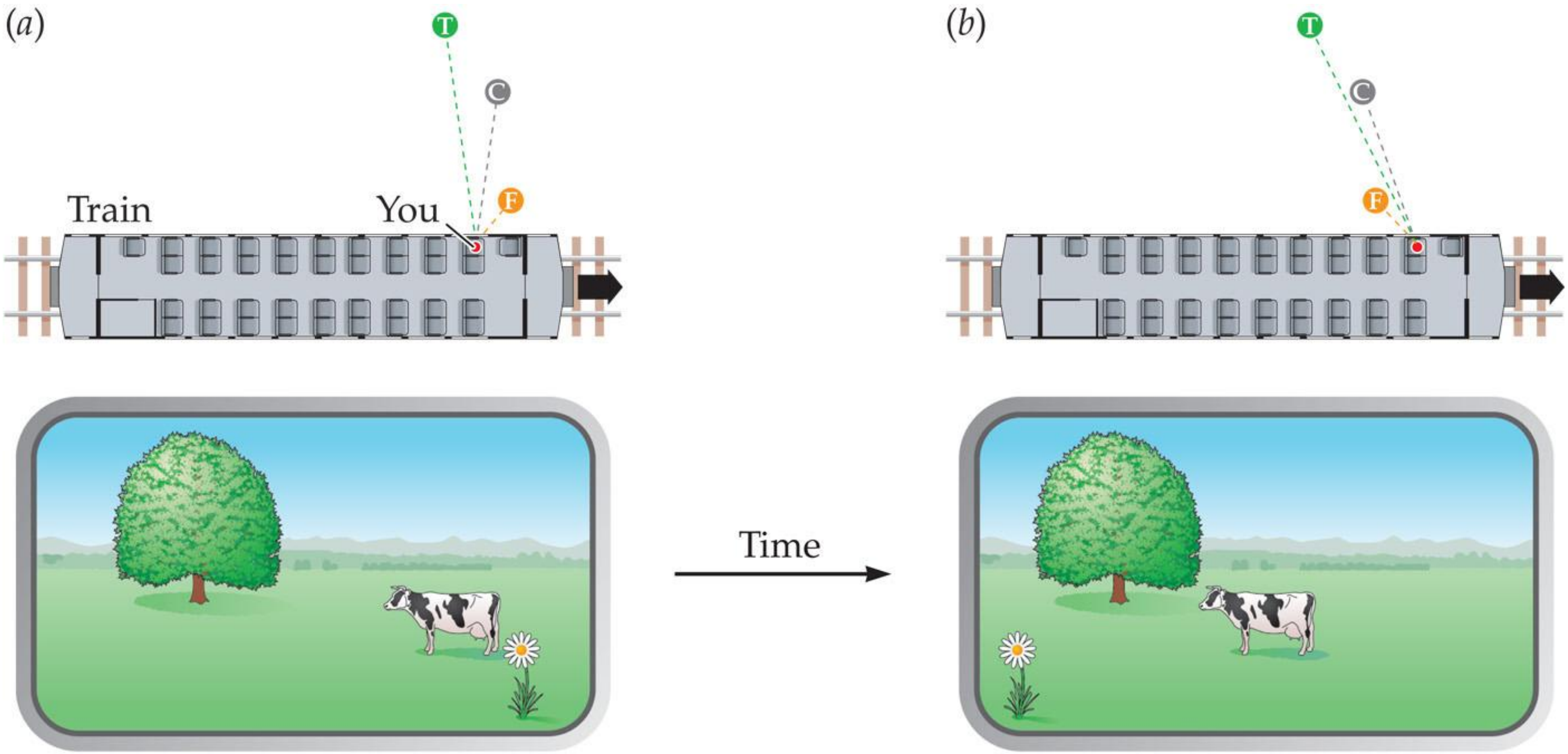
SENSATION & PERCEPTION 4e, **Figure 6.20**

Monocular Cues to Three-Dimensional Space

Motion parallax: Images closer to the observer move faster across the visual field than images farther away.

- The brain uses this information to calculate the distances of objects in the environment.
- Head movements and any other relative movements between observers and objects reveal motion parallax cues.

Figure 6.21 Motion parallax



SENSATION & PERCEPTION 4e, Figure 6.21

Monocular Cues to Three-Dimensional Space

Accommodation: The process by which the eye changes its focus (in which the lens gets fatter as gaze is directed toward nearer objects).

Convergence: The ability of the two eyes to turn inward, often used to focus on nearer objects.

Divergence: The ability of the two eyes to turn outward, often used to focus on farther objects.

Corresponding retinal points: A geometric concept stating that points on the retina of each eye where the monocular retinal images of a single object are formed are at the same distance from the fovea in each eye.

Figure 6.23 This simple visual scene illustrates how geometric regularities are exploited by the visual system to achieve stereopsis from binocular disparity

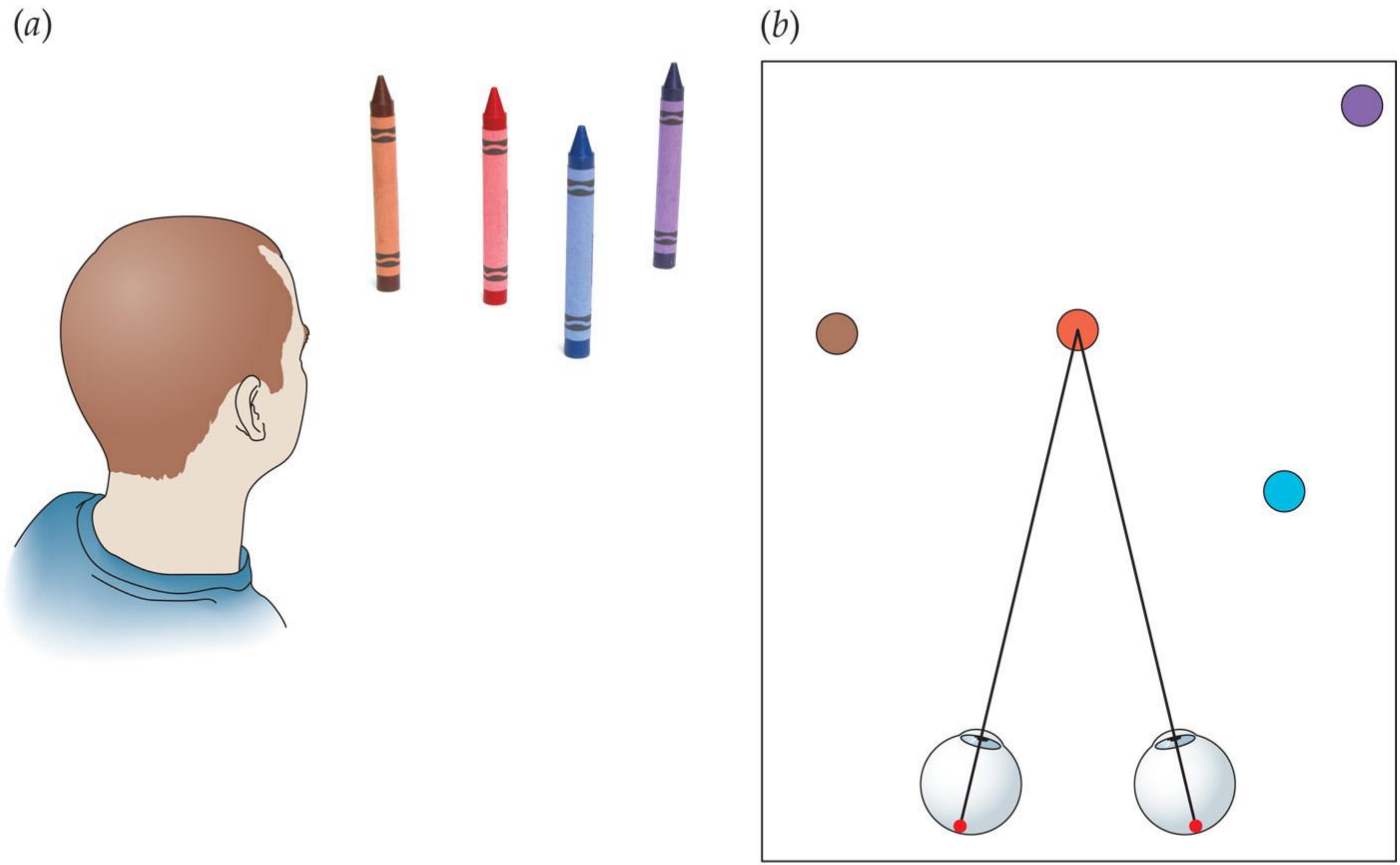


Figure 6.24 The overlapping portions of the images falling on Bob’s left and right retinas

Left retinal image

Right retinal image

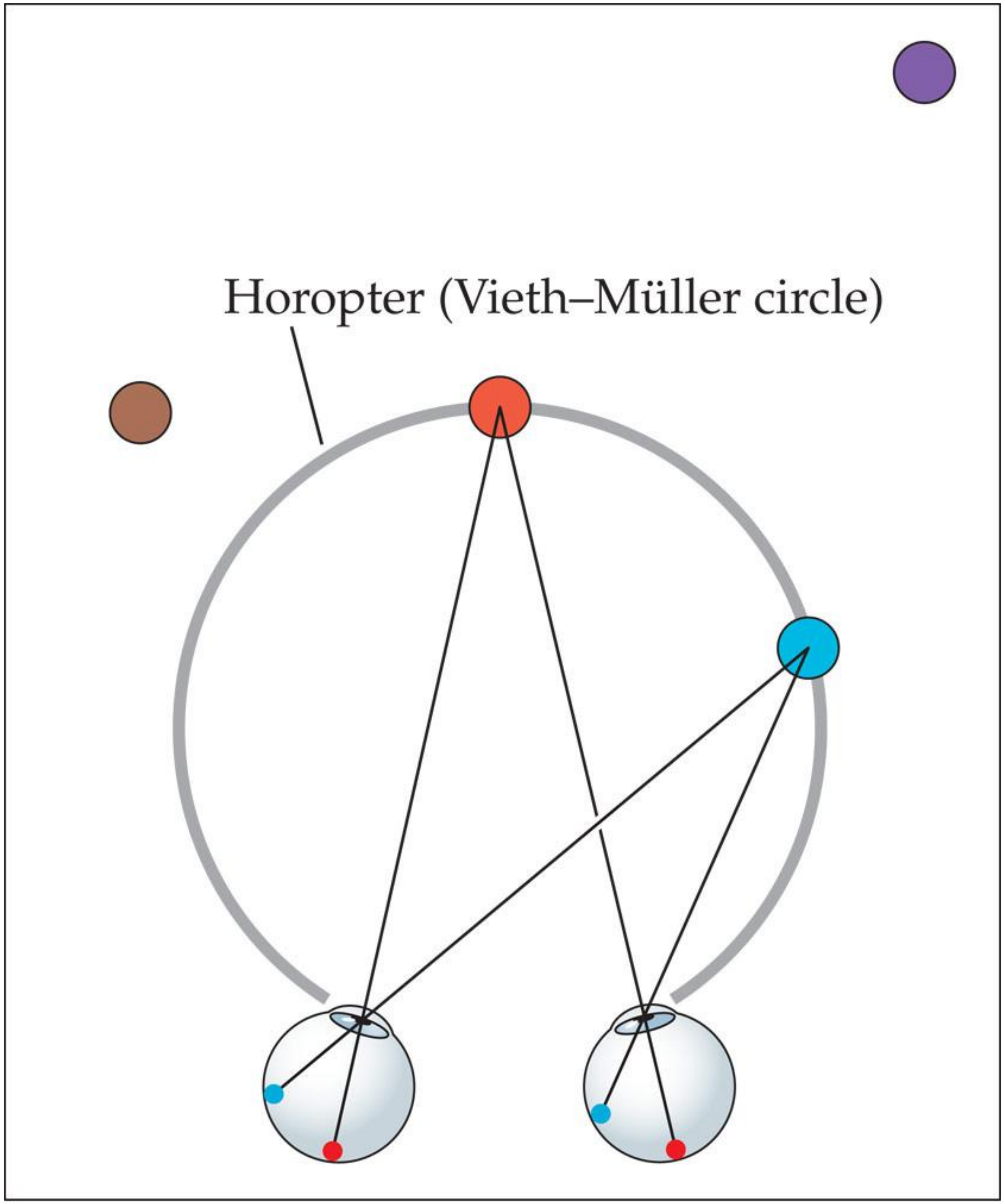
SENSATION & PERCEPTION 4e, Figure 6.24

Horopter: The location of objects whose images lie on the corresponding points. The surface of zero disparity.

Vieth–Müller circle: The location of objects whose images fall on geometrically corresponding points in the two retinas.

- The Vieth–Müller circle and the horopter are technically different, but for our purposes you may consider them the same.

Figure 6.25 Bob is still gazing at the red crayon



SENSATION & PERCEPTION 4e, Figure 6.25

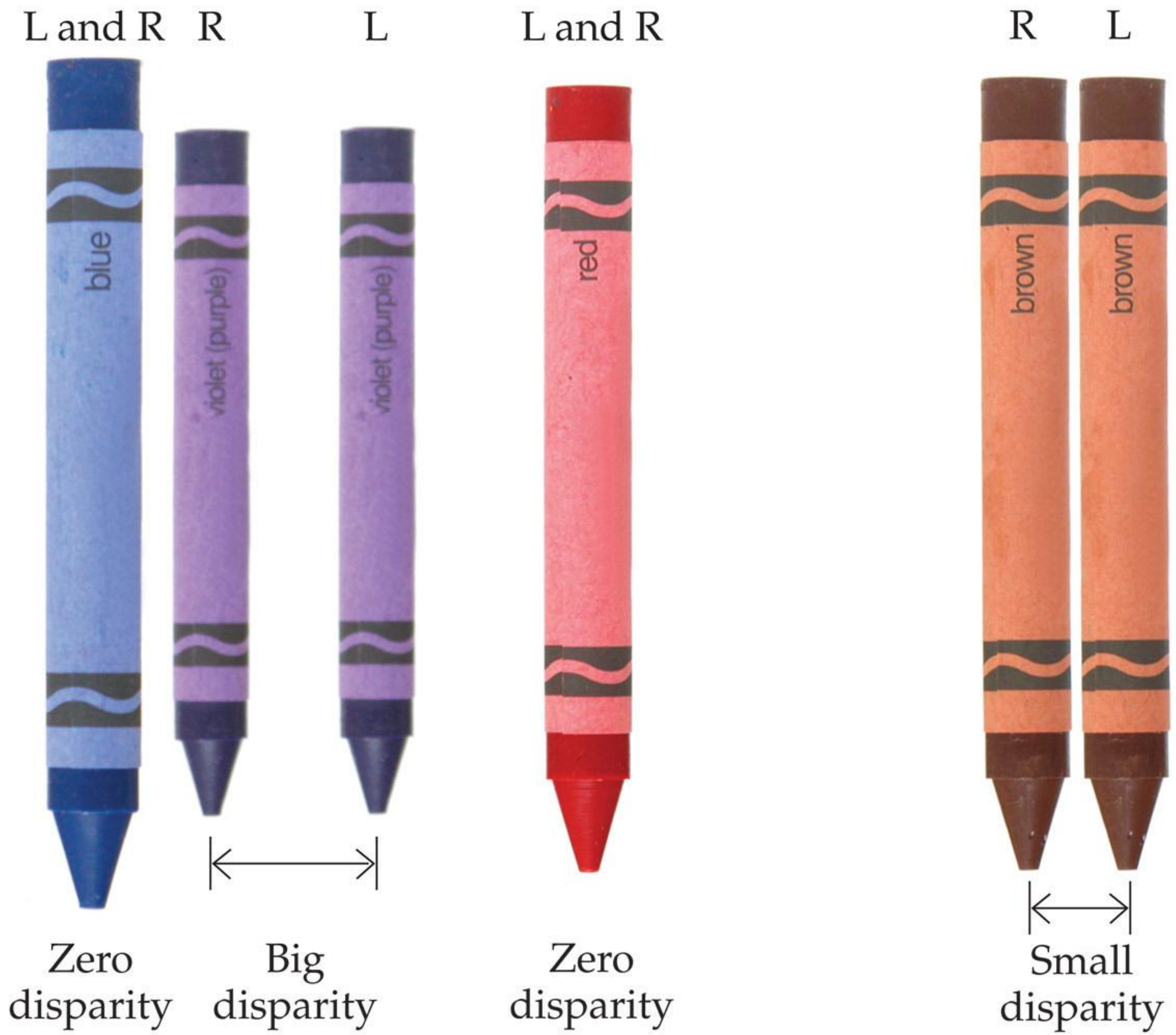
Objects on the horopter are seen as single images when viewed with both eyes.

- Panum's fusional area: The region of space, in front of and behind the horopter, within which binocular single vision is possible.

Objects significantly closer to or farther away from the horopter fall on noncorresponding points in the two eyes and are seen as two images.

- Diplopia: Double vision. If visible in both eyes, stimuli falling outside of Panum's fusional area will appear diplopic.

Figure 6.27 Superposition of Bob's left (L) and right (R) retinal images of the crayons in Figure 6.24, showing the relative disparity for each crayon



SENSATION & PERCEPTION 4e, Figure 6.27

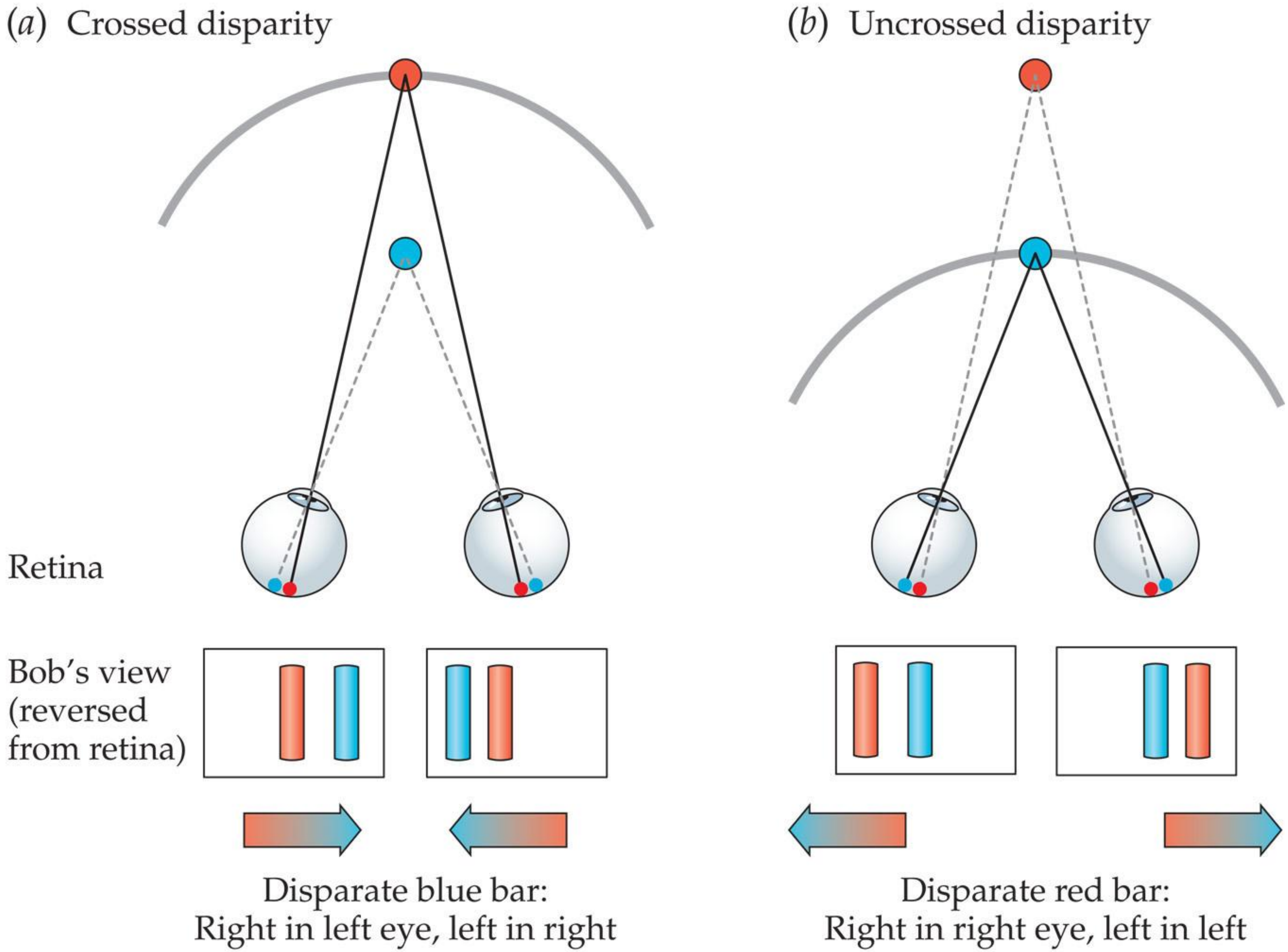
Crossed disparity: The sign of disparity created by objects in front of the plane of the horopter.

- Images in front of the horopter are displaced to the left in the right eye and to the right in the left eye.

Uncrossed disparity: The sign of disparity created by objects behind the plane of the horopter.

- Images behind the horopter are displaced to the right in the right eye and to the left in the left eye.

Figure 6.28 Crossed and uncrossed disparity

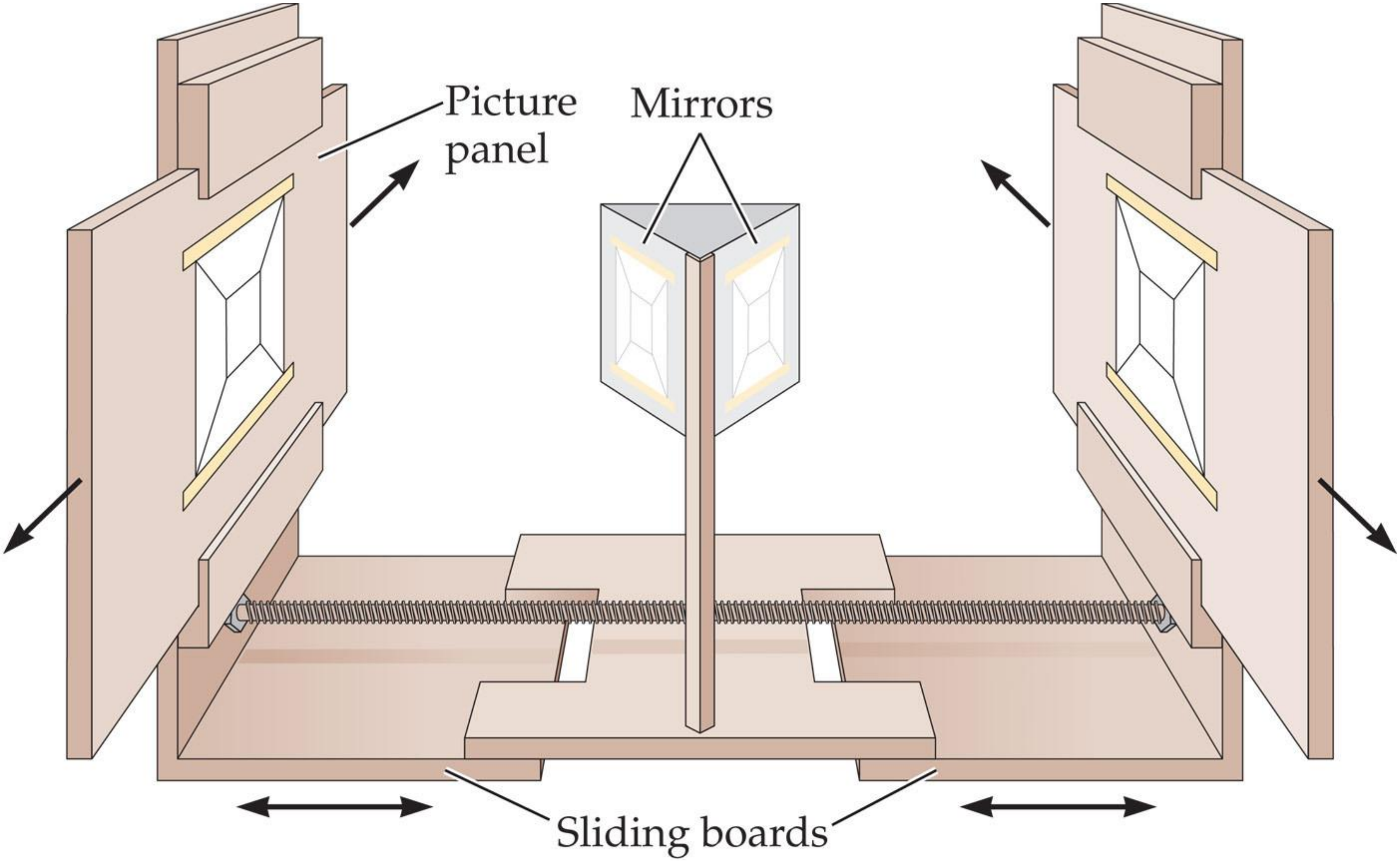


SENSATION & PERCEPTION 4e, Figure 6.28

Stereoscope: A device for presenting one image to one eye and another image to the other eye.

- Stereoscopes were a popular item in the 1900s.
- Many children in modern days had a ViewMaster, which is also a stereoscope.
- The Oculus Rift headset is a more modern example of a stereoscope.

Figure 6.29 Wheatstone's stereoscope



SENSATION & PERCEPTION 4e, Figure 6.29

Figure 6.30 Stereopsis for the masses

(*a*)

(*b*)

SENSATION & PERCEPTION 4e, Figure 6.30

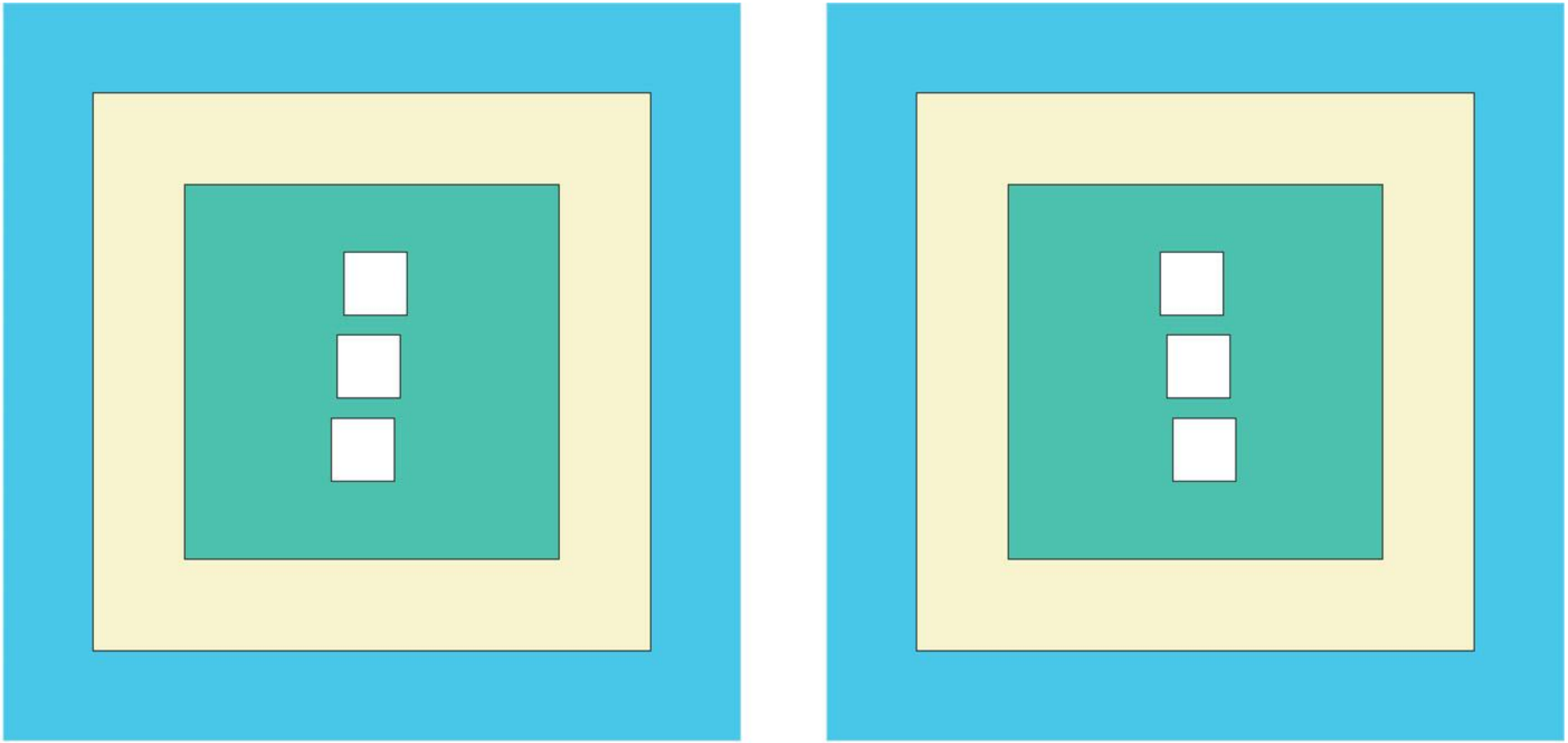
Free fusion: The technique of converging (crossing) or diverging (uncrossing) the eyes in order to view a stereogram without a stereoscope.

- "Magic Eye" pictures rely on free fusion.

Stereoblindness: An inability to make use of binocular disparity as a depth cue.

- Can result from a childhood visual disorder, such as strabismus, in which the two eyes are misaligned.
- Most people who are stereoblind do not even realize it.

Figure 6.31 Try to converge (cross) or diverge (uncross) your eyes so that you see exactly three big blue squares here, rather than the two on the page



SENSATION & PERCEPTION 4e, **Figure 6.31**

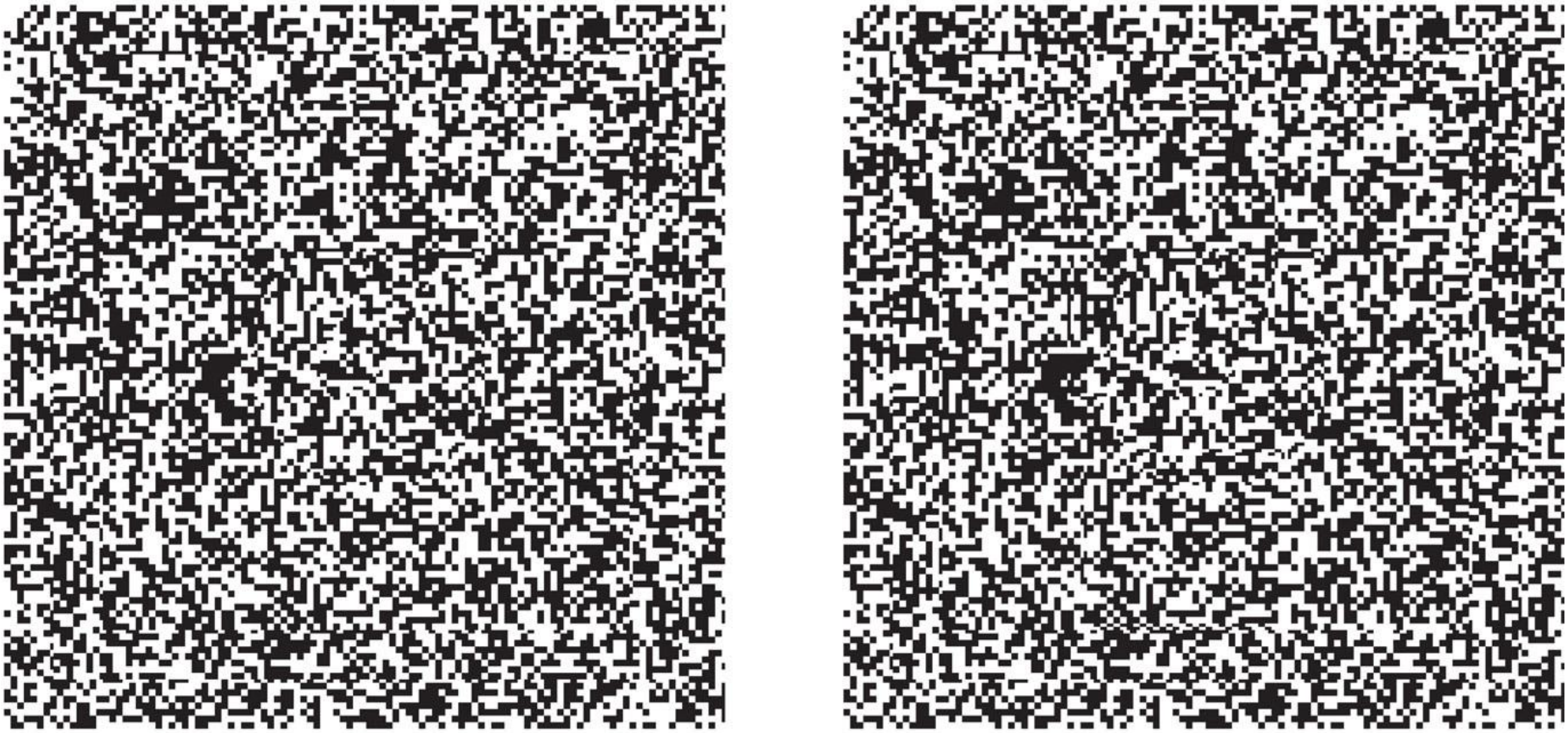
Recovering Stereo Vision

- Susan Berry had strabismus as an infant and never developed stereo vision.
- At age 48, began visual therapy to improve coordination between her two eyes.
- One day she suddenly developed stereo vision!
- Suggests that binocular vision might possibly be developed outside of the normally accepted “critical period.”

Random dot stereogram (RDS): A stereogram made of a large number of randomly placed dots.

- RDSs contain no monocular cues to depth.
- Stimuli visible stereoscopically in RDSs are cyclopean stimuli.
- Cyclopean: Referring to stimuli that are defined by binocular disparity alone.

Figure 6.33 If you can free-fuse this random dot stereogram you will see two rectangular regions: one in front of the plane of the page, the other behind the page



SENSATION & PERCEPTION 4e, **Figure 6.33**

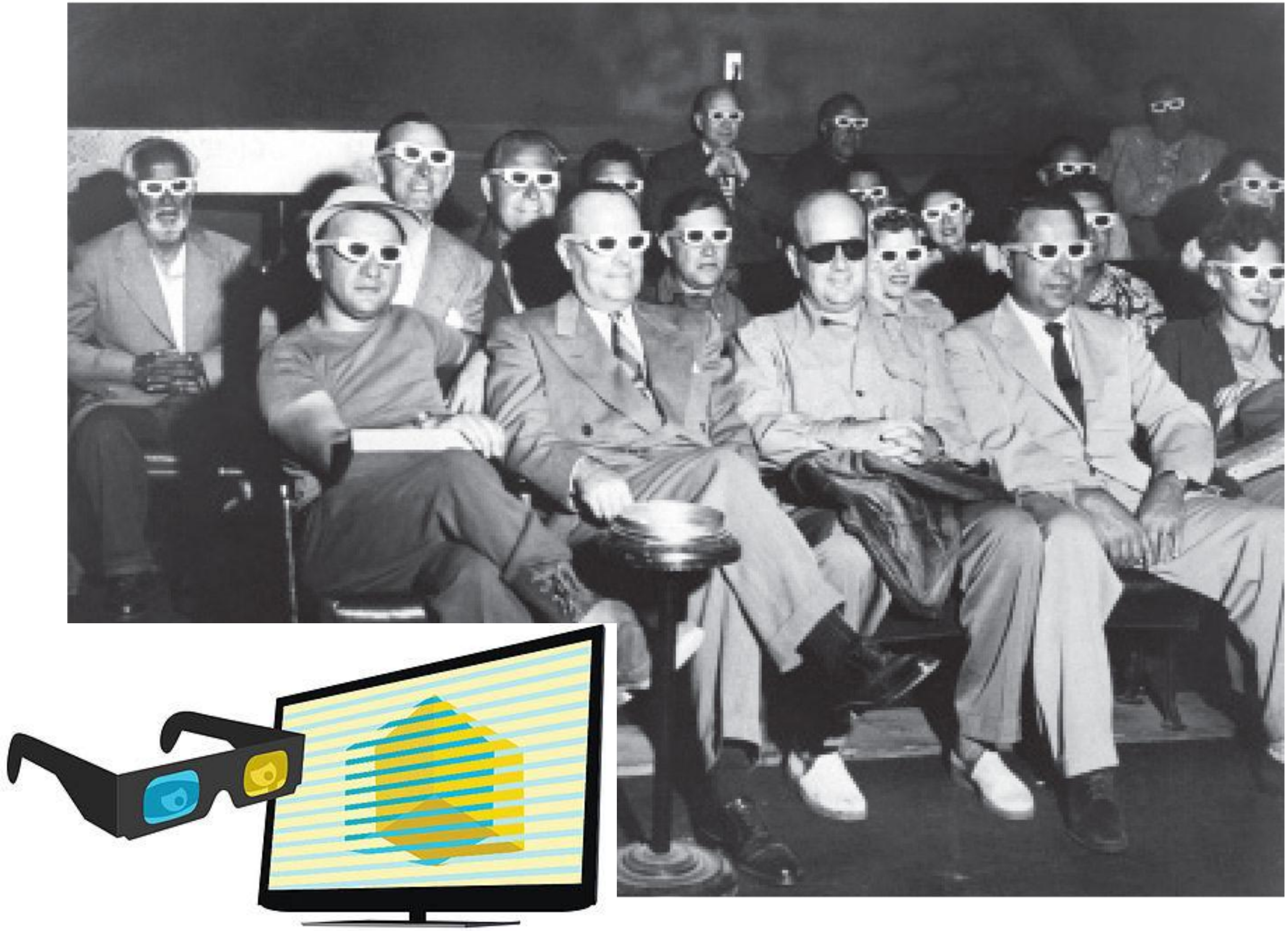
3D movies were popular in the 1950s and 60s and have made a resurgence in recent years.

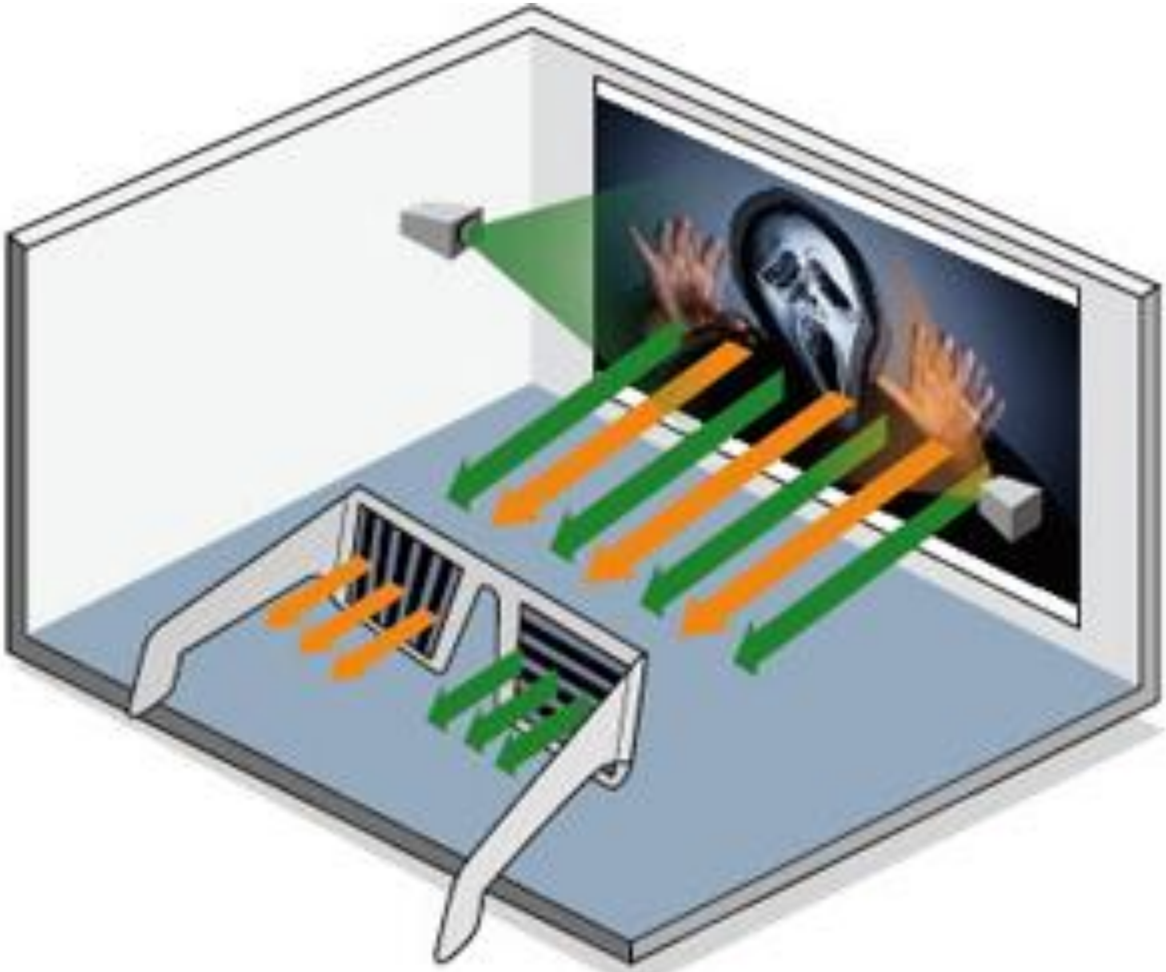
For movies to appear 3D, each eye must receive a slightly different view of the scene (just like in real life).

- Early methods for seeing movies in 3D involved “anaglyphic” glasses with a red lens on one eye and a blue lens on the other.

- Current methods use polarized light and polarizing glasses to ensure that each eye sees a slightly different image.

Figure 6.34 An audience watching a stereo movie in the 1950s

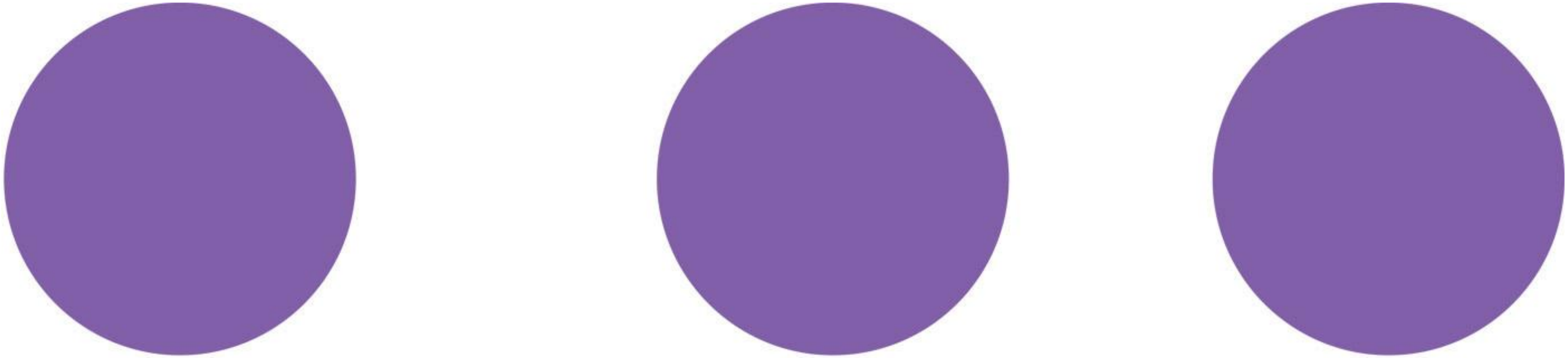




Correspondence problem: In binocular vision, the problem of figuring out which bit of the image in the left eye should be matched with which bit in the right eye.

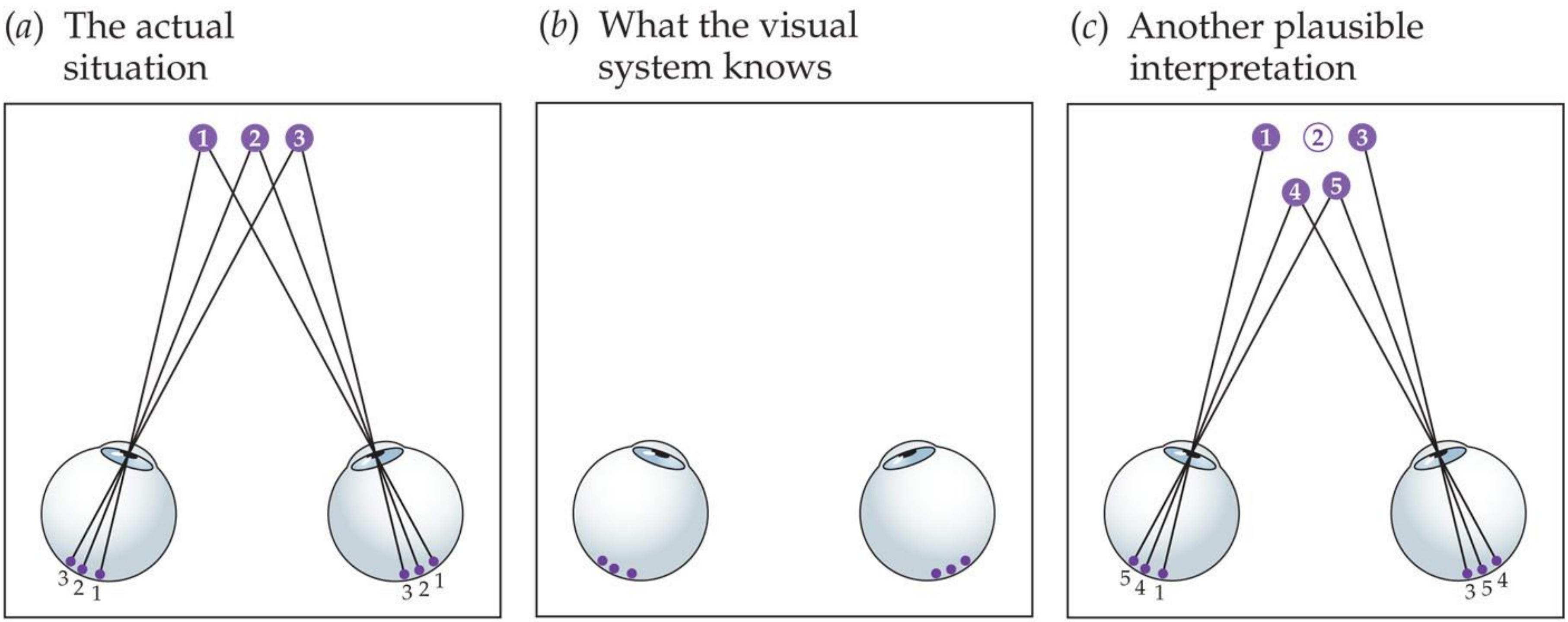
- The problem is particularly vexing in images like random dot stereograms.

Figure 6.37 Is this a simple picture or a complicated computational problem?



SENSATION & PERCEPTION 4e, **Figure 6.37**

Figure 6.38 Interpreting the visual information from the three circles in Figure 6.37



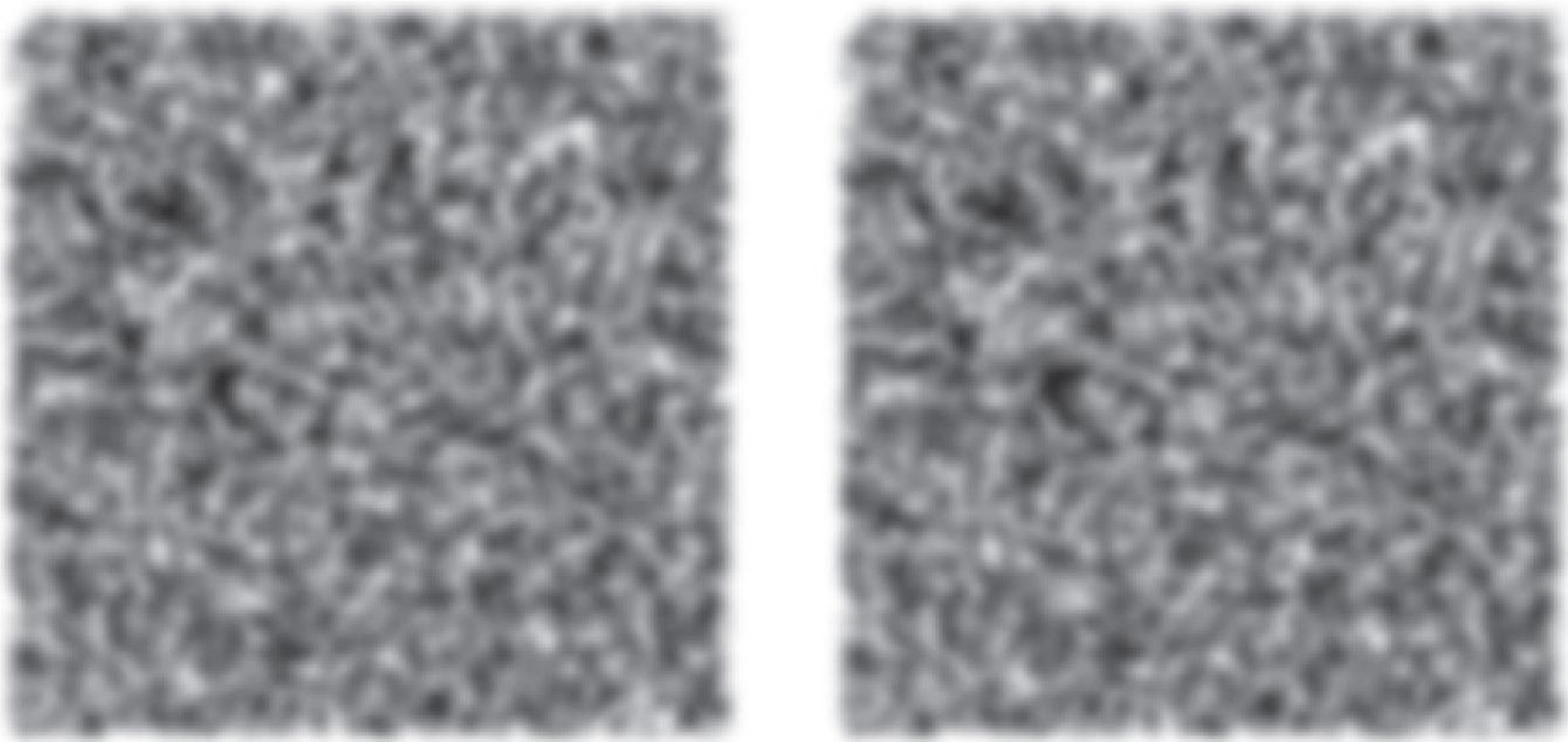
SENSATION & PERCEPTION 4e, Figure 6.38

There are several ways to solve the correspondence problem:

- Blurring the image: Leaving only the low-spatial frequency information helps.

- Uniqueness constraint: The observation that a feature in the world is represented exactly once in each retinal image.
- Continuity constraint: The observation that, except at the edges of objects, neighboring points in the world lie at similar distances from the viewer.

Figure 6.39 A low-spatial-frequency–filtered version of the stereogram in Figure 6.33



SENSATION & PERCEPTION 4e, Figure 6.39

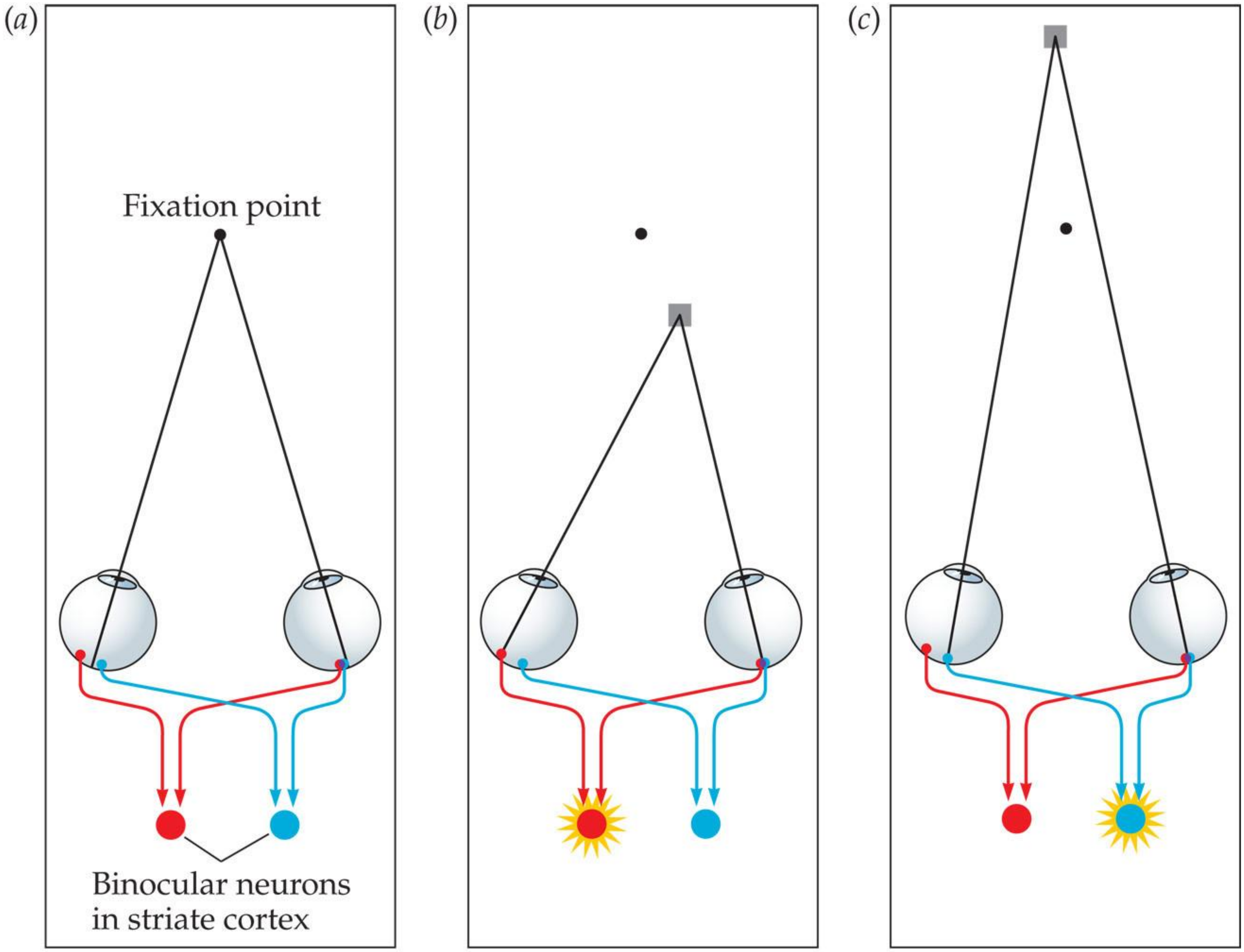
How is stereopsis implemented in the human brain?

- Input from two eyes must converge onto the same cell.

Binocular Vision and Stereopsis

- Many binocular neurons respond best when the retinal images are on corresponding points in the two retinas: Neural basis for the horopter.
- However, many other binocular neurons respond best when similar images occupy slightly different positions on the retinas of the two eyes (tuned to particular binocular disparity).

Figure 6.40 Receptive fields for two binocular-disparity–tuned neurons in primary visual cortex



SENSATION & PERCEPTION 4e, Figure 6.40

Stereopsis can be used as both a metrical and nonmetrical depth cue.

- Some cells just code whether a feature lies in front of or behind the plane of fixation (nonmetrical depth cue).
- Other cells code the precise distance of a feature from the plane of fixation (metrical depth cue).

Combining Depth Cues

The Bayesian Approach, Revisited (first mentioned in Chapter 4).

Like object recognition, depth perception results from the combination of many different cues..

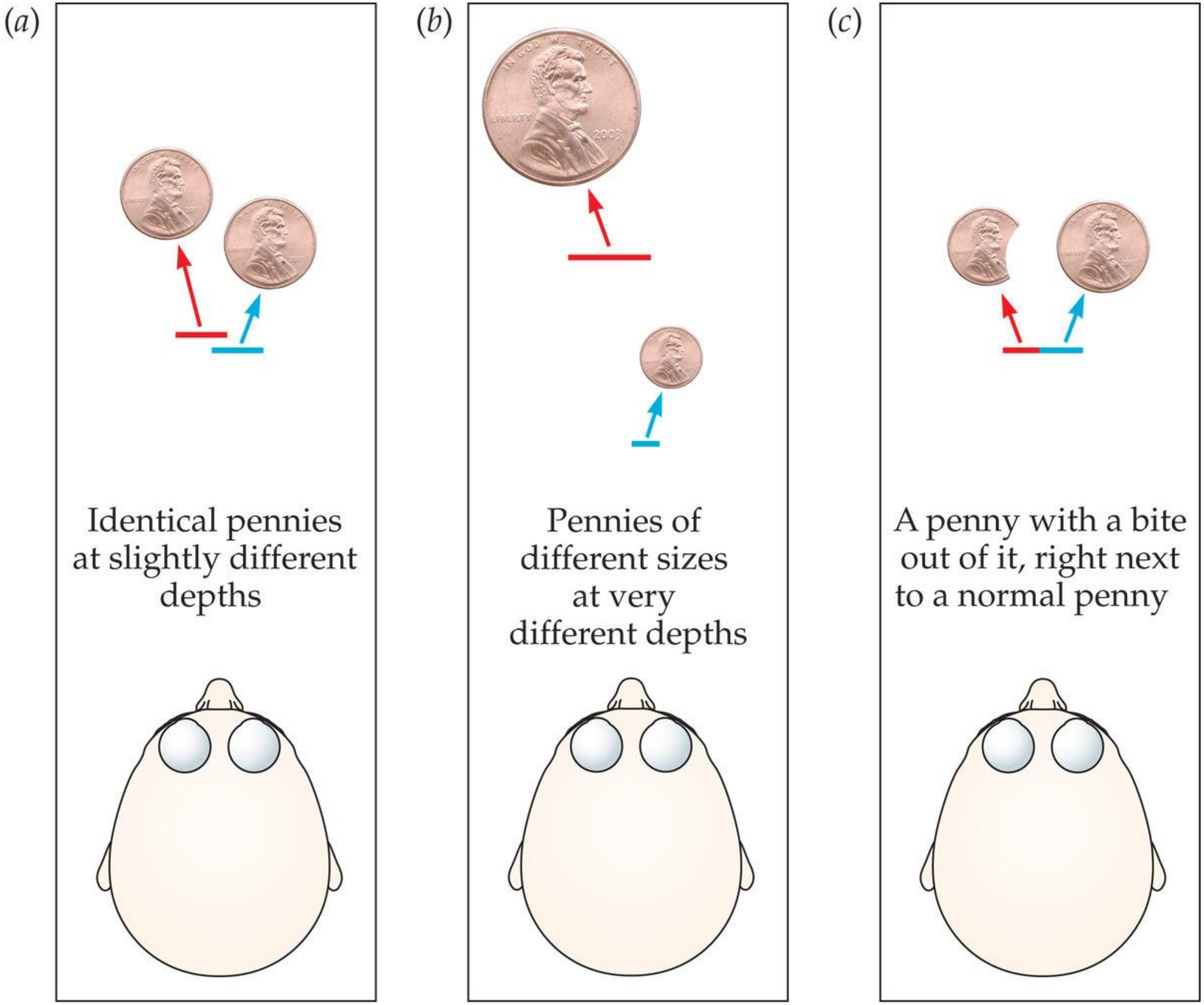
Combining Depth Cues

The Bayesian approach: A way of formalizing the idea that our perception is a combination of the current stimulus and our knowledge about the conditions of the world—what is and is not likely to occur.

- Thus, prior knowledge can influence our estimates of the probability of an event.

Figure 6.41 Retinal image of a simple visual scene

Figure 6.42 Three of the infinite number of scenes that could generate the retinal image in Figure 6.41



SENSATION & PERCEPTION 4e, Figure 6.42

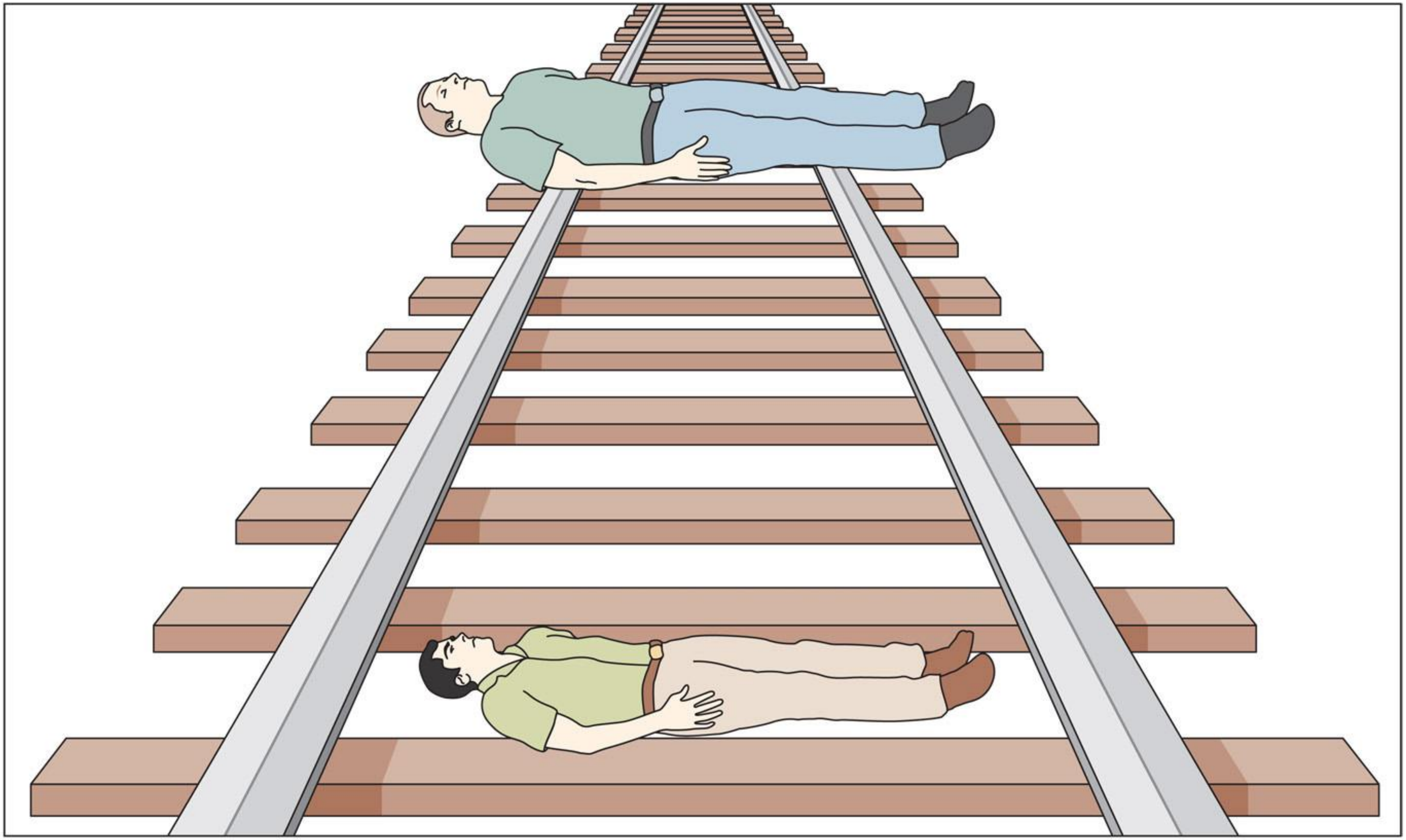
Illusions and the construction of space

- Our visual systems take into account depth cues when interpreting the size of objects.

Figure 6.43 In which image are the two horizontal lines the same length?

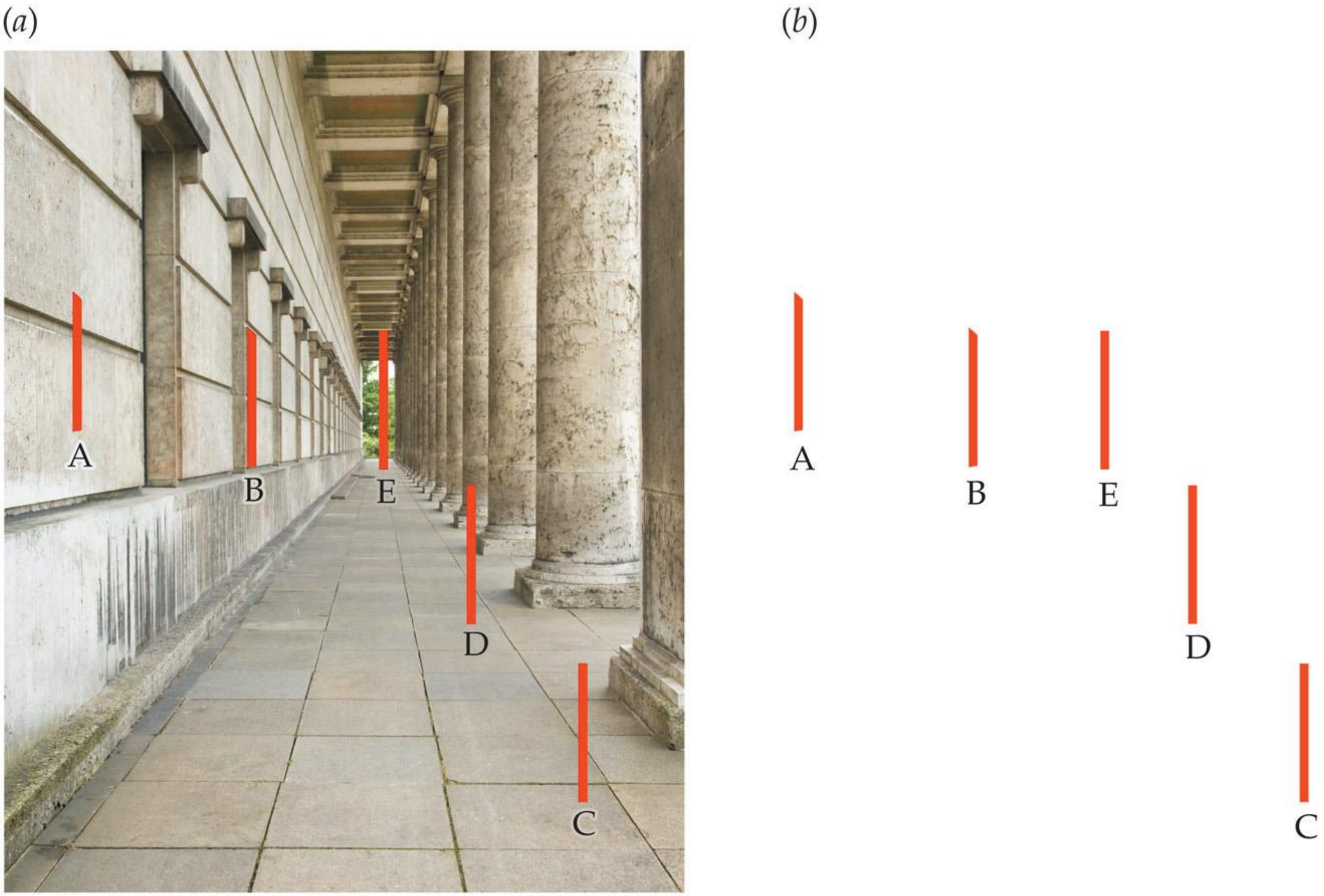
SENSATION & PERCEPTION 4e, Figure 6.43

Figure 6.44 The two people lying across these train tracks are the same size in the image



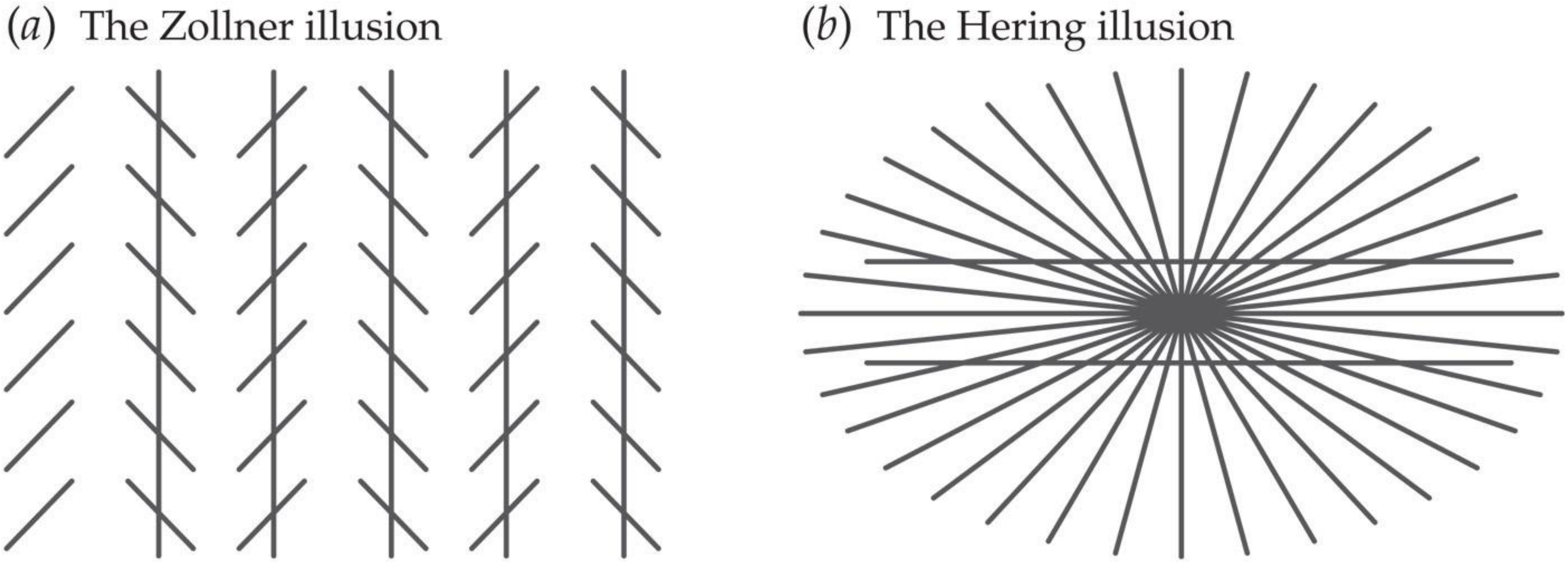
SENSATION & PERCEPTION 4e, Figure 6.44

Figure 6.45 All of the red lines in this illustration (*a*) are the same length, as you can see in (*b*)



SENSATION & PERCEPTION 4e, Figure 6.45

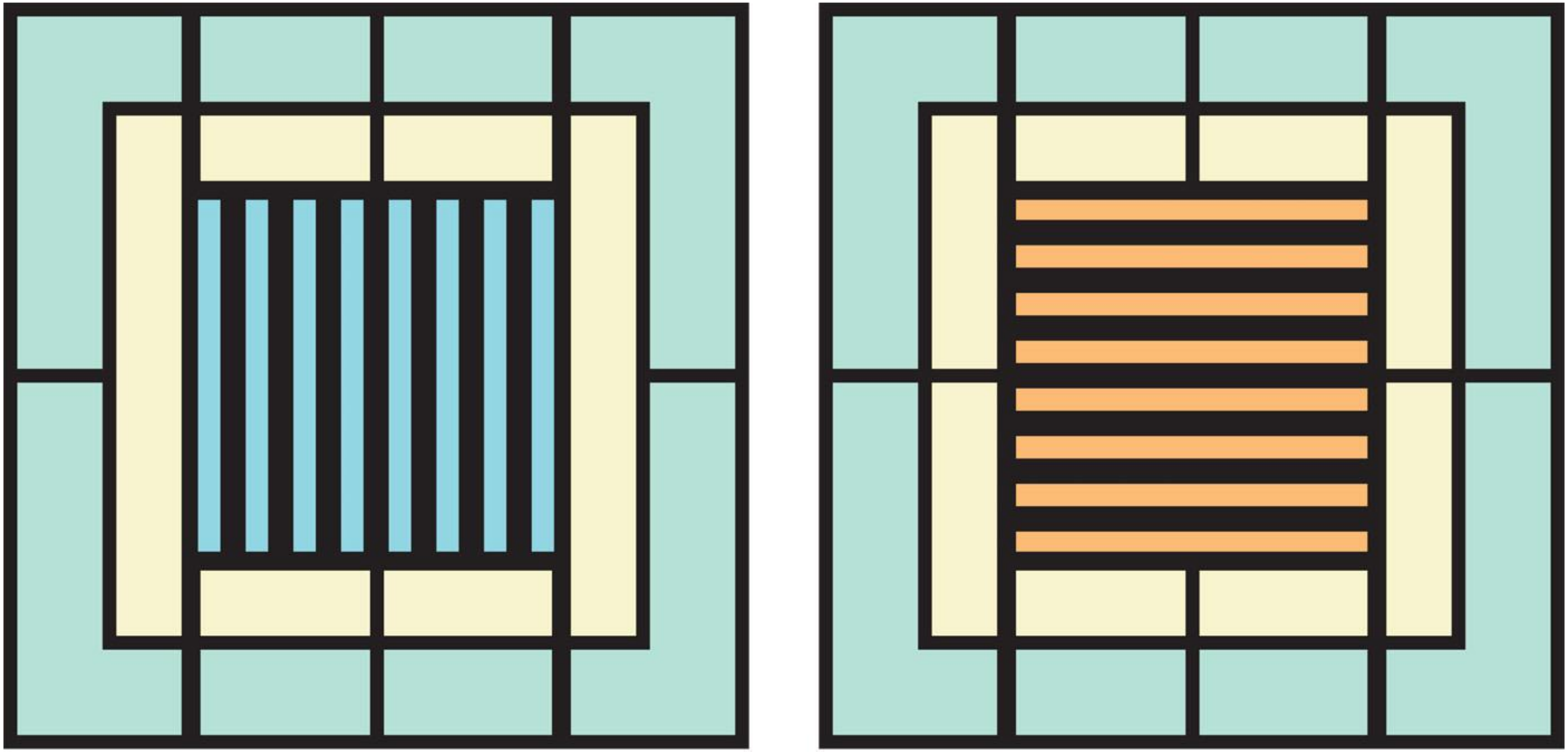
Figure 6.46 Despite their appearance, the vertical lines are parallel in (*a*), as are the horizontal lines in (*b*)



Combining Depth Cues

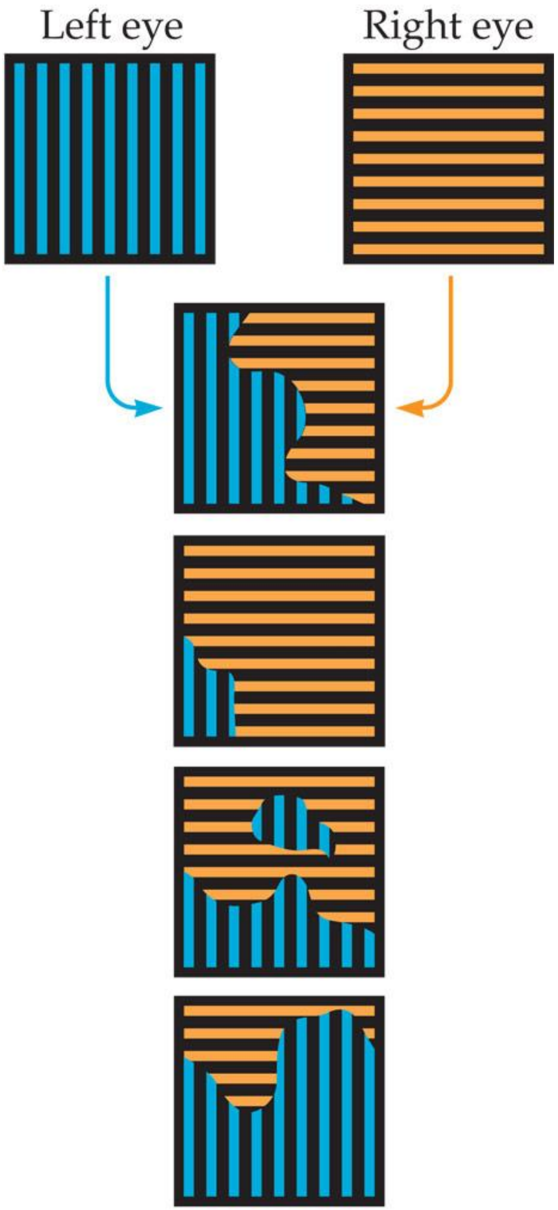
Binocular rivalry: The competition between the two eyes for control of visual perception, which is evident when completely different stimuli are presented to the two eyes.

Figure 6.47 Binocular rivalry



SENSATION & PERCEPTION 4e, Figure 6.47

Figure 6.48 If blue vertical bars are shown to one eye while orange horizontal bars are shown to the other, the two stimuli will battle for dominance



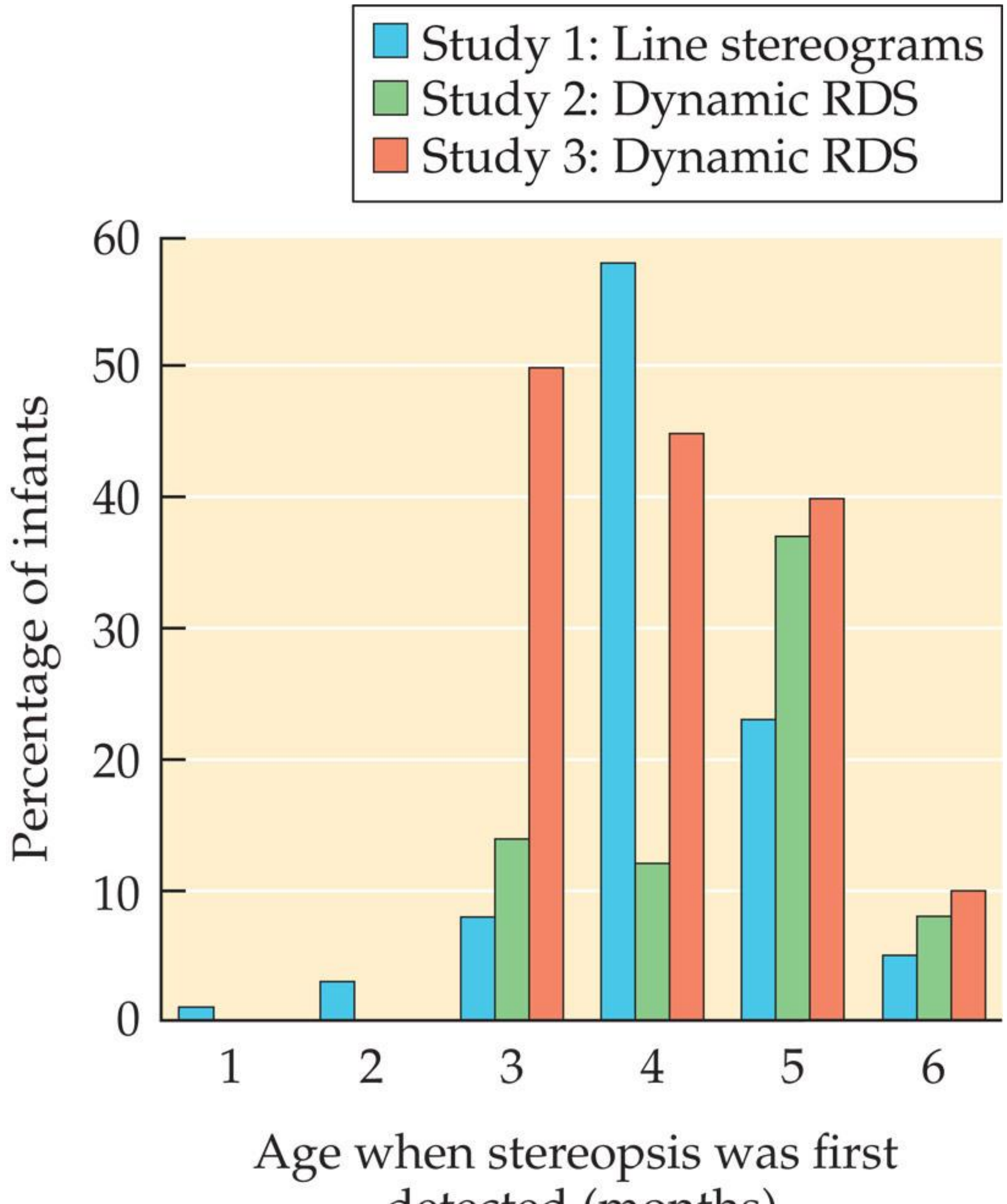
SENSATION & PERCEPTION 4e, Figure 6.48

Stereoacuity: A measure of the smallest binocular disparity that can generate a sensation of depth.

Dichoptic: Referring to the presentation of two stimuli, one to each eye. Different from binocular presentation, which could involve both eyes looking at a single stimulus.

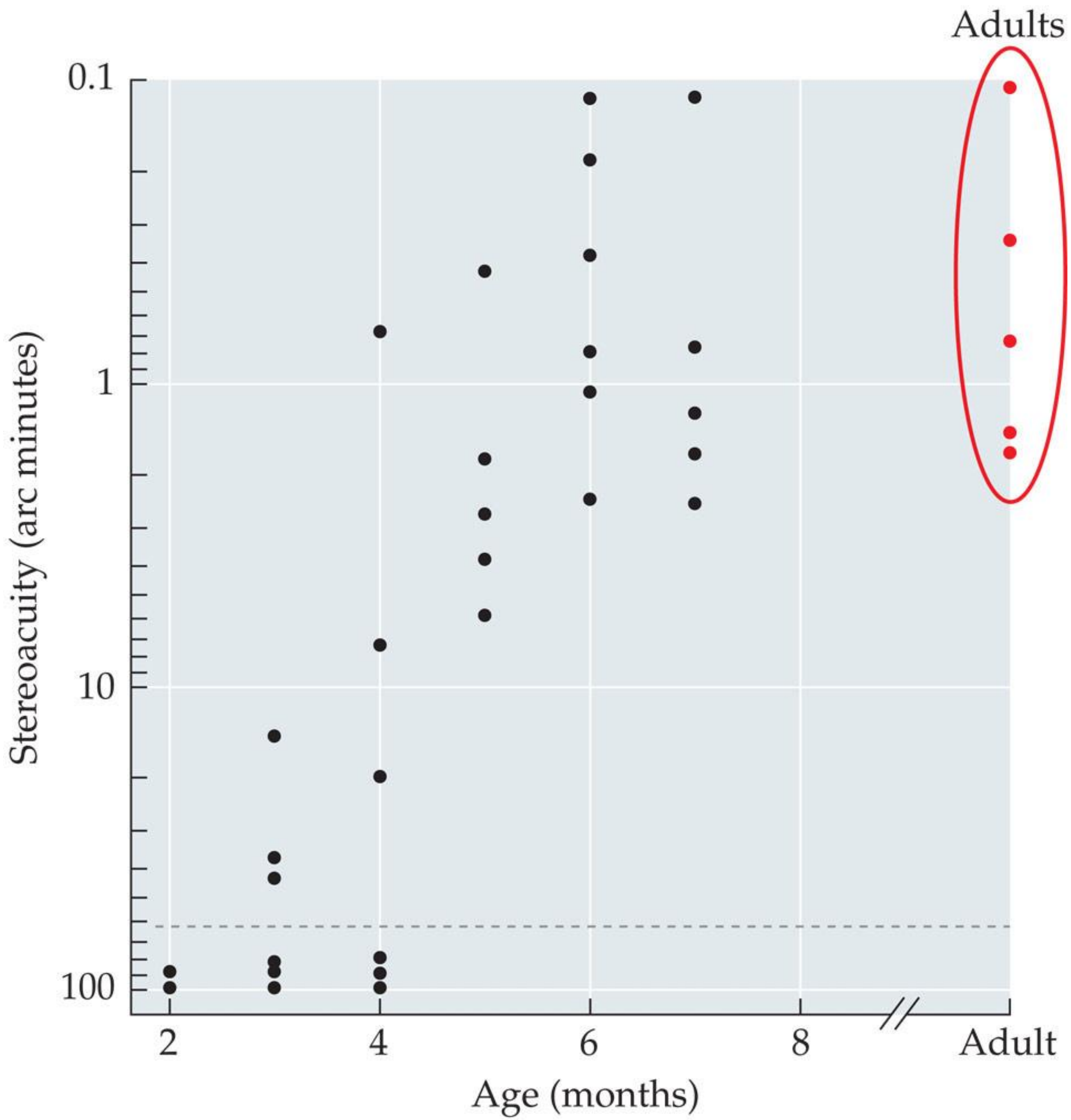
- Stereoacuity is often tested using dichoptic stimuli.

Figure 6.50 The onset of stereopsis



SENSATION & PERCEPTION 4e, Figure 6.50

Figure 6.51 The development of stereoacuity



SENSATION & PERCEPTION 4e, Figure 6.51

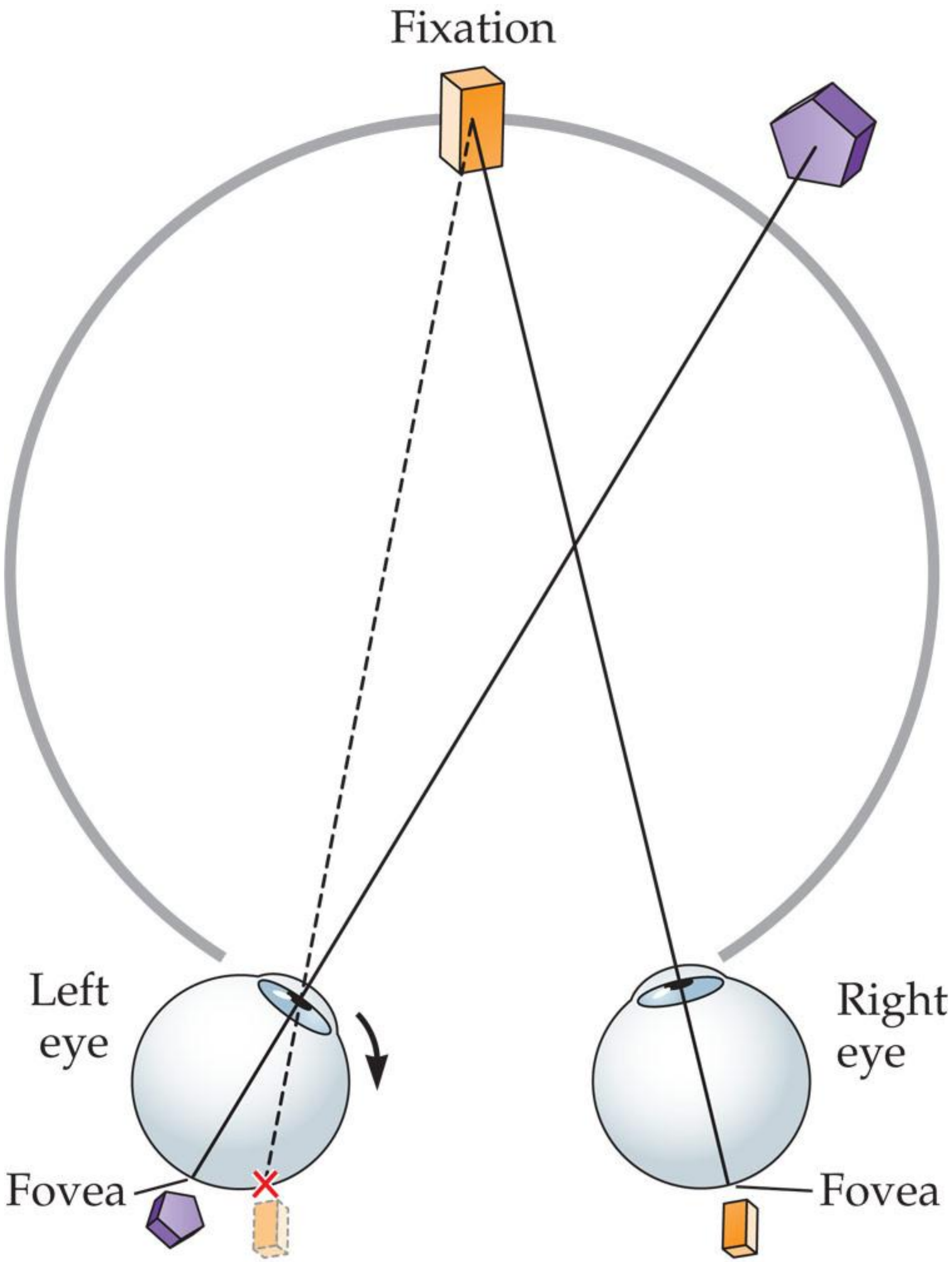
Abnormal visual experience can disrupt binocular vision:

- Critical period: In the study of development, a period of time when the organism is particularly susceptible to developmental change.

Strabismus: A misalignment of the two eyes such that a single object in space is imaged on the fovea of one eye, and on the nonfoveal area of the other (turned) eye.

Suppression: In vision, the inhibition of an unwanted image.

Figure 6.53 Left esotropia

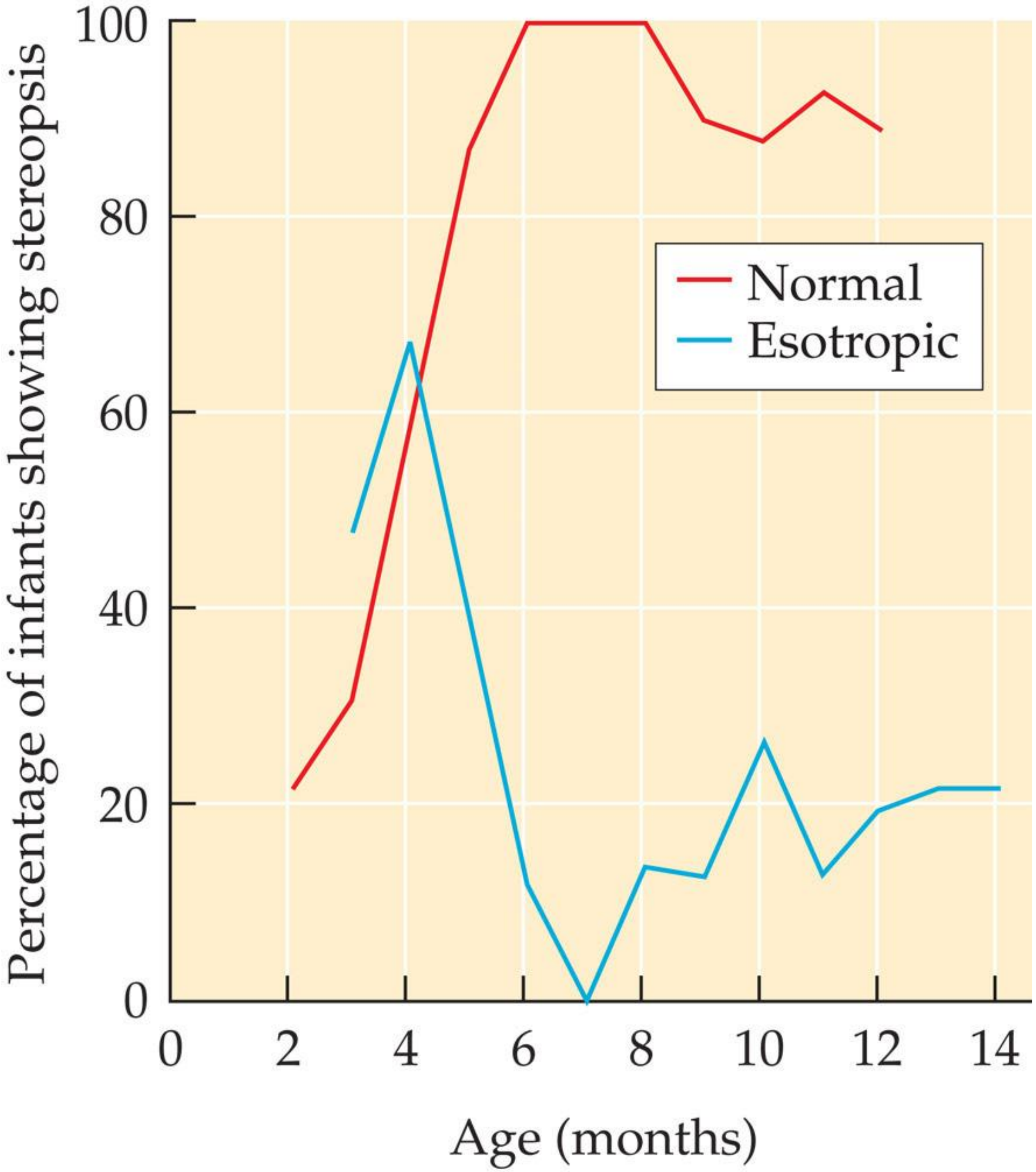


SENSATION & PERCEPTION 4e, Figure 6.53

Esotropia: Strabismus in which one eye deviates inward.

Exotropia: Strabismus in which one eye deviates outward.

Figure 6.54 Development of stereopsis in normal infants (red line) and in esotropes (blue)



SENSATION & PERCEPTION 4e, Figure 6.54