“REWIRING” THE BRAIN

Directions for Teachers

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SYNOPSIS

Students throw beanbags at a target while wearing specially prepared goggles that demonstrate how their brains adapt to changing sensory cues. Experiments are designed and conducted to learn more about the adaptation called plasticity.

LEVEL

Exploration, Concept/Term Introduction Phases

Application Phase

Getting Ready

See sidebars for additional information regarding preparation of this lab.

Directions for Setting Up the Lab

Exploration

Make photocopies of Figure 2 for students.

The beanbags can be made inexpensively by cutting and sewing squares of material from nylon hose, old sheets, pillowcases, or t-shirts, and then filling the squares with beans from the local grocery store. If you are near a rural area, the fill material could be soybeans or corn from a nearby farm. The students can be responsible for making the bags for their team. These bags can be saved for other classes and for classes in subsequent years.

As you read the following description for preparing the prism goggles, refer to Figures 1a–d on the following page. Prism goggles are made by attaching special prism lenses (Figure 1a) to standard lab/workshop goggles (Figure 1b) with the diffraction gradient for both lenses in the same direction. The lenses must be cut to fit the goggles (Figure 1a). The direction of displacement (right or left) will depend on how the “Press-On Optics” are cut and attached to the goggles (see Figure 1c). Both lenses *must* be attached to the goggles in the same direction of the displacement. See enlargement of lens in Figures 1a and 1c. An optician may be able to supply the safety goggles and attach the lenses. The finished set of prism goggles will resemble Figure 1d.

Concept/Term Introduction

If students watch the videodisc referred to in the **Procedure**, locate it and schedule the videodisc player.

STUDENT PRIOR KNOWLEDGE

Before participating in this activity students should be able to:

- Explain the basic interactions between neurons and their role in the circuitry of the nervous system.
- Describe how the human eye receives and interprets light stimuli.

INTEGRATION

Into the Biology Curriculum

- Health
- Biology I, II
- Human Anatomy and Physiology
- AP Biology

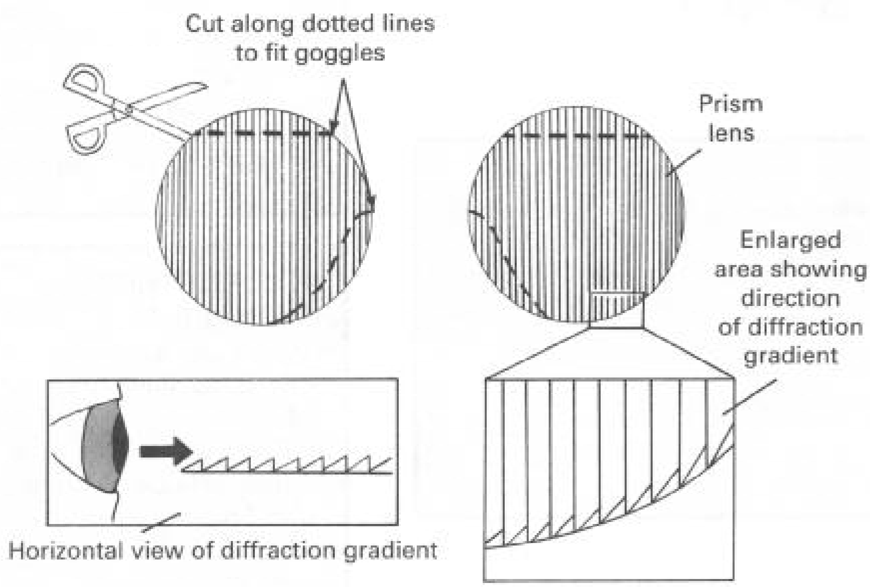
Across the Curriculum

- Physics
- Psychology

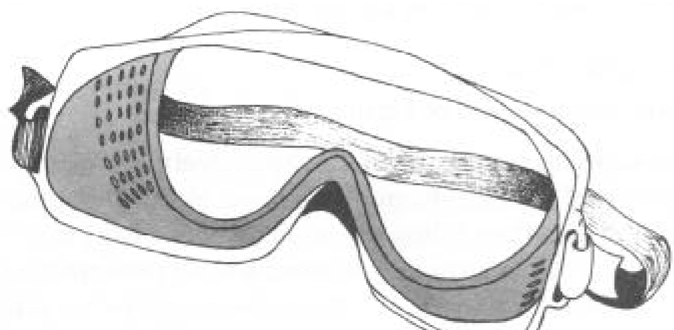
OBJECTIVES

At the end of this activity students will be able to:

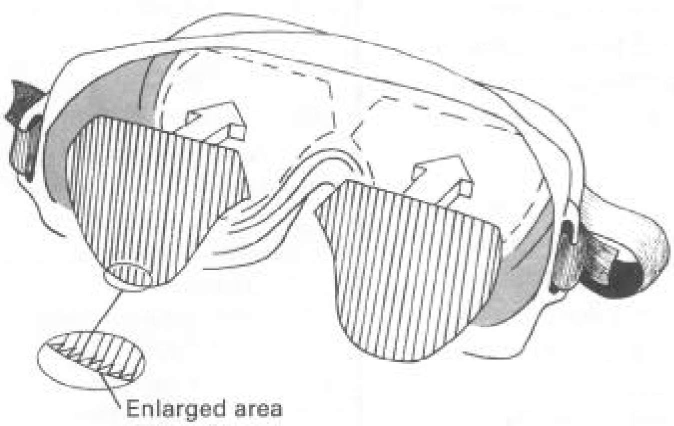
- Describe neuronal circuitry that underlies visual processing and perception that affects motor output.
- Design an experiment to explore the neuronal basis for adaptation/plasticity.
- Describe broader applications of neuronal plasticity in relation to learning and memory.



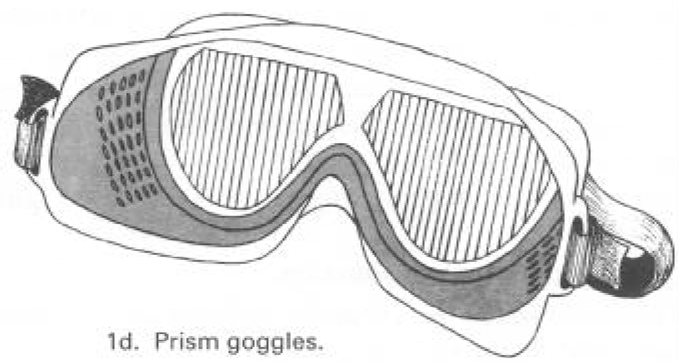
1a. Prism lenses with enlarged area showing the direction of the diffraction gradient of the lenses. Note that as they are cut, the diffraction gradient of each lens is going in the same direction.



1b. Safety goggles.



1c. How to apply the lenses to the safety goggles.



1d. Prism goggles.

Figures 1a–1d. Steps in preparing prism goggles.

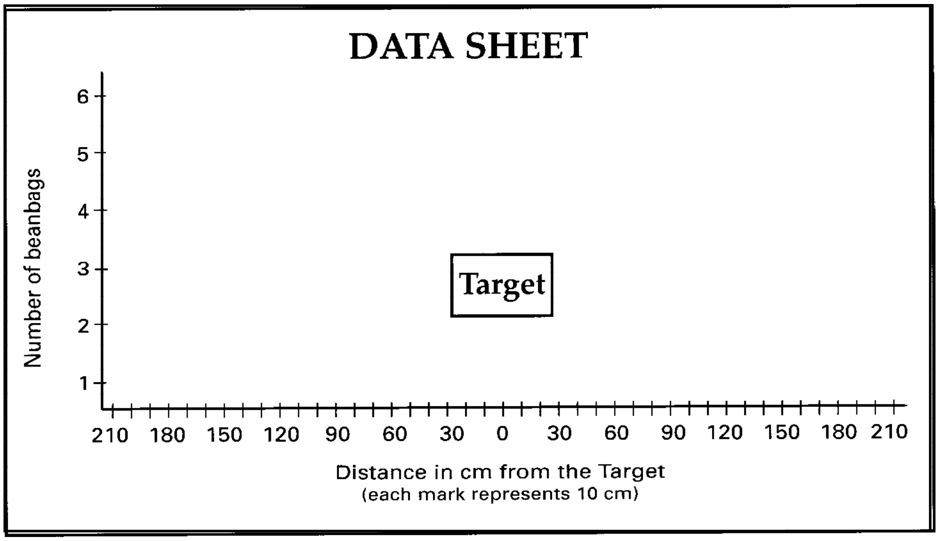


Figure 2. Suggested student data sheet for the **Exploration** *activity.*

Teacher Background

The capacity to learn is one of the most profound aspects of the human nervous system. Despite our knowledge of the anatomy and related circuitry or hard-wiring of the central nervous system (CNS), many neuroscientists continue to search for the underlying basis of the brain's ability to adapt rapidly to new experiences. This adaptability, both conscious and uncon-

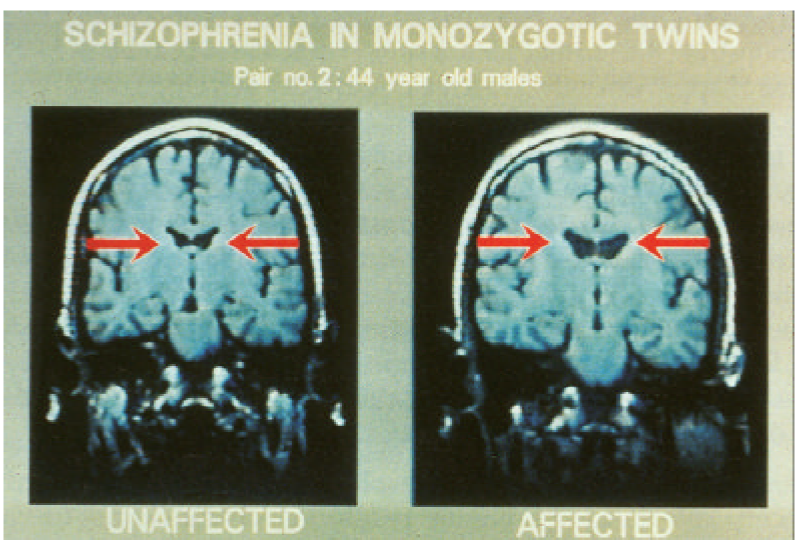


Figure 3. Magnetic Resonance Imaging (MRI).

LENGTH OF LAB

A suggested time allotment follows:

Day 1

[E] *15 minutes* — Conduct initial demonstration.

[C] *15 minutes* — Develop explanations for the demonstration.

15 minutes — Brainstorm hypotheses.

Day 2

[A] *45 minutes* — Design and conduct experiments.

Day 3

[A] *30 minutes* — Analyze experimental data and discuss results.

MATERIALS NEEDED

You will need the following for the teacher-led introduction:

- 1 teaspoon
- 220 mL (8 oz) drinking glass
- 110 mL (4 oz) tap water

[E] You will need the following for each group of four students in a class of 24:

- 1 pair of 30-diopter prism goggles
- 10 beanbags, numbered 1 through 10
- 1 meter stick or measuring tape
- 7.5 x 7.5 cm (3 x 3 inch) Post-it™ notes
- 1 roll brightly colored plastic tape
- 1 pair scissors
- 1 cardboard box, approximately 45 x 30 x 25 cm
- 4 student data sheets (Figure 2) or sheets of graph paper

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MATERIALS —Continued

C You will need the following optional materials for a class of 24:

- *Atoms to Anatomy* videodisc
- Photographs of Magnetic Resonance Imaging (MRI) and Positron Emission Tomography (PET) scans of the human brain (Figures 3 and 4). These figures are also provided as slides with this lab manual.

A In addition to the materials listed in E, you may need the following materials for each group of four students in a class of 24:

- Prism lenses of different diopters than those used in E, such as 10, 15, 20, 40

PREPARATION TIME REQUIRED

E
- *1 week* to order and receive prism lenses
- *3 hours* to assemble lenses on goggles
- *3 hours* to make or purchase beanbags
- *1 hour* to obtain all other materials, including photocopying Figure 2

C
- *4 weeks* to obtain optional materials

SAFETY NOTES

- Students who are observing must stand behind the thrower during the ***Exploration*** activity.
- The student wearing prism goggles must stand squarely in front of the

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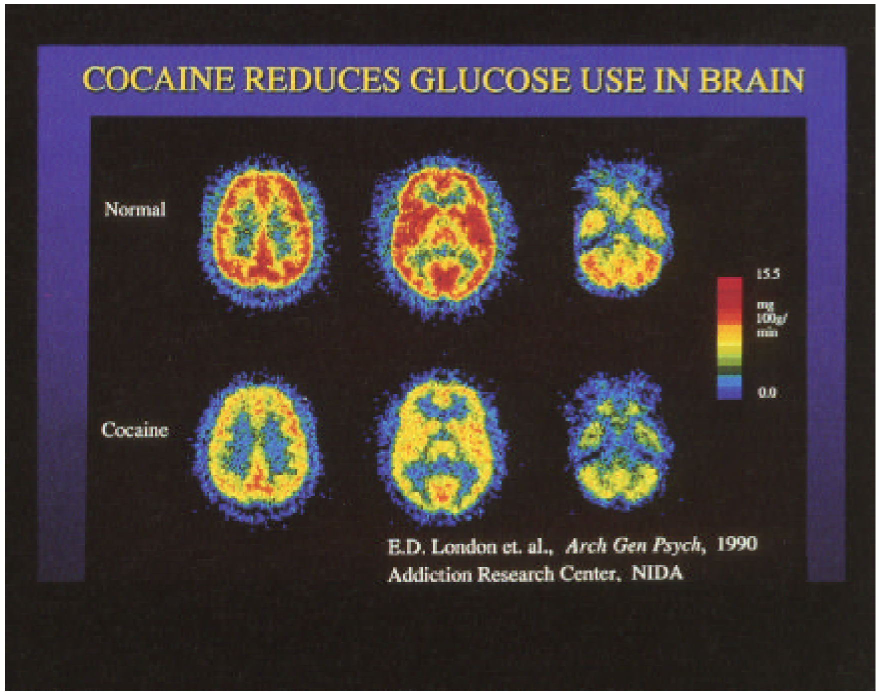

Figure 4. Positron Emission Tomography (PET).

scious, is often termed *neuronal plasticity* and is considered to be memory in the short-term and learning if remembered over the long-term.

Neuronal plasticity is demonstrated easily in this laboratory when a subject wearing specially prepared goggles throws beanbags at a target. To demonstrate the normal state, a subject first tosses beanbags, from a distance of approximately 3 to 4 meters, directly at a target, such as a Post-it note, placed on a wall 0.5 m above the floor. Next, the subject puts on prism goggles that bend the light and throws at the target again. During this second trial, the goggles should cause the wearer to throw the beanbags approximately 15 degrees off target. See Figures 5a and b. Subsequent trials wearing the goggles will create an adaptive situation that influences motor performance that corrects for the lenses' shift and becomes part of the brain's interpretation of what the eye is seeing. As a result, if the subject performs a trial immediately after removing the goggles, the beanbags should land approximately 15 degrees from the target on the opposite side of the original displacement.

Numerous regions of the brain are involved in this visuomotor activity that incorporate the necessary sensory information and control the motor output. As the student throws the beanbags and identifies the target, reflected light from the target enters the eye. The retina transduces this light into an appropriate signal for the nervous system that is carried to multiple components of the visual system. (For more information on the visual system, including diagrams, refer to "Is Seeing Believing?" on p. 239.) A visual perception of the target occurs. To move the muscles of the arm to toss a beanbag at the target, the visual system signals the motor system

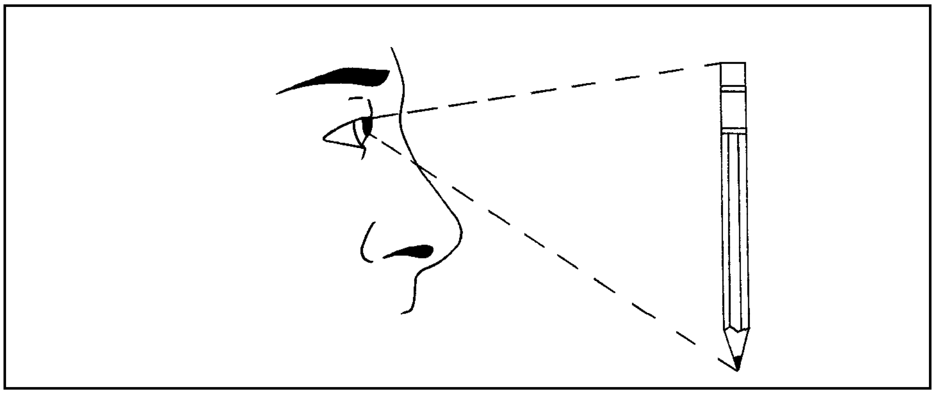

Figure 5a. Individual's view of pencil without prism goggles.

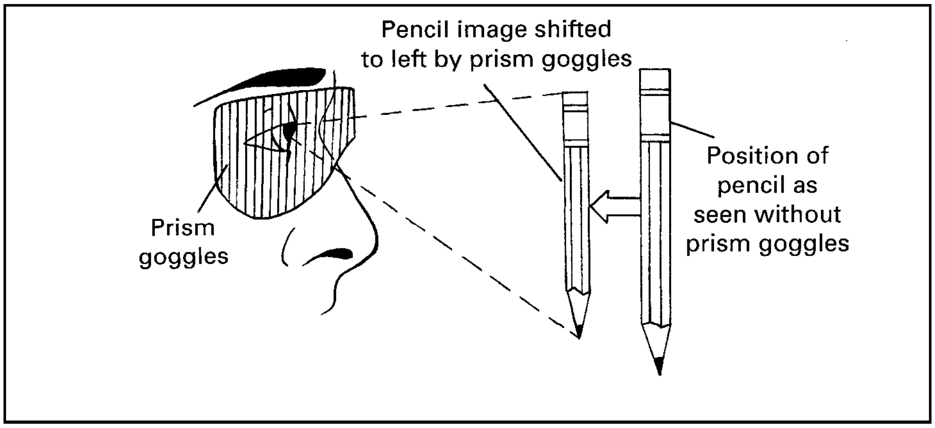

Figure 5b. Diagram showing how the prism goggles diffract the light and the individual sees the pencil to the left of the original position.

through cortical outflow directed toward the spinal cord. Here appropriate motor neurons are activated to excite muscle fibers. Usually, the student has the appropriate neural circuitry and hits the target on the first trial.

Of tremendous importance is the brain's response to the shift of the original visual signal due to the prism lenses that bend light and displace the original visual input to a different location on the retina. See Figure 6. The arm subsequently throws a beanbag to the original or wired location. Then the visual system receives a new signal and a perception indicating that the target has not been hit. With subsequent trials with the prism goggles, the brain adapts and reconfigures this information. The new portion of the retina is rewired to a new area in the cerebral cortex so that correct muscle groups are activated to hit the target.

The plasticity of the new response occurs rapidly and is remembered, as shown by the response when the prism goggles are removed. The previously learned *correction factor* is maintained in the first few tries until the brain quickly corrects the action and returns to its original state.

While adaptation/plasticity is demonstrated easily in the visuomotor activity, similar processes occur throughout the CNS and are especially prevalent at the level of the cerebral cortex. Each sensory system, in all likelihood, has an ability to adapt the sensory information that it receives to changing events. More significantly, the extent of these mechanisms in the human brain underlies our

SAFETY NOTES —*Continued*

target and not rotate his/her body position during the testing period.

- Some students may experience nausea while wearing prism goggles and should be excused from the role of thrower.
- The diopter goggles should be sterilized in a goggle cabinet between uses or swabbed with alcohol.

TEACHING TIPS

- Although prism lenses may be obtained from an ophthalmologist or optician, it may be easier to order them from a distributor. Made by 3M Health Care, Specialties Division, the lenses are called "Press-On Optics" and can be obtained from:
  The Fresnel Prism & Lens Company
  7975 N. Hayden Road,
  Suite A-106
  Scottsdale, AZ 85258-3242
  (800) 544-4760
  (602) 596-3998

The goggles are graded on the magnitude of visual shift (that is, diopters of displacement where one diopter is approximately 0.5 degrees of displacement). The 30-diopter lens recommended for the main activity will shift light 15 degrees. For each pair of goggles, order two lenses ($12–$13 each) with the same displacement.

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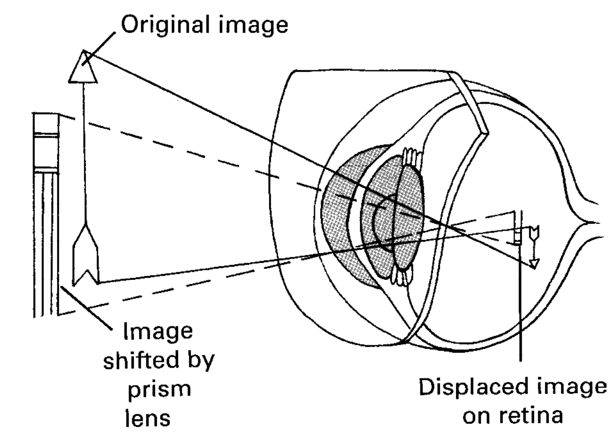

Figure 6. Retina showing displacement of image due to the prism lens.

vast neural capabilities in memory and learning that distinguish us from other species.

Procedure

Introduce the activity with a spoon in a glass of water set up on the demonstration table. Ask the students to explain what they see.
Questions to help students with their observations are:

- Why does the spoon look like it is cut in half?
- Are there other examples you can remember in which you were fooled by what you saw? For example, have you tried to retrieve a penny from the bottom of the pool?

Have the students read the **Introduction** in **Directions for Students** and do the ***Exploration*** below.

E Exploration

The ***Exploration*** activity demonstrates the concept of neuronal plasticity. The student procedures are listed below, and details about how to construct prism goggles appear in **Teaching Tips**. The **Teacher Background** section explains what happens neurologically as students participate in the activity.

The numbers of beanbags and prism goggles available will determine how this activity is carried out. If materials are limited, a class demonstration will be necessary. If enough materials are available, divide the class into six groups of four students each and have each group conduct the activity. If possible, give each student who wants to do this activity the opportunity to experience the "rewiring" of the brain. Have the person throwing the beanbags describe the sensation.

Procedures to conduct the activity with small groups are given below. Directions for modifying the activity for a large class demonstration follow this procedure.

1. Assign each student in a group a role as follows:
   - Thrower

TEACHING TIPS
—Continued

- The number of beanbags needed will be determined by your class size and the number of students you have in each group; to extend the number, 60 beanbags would allow 10 per group of four students for a class of 24. It is very helpful to have beanbags numbered 1 to 10, so that their positions on the floor relative to the target can be charted for later analysis by the students.
- If you can arrange for more beanbags, data collection will be easier by following this procedure:
  - Give each group of four students 30 beanbags instead of 10.
  - The beanbags should be three different colors, with 10 of each color.
  - Each set of 10 bags of a given color should be numbered from 1 through 10.
  - Use a different color of beanbags for each of the three throwing trials. This way, the bags can be left on the floor throughout the **Exploration**, and all data can be collected at the end.
- *Atoms to Anatomy*, a videodisc presentation from VideoDiscovery™, contains a sequence of visuals that augment the activities presented here. Among the visuals is a set of brain scan photographs that shows the location of brain activity while the subject is engaged in various cognitive tasks. For information, call

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- Materials coordinator
- Measurer
- Data recorder.

2. The measurer should place a small target, such as a 7.5 x 7.5 cm Post-it note, 0.5 m above the floor. With brightly colored plastic tape, mark a distance of two meters on the floor on either side of the target into 10 cm intervals.
3. The measurer should measure a distance approximately three to four meters from and directly in front of the target and mark this spot on the floor with another Post-it note. This spot is where the thrower will stand. All other members of the group should stand behind the thrower and slightly to the side. See Figure 7.
4. The materials coordinator should hold the numbered beanbags in a box for the thrower and give them to the thrower in numerical order.
5. The thrower should throw the beanbags at the target in rapid succession.
6. The measurer should measure the distance that each numbered beanbag landed from the target, and the data recorder should record this information. The materials coordinator should collect the beanbags and place them in numerical order.
7. The thrower should put on the prism goggles and repeat the test with the beanbags as was done in Step 5.
8. The thrower should continue wearing the prism goggles as the measurer, data recorder, and materials coordinator quickly repeat Step 6.
9. The thrower should remove the prism goggles and QUICKLY continue the test with the beanbags as was done in Step 5. (Note: This exercise

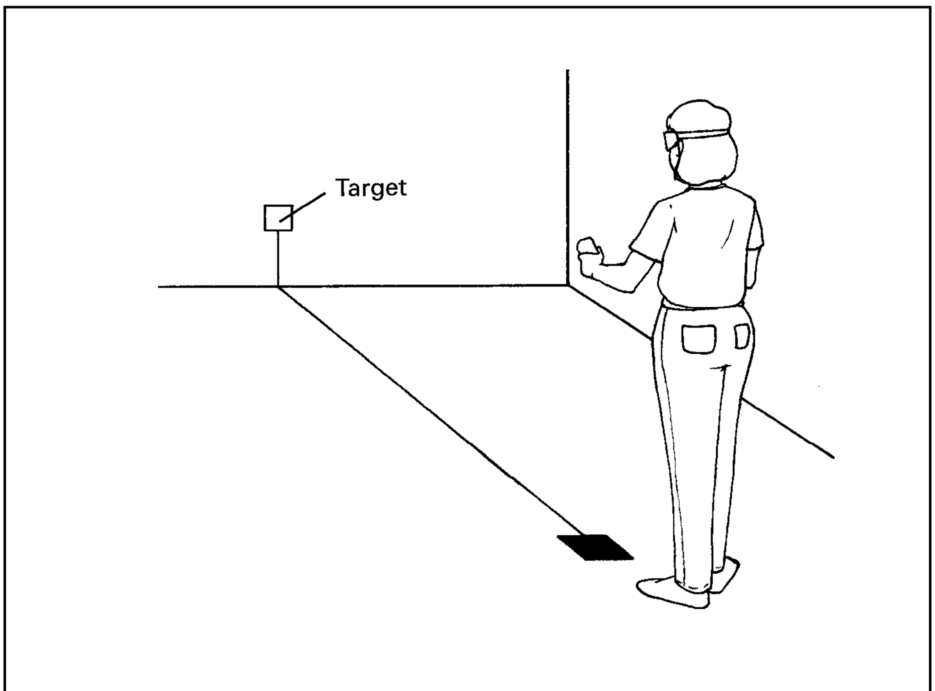

Figure 7. Setup for throwing beanbags.

TEACHING TIPS
—Continued

VideoDiscovery at (800) 548-3472.

SAMPLE HYPOTHESIS

If the thrower stands six meters from the target wearing 30-diopter prism goggles, then the accuracy of all of the throws will be increased, as compared with a distance of three to four meters.

SAMPLE PROCEDURE

Repeat Steps 1 through 11 of the ***Exploration*** section of this activity. The only change will be that the thrower will stand six meters from the target instead of three to four meters.

SUGGESTED MODIFICATIONS FOR STUDENTS WHO ARE EXCEPTIONAL

Below are possible ways to modify this specific activity for students who have special needs, if they have not already developed their own adaptations. General suggestions for modification of activities for students with impairments are found in the AAAS *Barrier-Free in Brief* publications. Refer to p. 19 of the introduction of this book for information on ordering **FREE** copies of these publications. Some of these booklets have addresses of agencies that can provide information about obtaining assistive technology, such as Assistive Listening Devices (ALDs); light probes; and talking thermometers, calculators, and clocks.

Blind or Visually Impaired

- Identify the target by placing a Post-it note on the floor beneath the target site. Modify the area around the target by placing plastic tape or Velcro™ tabs at intervals of 10 cm, 2 m on either side of the target. The student may tactilely examine the target site before the beanbags are thrown.
- Make a raised grid of Figure 2 using liquid glue. The student may use a grease pencil to record the impact position of the beanbags as the data are relayed by a sighted partner.

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depends on short-term memory. An extremely small time interval between removal of the prism goggles and the last set of trials is necessary for the demonstration to work properly.)

10. All students in the group should record all the distances measured on their data sheets. See Figure 2.
11. The thrower should describe to the group what was experienced during each of the three trials.

To modify this activity into a large class demonstration, assign the roles of thrower, materials coordinator, and measurer to three students. All other students in the class will be observers/data recorders. Follow the steps in the order indicated.

C Concept/Term Introduction

If students are not already in small groups, divide them into small groups and have them follow the directions in **Directions for Students** for this section.

As students develop their explanations, it may be helpful to have them examine photographs or slides of MRI and PET brain scans that show blood flowing during cognitive activity (see Figures 3 and 4), or similar images found in the videodisc *Atoms to Anatomy*. The visuals may help students begin to relate learning to neuron activity and interaction. Information about ordering *Atoms to Anatomy* is found under **Teaching Tips**.

Have each group share its explanations with the class. It is very important that students understand the major concepts in this activity before designing experiments on their own. If you are concerned that students do not understand, you may want to use one of the following strategies:

- Suggest that the students return to their groups and summarize their findings. Then have the groups share their ideas with the class. By comparing notes and with teacher guidance, students will be able to see for themselves what issues they understand and where they need further assistance.
- Form a "Group of Teacher Assistants" and have those students take questions from class members. The teacher can determine who the assistants are by developing a set of questions to ask members of each group orally. Those who seem to understand the concepts based on these answers can travel to other groups and help to clear up misunderstandings. If those questioned by the teacher do not understand the concepts, the teacher can give them additional questions to work on and the teacher can repeat the process with another group to identify "assistants."

A Application

Students can now build on their previous experiences to extend the prism goggles experiment and learn more about visuomotor activity. Have them work in their groups to design and conduct their experiments and analyze their data. As they conduct these investigations, encourage students who did not throw the beanbags in the original experiment to do so as time allows.

Afterwards, each group should share its results with other members of the class. Students can quantify their data by plotting the distance from the target that the beans bags land both with and without goggles.

Suggested questions students may wish to investigate include the following:

- Do left-handed people perform the same in this activity as right-handed people?
- Does a person perform differently in this activity if the beanbags are thrown with the hand that is not dominant? For example, a right-handed person throws the beanbags with the left hand.
- Does the outcome of the experiment change if the distance between the thrower and the target is changed?
- Does the thrower perform differently if prism goggles are worn that displace the vision in different amounts? For example, how would the individual perform wearing goggles with 10, 15, 20, or 40 diopter lenses?

Your students probably will develop other questions related to neuronal plasticity. In the sidebar on p. 101 is a sample hypothesis and procedure that students might derive related to this activity. This example has been included as a suggested outcome of the activity and is not meant to be given to the students. Students should develop their own hypotheses and procedures. Make sure they understand that there is not just one correct hypothesis and procedure.

Answers to Questions in "Directions for Students"

[C] Concept/Term Introduction

Focus Questions

1. Visual pathways (eyes/retina, thalamus, visual cortex), cortical association pathways (visual cortex to motor cortex), motor pathways (pyramidal tract, motor neurons, muscles).
2. Usually, yes. Individuals may vary, however, in their rate of adaptation. Some may adapt after only one throw.
3. The visual displacement caused by the prism goggles forces the first toss of the beanbag to be aimed at a target that seems to be straight ahead. In reality, it has deviated in a direction opposite to the displacement.
4. During the learning trials, adaptation/plasticity in the neural pathways incorporates a correction factor to ensure that the target is hit as the beanbags are tossed. The correction factor is remembered when the goggles are removed.
5. Although the activity is "remembered" for only a short period of time, the plasticity that has been demonstrated is thought to subserve memory and learning and is considered to be a generalized property of many portions of the CNS.

[A] Application

SUGGESTED MODIFICATIONS
—Continued

- Provide raised line drawings of student Figure 1 and a representation of the spoon in a glass of water for students who are blind. For students with residual sight, provide photo-enlarged forms.
- Construct a tactile diagram representation of the MRI and PET (Figures 3 and 4) using different grades of sandpaper or different textures of fabrics such as wool, corduroy, fleece, or silk.
- Give an oral interpretation of information visually depicted on the videodisc.
- Have the student with a visual impairment act as a data recorder, with oral information regarding the data provided by a sighted partner.

Deaf or Hard-of-Hearing

- Sign interpretation or closed captioning of the videotext information should be provided for the student with a complete hearing loss.
- Position the student who acts as an observer so that he/she physically sees all the events that are occurring regardless of his/her communication mode.

Gifted

Examine other sensory systems to identify examples of plasticity. Design experiments to test these findings.

Mobility Impaired

Depending upon the type of impairment, a student with a physical impairment should

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SUGGESTED MODIFICATIONS — *Continued*

be able to play one to several roles in this exercise. Assign roles according to the type of physical impairment. Here are suggested role assignments for the student with:

- Limited use of his/her upper extremities: a data recorder
- Full use of his/her arms, but limited use of his/her legs: thrower or data recorder from a seated position.

Analysis

1–5. Answers will vary depending on experiments students conduct.

Suggested Reading

Barinaga, M. (1992). The brain remaps its own contours. *Science, 258,* 216–218.

Desimone, R. (1992). The physiology of memory: Recordings of things past. *Science, 258*, 245–246.

Kandel, E.R. (1991). Cellular mechanisms of learning and the biological basis of individuality. In E.R. Kandel, J.H. Schwartz & T.M. Jessell (Eds.), *Principles of neural science* (pp. 1009–1030). 3rd ed. New York: Elsevier Science Publishing Company.

Kupfermann, I. (1991). Genetic determinants of behavior and learning and memory. In E.R. Kandel, J.H. Schwartz & T.M. Jessell (Eds.), *Principles of neural science* (pp. 987–1008). 3rd ed. New York: Elsevier Science Publishing Company.

Mayher, J.S. (1983). *Learning to write/ writing to learn.* Portsmouth, NH: Boynton/Cook Publishing.

Norman, D.A. (1982). *Learning and memory.* New York: W.H. Freeman and Company.

Petersen, S.E. et al. (1991, August). The use of neuroimaging in the study of vision. *Optics and Phonetics News,* pp. 31–36.

Roland, P.E., Gulyas, B. & Seitz, R.J. (1991). Structures in the human brain participating in visual learning, tactile learning, and motor learning. In L.R. Squire, N.M. Weinberger, G. Lynch & J.L. McGaugh (Eds.). *Memory: Organization and locus of change* (pp. 95–113). New York: Oxford University Press.

Shatz, Carla J. (1992). Dividing up the neocortex. *Science, 258*, 237–238.

Wotring, A. & Tierney, R. (1981). *Two studies in high school science.* Classroom research study #5. Berkeley, CA: Bay Area Writing Project.

"REWIRING" THE BRAIN

Directions for Students

Introduction

Outside of Mr. Melton's classroom, you can hear this exchange of words. "Get that fish. He's over there. No! Farther to the right! Can't you see that?"

"Well, it doesn't look like it's there to me. You are looking at it from the side and I am looking at it from the top. Mr. Melton, what's going on here?"

"Indeed, what is going on in this classroom?" you say to yourself. As you enter the room, you hear Mr. Melton saying, "Well, let me tell you what is happening as you try to catch that fish in the aquarium. On second thought, let's have you figure it out. I'm going to give you something to do that will make you ask more questions."

"More questions, Mr. Melton. Who needs more questions? We just want answers."

Sometimes more questions can give you answers or make you think about your answers. They make you think of situations in different ways. You may get some answers as to what may be happening as you try to catch that fish in the aquarium.

You may have had this same type of experience. Looking at something and thinking it was in one place, only to find out it was in a completely different place. Have you ever tried to retrieve a penny from the bottom of the pool? Seeing isn't always believing, as the demonstration your teacher will give you will show.

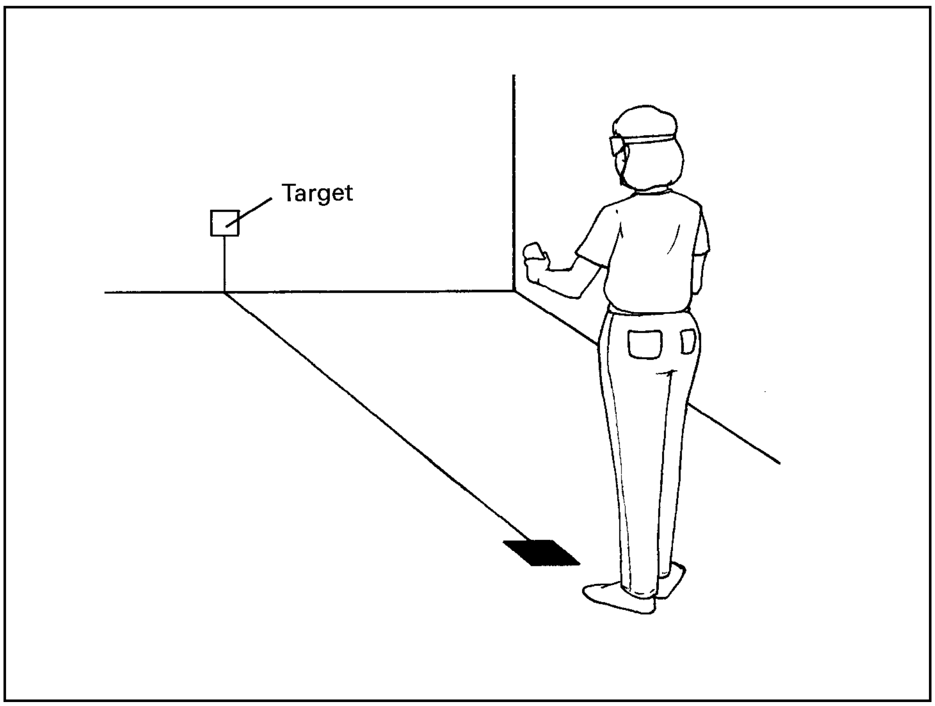

Figure 1. Setup for throwing beanbags.

MATERIALS

Materials will be provided by your teacher and consist of the following per group:

- 1 pair of 30-diopter prism goggles
- 10 beanbags, numbered 1 through 10
- 1 meter stick or measuring tape
- 7.5 x 7.5 cm (3 x 3 inch) Post-it™ notes
- 1 roll of brightly colored tape
- 1 pair scissors
- 1 cardboard box, approximately 45 x 30 x 25 cm
- 4 student data sheets or sheets of graph paper

SAFETY NOTES

- Students not throwing beanbags must stand behind and slightly to the side of the thrower during the ***Exploration*** activity.
- The thrower must stand squarely in front of the target and not rotate his/her body during the trials.
- If you become nauseated while wearing the prism goggles, stop the activity and let your teacher know.

Procedure

E Exploration

After your teacher introduces the activity, you will conduct a simple activity. Follow the directions your teacher gives you.

C Concept/Term Introduction

Work with your teacher and other students to analyze the data just gathered. Develop an explanation of what took place.

1. Analyze the data and brainstorm ideas about what occurred in the activity and why. The group discussion coordinator will monitor each group.
2. Make a list of possible hypotheses to explain what the data showed. Then the group will select the hypothesis they feel is best to share with the rest of the class.
3. Research individually the group hypothesis and return to the class with information for developing a procedure to test the hypothesis.
4. Your teacher may give you directions at this point for clarifying any misunderstandings you might have about the activity.

FOCUS QUESTIONS

Answer the following questions in your group:

1. What components of the nervous system were utilized by the thrower during this activity?
2. Did the thrower's performance change each time the prism goggles were put on or taken off?
3. If so, how do you explain any difference between throwing the beanbags with and without the goggles?
4. How do you explain any difference between throwing with the goggles and then removing them?
5. Does this activity demonstrate learning?

A Application

Think of questions that arose as you conducted your ***Exploration*** activity, discussed your results as a class, and answered the **Focus Questions**. You may wish to draw on information you gathered to develop your hypothesis earlier. Decide as a group what question you wish to test. Then design a simple experiment to test that question. Write your procedure in a numbered list. Make sure that your group does the following:

- Writes the question as a hypothesis or in the form of an "if... then" statement.
- Gathers quantifiable data.

- Decides what variables must be controlled and plans how to control these.

Teacher approval must be obtained before you begin this activity!

Analysis

1. Did your group obtain the results you expected? How do you explain your results in terms of what you learned during group sharing?
2. Draw a concept map to explain your results.
3. How did you express your data quantitatively?
4. If you were to repeat this experiment, what would you do differently?
5. What might have been sources of error in your experiment?

DATA SHEET

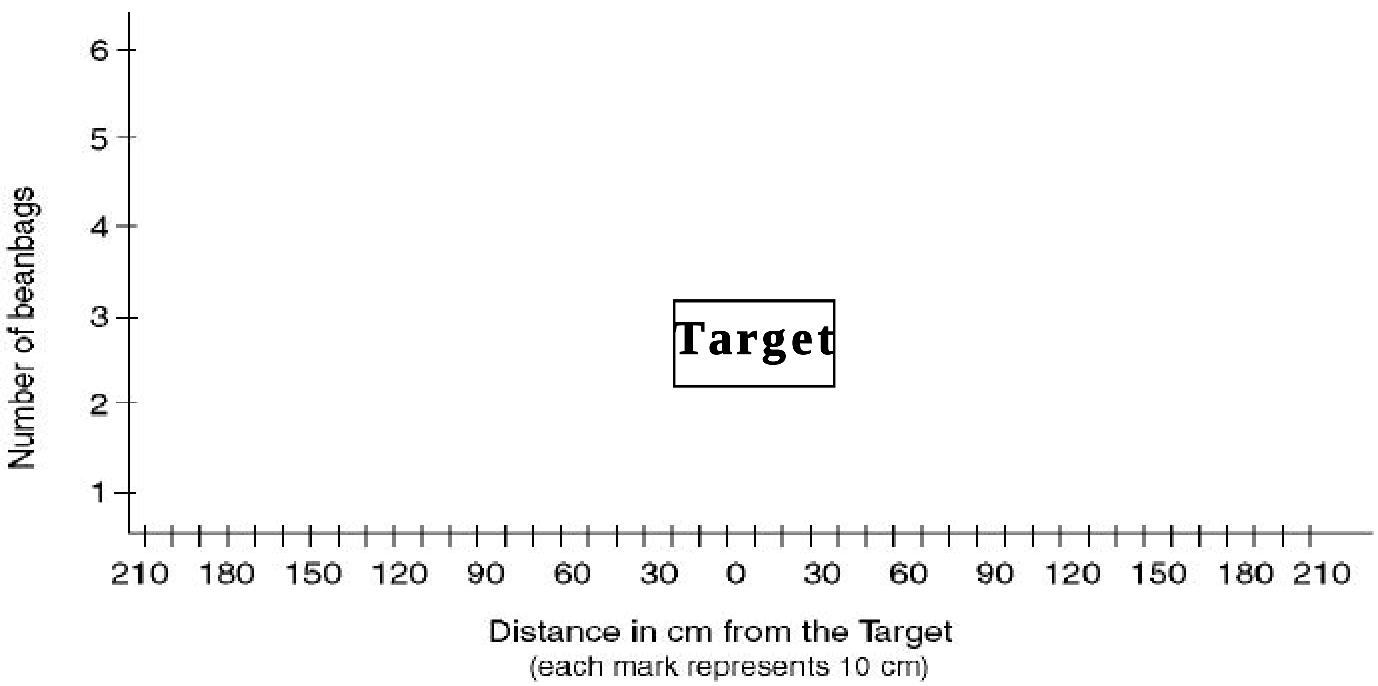

Figure 2. Suggested student data sheet for the **Exploration** *activity.*

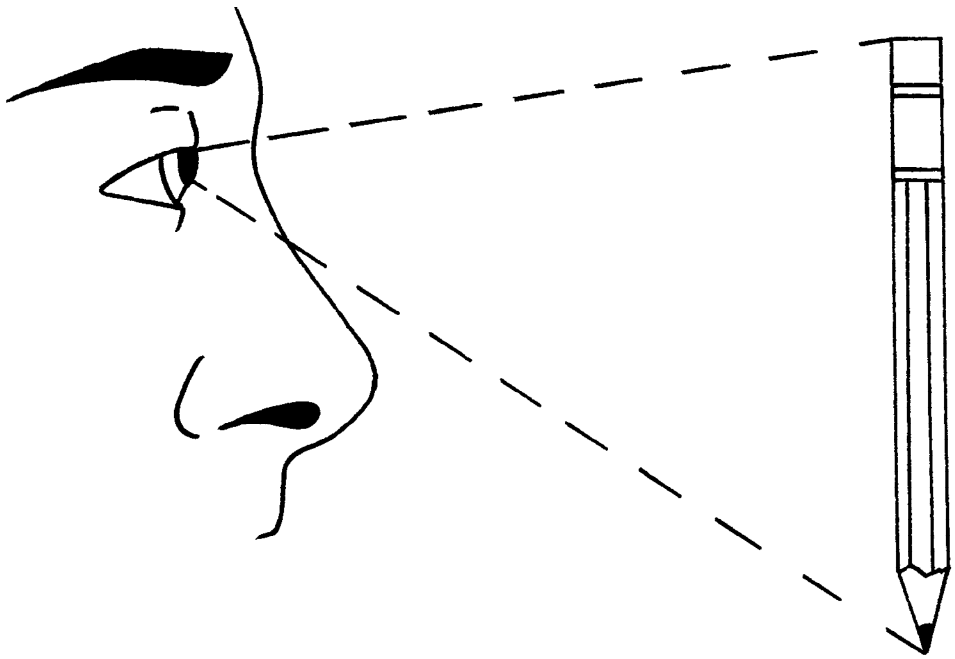

Figure 5a. Individual's view of pencil without prism goggles.

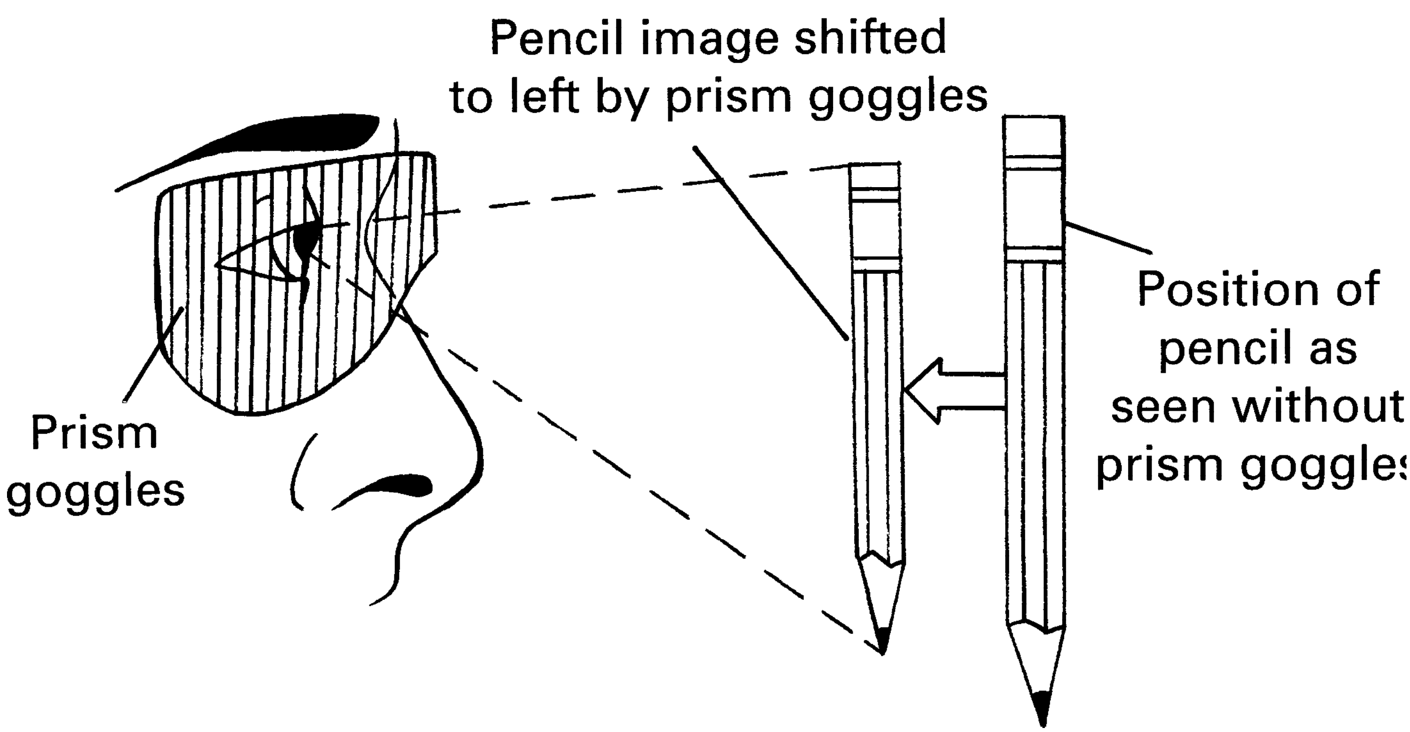

Figure 5b. Diagram showing how the prism goggles diffract the light and the individual sees the pencil to the left of the original position.

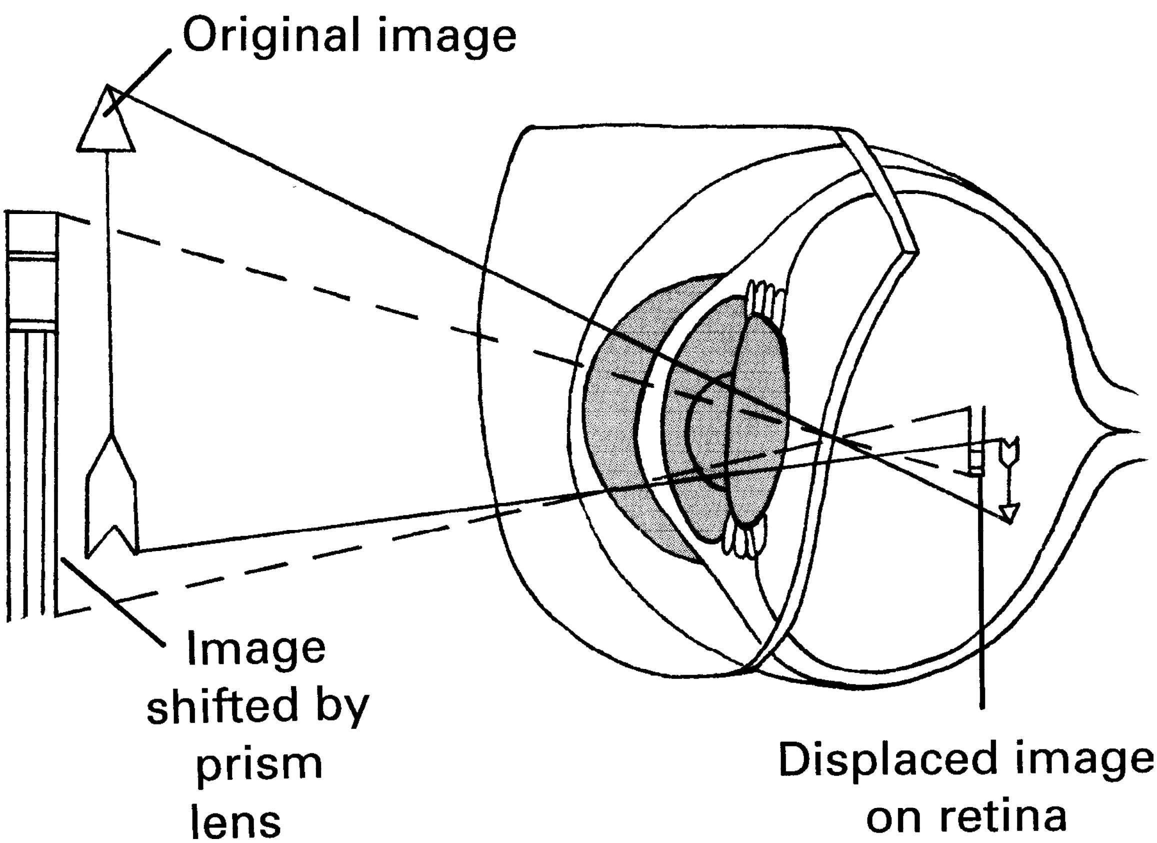

Figure 6. Retina showing displacement of image due to the prism lens.

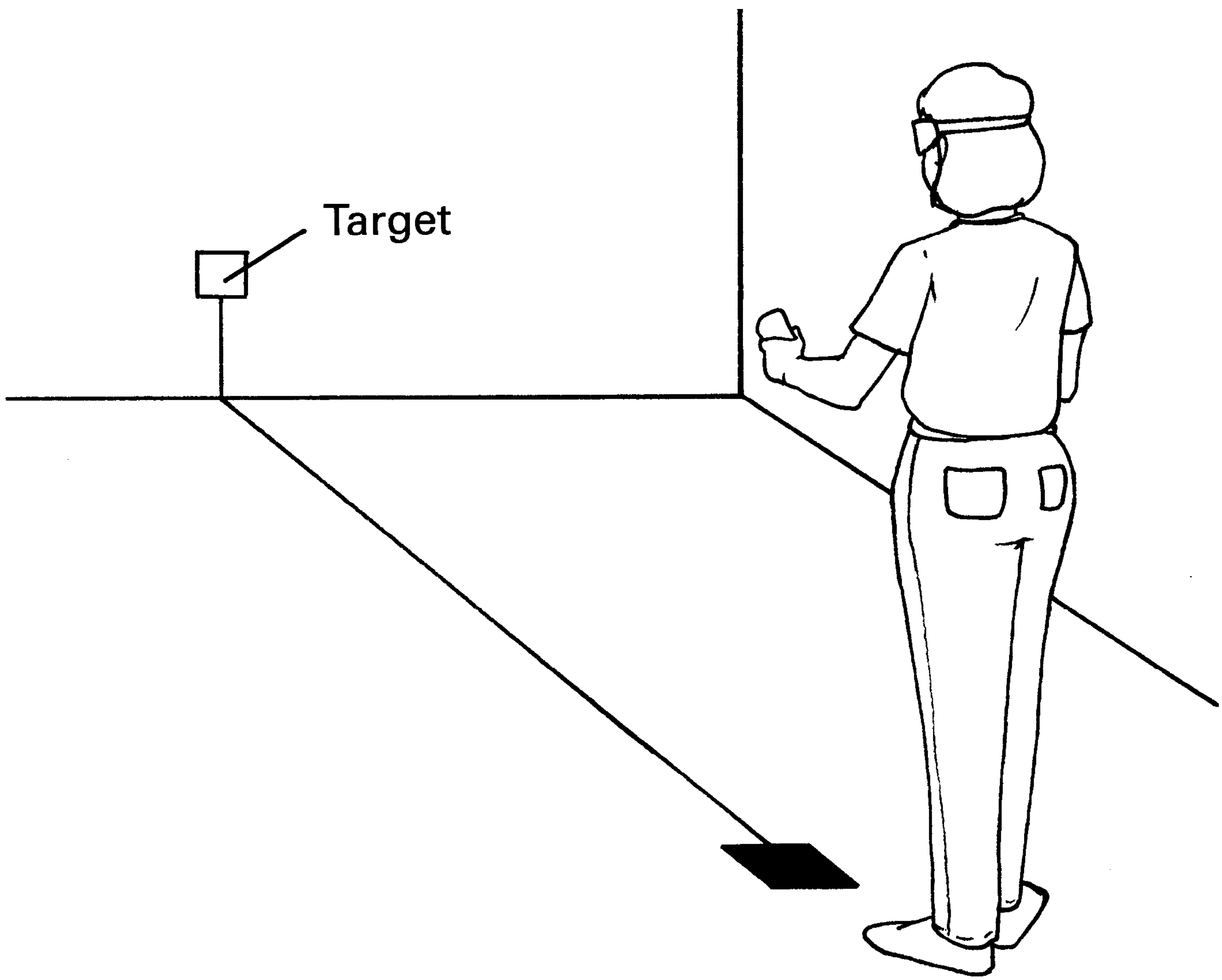

Figure 7. Setup for throwing beanbags.