One of our approaches to teaching a course in anatomy and physiology is to stress the fundamental, systems-level concepts. One successful strategy we use is to continually highlight the relationships among anatomy, physiology, and behavior. In this article, we describe a set of classroom demonstrations that stress these links while fostering critical thinking. These demonstrations, on the topic of sensory system structure and function, rely on two perceptual consequences of neural adaptation in the visual system: afterimages and aftereffects. Viewing specific visual stimuli under binocular or monocular conditions with interocular transfer permits several concepts to be observed and discussed, including neural adaptation, anatomical and functional segregation of visual system pathways, and the relationship among visual system structure, function, and perception. This article discusses how to produce and present the required visual stimuli, suggests a set of questions to stimulate critical thinking, and presents student evaluation of this activity.

**Key words:** visual anatomy; visual physiology; visual aftereffects; classroom demonstration
ral adaptation, a fundamental property of sensory system function, involves a reduction in neural activity after prolonged exposure to a stimulus feature. We used neural adaptation and the effects it can have on perception in this unit. Specifically, we used the motion aftereffect and the color afterimage to demonstrate neural pathway anatomy and function. These activities were followed by a series of short questions and discussion that emphasized the important concepts and provided students with an opportunity for critical thinking and problem solving by the use of deductive reasoning.

In these two contexts, students first view specialized stimuli under binocular conditions and discuss the phenomena. Students are then asked to view the same stimuli under monocular conditions, where one eye is exposed to the adapting stimulus and the other, nonviewing, eye is used to test for the presence of the phenomenon. The presence of an afterimage or an aftereffect when viewing with the unexposed eye is called interocular transfer (IOT). The presence of IOT can be used to infer the location of the cells undergoing adaptation: before (retinal) or after (cortical) the site of binocular combination of input from the two eyes.

In a very short amount of time a student can personally experience several fundamental concepts that link visual anatomy, physiology, and perception (see Ref. 4 for a good, single source reference here). These concepts include:

**Neural Adaptation.** Cells in the visual system undergo physiological changes as a result of prolonged stimulation. One consequence of continued stimulation by a particular visual feature is the reduction in neural activity of the specific pool of cells sensitive to that stimulus feature. For example, exposure to visual motion to the left can “fatigue” cells sensitive to this specific visual feature (leftward motion) whereas those cells sensitive to the opposite direction of motion remain unchanged.

**Anatomical segregation of the visual system.** The visual pathways from eye to brain are anatomically segregated. About 50% of the optic nerve fibers that leave each eye cross at the optic chiasm, ensuring that information from each eye crosses midline and projects to each lateral geniculate nucleus (LGN) of the thalamus. Although each LGN receives input from the left and right eyes, this input remains segregated in separate layers. Binocular combination of information from the two eyes does not occur until the primary visual cortex (area V1). For many students, the anatomical segregation of the visual pathways is only academic. Our activities illustrate anatomical segregation and make it more tangible and meaningful with the demonstration of the interocular transfer of visual information.

**Functional segregation of the visual system.** The visual pathways from eye to brain are also functionally segregated. The visual system processes visual features such as motion, color, form, and depth separately and carries this information in parallel neural pathways. This is called functional segregation and is a fundamental property of sensory systems. Functional segregation begins in the retina and continues to cortical area V1 and beyond. In the retina, there are two broad classes of ganglion cells: magnocellular (or M cells) and parvocellular (or P cells). M cells carry information primarily concerning motion, whereas P cells carry information primarily concerning color (Fig. 1). Our activities illustrate the principle of functional segregation by showing that motion- and color-sensitive cells can be modified independently.

**Link between anatomy, physiology, and perception.** Our sense of sight is dependent on the underlying visual anatomy and physiology. The activities used in this lesson illustrate this principle by showing that the physiological changes associated with neural adaptation have perceptual consequences. The presence or absence of IOT with these effects links the behavior and the physiology back to the anatomy, stressing the organization of neural pathways and stages of neural processing.

Finally, these activities work to foster critical thinking and problem solving by deductive reasoning, both of which are likely to increase students’ depth of understanding of the course material.

**METHODS**

Students in three different lab classes were given a handout on the day’s lab assignment containing a
short tutorial and a guide to the activities. The tutorial covered 1) gross anatomy of the eye, 2) anatomy of the visual pathways, including the retina, the LGN of the thalamus, and primary visual cortex, 3) functional distinction between the M and P layers of the LGN and the M and P pathways, and 4) the phenomenon of neural adaptation. Students were given time to read the lab handout and were guided through the demonstrations by the lab instructor.

Activities. After a brief introduction covering the material in the tutorial, we had students view two visual stimuli in two different conditions. One stimulus (the adapting stimulus) was used to adapt or fatigue a specific visual feature (motion or color). The second stimulus (a comparison stimulus) was used to make the changes that accompany adaptation apparent.

Initially, students were instructed to view the adapting stimulus binocularly for ~30 s. After 30 s, students were instructed to view the comparison stimulus for any changes due to adaptation. After this exercise, a short recovery period was permitted to allow the adaptation to diminish. This time was used for questions concerning the students’ observations and to review the organization of the visual pathways.

In the second part of each demonstration, we had the students close or cover one eye and view the adapting stimulus under monocular conditions for ~30 s. At the end of the adaptation period, we asked students to quickly close the adapted eye, uncover the unadapted eye, and view the comparison stimulus. Students were then viewing the comparison stimulus with the eye that was not exposed to the adapting stimulus. This tests for the presence of the IOT of
these effects. After this test, we again discussed what the students observed and how our understanding of the structure and function of the visual pathways can explain these illusory images.

**Motion aftereffect.** The first pair of stimuli permits students to experience the motion aftereffect. Students were instructed to fixate on a small spot in the center of a clockwise-moving spiral and to maintain this fixation without making eye movements. After 30 s, the moving spiral can be made to stop abruptly. The students were then instructed to continue fixating on the spot in the center and to note what they observe. Again, this exercise is performed binocularly and then monocularly. Students reported seeing motion in the stationary stimulus that is counterclockwise, that is, opposite to the motion of the adapting stimulus.

**Thought questions.** After the demonstrations were viewed, a handout containing a number of questions was used to elicit critical thinking. The first few questions were asked to help students clarify and articulate their experiences, and the remaining questions were used to help students relate their experiences to the structure and function of the visual system (Appendix 1).

**Color afterimage.** The second activity involves four stimuli that permit students to experience a color afterimage. Students were instructed to fixate on the center of a four-quadrant colored pattern (made up of a red, a green, a yellow, and a blue square) and to maintain this fixation without making eye movements for ~30 s. After 30 s had elapsed, students were instructed to move their gaze quickly to a similarly-sized four-quadrant pattern that was uniformly white and to note what they observed. As with the motion aftereffect, this exercise was performed binocularly and then monocularly. Students reported seeing a colored afterimage in the white pattern, where the red and green quadrants and the blue and yellow quadrants had changed positions.

**Thought questions.** Again, after the demonstrations were viewed, a handout containing a number of questions was used to elicit critical thinking and help students relate their experiences to the structure and function of the visual system (Appendix 2).

**EVALUATION**

This entire exercise can be performed in 15–20 minutes and fits well within any general laboratory on central nervous system function. An abbreviated version has also been used as a demonstration during a lecture. After the students had an opportunity to view the stimuli and answer the thought questions, the instructor closed with a question-and-answer period and a brief summary of the major points. Immediately after the demonstrations, the students were asked to formally evaluate the lab assignment.

At the end of the lab period, we used a short questionnaire to evaluate the activity. Students (n = 68) responded on a five-point scale stating the strength of their agreement with a set of seven questions. Students were asked to respond using the following choices:

<table>
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<tr>
<th>Strongly Disagree</th>
<th>Mildly Disagree</th>
<th>No Opinion</th>
<th>Mildly Agree</th>
<th>Strongly Agree</th>
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<tr>
<td>1</td>
<td>2</td>
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<td>5</td>
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Answers were assigned numeric values from 1 to 5, with Strongly Disagree = 1 and Strongly Agree = 5. These questions and the students’ mean responses are shown in Table 1. In brief, the students overwhelmingly reported that the demonstrations were good illustrations of the concepts of visual anatomy, neural adaptation, and functional segregation. They also reported that the demonstrations were relevant and helpful for understanding the material presented in a lecture and the textbook and should be used in future classes.

**SUMMARY AND DISCUSSION**

Integrating structure and function is one of the most difficult aspects of teaching physiology to undergraduate students. The stimuli and lessons we have used provide a simple, interactive method of teaching central nervous system pathways and functions that we have used to teach second graders through graduate students. In each case, the students overwhelmingly viewed these demonstrations as interesting and helpful in their overall understanding of the concepts. In summary, the conceptual issues addressed by these demonstrations are:
1) Neural adaptation. Prolonged viewing of a visual stimulus produces neural adaptation or fatigue in the visual system. Our demonstrations help students understand this concept by allowing them to experience the perceptual changes that are a consequence of neural adaptation.

2) Anatomical segregation of the visual system. There are anatomically distinct neural pathways from eye to brain. The IOT of neural adaptation is a compelling demonstration that single cortical regions integrate information from both the left and right eyes.

3) Functional segregation of the visual system. The visual system processes each visual feature (e.g., color, motion, etc.) separately. Our demonstrations illustrate the principle of functional segregation by showing that motion- and color-sensitive cells can be modified independently.

4) Link between anatomy, physiology, and perception. The visual sense is a product of the anatomical and physiological characteristics of the visual system. The described exercises demonstrate the link between anatomy, physiology, and perception by letting students directly experience the perceptual consequences of anatomical or physiological properties of the visual system.

Tips for teachers. The stimuli used to produce these effects can be created in a variety of ways and used in both laboratory and classroom. The strengths of these particular demonstrations are that they are inexpensive, take relatively little time, and do a wonderful job of making the material come alive for students. Also, if time is severely limited, the instructor can choose to shorten the demonstration to only a subset of the phenomena (e.g., only color or only motion, or eliminate the manipulation of IOT) and cover a smaller set of the conceptual issues.

These demonstrations can be produced with or without the aid of computers. If computers are available, freeware computer programs that produce appropriate visual motion are available on the internet. We have used presentation software to present both the motion and the color stimuli. An embedded “action button” in Powerpoint, for example, can be used to run an external motion program and objects drawn in Powerpoint can be used for the color afterimage. We have written such a file which is available for downloading from our web site (www.apsu.edu/visionlab/jphysio.htm). Alternatively, the motion programs can be downloaded separately from our site or elsewhere on the web. These demonstrations work just as well in large multimedia-equipped classrooms as they do in the lab.

If computers are not available, a spinning disk can be used to produce the motion aftereffect, and color transparencies can be used to produce the color afterimages. A limitation of producing the stimuli in this form is that, in very large classrooms, the motion aftereffect will be much less compelling for those in the back of the room.

APPENDIX 1

1. The first set of conditions involves viewing the adapting stimulus with both eyes open (binocular viewing). After the stimulus stopped moving, what was your perception of the stationary stimulus? Did the image appear to rotate? If so, in what direction and for how long?
2. This is an example of neural adaptation. You adapted the cells sensitive to specific directions of motion. Why did this neural "fatigue" produce an illusion of motion in the opposite direction?

3. View the adapting stimulus again, but with only one eye. Cover or close the other eye. When the movement stops, quickly cover the eye used to view the moving spiral and view the stationary stimulus with the other, previously covered, eye. After the stimulus stopped moving, what was your perception of the stationary stimulus? If it appeared to rotate, in which direction and for how long?

4. If you observed continued movement after switching eyes, then you experienced the aftereffect while viewing with an eye that was not exposed to the moving stimulus. This is called interocular transfer (IOT). Given your knowledge of the layout of the visual pathways from retina to cortex, how can this phenomenon be explained?

APPENDIX 2

1. The first set of conditions involves viewing the adapting stimulus with both eyes open (binocular viewing). After viewing the four colored quadrants for 30 seconds, what was your perception of the stimulus with four white quadrants? Did this stimulus pattern appear colored? If so, can you remember which color appeared in each quadrant?

2. This is an example of color afterimages. You adapted the cells sensitive to specific colors. You may have noticed that the colors that appeared in the comparison stimulus were the same as the colors in the adapting stimulus. However, did you notice anything systematic about their new positions?

3. View the adapting stimulus again, but with only one eye. Cover or close the other eye. After 30 seconds, quickly cover the eye used to view the color stimulus and view the white comparison stimulus with the other, previously covered, eye. Did the comparison stimulus appear colored? If so, in any systematic way?

4. You should not have experienced a color afterimage in this condition: There is no IOT for color afterimages. Given the layout of the visual pathways from retina to cortex, can you infer where the site of adaptation must be?

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