Investigative Laboratory on "Filling In" by the Brain of the Blind Spot of the Visual Field

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Introduction

An important function of the brain is to integrate disparate types of sensory information and to create from them the perception of a coherent whole. When confronted with incomplete information, the brain takes the available data and makes a “best guess” about that which is missing. The rules by which the brain makes its “best guess” can be investigated experimentally by students in the case of missing information in the blind spot of the visual field.

The phenomenon of the blind spot is familiar to many instructors of biology. It occurs because there are no light receptors on the optic disc, a small area of each retina where nerve fibers converge to form the optic nerve. Light falling on this portion of the retina is undetected. One does not notice a blind spot when using both eyes, because an object that falls within the blind spot of one eye can be seen by the other. Even when using only one eye, an observer rarely detects a blind spot because the brain often “fills in” at least certain kinds of missing information. For example, when a vertical line is viewed with one eye such that a portion of the line falls within the blind spot, the line nevertheless appears continuous. More interesting, when a vertical line with a gap in it is viewed with one eye such that the gap falls within the blind spot, this line, too, appears continuous; the brain “fills in” the non-existent segment of the line.

Upon experiencing a few such examples of “filling in” by the brain, students immediately begin to ask questions about what other kinds of information the brain will fabricate. If the brain fills in a black line, will it fill in a colored line? What about a textured bar? Or a moving line? One of the advantages of this topic of inquiry is that students quickly formulate hypotheses and readily design experiments to test their hypotheses. We find that students are excited and come up with interesting and original ideas to test. Because the experiments can be done quickly, students can refine their experiments based on their initial results and can thus experience the iterative nature of scientific inquiry.

An investigative laboratory based on experiments with the blind spot can be adapted for students at almost any level of preparation. We have used it to introduce experimental science to students with no previous college science background. It also works well, however, with advanced students who are capable of a more sophisticated analysis and interpretation of their results.

Materials

In order to create the visual images with which to test their subjects, students need the following supplies: paper (white, black and assorted colors), pens, rulers, scissors, protractors, compasses and glue or tape. Some students ask whether they may use a computer to generate their test images. Since this is practicable in our situation we permit them to do so. Computer-generated images are by no means necessary, however, and we find that excellent experiments can be carried out with simple stationery supplies.

Notes for the Instructor

In order to design experiments, students must have some background information upon which to construct rational hypotheses. Students need to understand enough about the anatomy of the retina to understand why there is a blind spot. They should also be aware that visual acuity is highest at the fovea and poorer toward the periphery of the retina, including the region surrounding the optic disc. Thus, in the part of the visual field surrounding the blind spot, objects are seen less clearly than when we focus on them directly. Kolb (2003) provides a well-illustrated description of the functioning of the retina. Ramachandran’s (1992) excellent and highly readable article describes a number of experiments that probe the process of filling in of the blind spot by the brain.

Students design more sophisticated experiments when they understand that the visual system has specific functional properties associated with specific anatomical structures. At the highest level of visual processing, there are at least four distinct areas that process various aspects of a visual image: form, color, movement, and depth (Livingstone and Hubel, 1988). For example, humans suffering strokes sometimes suffer impairments that have been found to produce surprisingly specific deficiencies in one aspect of visual perception while leaving others apparently normal. Individuals may lose motion perception, yet retain perception of color and form (Zihl, Von Cramon and Mai, 1983). Others may lose the ability to recognize human faces yet retain the ability to recognize most other categories of objects (Ramachandran and Blakeslee, 1998). Still others may lose the ability to see color while other aspects of their visual perception remain intact (Sacks, 1995). Armed with this information, even beginning students easily begin to design interesting experiments that test the brain's ability to restore missing information about form, motion, color, or depth.

Livingston and Hubel (1988) provide a comprehensive review of the anatomy and physiology of visual processing in the brain. They begin with the retina, proceed through the lateral geniculate body, through the primary and secondary visual cortex, and continue all the way to the broad association areas of the temporal, parietal, and occipital lobes of the brain. For each area, these authors describe physiological experiments and visual deficits produced by strokes that clearly indicate that the various parts of the visual system can analyze a large number of specific attributes of a visual image. For example, the lateral geniculate body and retina have the specific ability to sort out wavelength (color), contrast (brightness and illumination), acuity (resolution), and movement (orientation and speed) in ways unique to each of these systems. These same authors describe many illusions that can be correlated with the functions of various divisions of the visual pathway. The many additional physiologically and anatomically discrete areas suggest more sophisticated experiments that may be directed at any of these visual attributes by students who have a higher understanding of the visual system. By noting the sorts of functions correlated with specific areas of the visual system, students can design more sophisticated experiments to help sort out these complexities.

Student Outline

We think of our eyes as the brain's window on the world, the pathway through which the brain receives visual information about the world outside the body. While this is true, it is equally true that the eyes can serve as a means to probe the inner workings of the brain. In particular, experiments that require the brain to process incomplete visual information allow us to explore the ways in which the brain compensates for missing data.

An important job of the brain is to integrate various types of incoming sensory information to create from them the perception of a meaningful, unified whole. For example, visual information regarding *form, movement, color* and *depth* are each processed by a different group of neurons in the brain. Yet when we view a scene we experience it not as a jumble of color, form, depth and movement but as coherent and unitary.

In order to create this sense of a seamless visual reality, the brain must not only integrate different types of information but it must also deal with the problem of incomplete information. Of the many situations in which the brain must deal with missing information, one of the easiest to investigate experimentally is the case of the blind spot of the visual field. The light receptors in each eye are located in the retina, which lines the inner surface of the back of each eyeball. There is a small area on each eyeball where nerve fibers converge to form the optic nerve. At this small spot, known as the optic disc, there are no light receptors. Because light falling on this portion of the retina is not detected, each of us has a blind spot in a small portion of the visual field of each eye.

When we view a scene with both eyes we do not detect a blind spot because an object that falls within the blind spot of one eye can be seen by the other eye. Even when using only one eye, an observer rarely notices a blind spot. This is because the brain often "fills in" at least certain kinds of missing information. For example, if you look at a wallpapered wall, you generally do not notice a gap in the wallpaper design because the brain fills it in. On the other hand, if you cover one eye and look in such a way that the clock on the wall falls within your blind spot, the clock may disappear.

Demonstrate to yourself that you have a blind spot. Close your right eye and look at the small square in Figure 1 with your left eye. Start with the figure about 30 cm away from your face and gradually move the page closer until the circle disappears. You may have to move the page back and forth a few times until you find the critical distance at which the circle falls within your blind spot. At that point, the circle will seem to disappear.

Figure 1. Demonstration of the blind spot. Close your right eye and focus the left on the black square. Move the page toward and away from your face until the circle disappears.

Now, demonstrate the phenomenon of "filling in" by the brain. Close your right eye and look at the black square in Figure 2 with your left eye. Move the page toward you until the circle disappears. What do you see where the circle used to be? Do you see a gap, or does the vertical line appear continuous? Most people see the vertical line as continuous; the brain fills in the missing segment of the line.

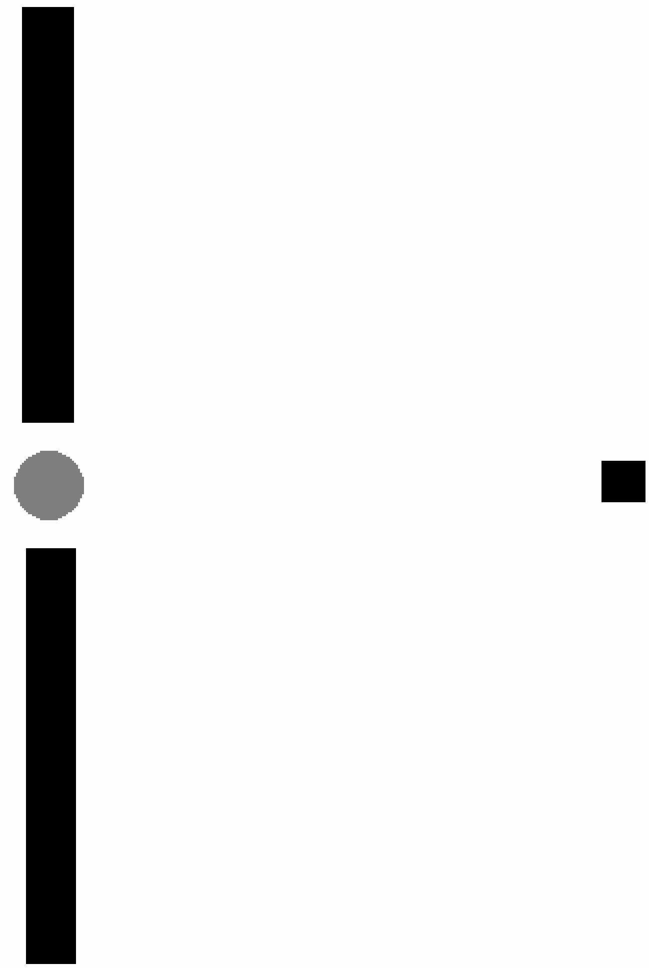

Figure 2. Demonstration of "filling in" by the brain. Close your right eye and focus the left on the square. Move the page toward and away from your face until the circle disappears and the line appears continuous.

Figure 3 can also be used to demonstrate "filling in." Again, close your right eye and focus on the white square with your left eye. Gradually move the page toward your face until the center of the wheel falls on your blind spot. What do you see? Most subjects report seeing the spokes of the wheel converging in the center of the circle. The brain extends the spokes inward, fabricating data to fill in the missing information from the blind spot.

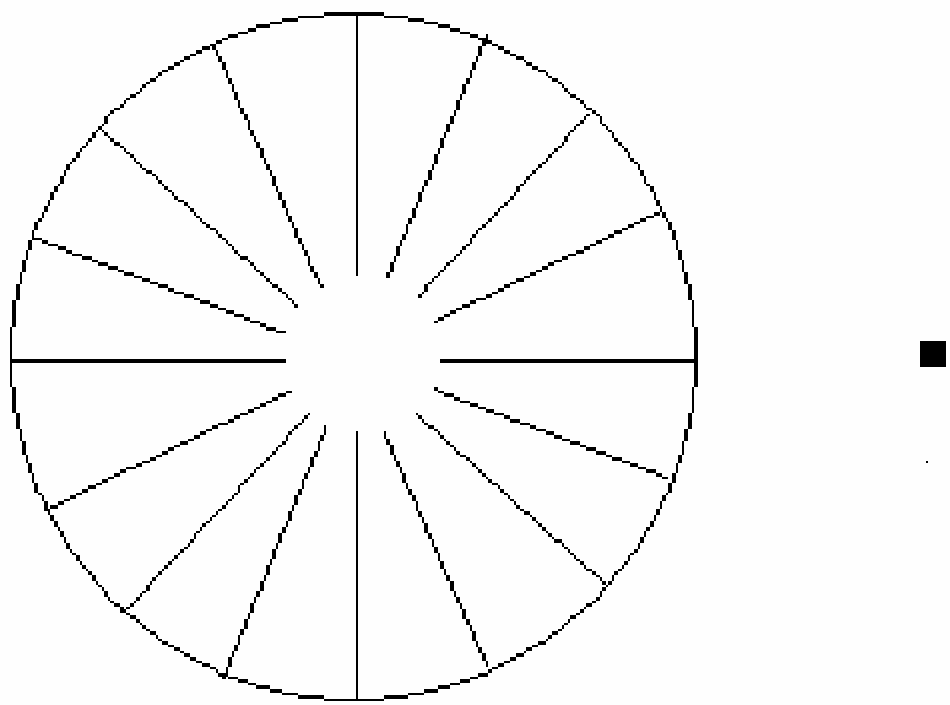

Figure 3. Another example of "filling in" by the brain: spokes on a wheel. Close your right eye and focus the left on the square. Move the page toward and away from your face until the spokes of the wheel appear to converge in the center of the circle.

These demonstrations may have raised additional questions in your mind about the process of filling-in by the brain to compensate for missing information from the blind spot. Your assignment today is to design and carry out an experiment to find out about the kinds of information that the brain "fills in." The first step in carrying out your assignment is to brainstorm with your lab partners. What questions do you have about the kinds of information the brain will fill in? How can you frame your questions as hypotheses? What kinds of experiments could you perform to test your hypotheses?

For these experiments your classmates will be your subjects. In order to make visual images with which to test your subjects, materials are available including paper of various colors, pens, pencils, rulers, protractors, scissors, tape and glue. After your group has come up with a list of possible questions and experiments, discuss them with your instructor. Together, you will decide which experiments to perform.

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