Lecture 6 – Absolute Sensitivity of the Human Eye

HECHT, SCHLAER & PIRENNE'S FAMOUS EXPERIMENT

(Reference: Cornsweet, T. Visual Perception. Academic Press, New York, 1970. Chapter 2.)

In 1942, three scientists, named Hecht, Schlaer & Pirenne performed a famous experiment to answer the following question.

- *Under ideal conditions, what is the minimum amount of light that the human eye can detect?*

In other words, they wanted to measure the absolute sensitivity of the human eye. I'd like to review this classic experiment because their discovery was so amazing, and it is a great opportunity to study basic principles that scientists and clinicians must consider when testing vision. (Schwartz briefly mentions this experiment in Chapter 3, page. 30)

At first this might seem to be a simple experiment. You should be able to measure the dimmest light that a human eye can see by showing a subject a light and reducing its brightness until it is no longer visible. It reminds me of the comment an entering graduate student made while I was at Indiana University. He asked, "What's so hard about getting a PhD? All you do is take the required courses, do some experiments, collect data and write it up." It didn't take long for him to discover that, when it comes to science (if you do it properly), things are **much** more complicated that you might think at first!

A description of Hecht's apparently simple experiment quickly becomes complicated when you consider the details. Besides building an apparatus that could precisely control the brightness of the light, they had to consider the following in their experimental design.

- How long should the subject dark adapt prior to starting the experiment?
- Where should the test light be presented in the visual field?
- How big should the light be?
- How long should it be left on?
- What color should the test light be?

DARK ADAPTATION

We know that the eye is much more sensitive if you've been in the dark for some time. For example, if you enter a theater on bright sunny day, you won't be able to see anything at first. With time, however, your eyes adjust to the dark and you will begin to see well even though the light level is very low.

Since they wanted to measure the ultimate sensitivity of the human eye, Hecht et al. wanted to test when the eye was maximally sensitive. Therefore, it was obvious that the subject should first let his eyes adjust to the dark.

The question arose: How long should the subject remain in the dark prior to beginning the experiment? Thirty minutes? Two hours? Eight hours? Research data was already available to indicate how the eye's sensitivity increases with time in the dark; this is called the **dark adaptation function** (Fig. 1).

Dark adaptation, or the ability of the eyes to adjust to the dark, increases rapidly but levels off after about thirty minutes. Therefore, they decided to dark adapted their subjects for at least forty minutes.

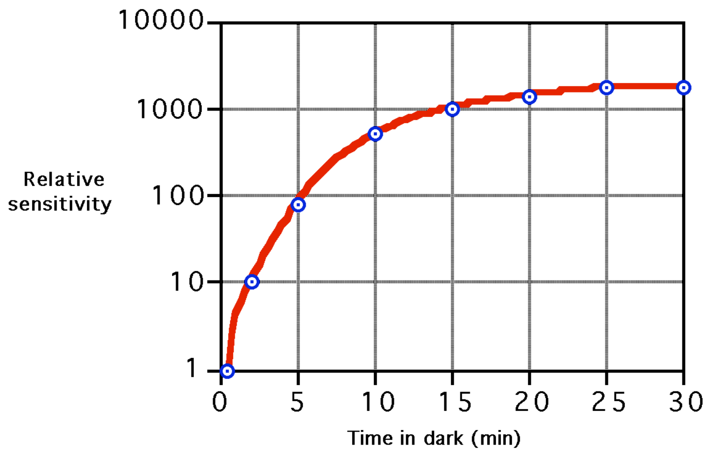

Figure 1. Dark adaptation curve.

SENSITIVITY ACROSS THE VISUAL FIELD

Visual acuity varies for different parts of the retina. Best visual acuity is measured at the fovea. Similarly the sensitivity of the eye varies with retinal location. This is primarily a function of rod photoreceptor density, so Hecht decided to place the test light so that its image would fall on the part of the retina with maximum rod density. Figure 2 shows rod density across a horizontal cross-section of the retina.

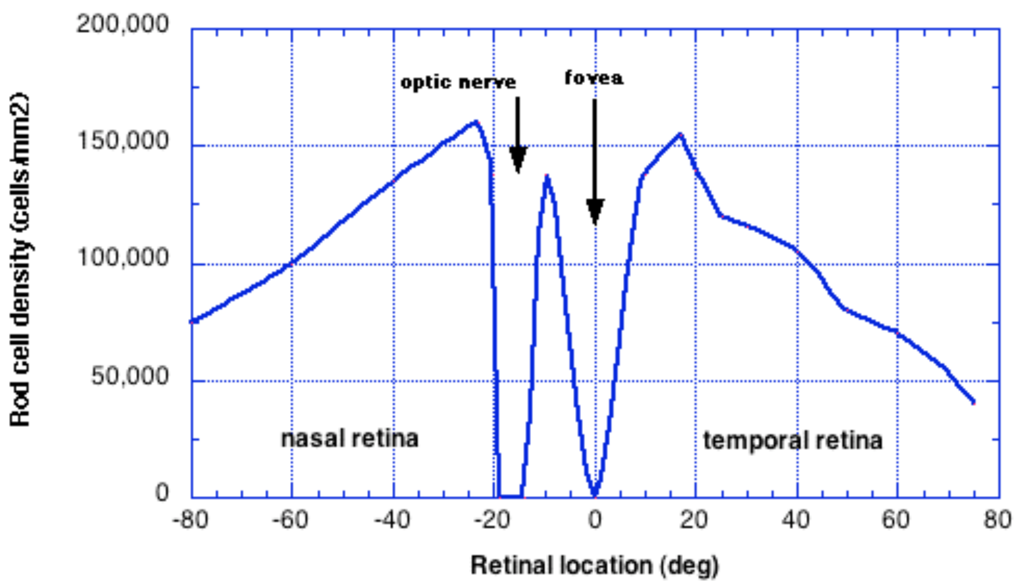

Figure 2. Rod density across the retina (redrawn from Visual Perception, by Tom Cornsweet p. 11)

Rod density reaches a maximum at about 20° nasal or temporal to the fovea. Hecht decided to project the image to a point 20° temporal to the fovea, so he positioned the test light so that it was 20° nasal to a faint red fixation light, as illustrated in Figure 3.

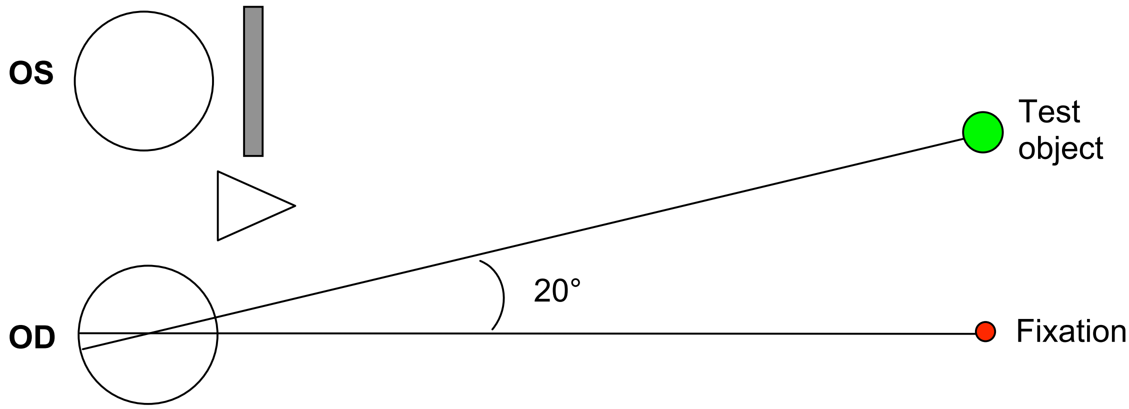

Figure 3. Stimulus for the right eye was placed 20°to the left of fixation, so the image would fall on the temporal retina, where rod photoreceptor density was maximum.

STIMULUS SIZE
Studies had been done to determine the relationship between total number of quanta needed to detect a light and its size. As long as the test spot was less than about 10 arc minutes in diameter, the total light required for detection was constant. Beyond this size, more light was required to detect the stimulus. This is related to a phenomenon known as **spatial summation** and **Ricco's law**, topics we'll study in greater detail later. Hecht and his team decided to make their test spot 10 arc minutes in diameter, though a smaller light would have also been acceptable (Fig. 4).

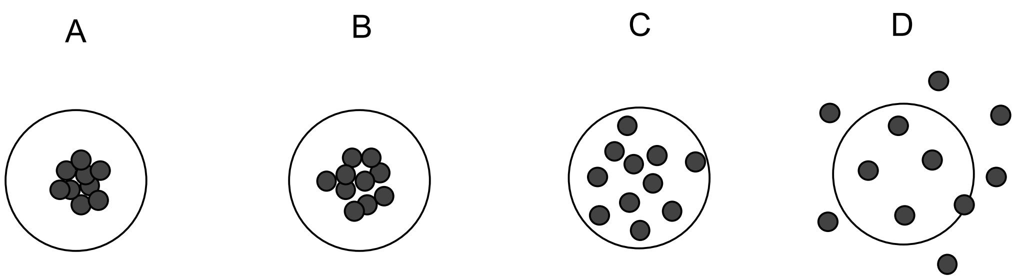

Figure 4. Affect of spot size. As long as all of the light fell within a 10-arc-minute diameter circle (A-C), the amount of light need for detection did not matter. Dots show the distribution of photons. If the light distribution exceeded a diameter of 10-arc-minutes (D), more light was needed for detection.

STIMULUS DURATION
Tests had already been done to study the relationship between the total number of quanta needed for detection and flash duration. As long as the flash duration was less than 100 milliseconds, the total number of quanta required for detection was the same. For longer durations, more light was required. This is related to **temporal summation** and **Bloch's law**, topics we'll study in more detail later in the course. Hecht selected a flash duration of 1 millisecond.

STIMULUS COLOR
Hecht conducted an experiment with the above conditions, but he used lights of differing wavelengths. He measured the minimum amount of quanta necessary for the subject to detect the light for different wavelengths, and found that under those conditions the eye was most sensitive to 510 nm (green) light (Fig. 5).

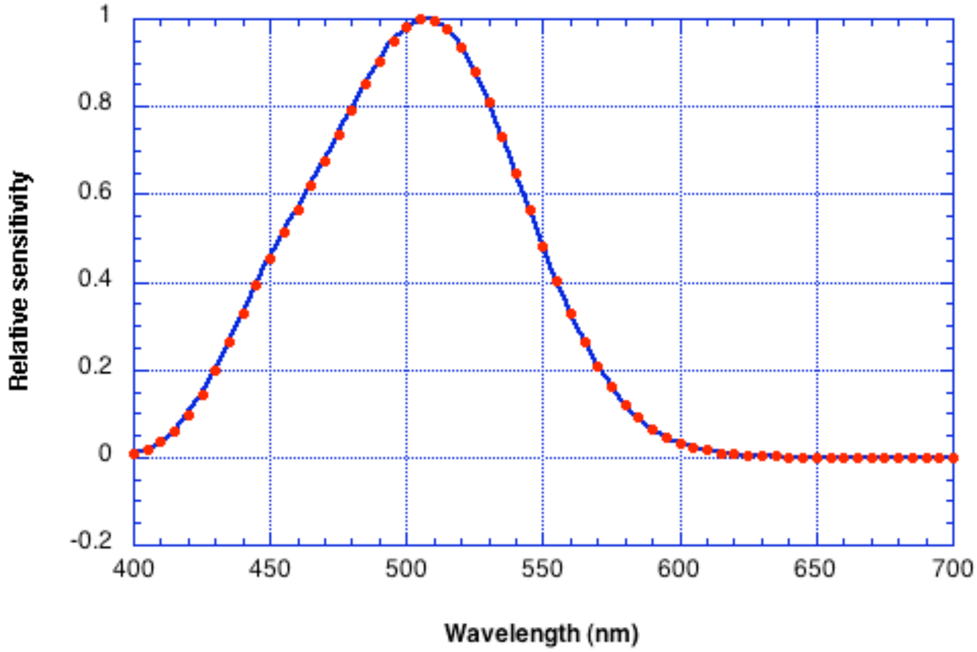

Figure 5. Sensitivity plotted as a function of wavelength, under dark adapted conditions

THE EXPERIMENT AND RESULTS

After working out these details, Hecht conducted the experiments with the following conditions.

- dark adapted subjects for 40 minutes
- one eye occluded, tested monocularly
- subjects fixated a very faint dim red light
- stimulus (test spot) was located 20° nasal to fixation
- test spot diameter was 10 arc minutes
- test light was flashed for 1 millisecond
- wavelength was 510 nm (green)

When he was ready, the subject would press a button, and the test light would flash. He would then signal whether or not he saw it. Light intensity was then reduced to find the minimum he could see.

Hecht determined that under these conditions, a person could barely see the light if just 90 quanta entered the eye. This is incredibly sensitive compared to any man-made light sensor.

This result led to another more interesting question: “If at least 90 quanta must enter the eye to be visible, what is the minimum amount of light that a rod photoreceptor can detect?”

If 90 quanta must enter the eye for detection, this does not necessarily mean that the retinal photoreceptors required a minimum of 90 quanta, because not all 90 photons would reach the retina. Most of the 90 quanta incident on the eye never reached the retinal photoreceptors. Hecht et al accounted for the 90 photons as follows:

Of the 90 quanta incident on the eye,

- about 3% are reflected off the cornea
- about 47% are lost to absorption by optical media and pigment
- about 40% falls between the rods on the retina

That leaves an estimated 10% of the incident light. Therefore, only about 9-10 photons actually reached the retina and were absorbed by rods.

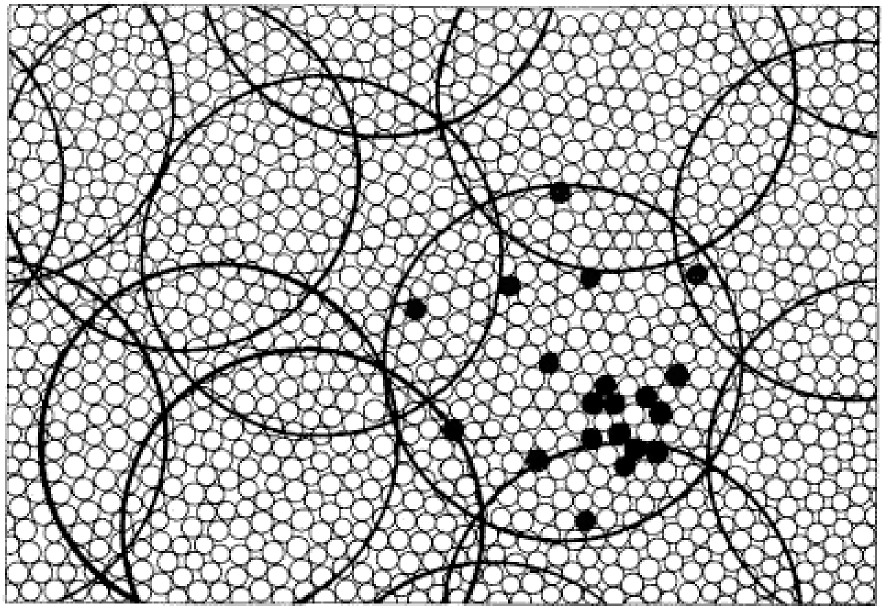

Figure 6. Illustration of a few photons scattered across a 10-arc-minute area of the retina. The small white circles represent rods. [From Cornsweet (1970) p. 17]

These 10 photons fell on a 10-arc-minute area of the retina, which contained an estimated 500 rods. If the photons were randomly distributed we can safely assume that each photon fell on a different rod. Hecht concluded that, if as few as 10 rods (within a 10 arc minute area) captured a photon, the person would detect the light. The most amazing conclusion was, quoting from Cornsweet ...

> *This means that **a single quantum** must be sufficient to activate a rod, and that the effects of the activation of about ten rods all near each other are somehow added up by the visual system. ... the principle finding of Hecht et al., that a single quantum is sufficient to activate a rod, is firmly established.* (Cornsweet, T. Visual Perception. Academic Press, New York, 1970. p. 25-26.)