

Clinical Visual Optics OPTO 223

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Week VII & VIII

Outline of weeks VII & VIII

- Light and dark adaptation
- Mechanisms of light and dark adaptation
- Aftereffects
- Contrast
- Brightness
- Absolute Threshold & seeing curve



Light and Dark adaptation

Introduction

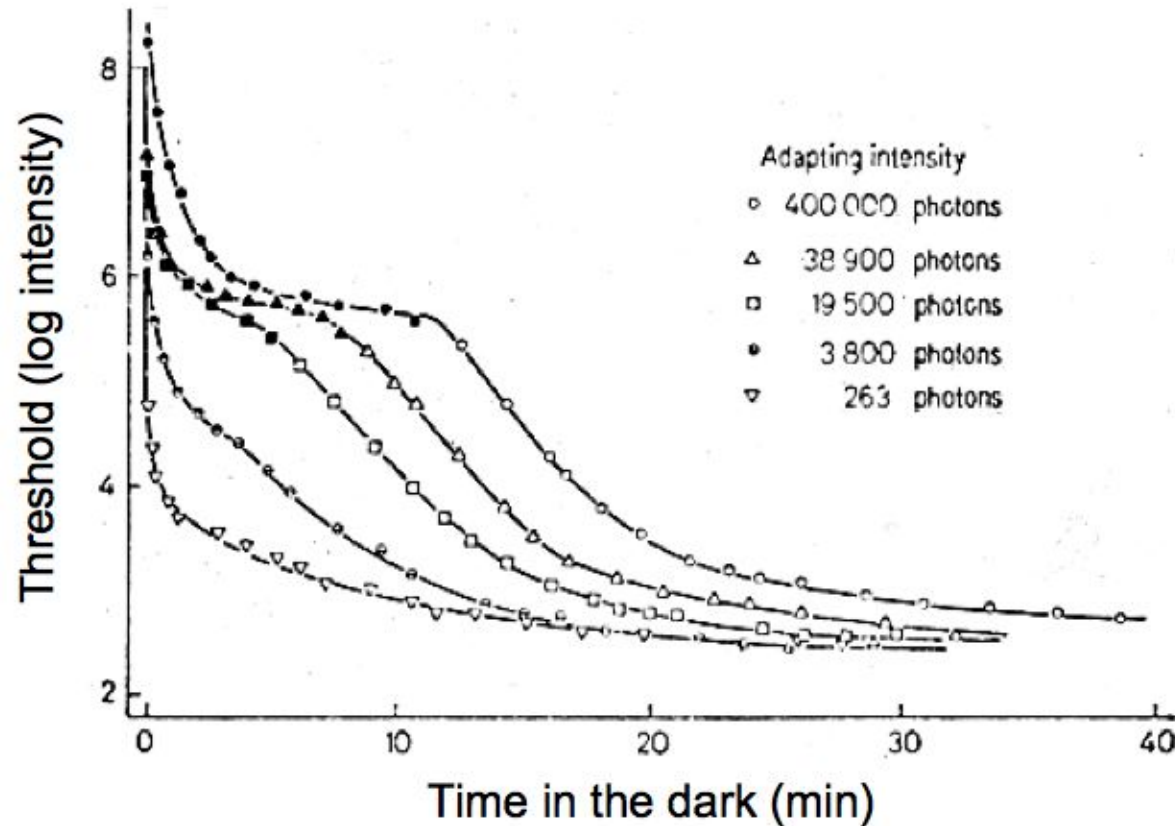
- One of the most important jobs (perhaps second only in importance to transduction by the photoreceptors) that the retina performs is light and dark adaptation. A fundamental challenge that is common to the signals carried by all visual neurons is that they must remain sensitive as the ambient light intensity varies over many orders of magnitude. There's well over a million-fold change in intensity between a starlit night and a bright sunny day at the beach. This is a challenge for the nervous system because neurons have a very limited response range: -80mV to +50 mV of graded potential in the non-spiking cells of the retina, or 0 to about 200 spikes per second for ganglion cells. The retina solves this problem by adapting to the ambient level of illumination. If the light level changes by a relatively small amount, then the visual system compensates for the change almost immediately. However, if the light level changes by a lot, then the eye takes a long time to re-adjust.

Surface luminance levels

- Sunlight: 10^5 candelas/meter² (cd/m²)
 - Approx. 10^{22} photons/m²/sec
 - 3%-90% of photons are reflected as luminance
 - 3% for black surfaces, 90% for white surfaces
 - Only some of the reflected photons enter the pupil of eye
- Indoor lighting, CRTs: 10^2 cd/m²
- Moonlight: 10^{-1} cd/m²
- Starlight: 10^{-3} cd/m²
- The eye can adjust to changes in light level by a factor of 100,000,000!
- Yet firing rates only typically range from 0-400Hz.

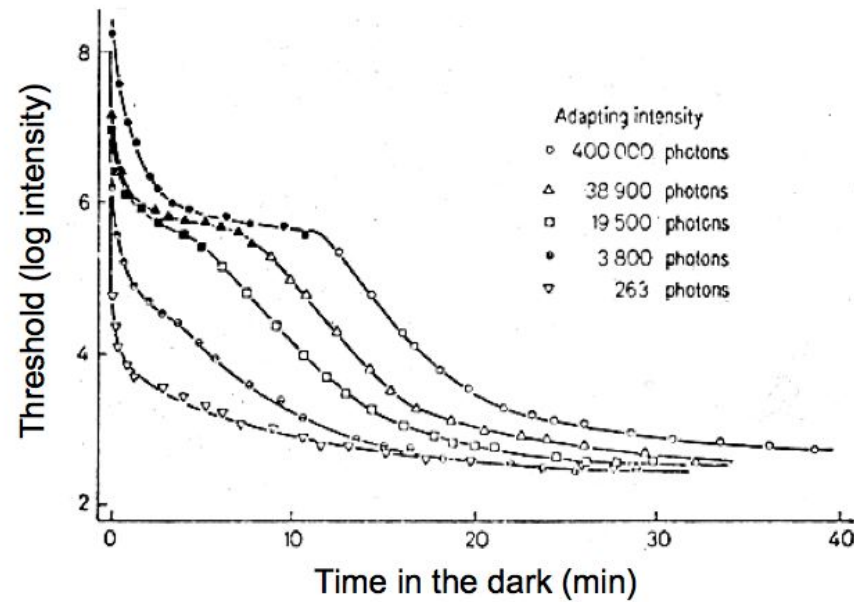
- You must have noticed this phenomenon. When you are outside on a sunny day, and then walk into a darkened room, at first you can hardly see anything. For example, if people come into a darkened movie theater they are constantly tripping and stumbling over their seats on the way in. However, after being in the theater for a while, you adjust to the lower light level of the theater, and it becomes very easy to see your way around. This phenomenon is called *adaptation*, and the particular direction I just mentioned, where you adjust from the light to the dark, is called *dark adaptation*.

Dark adaptation



- This figure shows the results of an experiment that quantifies this common experience. A subject was exposed to a bright adapting light, and then (while in the dark) their threshold was measured for detecting a very weak test light at various times after exposure to the bright light. The test light was violet in color. Filled symbols correspond to when the violet spot had threshold intensity and the violet color was evident at threshold. Open symbols mean that the violet color was not noticeable. Each curve corresponds to a different light level for the adapting light. The

Dark adaptation



- There are two very striking features. First, the data fall naturally into two parts - this double-branching is due to the transition from cones to rods. Second, the recovery is a fairly slow process - the subject's sensitivity to the light flash continued to increase over a very long time. In fact, after exposure to a very bright light, such as the subject was exposed to in the top curve of the figure, the subject did not fully recover to the best value for nearly forty minutes in the dark.

Light adaptation in the retina

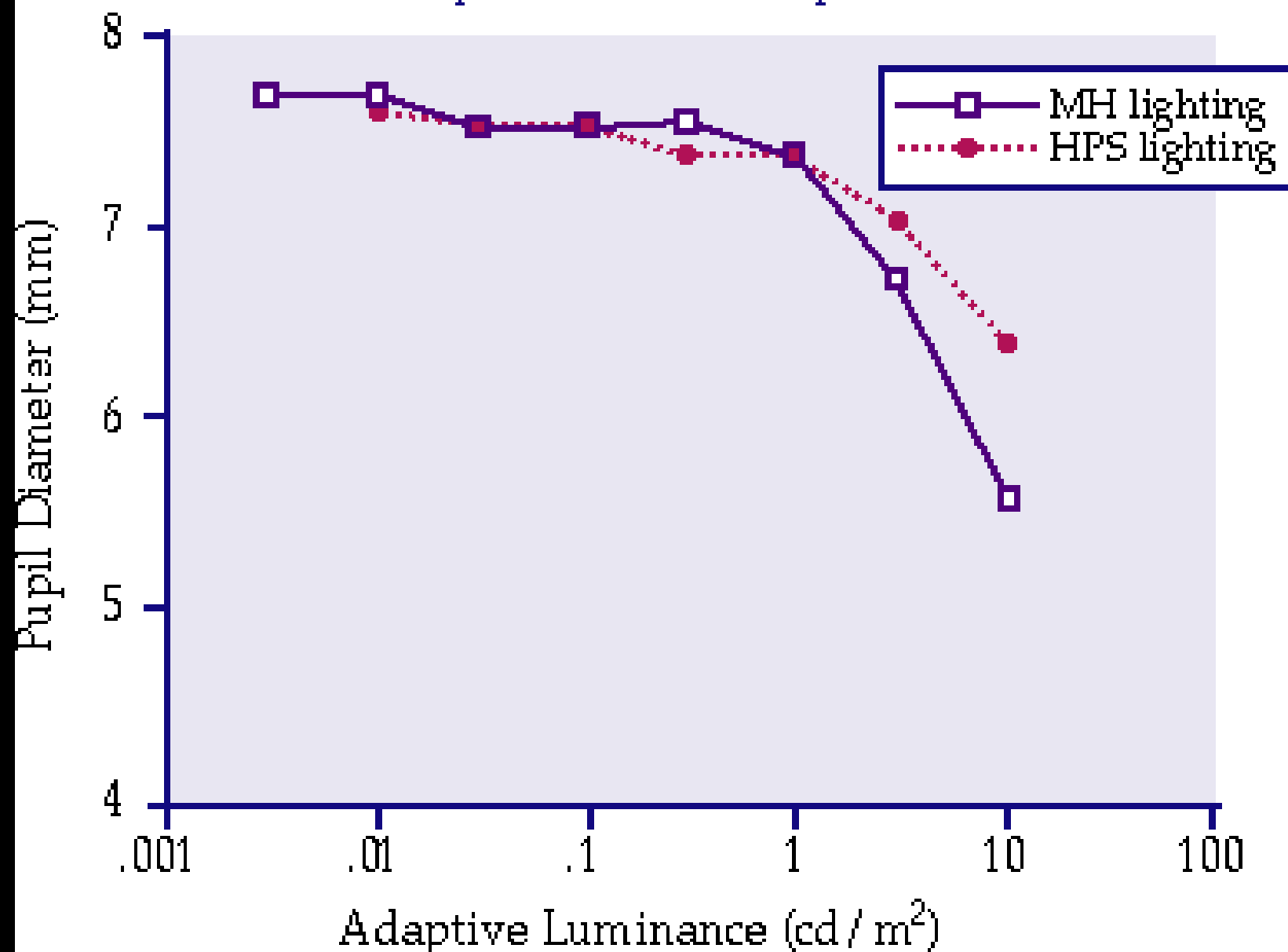
- The basic mechanisms responsible for controlling light/dark adaptation are quite complex.
- Part of the mechanism is the switch-over from rods to cones. But even within the pure rod (or pure cone) regime there is still significant adaptation.
- Only a small part of the adaptation is due to changes in pupil size; the pupil diameter only ranges from 1 or 2 mm to about 8 mm, for an increase in area (or total light entering the eye) of a factor of 16-64. A lot of the adaptation occurs in the photoreceptors themselves.
- Part of the adaptation within the photoreceptors is due to photopigment bleaching - less photopigment available at high light levels results in weaker responses to light increments at those high light levels. Adaptation within the photoreceptors is also helped along by feedback from horizontal cells onto the photoreceptors to control the responsiveness of the photoreceptors. If the horizontal cells respond strongly then they tell the photoreceptors to turn it down a bit.

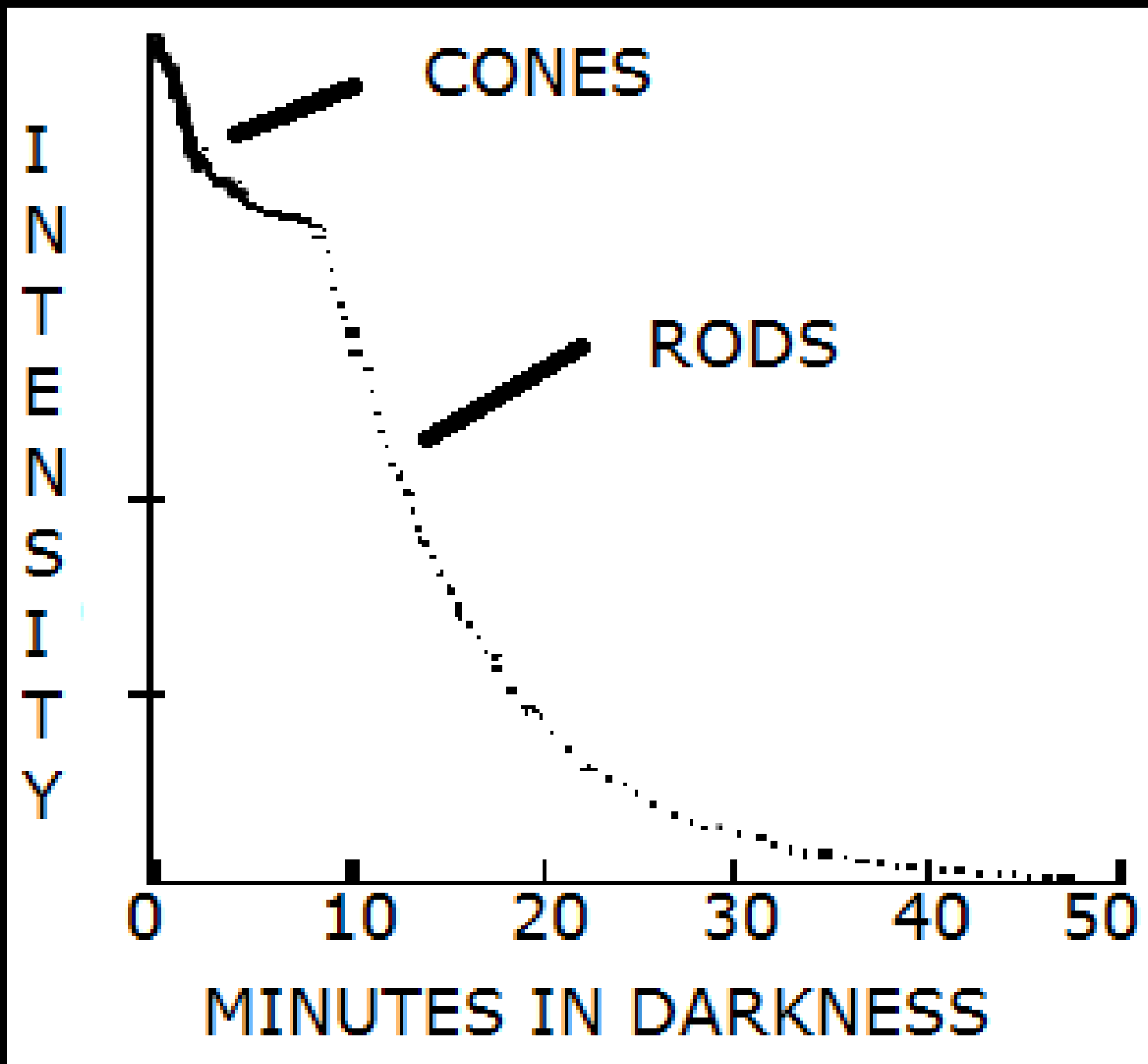
Mechanisms of light/dark adaptation

- Pupil size
- Switchover between rods and cones
- Bleaching/ regeneration of photopigments
- Feedback from the horizontal cells to control the responsiveness of photoreceptors.



Monocular Pupil Size vs. Adaption Luminance





Differences between rod and cone vision

- There are a number of differences between daylight vision (*photopic* light levels, using your cones) and low-light levels (*scotopic* light levels, using rods).
- The first, higher branch of the above dark adaptation curves involves your photopic or cone system. Cones are most numerous at the fovea, and sensitivity is best there for photopic vision. Cones come in three types, responsible for your ability to discriminate colors . Thus, in the above curves the violet color of the test light was evident for the photopic/cone portion of the curve.
- Photopic spectral sensitivity peaks at 560 nm, so that in photopic vision a yellow flash will be easiest to detect, and will appear the brightest. Cones are fast responders, so in the photopic range your ability to see fast flicker is high.

Differences between rod and cone vision

- Finally, cones are more sensitive to stimuli passing through the center of the pupil than passing through the edge of the pupil (this is called the *Stiles-Crawford effect*) because the cones are positioned and oriented toward the center of the pupil. For rods (scotopic vision, the second branch of the dark adaptation curves) we see different effects: sensitivity is highest in the parafovea (around the fovea), spectral sensitivity peaks at about 507 nm (so that green objects appear brightest), rods are slow (and can only detect very slow flicker) and show no Stiles-Crawford effect. At twilight light levels (*mesopic* light levels), both cones and rods are available for vision.

Afterimages



- After being exposed to a bright light (e.g., flashbulb) you experience an afterimage, that is a (sometimes blueish) spot in your visual field. What causes the afterimage?
- The afterimage moves with you when you move your eyes. Why? After exposing a bit of your retina to bright light, the retinal becomes light adapted, but *only where the light fell*. In other words, light adaptation is local to the region of the retina that was stimulated. If after adapting to a small, bright light, you then look at a bright uniform field (e.g., a white wall), the adapted retina will be less sensitive, and that portion of the wall will look darker.
- This is called a *negative afterimage*. On the other hand, if you instead look at a very dark uniform field, there will again be an afterimage, but it will appear lighter than the background. This is called a *positive afterimage*, and the theory is that the adapted retina is signalling a weak stimulus when no stimulus is present, often referred to with the wonderful term: *dark light*.

Consequences for studying the rest of the visual system

- Light/dark adaptation is a big effect and it happens at the front end of the visual system. One of the important consequences of this is that we need to be very clever to avoid effects of light/dark adaptation when we want to study later stages of visual processing. Let's say we are recording from a retinal ganglion cell. If we use visual stimuli that vary between being very bright and very dark, then we will see a lot of light adaptation (that is mostly due to processing in the photoreceptors and horizontal cells).

- We can, however, safely ignore light adaptation by restricting our choice of visual stimuli to intensity distributions that modulate (transiently) about a fixed mean/background intensity. Examples are moving or flickering grating patterns and moving or briefly flashed bars that are either brighter or darker than the mean. The mean/background light intensity is typically chosen to be half the brightest intensity attainable on the display device.

Contrast

Observe the following pictures, and tell where is the sun?
approximate the time of the day that is taken.

Justify your answer! Compare which picture was easier to
determine the time of day





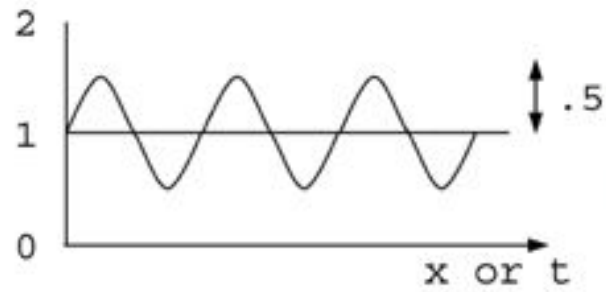
Contrast

- You probably could tell the location of the sun in both pictures, but it was much easier and obvious that the second picture was much easier to determine the time from it.
- The first picture was harder because its contrast was 50% less than the second.
- Higher contrast means the ability to distinguish different hues/ shades of colours and more details the picture bears.
- However, what would be a quantitative and scientific way to define contrast ?

Contrast

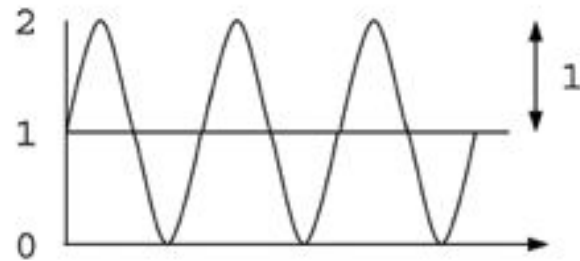
Contrast is the percent change in the light intensity in an image relative to the average light intensity.

Contrast



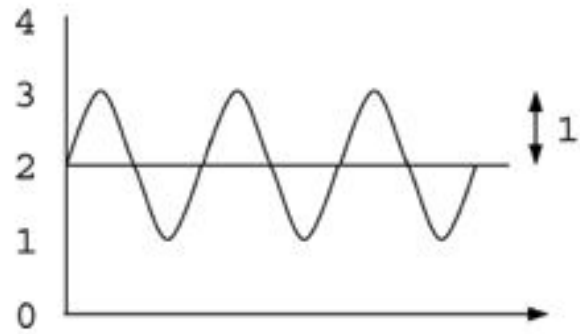
mean = 1
contrast = 50%

Intensity



mean = 1
contrast = 100%

$$\text{contrast} = \frac{\text{amp of modulation}}{\text{mean}}$$

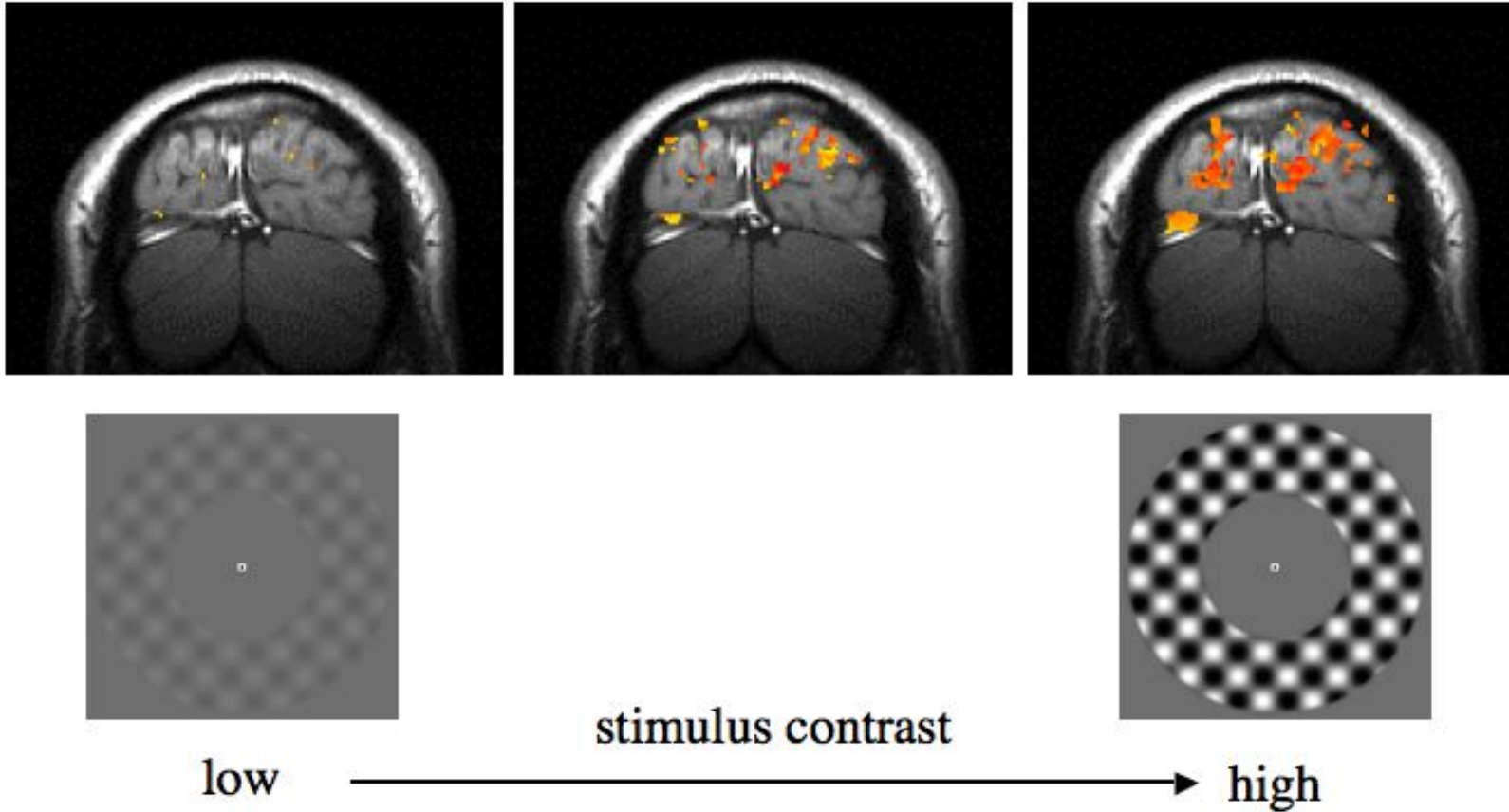


mean = 2
contrast = 50%

Time or space

- The contrast of a sinusoidal grating stimulus is defined as the difference between the highest and lowest intensities, divided by the sum of the two, or equivalently as the amplitude of modulation divided by the mean.
- The maximum possible contrast is 1 (100%), which is attained when the lowest intensity is zero and the highest intensity is twice the mean/background intensity.
- The contrast can go no higher than this, as this would imply having the intensity of the darkest portions of the stimulus go negative, which is physically impossible.
- The contrast of a stimulus is changed by scaling the image intensities above and below the fixed mean/background intensity.

Responses increase with contrast



Neural responses in most of the visual system increase with contrast. The figure above, for example, shows that activity in visual cortex increase with contrast.

Summary

There are 4 mechanisms underlying light/dark adaptation:

- Pupil size
 - Switchover from rods to cones
 - Bleaching/regeneration of the photopigments
 - Feedback from the horizontal cells to control the responsiveness of the photoreceptors
-
- The combined effect is to make the retina more sensitive at low light levels and less sensitive at high light levels. This has important consequences for perception as we shall see next as we study **brightness**.

Brightness

- The retina does not simply record light intensities. Rather, retinal responses depend on the surrounding context (center-surround receptive field):

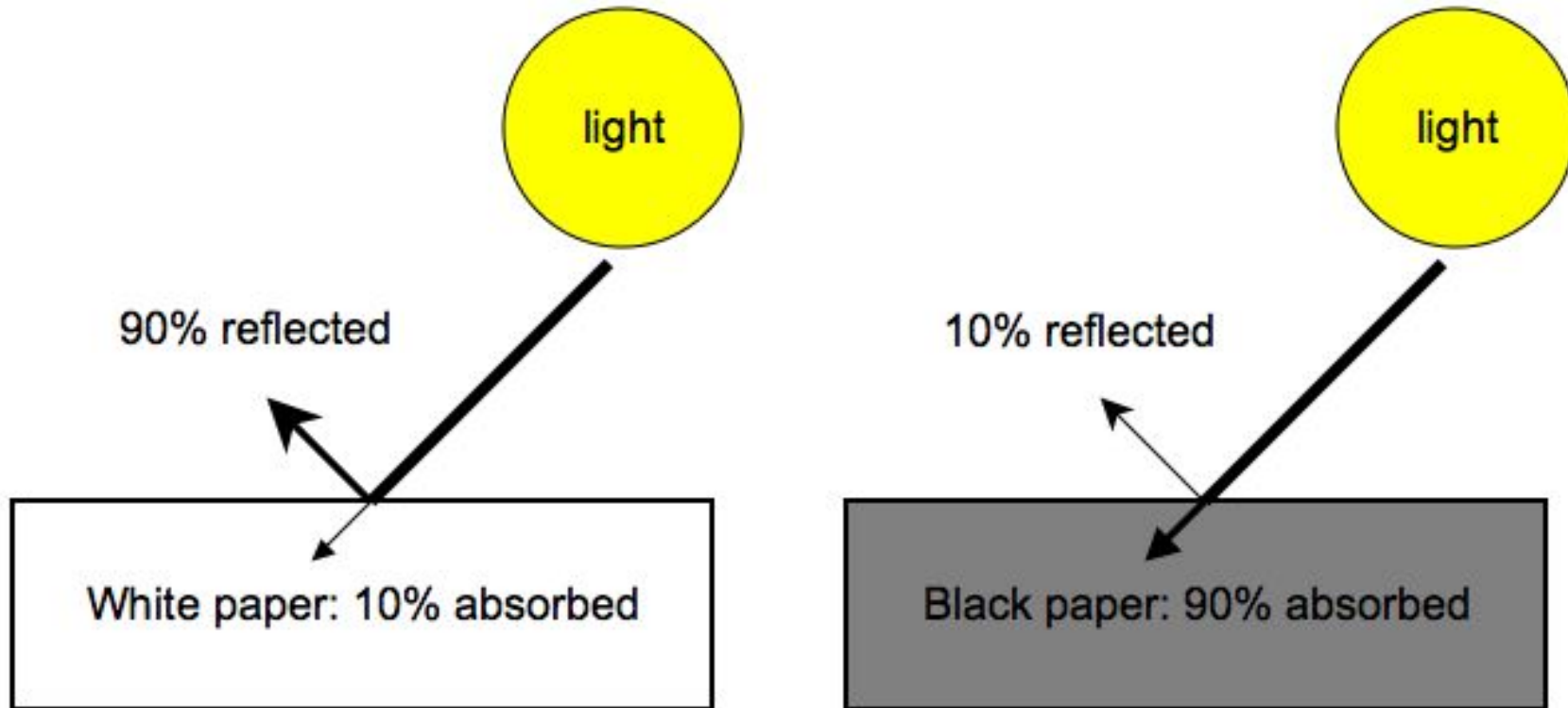
1) Photoreceptor sensitivity depends on the average/ambient light intensity, due to light adaptation.

2) Retinal ganglion cell responses depend on the difference between light intensity in the center and that in the immediate surround

Light Adaptation and Brightness Perception

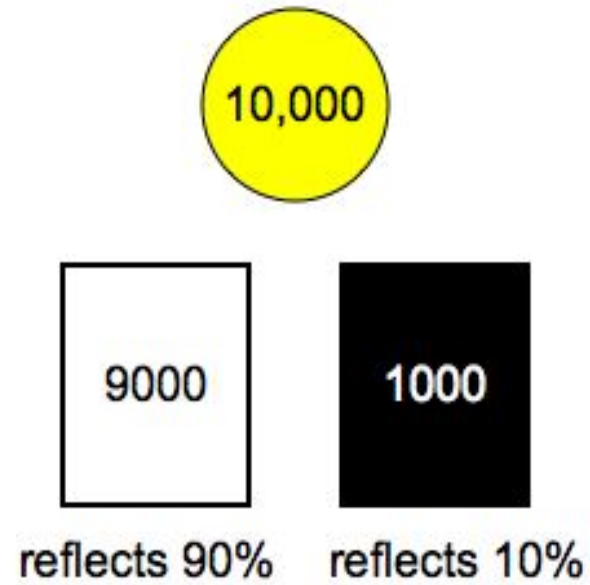
- Consider two pieces of paper, one black and one white Let's say we were outside in bright sunlight (instead of being in this dingy lecture hall). What color do you imagine they would look like? Still black and white. This is actually a surprising fact!

Surface reflectance



- The image of the black paper outdoors is actually more intense than the image of white paper indoors. Why does the black paper outdoors still look black even though it is physically more intense? We call this phenomenon **brightness** constancy. Perceived brightness is not equal to the actual physical intensity of the stimulus. Rather, perceived brightness depends on the surface reflectance, **independent** of the illumination conditions

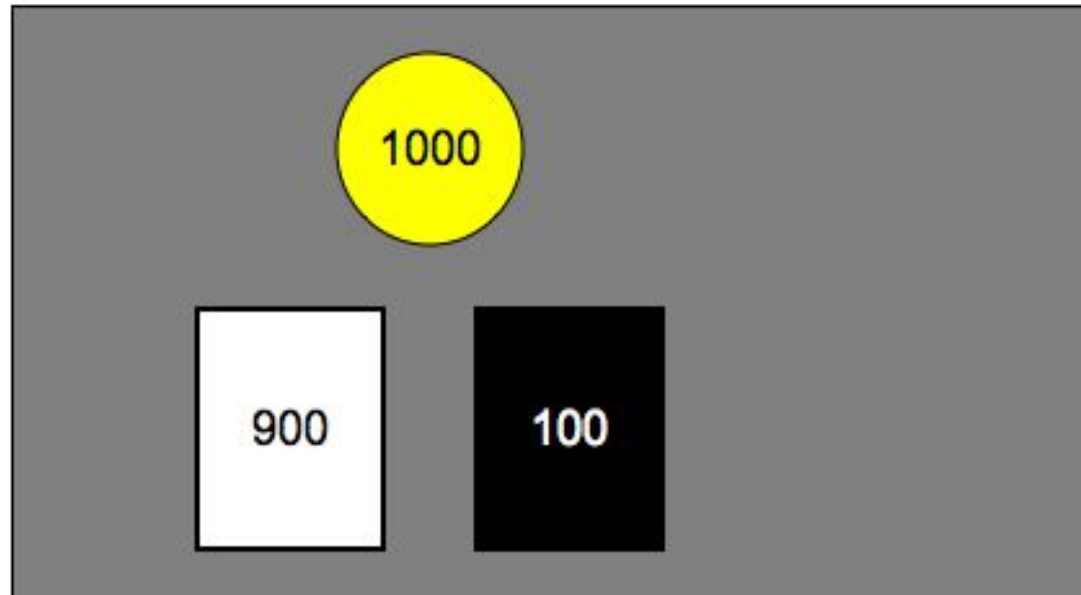
- This is obviously a good thing that white paper looks white and black paper looks black regardless of the level of illumination. We don't sense the distal stimuli (the surface reflectance) directly because our eye is not rubbing up against the papers. Instead, light bounces off the paper and into our eyes.
- The visual stimulus that reaches the eyes depends both on the illumination level (indoor light vs. outdoor light) and the reflectance of the surfaces. But we are not actually interested in the visual stimulus itself. Rather, we are interested in the physical properties of the surfaces in the world (the reflectances of the black and white paper) that gave rise to the visual stimulus. So the visual system factors out the illumination and all we typically perceive is the relative reflectance (black vs. white) of the paper.



Ratios

black = $1/5$

white = $9/5$



Ratios

black = $1/5$

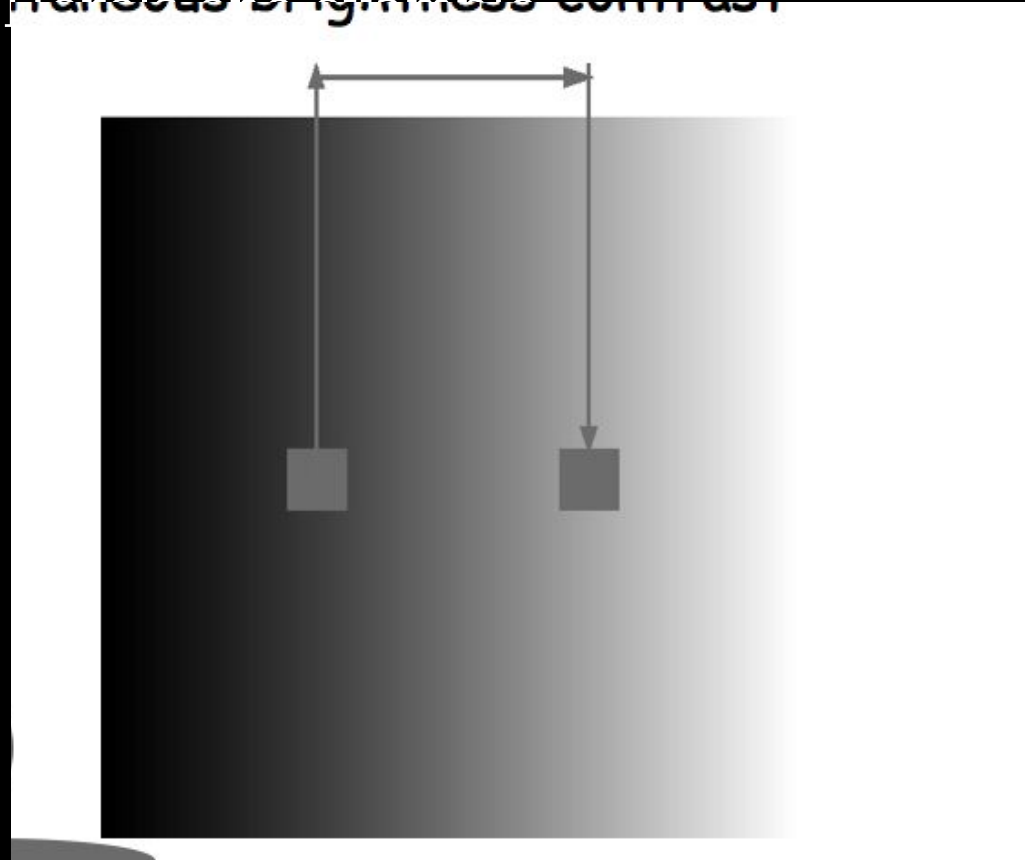
white = $9/5$

Perceptual constancy

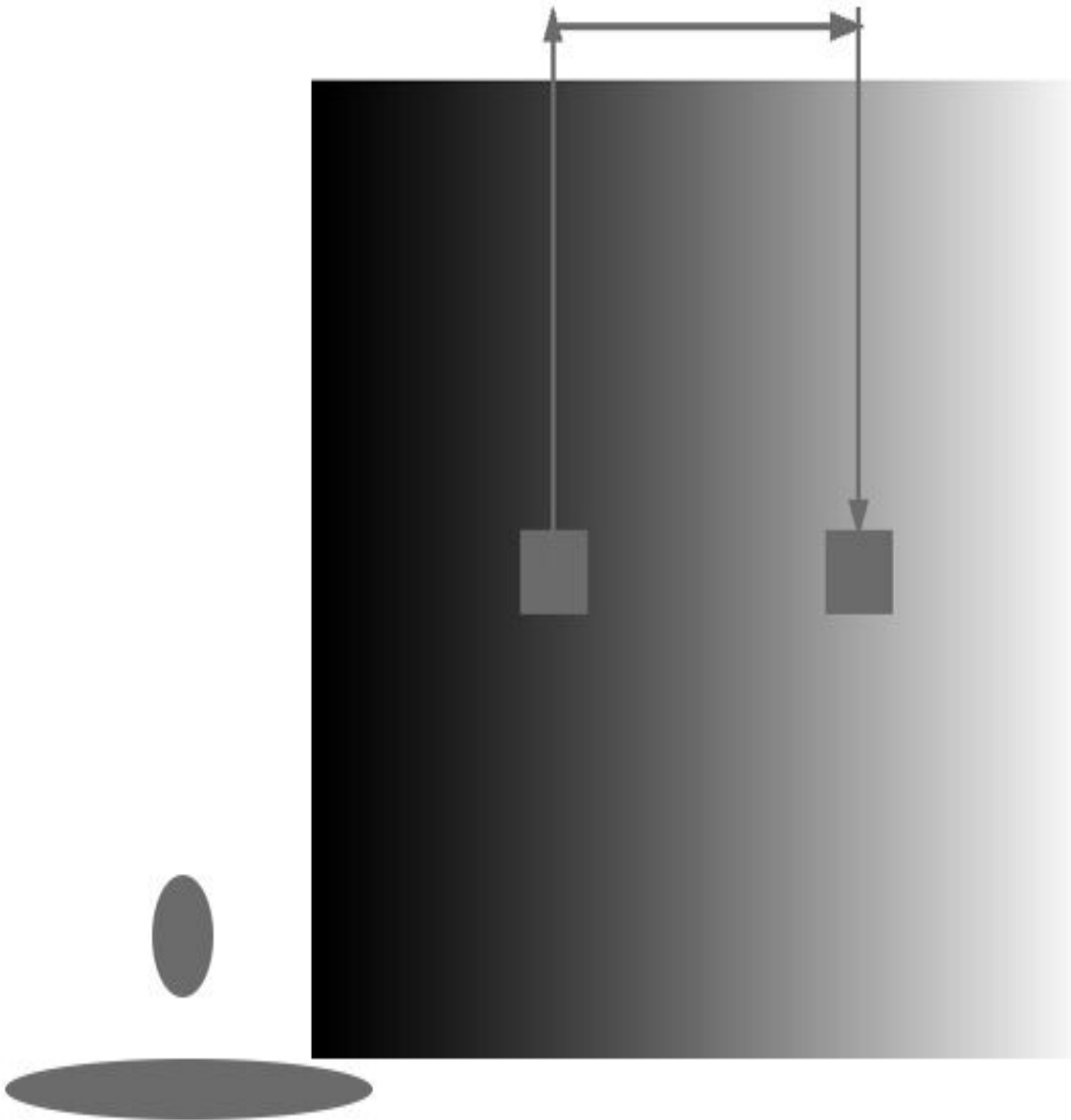
- The light/dark adaptation mechanisms in the retina effectively re-normalize or divide by the average intensity in the image to compensate for (or factor out) the level of illumination. This helps the visual system achieve
- *Perceptual constancy*: white looks white and black looks black regardless of the level of illumination.

Simultaneous brightness contrast

- having a brightness percept that depends on the context (mean/average light level) also predicts some other (perhaps counter-intuitive) phenomena. ~~Handerson's original contrast~~



Simultaneous brightness contrast



Compare the brightnesses of the two gray squares. The one on the right should appear brighter. In fact, this is a visual illusion; the two central gray squares are physically identical, one surrounded by white and the other surrounded by black. This illusion can be explained by what we know about the visual processing in the retina. Retinal responses depend on the local average image intensity. On the right, the background is black so the average intensity there is pretty small. Here we divide by a small number yielding a brighter percept. On the left, however, the background is white so the average intensity there is pretty large. Here we divide by a large number yielding a darker percept.

Koffka ring illusion

Top: A gray ring on a light/dark background looks uniform.



Middle: But when the halves are split they look quite different. This is like a variant of the simultaneous brightness contrast illusion.



Bottom: A version in which the halves are slid vertically, giving an impression of transparency.



Even though the half-rings are set against the same backgrounds, their appearance depends on the overall spatial configuration.

Testing the theory

- At this time, it's worth pointing out how to do an experiment to test this theory. Let's say we do a detection/discrimination experiment. We have the subject adapt to a certain background/ambient level of illumination. Then, we measure the threshold for detecting a test light superimposed on that background.
- To do this properly, we use a forced choice so that the test light is presented on only half the trials. We measure hits and false alarms to get d' and determine the test light intensity that yields $d'=1$. Then, we repeat the whole experiment over again using a different level of background/ambient adapting light.
- What do you expect will be the outcome of this experiment?
- How will the detection threshold depend on the level of the adapting light?
- Why? Discuss...
- How could you do an electrophysiological experiment to test this theory? Discuss...

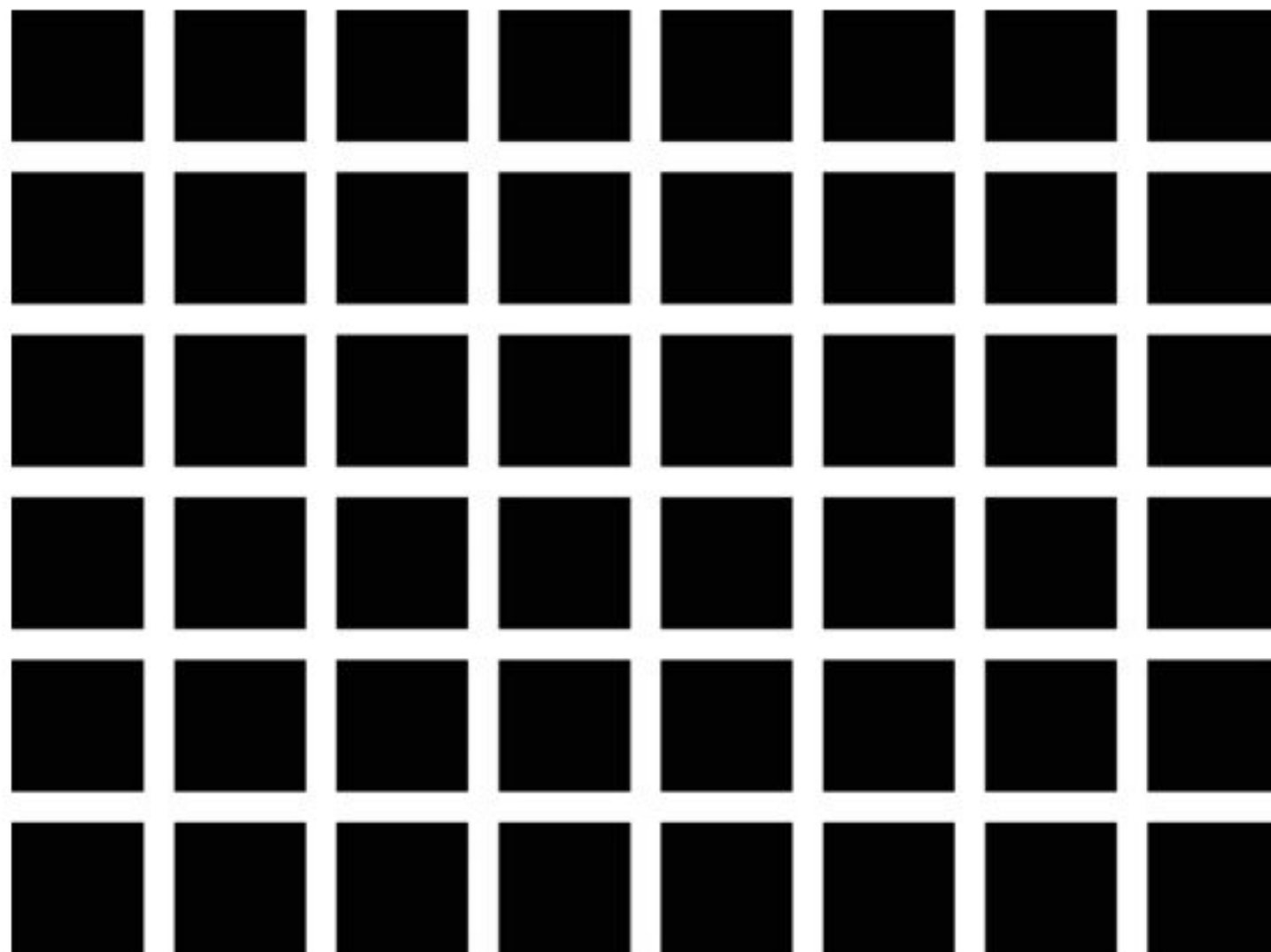
Summary (so far)

- The visual system is designed to try to achieve a perceptual constancy.
- Black looks black and white looks white regardless of the level of illumination. The putative mechanism for brightness constancy is light adaptation - retinal responses depend on average intensity. Most of the time this works great.
- However, sometimes it screws up, e.g., yielding the **simultaneous brightness contrast illusion**.

Spatial Filtering and Brightness Perception

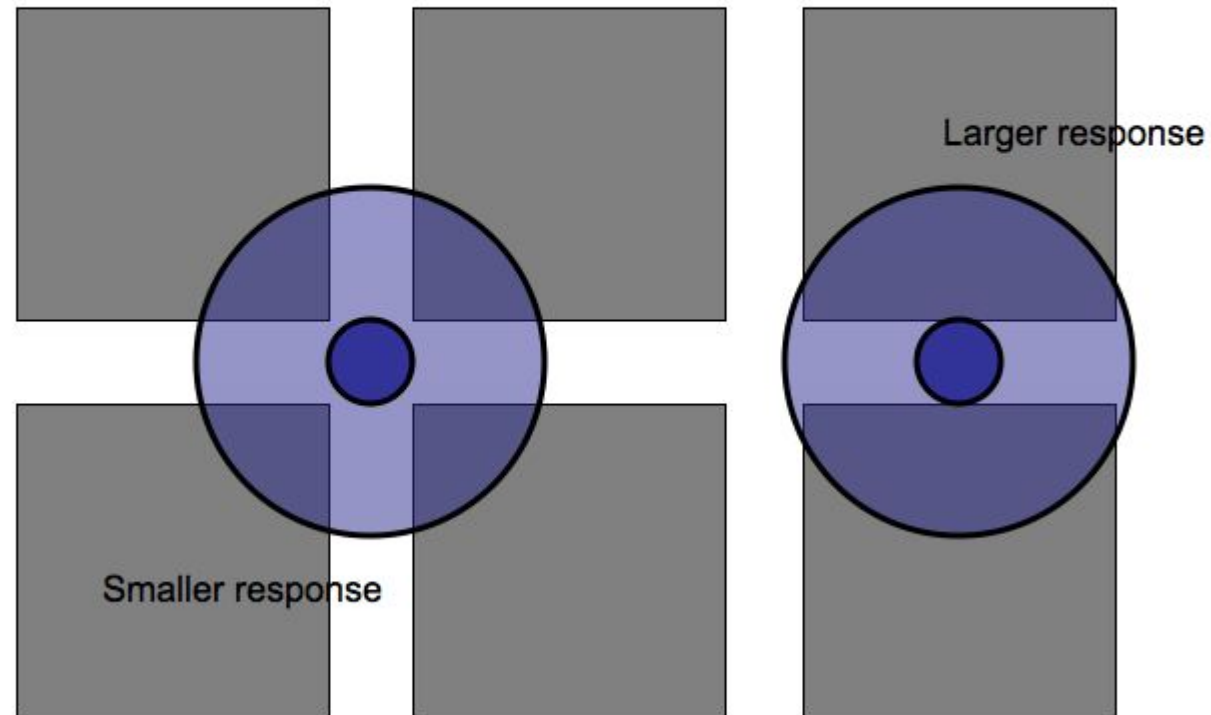
Look carefully at the next picture, what do you
? observe

Hermann grid



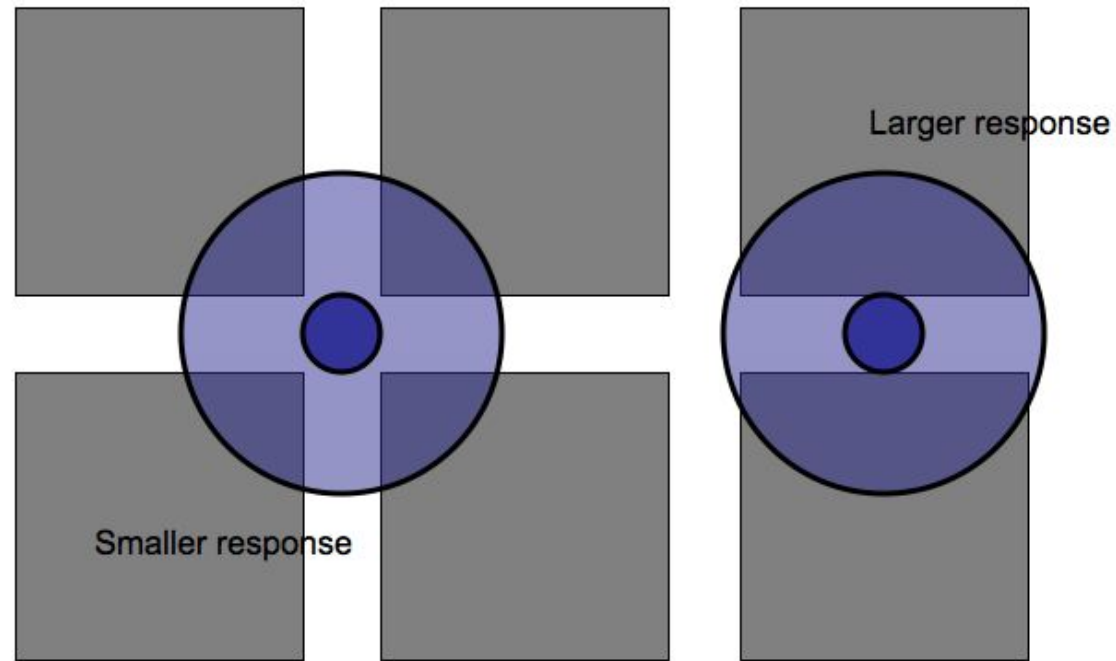
- Notice the illusory gray spots at the intersections, and the fact that these spots depend to some extent on where you fixate. Consider how ganglion cells respond to this stimulus.

Explanation of Hermann grid

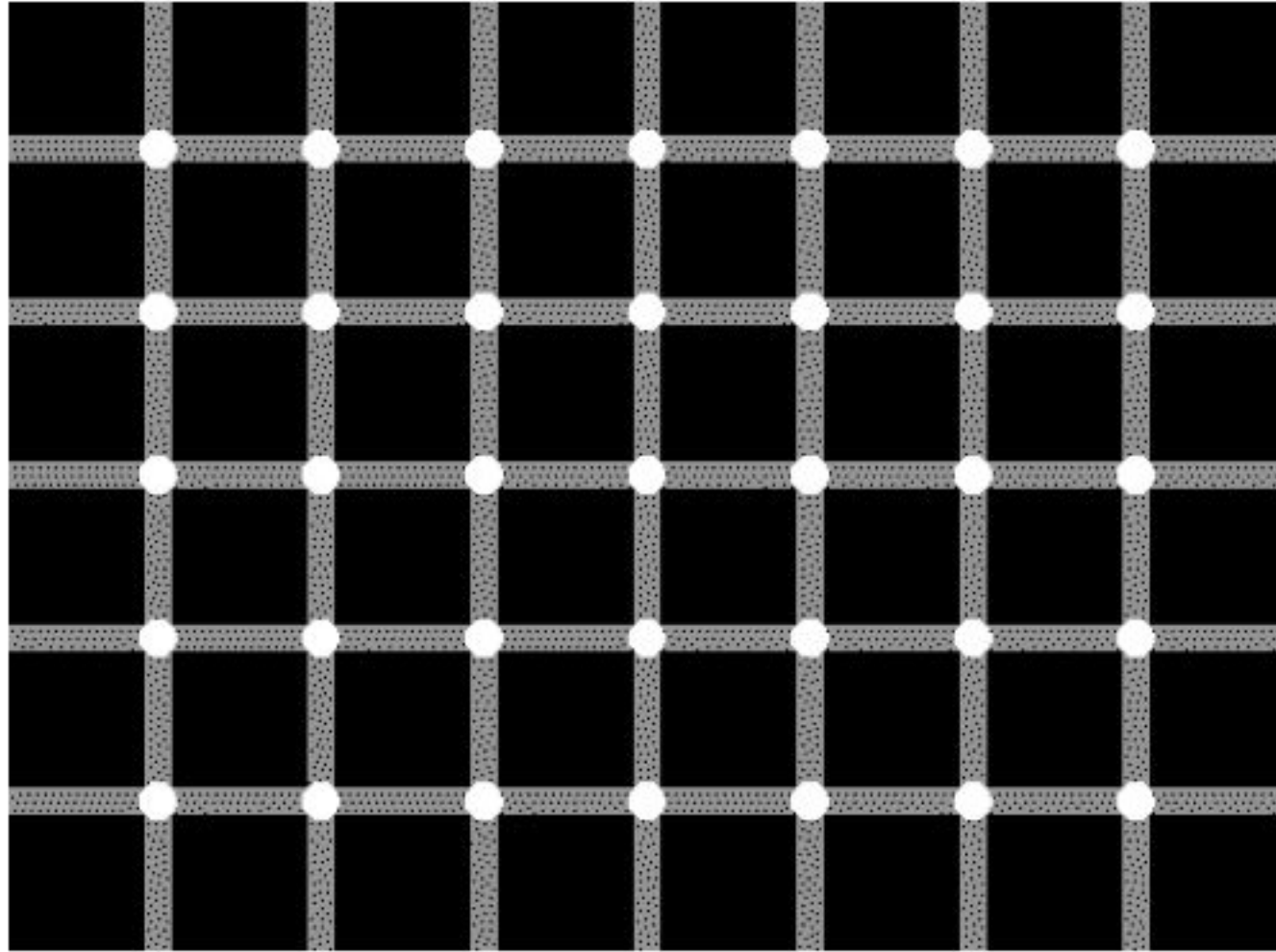


- The intersections of the white "streets" in the pattern are surrounded by more white.
- This results in more inhibition from the surround in on-center, off-surround receptive fields.

Explanation of Hermann grid



Stronger variant of the Hermann grid



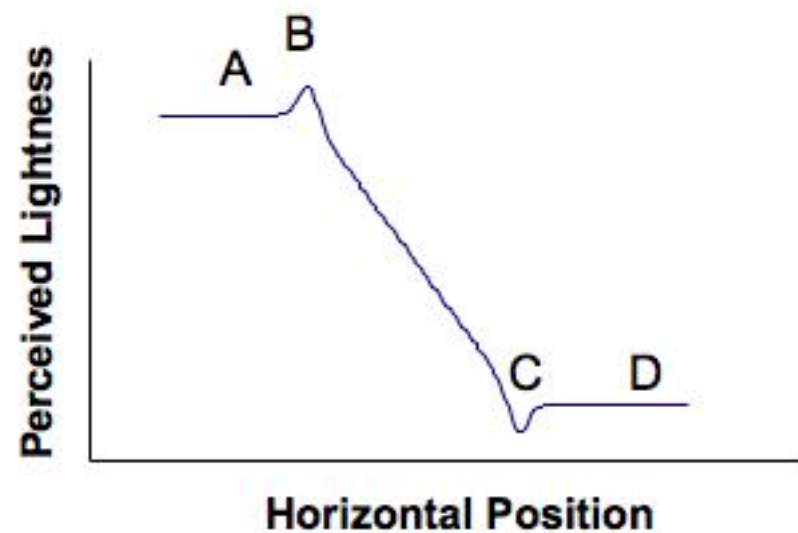
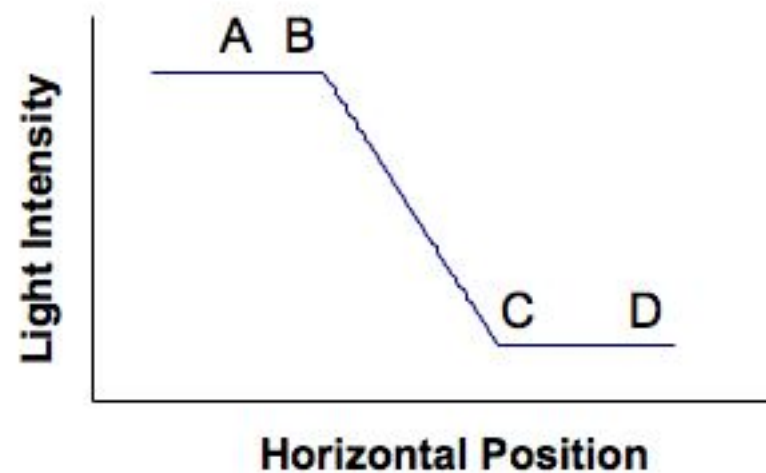
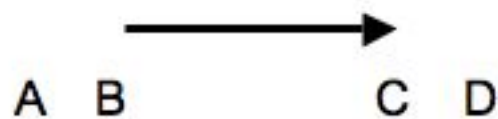
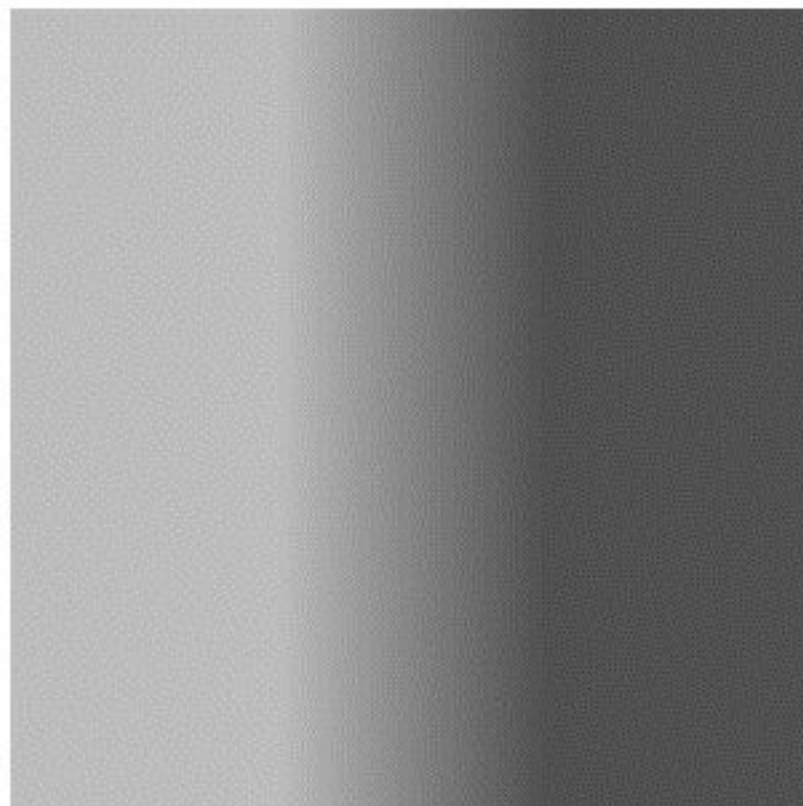
Discussion

- But why do the gray spots disappear when you look at them?
- Receptive fields sizes depend on retinal position. Those in central fovea (corresponding to where you fixate) are the smallest.
- They may be so small that they fit inside the intersection entirely, resulting in no difference in ganglion cell response between the intersections and the streets in central fovea.
- Does this explanation really work? Discuss...

Mach bands

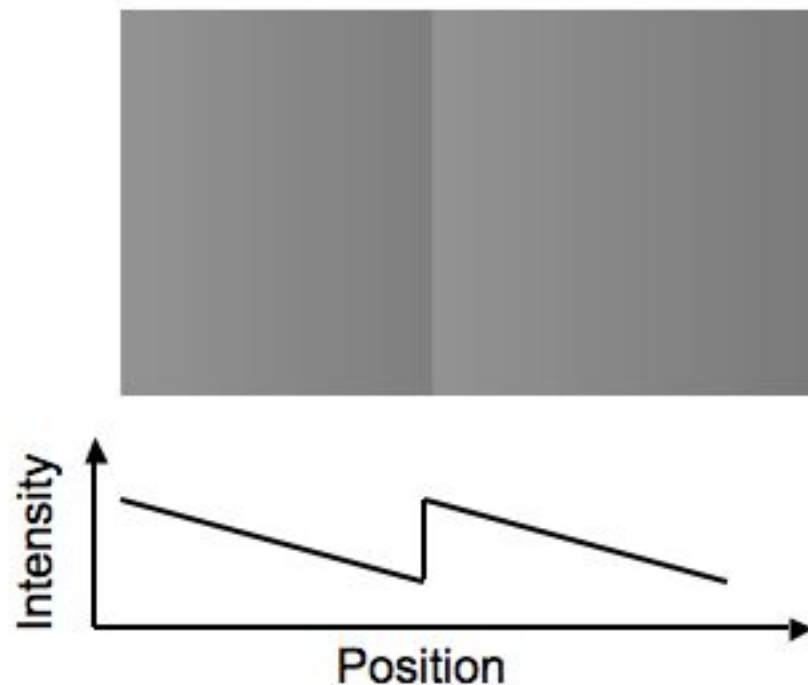
- Mach bands are a similar illusion with a similar kind of explanation: spatial filtering in ganglion cells.
- Once again, we see that the retina emphasizes edges. See text book for details. Mach bands are typically not perceived near step edges (despite what your textbook says), but rather near gentle, ramp edges.

Mach bands

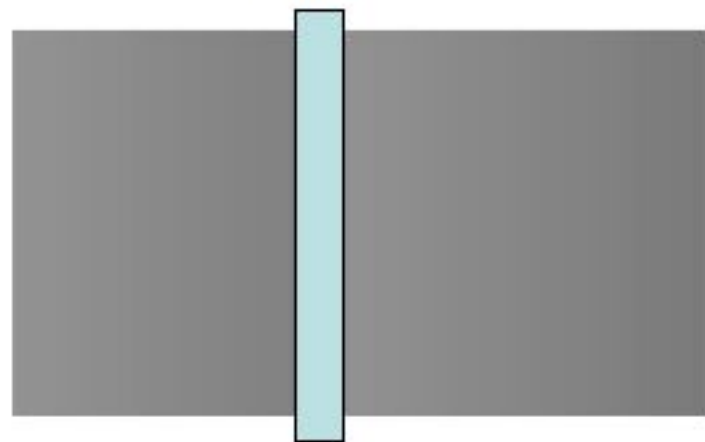


Craik O'Brien Cornsweet illusion

Top: Each square is an identical intensity ramp, very slightly lighter on the left and slightly darker on the right. Our visual system responds strongly to sharp changes in intensity, but responds weakly to gradual changes. Thus the edge between the squares is much more visible than the gradual gradient within the squares.

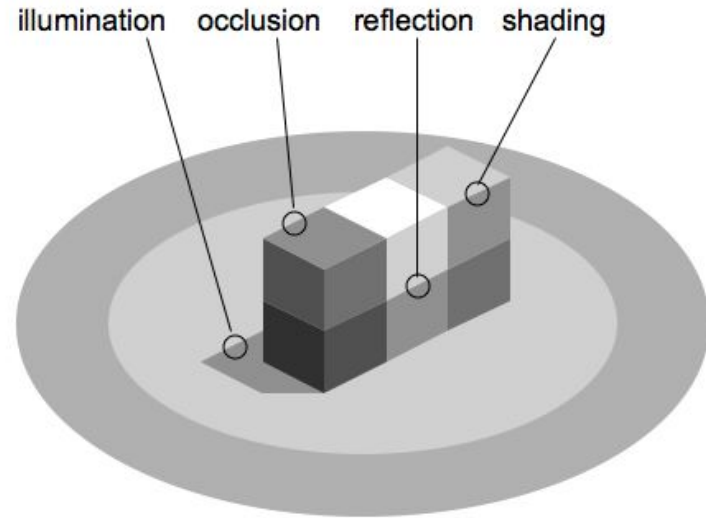


Bottom: Covering the edge completely changes the percept. Now it looks like a uniform field of gray.



Surfaces and Brightness Perception

Shading, reflection, and illumination



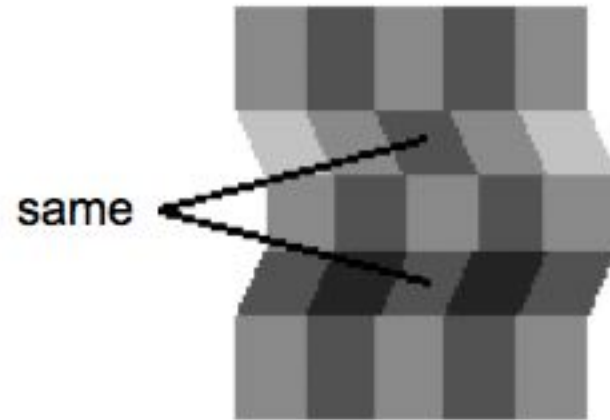
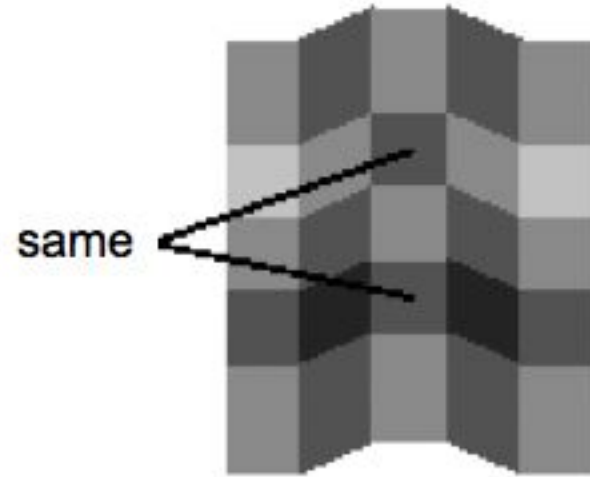
This figure shows different types of edges:

- *Shading*: change in surface orientation from a to b.
- *Reflectance*: change in surface material (e.g., paint) from b to c.
- *Illumination*: the shadow has less illumination than the unshadowed portion of the ground

Adelson corrugated plaid illusion

Top: The two squares are the same shade of gray and they look almost the same.

Bottom: The upper square looks much darker even though all the squares have the same grays as in the top picture. The change in geometry causes a change in the perceived lightness.



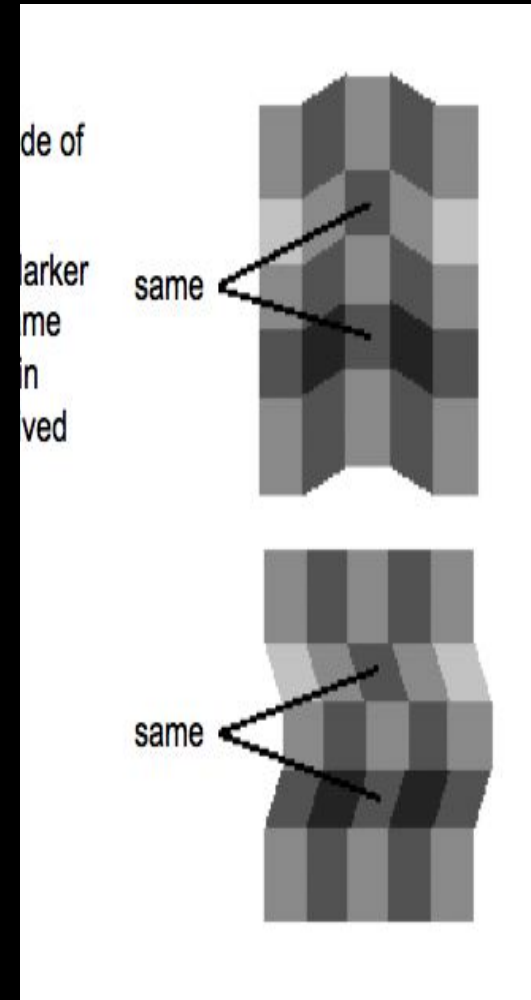
Brightness judgements can be influenced by high-level perceptual factors (e.g., 3D interpretation).

Top: The two labeled squares are the same physical shade of gray and they appear the same.

Bottom: The same two squares now look very different. This pattern is made of patches with the same gray shades, but has a different geometry (contours) leading to a different 3D interpretation and a strong brightness illusion.

The brightness percept depends on the perceived reflectance of the surfaces. Because the light appears to come from above, the visual system infers that the upper square is receiving more incident light than lower square. Because the two gray patches have the same physical intensity, the upper one must be less reflective than lower one.

The stronger brightness illusion at the bottom can not be explained by the light adaptation and spatial filtering mechanisms discussed above.



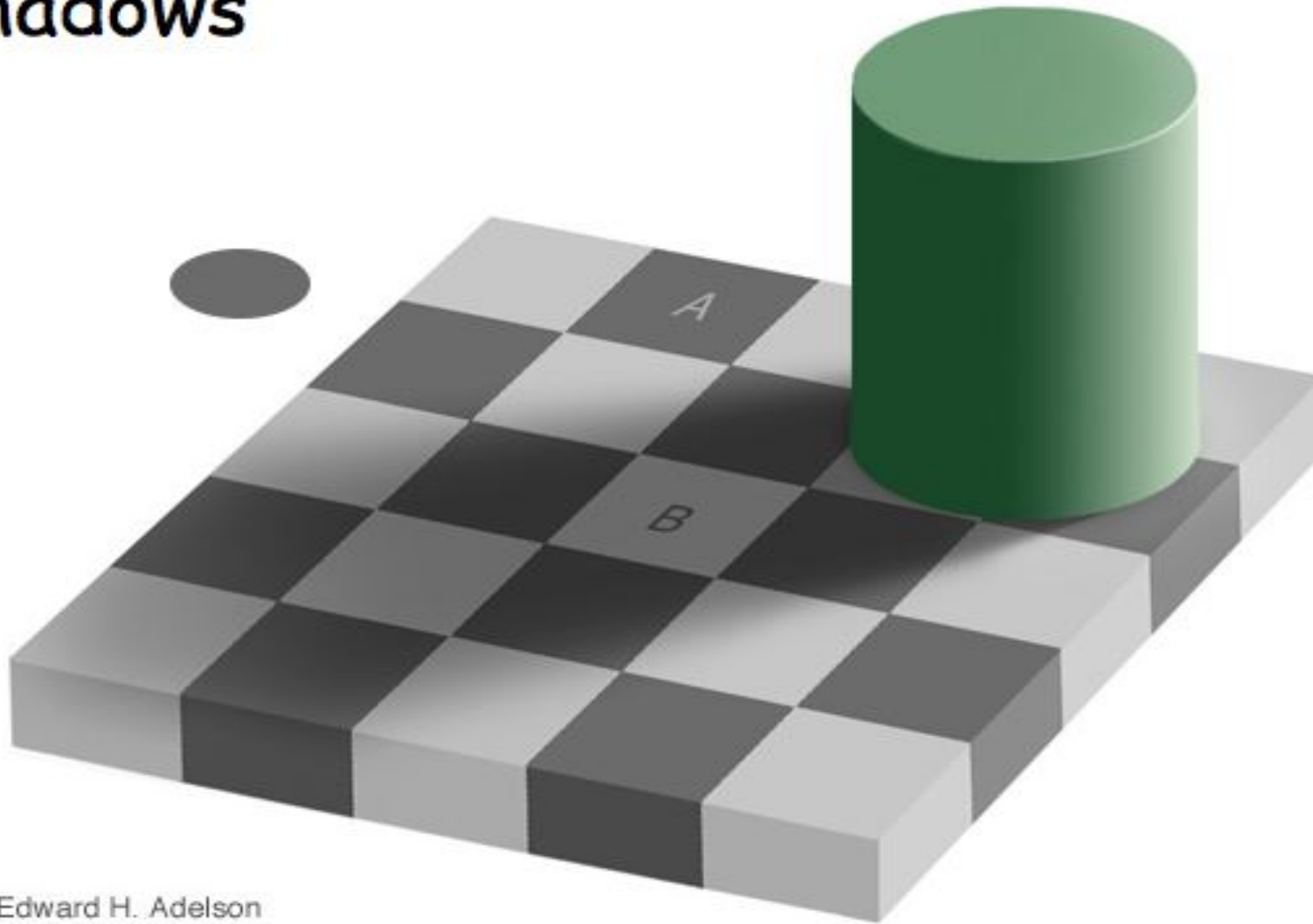
Surface Shading and Illumination (Maloney and Brainard)



Same surfaces (light gray and dark gray) in different geometric arrangement

These are real photos illustrating the same effect. The same surfaces look different depending on their geometric arrangement.

Shadows



Edward H. Adelson

Squares A and B are the same shade of gray, yet appear to have different brightness because B is seen as being in shadow.

Adelson snake illusion

Top: Strong illusion. The lightness of the diamonds are compared with the other grays in the same horizontal strip. The diamonds are the brightest features within the dim strip at the top, but they are the darkest feature within the light strip at the bottom.

Bottom: Weak illusion without the horizontal strips, from simultaneous brightness contrast.

The only difference between the snake and anti-snake is the addition of some half-ellipses that define the horizontal strips.

snake



anti-snake



Summary

Three processes in vision affect perceived brightness:

- Light adaptation (divide by the mean, convert to contrast)
- Spatial filtering/lateral inhibition in retinal ganglion cells. Since these neurons do not respond much to uniform fields, edges are critical.
- 3D interpretation (shading, reflectance, illumination, transparency).

Absolute Threshold

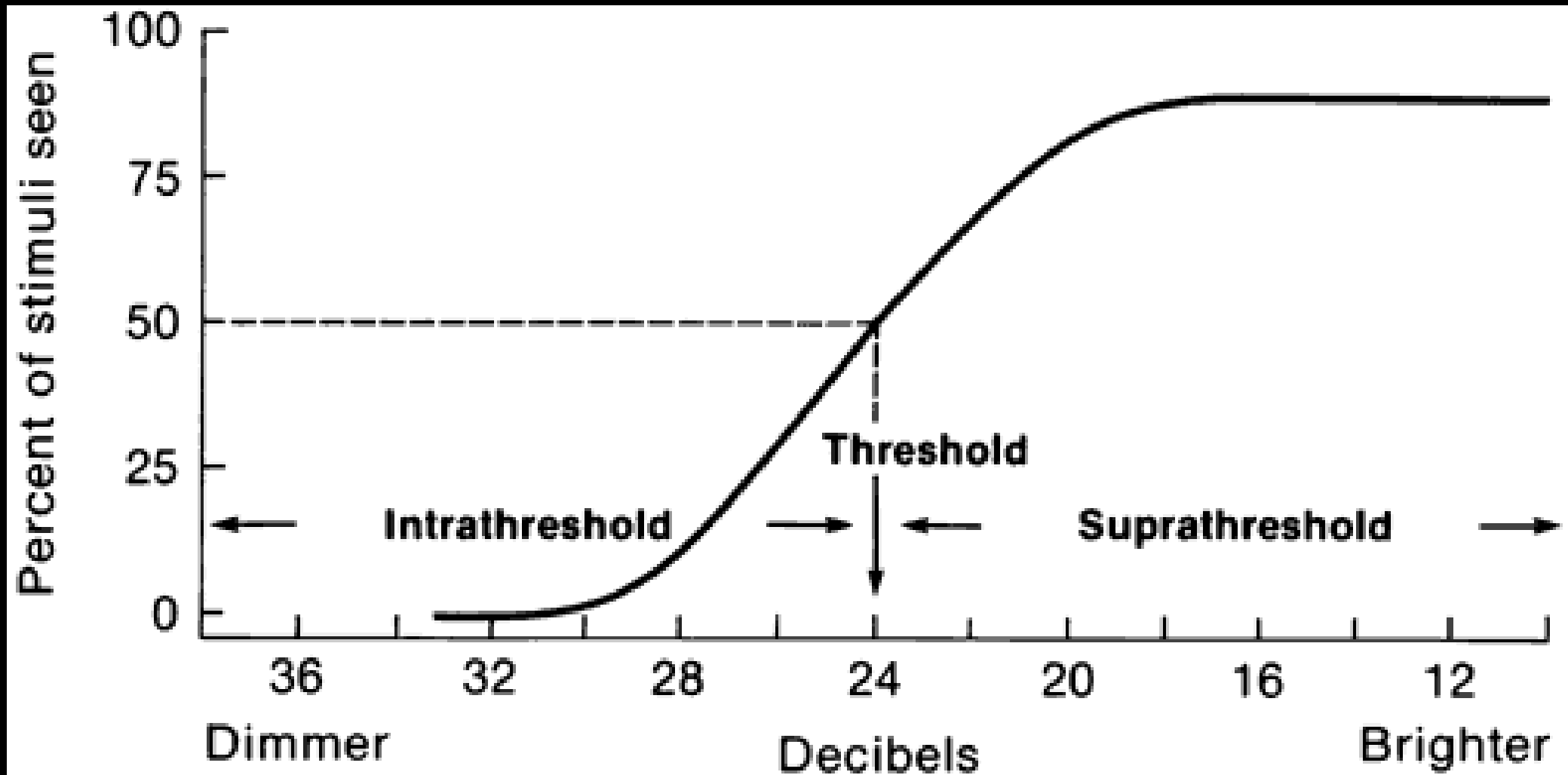
seeing curve&

Absolute threshold

- **Absolute threshold** was originally defined as the lowest level of a stimulus – light, sound, touch, etc. – that an organism could detect.
- A landmark 1942 experiment by Hecht, Shlaer, and Pirenne assessed the absolute threshold for vision. They tried to measure the minimum number of photons the human eye can detect 60% of the time
- It was found that only 5-14 photons were enough to stimulate the eye
- The researchers estimated that 5 to 14 of the estimated 500 rods in the test area would each absorb one photon, with a 4% chance that one rod would absorb two photons.

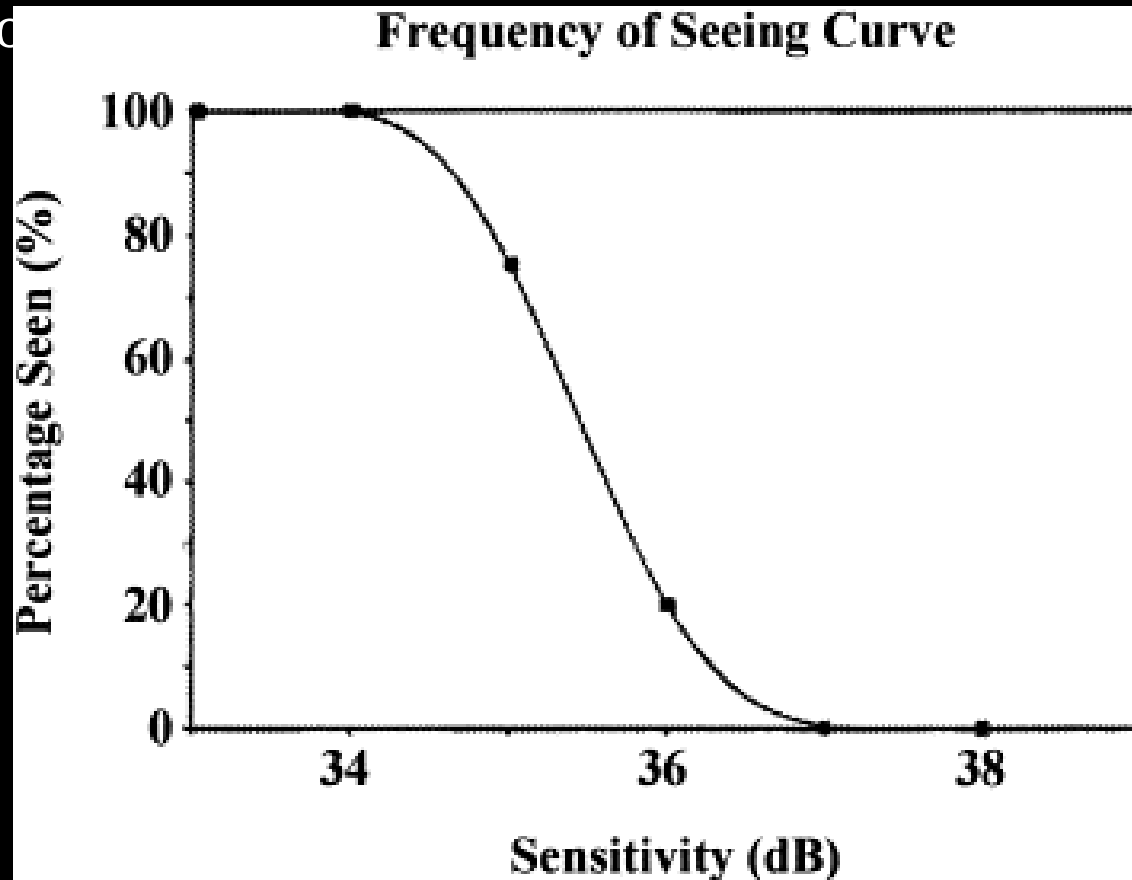
- A second absolute threshold for vision involves the minimum photon flux (photons per second per unit area). In this case the light covers a wide field over an extended period of time instead of being concentrated on one spot on the retina in a short burst. Knowing the pupil diameter and the wavelength of the light, the result can be described in terms of luminance (~ 0.000001 candela per square meter or 10^{-6} cd/m²) or retinal illuminance (~ 0.00002 Trolands).
- By including estimates for the probability of an average photon being absorbed by an average rod cell, the threshold stimulation for the rods is approximately one photon absorption per second per 5000 rods

Frequency of seeing curve



Frequency of seeing curve

- Stimuli of varying intensities are presented multiple times at one retinal location . Threshold is designated as the dimmest stimulus seen 50 % of



End of lecture

!Have a nice week

Next week will be the mid-term exam covering weeks I- VI

