Visual Sensory Physiology

Robert A. Linsenmeier[1] and Roberta W. Ellington[2]

[1]Dept. of Biomedical Engineering
2145 Sheridan Road
Northwestern University
Evanston, Il 60208
r-linsenmeier@northwestern.edu

[2]Dept. of Biological Sciences
2205 Tech Drive (2-100)
Northwestern University
Evanston, Il 60208
r-ellington@northwestern.edu

Abstract: This lab exercise teaches students about the location and size of the blind spot as well as the location in the visual field of the ability to do color discrimination. The exercise can be completed within a two-hour lab period and is suitable for students in High School AP Biology through the college sophomore level. Materials are inexpensive and can be reused.

Introduction

Part 1: Size of the Blind Spot/Optic Nerve Head

The back of the eye is lined with retina, except in one region. This region is the area where blood vessels enter the eye to nourish the retina, and where axons of retinal ganglion cells leave the eye to travel to the lateral geniculate nucleus of the thalamus and other parts of the brain. This region is located at the end of the optic nerve and is often called the optic nerve head. Since it is round, it is also called the optic disc. There are no photoreceptors or other neurons in this region, therefore it is "blind," and is also called the blind spot. In some retinal diseases, loss of retinal neurons causes other regions to be blind as well; these are called "scotomas" but we all have this one natural blind spot. What is remarkable is that under normal conditions, even when we only use one eye, the blind region causes us no problems and is basically undetectable. Interestingly, people with retinal disease often do not notice that they have scotomas either, unless the scotomas are large or in the central part of the visual field.

The optic nerve head can be located in your own eye and you can determine its size and location in the visual field. This is the goal of this exercise. Measurements in the visual field are generally made in degrees of visual angle, rather than distance. We first need to define the visual axis. If you look straight ahead, you will naturally bring your eye into a particular alignment. Suppose you fixate on the period at the end of this sentence. The visual axis is the line between your eyeball and this fixation point.

Extending the line into the eyeball, it will hit the fovea, the part of the retina with the largest concentration of photoreceptors and the most acute vision. We can measure visual angle relative to this axis, using the cornea as the vertex of the visual angle, as shown in Figure 1. (The actual vertex is inside the eye a bit.) The advantage of dealing in visual angle, rather than distance in cm across

the visual field, is that an image that hits a certain point on the retina will always be at a certain angle from the visual axis, whereas the distance in cm will depend on how far away the object is from you. Our visual field extends to about + and - 90 degrees of visual angle (actually the nose gets in the way and makes the nasal visual field smaller.)

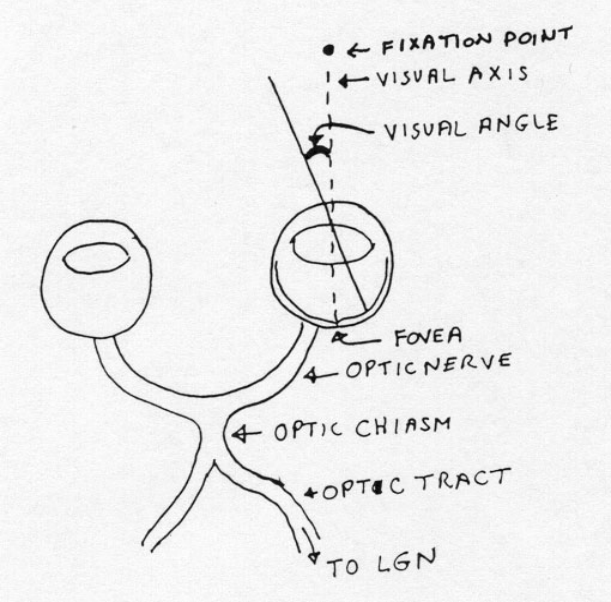

Figure 1. The visual angle using the cornea as the vertex of the angle.

Part 2: Color Vision

We often think that the cones in the retina are there so that we can see color. There are three types of cone receptors; each is sensitive to a different range of wavelengths (short, middle and long wavelength, or blue, green, and red); and the comparison in the retina of the signals from the three does allow color vision. Color vision is a nice feature of cone vision in people, some primates, and some other animals (birds and some fish). However, many animals (such as dogs and cats) have cones, but have terrible color vision, in that they are very poor at discriminating among different colors. Cones are present fundamentally to allow you to see under conditions of bright illumination where rod signals are saturated. Rods are very good at dim illumination, but overwhelmed by bright light. This experiment is to determine the region on the retina where you have good color vision, that is, where you can discriminate among colors.

There are two things you may want to know in order to help interpret your findings, although you will probably not be able to arrive at completely definitive conclusions. First, the receptive fields of ganglion cells are not the same size across the retina. They are smallest in the central visual field and larger in the periphery. Second, the cone density (cones/mm^2 of retinal surface) also varies. The cones are most concentrated in the central retina, as shown in Figure 2, which represents the sum of the three cone types.

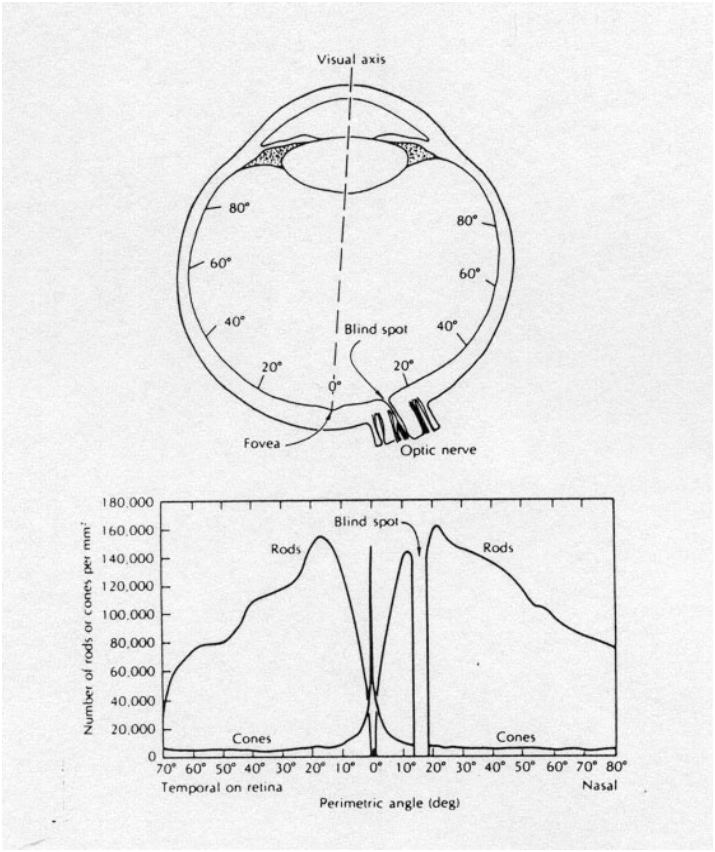

Figure 2. Top view of the left eye and corresponding densities of rods and cones cross the retina. Taken from Visual Perception by T.N. Cornsweet, Academic Press, 1970

Student Outline

Procedure for Part 1

- The materials that you will need include a tape measure; calculator with trig functions; an index card; 2 pieces of printer paper, scotch taped together lengthwise; and an appropriate marker that has a white body and a dark colored ink so that the tip is dark relative to the paper but the body of the marker is the same color as the paper. The object is to have a marker in which the tip contrasts with the paper but the body does not. If you wear glasses, you may need to remove them before doing this exercise.
- Tape the paper to the wall so that the long axis is horizontal. Mark a fixation point at eye level with the marker on either the left or right end of the paper. It should be about one cm in diameter, but the exact size is not important. Stand at a length of arm's length from the paper, so that you can just write on the board. Fixate on the right-hand fixation spot with your left eye, or on the left-hand fixation spot with your right eye. Cover the other eye with an index card. Make sure that you keep your head straight and not tilted. Your partner can help here. The blind spot is approximately on a horizontal line from the fixation point. Knowing this, extend your arm toward the paper and slowly bring the tip of the marker across the visual field until it disappears.
- Move the marker slowly, starting away from the blind spot and moving into it. Mark the point at which the marker tip just disappears. Do this starting from different initial locations in the visual field. This will trace out the size of the blind spot. Make sure you keep fixating on the fixation point at all times. Careful mapping may become tiring. You can take a break, as long as you stay the same distance from the paper. If it is difficult for you to fixate and move the marker, you may have your partner move the marker slowly; you will say when it disappears. Repeat all of your determinations at least once after writing down the data asked for below. Your partner will do the same experiment.
- The distance from your eye to the fixation point is 57 cm (or arm's length). Measure the distance from the fixation point to the far edge and to the near edge of the blind spot in cm. Record these numbers on your data sheet. You should measure the horizontal and vertical components of the blind spot (measure the distance across the blind spot in cm). Note the shape of the blind spot.

Procedure for Part 2

You will be using a piece of poster board with a fixation point near one edge, and lightly marked vertical lines showing distances of 5, 10, 15, 20, 25, 30, 35, and 40 degrees. If your eye is 57 cm from the fixation point, it turns out that one cm on the poster board is one degree of visual angle, so the 5-40 degree lines can be drawn 5-40 cm from the fixation point. Obtain a bag of 8 sticks with three different colored tapes in bands at one end.

1. One partner (the subject) will look at the fixation point with one eye, covering the other eye with an index card. The eye should be arm's length or 57cm from the poster board, so that one cm on the board = 1 deg of visual angle. Measure the distance using your tape measure. If you are using your right eye, the poster board will extend to the right and if you are using your left eye, the poster board will extend to the left – do not cross the field of vision.

2. The other partner (the experimenter) will hold a stick vertically at an eccentricity of 40 degrees, and ask the subject to name the colors from top to bottom. The experimenter will note on the data sheet whether the response was correct or not. (Some mark should be made whether the answer was right or wrong, because this will help the experimenter keep track of the total number of presentations.) The experimenter should move the stick into the desired position at moderate speed and then should hold it still. It could be brought in from the top, bottom or side, but be consistent. There is no partial credit - the subject either identifies all the colors correctly in order or not. The presentation of the colors in a research setting would ordinarily be brief. If the subject is taking more than a couple of seconds to respond, reject the trial and do another.
3. The experimenter will present the 8 different sticks at this location so that a meaningful "% correct" can be obtained.
4. The experimenter should occasionally remind the subject to look at the fixation point, and not at the sticks.
5. Repeat items 2 and 3 for all degrees of eccentricities listed in the data section.
6. After obtaining a complete set of data, partners should change roles and repeat the experiment.

Data Section

Part 1: Size of Blind Spot

Distance from eye to fixation point: _____ cm

Distance from fixation point to far edge of blind spot: _____ cm

Distance from fixation point to near edge of blind spot: _____ cm

Distance across blind spot (diameter): _____ cm

Shape of blind spot:

Part 2: Color Vision

Degrees of Eccentricity									
Trial	0	5	10	15	20	25	30	35	40
1									
2									
3									
4									
5									
6									
7									
8									
Mean % Correct									

Lab Report

1. A brief (3-4 sentences) Introduction. What is the purpose of this lab? How does this lab relate to the sensory physiology concepts you learned in lecture?
2. Results: Hand in your data sheet, and show your answers and calculations for the following (use Figure 3 to help you):

For Part 1:

a. How far in degrees is the blind spot from the fixation point? (Convert the distance measured to visual angle, using the surface of the eye as the vertex of the angle as noted above.)

b. Report the visual angle subtended by the diameter of the blind spot, in degrees.

c. The eye is about 24 mm deep (of course this varies depending on whether you are nearsighted or farsighted, but we will ignore that). With this knowledge you can construct similar triangles inside the eye to the ones you are drawing outside the eye. Knowing the visual angles just calculated, determine how far it is across the optic nerve head (in mm) in the eye, and how far this is from the fovea.

For Part 2:

d. Graph the percentages correct as a function of eccentricity, for yourself or your lab partner.

3. Discussion: This section should include answers to the following questions:

a. Blind Spot Experiment: The vertex of the visual angle is actually a little inside the eye. What does this mean about your estimates? What other sources of error can you think of in these measurements?

b. Blind Spot Experiment: Why do you suppose that the blind spot is ordinarily not a blank spot in your visual field? It may help to realize that the board did not disappear in the area where the marker tip disappeared.

c. Color Vision Experiment: Discuss at least one plausible hypothesis about the retina and visual system that would explain why the percent correct differs with different degrees of eccentricity.

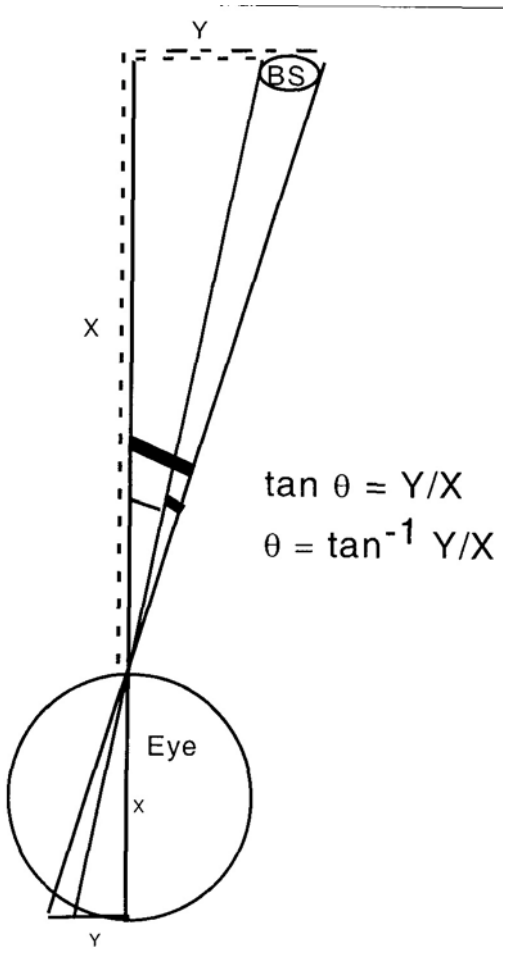

Figure 3. Diagram of the angles to aid students with calculations.

Instructor's Notes

1. If one partner is color blind, it may not be possible for that student to be either the experimenter or the subject in the color vision experiment. In this case, the student should obtain data to analyze from another member of the lab section or work as a group of three for this part of the lab exercise.

2. Arm's length or 57 cm can be used. But, there is a reason for the 57 cm. We are dealing with angles and tangents. The tangent of 1 degree is 0.0175 and 1/57 is 0.0175. Using arm's length gives comparable measurements and gives student individuality.

3. Materials Needed Per pair of students:
   - Tape measure
   - Lab marker—taped with white tape so that it blends with the white printer paper
   - Index card (3 x 5) for covering the eye
   - Popsicle sticks (8), in plastic bag, wrapped with tape—see chart below
   - Printer paper—2 sheets scotch-taped together lengthwise
   - White tape
   - Graph paper
   - Piece of poster board with a fixation point near one edge, and lightly marked vertical lines showing distances of 5, 10, 15, 20, 25, 30, 35, and 40 degrees. These marks will each be 5 cm apart.

4. Students will need to bring a calculator with trig functions.

5. The popsicle-sticks:
   - Each band should be about a cm high. The three bands will each be made from one of four colors, with each color used an equal amount across all sticks. If there are three bands per stick, and there are four colors to choose from (red, green, yellow, blue), with each color used only once per stick, the subject would be able to guess the order of the three colors on a stick with only about 4% probability [(1/4)*(1/3)*(1/2) = 1/24 = 0.04]. Each group receives eight sticks from the collection chosen at random. Place in a sandwich bag.
   - No writing is on the sticks, only tape.
   - The sticks will be taped in bands at one end only. There should be no space between the bands.

6. These supplies are used over and over again many times. The only supplies needing replenishing for each lab section are the 3 x 5 cards and the scotch-taped printer paper.

7. Purchasing the lab supplies:
   - Popsicle-sticks are purchased from any crafts store.
   - Poster paper is purchased from any supplier and cut in half.
   - Rolls of red, blue, green, and yellow electric tape are purchased from any hardware store.

Literature Cited

Cornsweet, T.N. 1970. Visual Perception. New York: Academic Press. p.137.

About the Authors

Robert A. Linsenmeier is a professor of Neurobiology and Physiology and also of Biomedical Engineering at Northwestern University. He received his PhD from Northwestern University. He teaches upper level physiology classes. His research has covered many areas of retinal physiology. He is the past chair of the Biomedical Engineering Department and is the current Associate Director of the VaNTH Engineering Research Center for Bioengineering Educational Technologies.

Roberta W. Ellington is a lecturer in Biological Sciences at Northwestern University. She received her MS from Loyola University Chicago. She is the Preparator for the Biology Labs and is the Lab Coordinator for the School of Continuing Studies (the Northwestern night school) Biology Labs.