WHAT ELSE DO EARS DO?

Directions for Teachers

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SYNOPSIS
Students will spin and manipulate a model that demonstrates how the vestibular (balancing) system of their ear senses different types of circular motion. Using these observations, students will design and conduct experiments to learn more about the effects of disturbances on this system.

LEVEL

Exploration Phase

Concept/Term Introduction, Application Phases

Getting Ready

See sidebars for additional information regarding preparation of this lab.

Directions for Setting Up the Lab

E Exploration

- Locate and obtain materials.
- Cut the fake fur fabric into 4 x 2 cm strips.
- Cut the Velcro™ into 8 x 2 cm strips, if necessary.

Teacher Background

The vestibular system within the inner ear detects both the position and motion of the head in space. The chief components of this system are the semicircular canals that contain hair cells specialized for sensing circular (angular) movement and the otolith organs that contain hair cells specialized for sensing linear movement. See Figure 1.

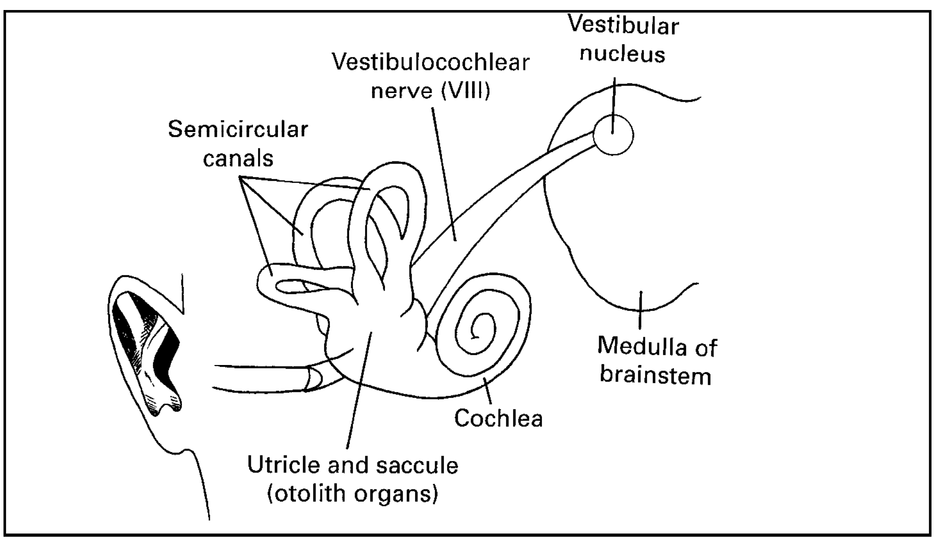

Figure 1. The vestibular system.

STUDENT PRIOR KNOWLEDGE

Before participating in this activity students should be able to:

- Describe the basic interactions between neurons and their role in the circuitry of the nervous system.
- Explain the concept of inertia.

INTEGRATION

Into the Biology Curriculum

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

Across the Curriculum

- Physics

OBJECTIVES

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

- Diagram the three planes of the ear canals in the vestibular system and label the motion associated with each plane.
- Identify the components of the ear canals as part of the vestibular system.
- Describe the processes at work in the vestibular system when the human body responds to circular motion.
- Describe the role of the vestibular system when the human body responds to circular motion.
- Describe the pathways from the semicircular canals to the eyes and the brain.

LENGTH OF LAB

A suggested time allotment follows:

Day 1

E *45 minutes* — Conduct initial demonstrations.

Day 2

C *15 minutes* — Discuss the demonstrations.

15 minutes — Brainstorm hypotheses.

Day 3

A *45 minutes* — Design and conduct experiments.

Day 4

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

MATERIALS NEEDED

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

- 2 m (3 cm-wide) masking tape
- 1 turntable or record player with 33 1/3 rpm speed
- 1 transparent glass or plastic dish, such as a 500 mL culture dish
- 250 mL water
- 1 piece (4 x 2 cm) of fake fur fabric with fur hairs 2-3 cm long
- 10 cm clear tape or small amount of waterproof glue
- 1 (8 x 2 cm) Velcro strip
- 1 pair of scissors (optional)

— *Continued*

A In addition to the materials listed in E, you

The semicircular canals are interconnected with the main sacs in the human ear, the utricle and the saccule, which make up the otolith organs. These organs are responsible chiefly for detecting linear movement, such as the sensation experienced when a person rides in an elevator.

This lab focuses on the semicircular canals, fluid-filled inner-ear structures designed to detect circular or angular motion. In situations such as riding in a Tilt-a-Whirl™, rolling at high speed in an airplane, performing ice skating or ballet spins, or spinning in a circle, your body detects circular motion with these canals. Sometimes this sense of moving in a circle may lead to dizziness or, in extreme cases, even nausea. People who have something wrong with this motion-sensing system often suffer from a condition known as vertigo, and feel as if they are spinning even when they are not.

Each ear contains three semicircular canals. Each set of canals is oriented in a different plane that corresponds to the major rotations of the head. The planes of the canals approximate head movements when the head is moved to indicate “no” (horizontal) and “yes” (posterior), and is shifted from shoulder to shoulder (superior). See Figure 2.

The vestibular system senses linear and angular acceleration. An example of linear acceleration is the sensation experienced when a person rides in an elevator. The sensation usually is felt when the elevator starts and stops. Linear acceleration also is sensed during the take-off and landing in an airplane. The otolith organs are responsible for the linear sensation. An example of angular acceleration is the sensation that occurs when the body is off balance. The semicircular canals respond to these movements. It is not known how the otolith organs and the semicircular canals work together in response to different situations.

How does the vestibular system accomplish its subtle and complex tasks? The semicircular canals are a series of circular chambers filled with fluid. Each canal has a highly specialized section to detect motion and transduce

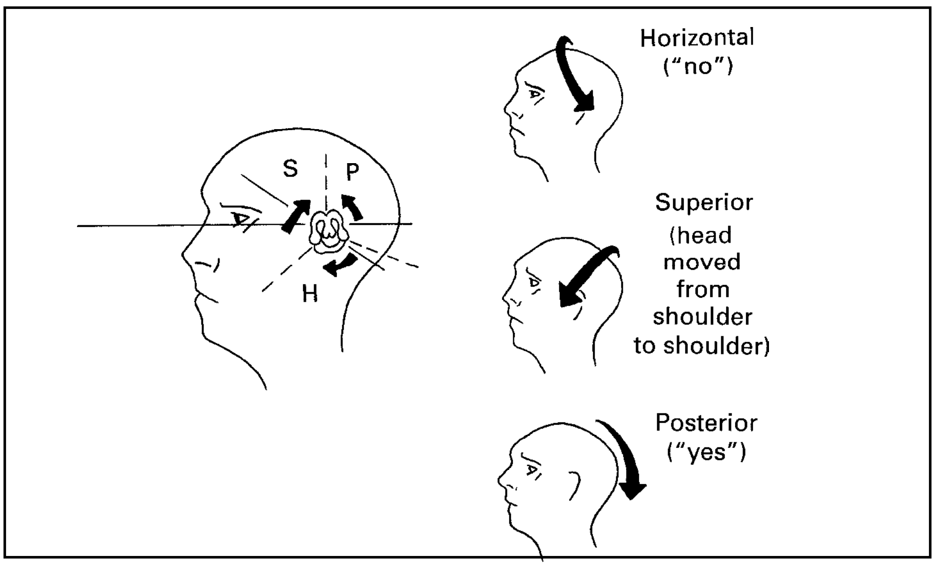

Figure 2. Planes of rotation of semicircular canals.

(change) it into a nerve signal. These specialized regions contain receptor cells. Each receptor cell contains a set of hairs or cilia that extend into the semicircular canal. If the fluid and the canal move at different speeds, the hairs are subjected to a shearing force because they are anchored on only one end. This force causes receptor cells to depolarize and send a signal to the adjacent nerve. The sensory cells therefore convert mechanical energy into electrical energy by detecting movement and sending a signal to the central nervous system.

The act of spinning in ***Exploration I*** will help demonstrate how the system works. When a person begins to spin, he/she senses rotation in the direction of the spin. The reason for this sensation is that the semicircular canals move, but due to inertia, the fluid in the canals does not move immediately. The movement of the canal bends the hairs and triggers an electrical signal. Thus, the hair cells are bent in the opposite direction of the spin. If the person continues to spin, eventually the fluid's inertia is overcome, and it begins to move at the same rate as the semicircular canals. During this period little or no bending of the hairs occurs, so no signal is sent and the person experiences little sense of movement.

If the fluid and the canals again move at different speeds, as when the person spins faster, slower, or stops spinning, the hairs will bend again and the sensory cells will send signals. When the person stops spinning, for example, the semicircular canals cease to move, but due to inertia, the fluid continues to move. The hairs now bend in the same direction as the spin was made and opposite to the direction they bent when the spin was started. This now causes people to feel as if they are moving in the direction opposite the spin. The result is dizziness. The faster the person spins, the longer the dizziness lasts because the fluid takes longer to stop moving. See Figure 3.

If you ask people who have just finished spinning to walk a straight line, they usually will walk lines that curve in the direction of their spins due to the continued motion of the fluid in their semicircular canals. If, however, you ask people to stop spinning and walk an actual straight line, such as a stripe on a football field, they usually can accomplish the task, even though they may tend to lean in the direction they were spinning. They are able to walk straight lines because they can use input from their visual systems to override information from their vestibular systems.

Another example of the visual system being able to overcome the effects of the vestibular system is found in ballet dancing and ice skating. These performers prevent dizziness as they spin by "spotting" — focusing their eyes on a point in the field of vision.

The manner in which the semicircular canals detect motion is modeled by the motion of fluid in a spinning dish in the ***Exploration II*** activity. At first, the fluid does not move when the dish is spun. Once the fluid has begun to spin, however, it continues to do so, even if the dish is no longer spun. This is due to inertia, whereby a body remains at rest or continues in uniform motion until acted upon by an outside force. The fake fur fabric

MATERIALS — *Continued*

may need the following materials for each group of four students in a class of 24:

- 250 mL clear cane syrup
- 1 watch/clock with second timer

PREPARATION TIME REQUIRED

E *1 week* to locate and obtain turntables*

3 hours to purchase and prepare fake fur fabric and Velcro*

30 minutes to obtain all other materials

* This time can be shortened if students cut the strips of fake fur fabric and Velcro, and bring in the turntables.

A *1 hour* to obtain materials

SAFETY NOTES

- Some students may experience nausea while spinning and should be excused from the role of spinnee.
- In the exploration and application phases of the Procedures, students should watch carefully and be prepared to stabilize the individual who is spinning.
- Spinning should be done in an open area, away from tables, lockers, or any other objects. The ideal spot is outdoors, on a grassy surface such as the football field. If done indoors, you may wish to lay athletic mats on the floor before ***Explorations I*** and ***III***, in case some students fall.

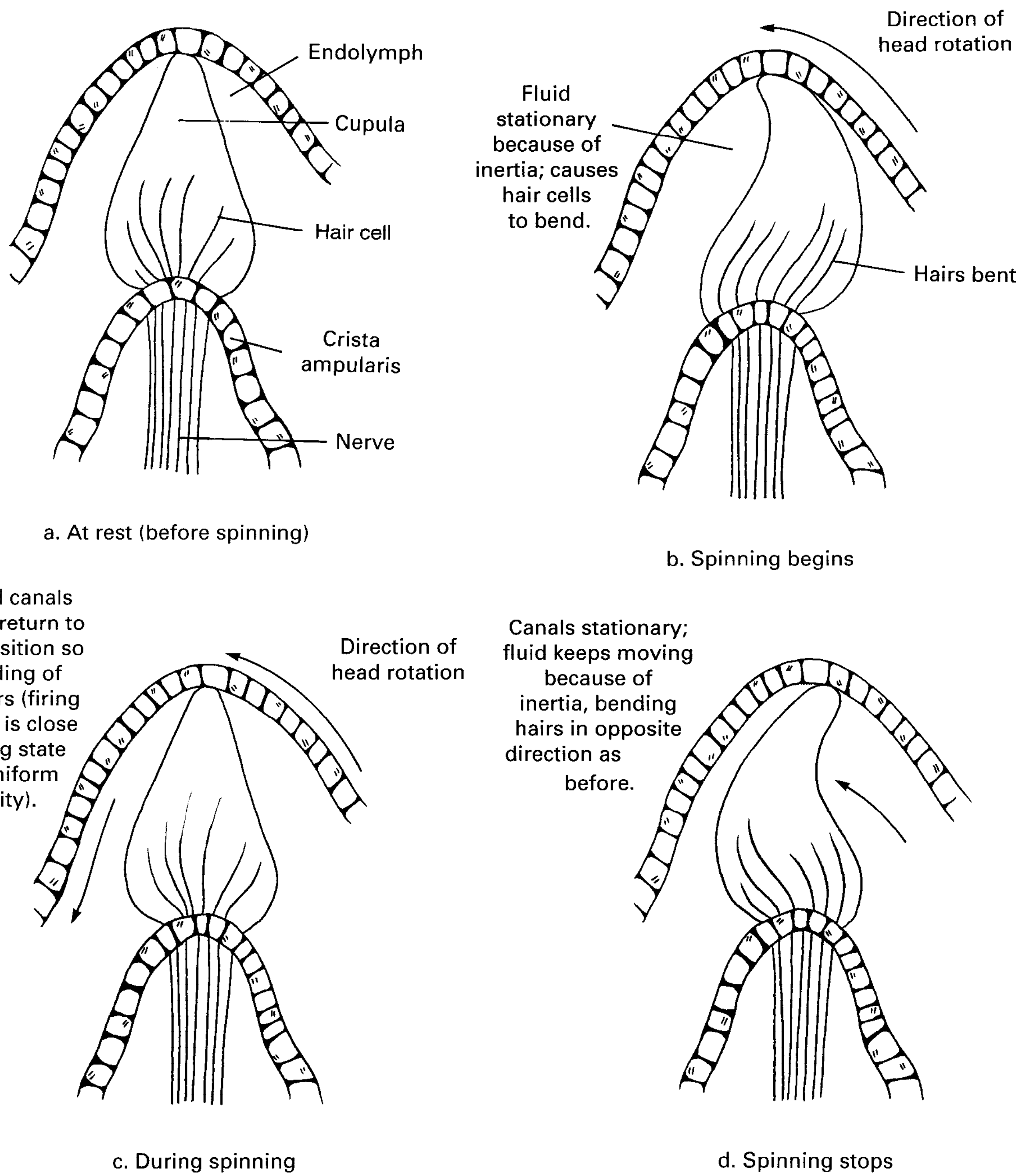

Figure 3. Motion of hairs in semicircular canals before, during, and after spinning.

> **TEACHING TIPS**
> - The music department of your school may have an old turntable you could borrow. Other sources of inexpensive turntables
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> **— Continued**

placed in the dish can help approximate the effect of spinning on the hair cells.

When the turntable begins to spin, the fluid remains in place due to inertia, and the hairs on the fur will be displaced in the direction opposite to the spin. After the turntable spins for a few moments, the water will begin to spin in the same direction, eventually spinning at the same rate as the dish. At this point, the hairs on the fur will no longer appear to be displaced. When the turntable is stopped, the water will continue to move in the direction of the spin, and the hairs on the fur will move in the same direction as the water.

Movement of the hairs in the semicircular canals causes the sensory cells to send a stream of action potentials to the eighth cranial nerve that leads to the vestibular nuclei in the brainstem. The information then goes to the cerebellum, thalamus, and somatosensory cortex where a reflex pathway is set up in the oculomotor system that controls the movement of the eyes. See Figure 4 for a diagram of the vestibular-oculomotor connection.

This pathway helps the eyes to remain fixed on a visual field. Continued movement of the fluid in the horizontal semicircular canals causes jerky, side-to-side movements of the eyes called nystagmus (Nis-'stag-mus). In ***Exploration III***, the students will observe this side-to-side eye movement associated with the eye and inner ear. It is seen immediately after the

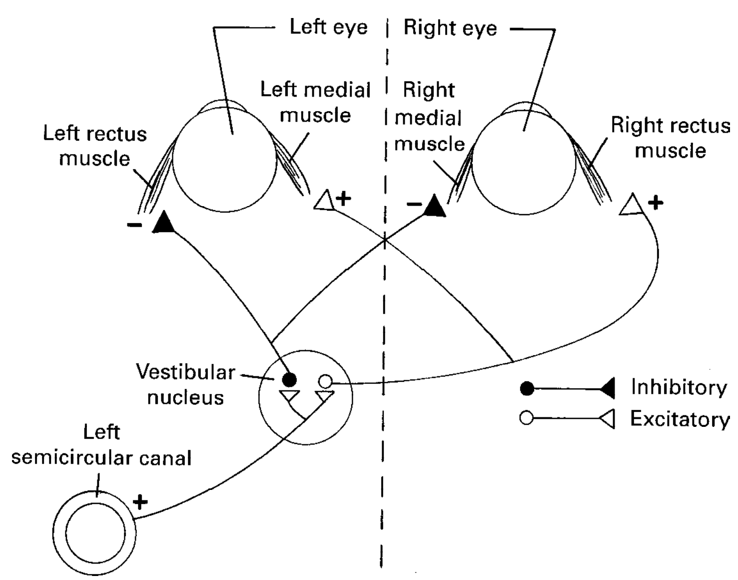

Figure 4. The vestibular-oculomotor connection.

student stops spinning in a circle. Figure 5 indicates how this works. This reflex movement is caused when the fluid in the canal displaces the hair cells in a direction opposite to their initial position when they started spinning. This stimulates the eyes to move quickly in a direction opposite of the spin. The eyes will continue to move back and forth until the motion of the fluid stops. ***Exploration III*** demonstrates how the connection between the semicircular canals and the eyes helps to keep the visual field as stable as possible to provide information about the orientation of the body continuously.

A practical application of the reflex connection between the semicircular canals and the eyes can be demonstrated in the following way. Look at the

TEACHING TIPS

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are yard sales or donations from parents.

- To shorten preparation time, have students bring in turntables, and cut the strips of fake fur fabric and Velcro.
- Fake fur fabric for ***Exploration II*** can be purchased at a fabric craft store. Make sure the hairs of the fake fur are 2–3 cm long.
- A blindfold should NOT be worn for ***Explorations I*** or ***III***. Instead, have students close their eyes as they are spun. The time required to remove the blindfold prevents other students from seeing the full effects of spinning in both ***Explorations***. In ***Exploration III***, nystagmus is most vigorous when the spinnee stops.

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

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SUGGESTED MODIFICA-TIONS
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Assistive Listening Devices (ALDs); light probes; and talking thermometers, calculators, and clocks.

Blind or Visually Impaired

- For students who are blind, use a Sewell Drawing Kit to make raised line drawings of all figures or make tactile diagrams using string, glue, buttons, or any "found" items.
- Construct a three-dimensional model of the semicircular canals from a Tinker Toy™ set or Play Doh™ for the student who is blind.
- A student who is blind and who navigates with a cane might choose to be the spinnee in ***Exploration I***. If the student normally uses a guide dog, he/she probably should not use the dog during the ***Exploration*** since the spinnee would be guided in a straight line.
- For ***Exploration III***, the student who is blind could be the spinner, but not the spinnee, because eye tracking movements would be affected by blindness.
- For all ***Exploration*** activities, make sure that the student who is blind has a peer who is sighted describe everything that is going on in the classroom.

n For students with low vision, the text and

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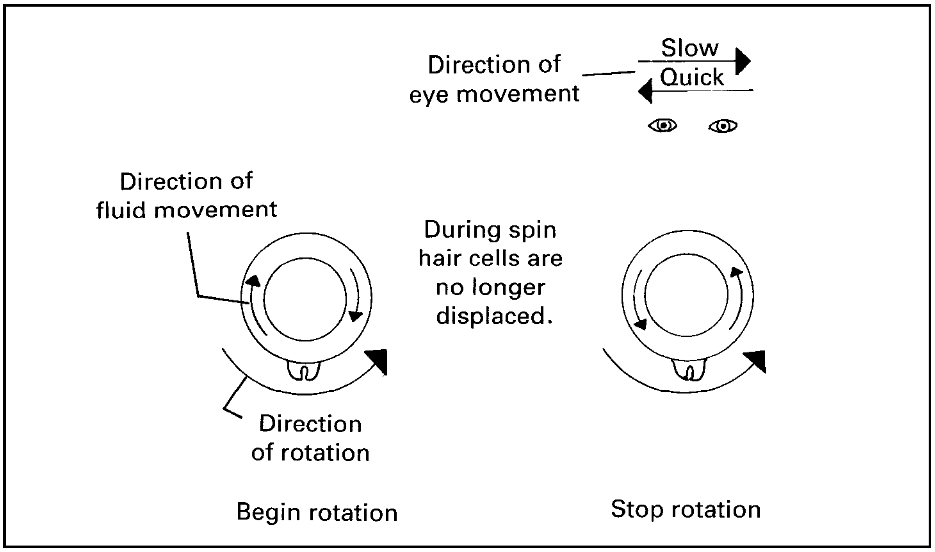

Figure 5. Illustration of nystagmus (jerky, side-to-side movements of the eyes) as a result of spinning.

words on this page and turn your head to the right. As your head moves to the right, your eyes stay focused on the page by moving to the left at the same rate of speed you move your head to the right. The ability to see the words clearly even as you move your head is possible because of the coordination of input information between the eyes and canals.

Another application of this reflex connection is used by physicians to diagnose and detect problems in the vestibular system. Warm and cold water are placed in the ear canal. The thermal currents of the water are sufficient to move the hair cells, resulting in nystagmus.

Procedure

E Exploration

Exploration I: Walking the Line

1. Place a 2-meter strip of wide masking tape on the center of a hallway floor.
2. Ask a student to volunteer to be spun and be the "spinnee"; the teacher will be the "spinner" and will spin the student.
3. Line up the rest of the class about one meter away from either side of the tape.
4. Have the spinnee face the line and shut his/her eyes.
5. Instruct the spinnee to keep his/her arms by his/her side during spinning. The teacher will spin the spinnee 5 times from behind and stop the spinnee so that he/she faces the line and is perpendicular to it.
6. Then ask the spinnee to open his/her eyes and immediately "walk the line."
7. All students should write down their observations.

Exploration II: Spinning Water

1. Assign each student in the group one of the following roles:
   - Materials technician
   - Spinner
   - Observer
   - Recorder.
2. The materials technician should glue or tape a 4 x 2 cm strip of fake fur fabric on the bottom of a circular glass dish toward the dish's side, as shown in Figure 6.
3. The materials technician should fill the dish with about 5 cm of water and use Velcro strips to attach the dish to the outer 4 cm of the turntable, as shown in Figure 7. The materials technician and the spinner should test to make sure that the Velcro strips are sufficient to hold the dish on the turntable. The spinner should then begin spinning the turntable slowly.

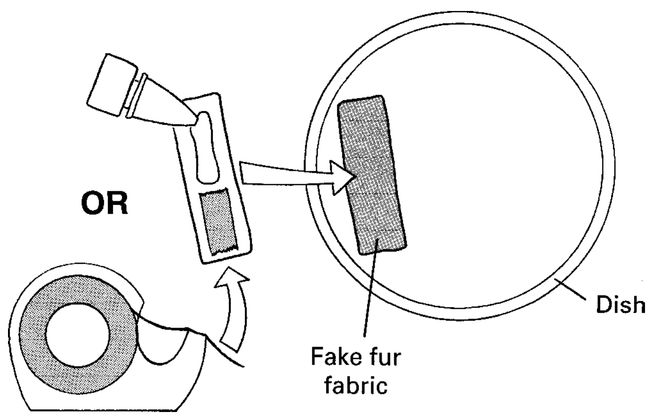

Figure 6. Gluing fake fur on the bottom of glass dish.

4. The observer should describe the motion, or the lack of motion, of the dish, the water, and the hairs of the fur.
5. The recorder should enter these observations into the lab journal.
6. The observer and recorder should repeat Steps 4 and 5 as the spinner changes the speed of the turntable. Three different phases of motion should occur: speeding up (acceleration), constant speed, and slowing to a stop (deceleration).

Exploration III: Eye Tracking

1. Ask a student to volunteer to be spun (spinnee), and another volunteer to do the spinning (spinner).
2. Have the other students in the group stand in front of the spinnee so they can see his/her eyes.
3. The spinner should stand behind the spinnee. The spinnee should have his/her eyes closed during the spinning procedure.
4. The spinner should turn the spinnee five times. The spinnee should keep

SUGGESTED MODIFICATIONS — Continued

figures should be photo-enlarged. Students with low vision could assume any of the roles that students who are blind could assume.

- For ***Exploration II***, the student who is blind could be the spinner or recorder.

Deaf or Hard-of-Hearing

- If a student who is hearing impaired acts as an observer, he/she should be in a physical position to see clearly all of the events that are occurring, regardless of his/her communication mode.

Mobility Impaired

- A student who uses an electric wheelchair would travel in a straight line even after the student had been spun. This student, therefore, would not be able to assume the role of spinnee in ***Exploration I***. However, a student who uses a manually operated wheelchair could assume the role of spinnee in ***Exploration I***.
- If a student using canes or crutches chooses to be the spinnee in ***Explorations I*** or ***III***, have him/her sit on a spinnable seat in order to be spun. If a person who has a problem with balance stands while spinning, the spinnee could fall. After spinning, the spinnee should walk

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SUGGESTED MODIFICATIONS — *Continued*

slowly using his/her crutch or cane with another student on either side to stabilize the spinnee if he/she begins to fall.

- A student who has limited or no use of his/her arms could be an observer or recorder in ***Exploration II***.

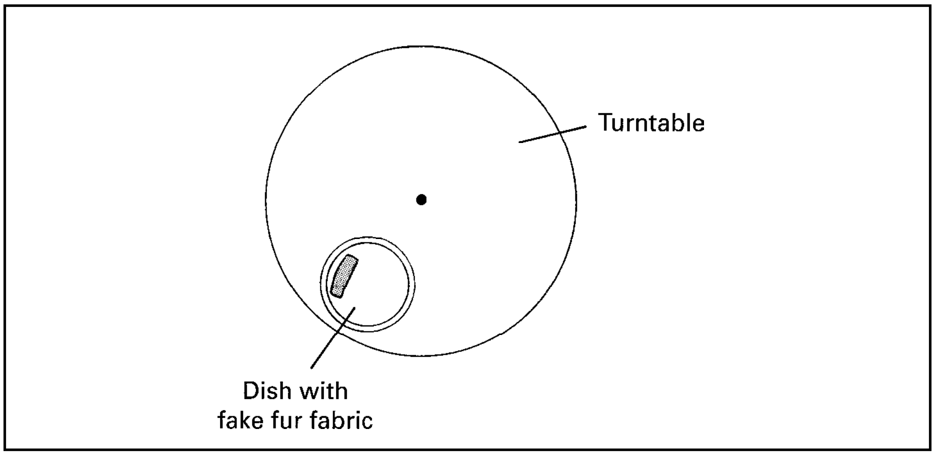


Figure 7. Attaching the glass dish to the turntable.

his/her arms at his/her side during the spinning. The spinner should make sure that the spinnee stops facing the rest of the students in the group.

5. Have the spinnee open his/her eyes immediately after the spin.
6. The rest of the group should observe the eye movement.
7. If time permits, repeat the procedure with another volunteer spinner and spinnee team.
8. The students should again record what eye movement is observed in each spinnee.

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. Designate one person in each group to be the group discussion coordinator. 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 what is occurring, you may want to use one of the following suggested 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 should 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 answer questions within groups. The teacher can determine who the assistants are by developing a set of questions to ask each member of a group orally. Those who understand the concepts based on these answers can help other groups clear up misunderstandings. If those questioned do not understand, the teacher can give them additional questions, and repeat the process with another group to identify teaching assistants.

Application

Students can now build on their previous experiences to extend the ***Explorations*** and learn more about the vestibular system. Have them work in their groups to design and conduct their experiments and analyze their data. Afterwards, each group should share its results with other members of the class.

Suggested questions students may wish to investigate include the following:

- Would the results of the fake fur fabric experiment change if fluid of a different viscosity than water were used?
- Would the results of the walking the line ***Exploration*** change if the spinnee:
  - had his/her eyes closed?
  - were spun with the head in a different position?

Your students probably will develop other questions related to the vestibular system. In the sidebar on p. 46 are sample hypotheses and procedures that students might derive related to this activity. These examples have been included as suggested outcomes of the activity and are 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"

Concept/Term Introduction

Focus Questions

1. Structures in the inner ear contribute to the "sense" of balance and the ability to maintain orientation. The ear in humans is specialized for two primary functions — hearing sound and maintaining balance.
2. Each receptor cell contains a set of hairs, or cilia, that extend into the semicircular canal. Information is relayed from the semicircular canals to the cranial nerve to the vestibular nuclei in the medulla to the cerebellum. (Refer to **Teacher Background** for more information.)
3. Students could demonstrate the simple example by closing their eyes and standing on one foot. Vision provides important feedback to the brain about balance, as does the "sense" of the stretched muscle that indicates body position. Students may also come up with other examples, such as vertigo, that is sometimes induced by heights.
4. Both phenomena are related to the imbalance of fluid in the semicircular canals. However, in seasickness visual input is also variable. Often, the effects of seasickness decrease or disappear if the person can see the shoreline.

Application

Analysis

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

SAMPLE HYPOTHESES

● If the walking the line activity in ***Exploration I*** is done with the spinnee's eyes closed the entire time, the spinnee will not be able to walk the line as well as he/she could with his/her eyes open after being spun.

● If a fluid of heavier viscosity is used in place of water in ***Exploration II***, then the hairs on the fake fur fabric will not move at all.

SAMPLE PROCEDURES

● Repeat Steps 1 through 6 of the walk the line activity in ***Exploration I***, having the spinnee keep his/her eyes closed even after being spun. Quantify the data by counting the number of seconds from the time the person stops spinning until the time the person is able to walk a straight line, as indicated by his/her making two consecutive footsteps on the masking tape. Repeat the procedure with at least three different spinnees, and average the data.

▲ Repeat Steps 1 through 4 of ***Exploration II***, using clear cane syrup instead of water. Quantify whether the fake fur hairs move at different phases of the spinning by marking on a data chart:

- a (+) if the fake fur hairs move, and
- a (-) if the fake fur hairs do not move. The direction of movement of the hairs, if any, should also be recorded.

Repeat the procedure with two other dishes containing cane syrup and fake fur fabric. Average the number of (+) and (-) symbols for the three trials.

Suggested Reading

Goldberg, M.E., Eggers, H.M. & Gouras, P. (1991). The Ocular Motor System. In E.R. Kandel, J.H. Schwartz & T.M. Jessell (Eds.), *Principles of neural science* (pp. 660–678). New York: Elsevier Science Publishing Company.

Kelly, J.P. (1991). The Sense of Balance. In E.R. Kandel, J.H. Schwartz & T.M. Jessell (Eds.), *Principles of neural science* (pp. 500–511). New York: Elsevier Science Publishing Company.

WHAT ELSE DO EARS DO?

Directions for Students

Introduction

One beautiful, cool Friday evening you and your friends go out to the amusement park. When you arrive at the midway, your friends dare you to ride the world's "baddest" Tilt-a-Whirl™. You accept the challenge. You confidently stride up the platform and take a seat. The music starts and the Tilt-a-Whirl begins swinging you around, and moving up and down. After the ride stops, you stand up. You can't believe it. You stagger and stumble until you finally get your balance. What happened "inside your head" to cause you to lose your balance? What happens "inside your head" to regain your balance? Where is your "sense of balance"?

Procedure

E Exploration

Your teacher will lead you through three exploration activities. Follow your teacher's directions.

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 ***Exploration*** activities and why. Each group will have a discussion coordinator to monitor this discussion.
2. Make a list of hypotheses to explain what the data showed. Then, as a group, select a hypothesis to share with the rest of the class.
3. Individually, research the group hypothesis and return to the class with information to develop a procedure to test the hypothesis.
4. Your teacher may give you directions at this point for clarifying any misunderstandings you may have about the activity.

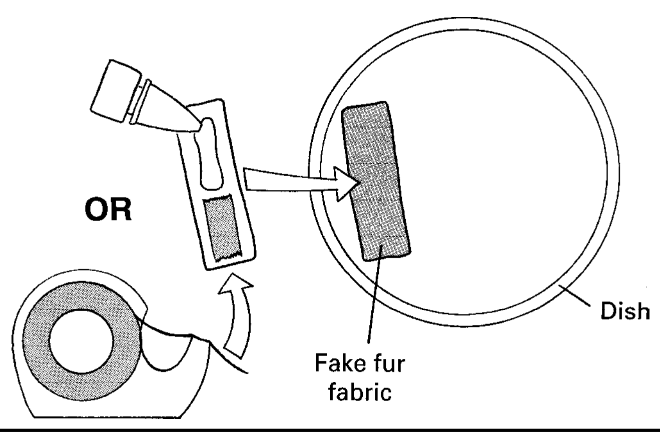


Figure 1. Gluing fake fur on the bottom of glass dish.

MATERIALS

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

- 2 m (3 cm-wide) masking tape
- 1 turntable or record player with 33 1/3 rpm speed
- 1 transparent glass or plastic dish, such as a 500 mL culture dish
- 250 mL water
- 1 piece (4 x 2 cm) of fake fur fabric with fur hairs 2–3 cm long
- 10 cm clear tape or small amount of waterproof glue
- 1 8 x 2 cm Velcro™ strip

SAFETY NOTES

- In the ***Exploration*** and ***Application*** phases of the procedures, watch carefully and be prepared to stabilize the individual who is spinning.
- Spinning should be done in an open area, away from tables, lockers, or any other objects.
- If you become nauseated while spinning, stop the activity and let your teacher know.

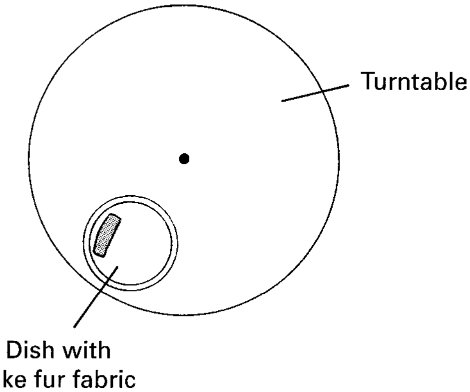


Figure 2. Attaching the glass dish to the turntable.

FOCUS QUESTIONS

1. Fish do not use their ears for hearing at all, and many vertebrates have no outer ear. What function do inner ear structures serve for these animals and for humans?
2. Each sense has specialized sensory receptors. What are the specialized sensory receptors in the semicircular canals? How do they communicate with the brain?
3. What senses have input into balance? Include examples.
4. What similarities would you hypothesize there may be between the spinning-induced dizziness and seasickness?

A Application

Think of questions that arose as you conducted the ***Exploration*** activities, 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 an 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 them.

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 may have been sources of error in your experiment?

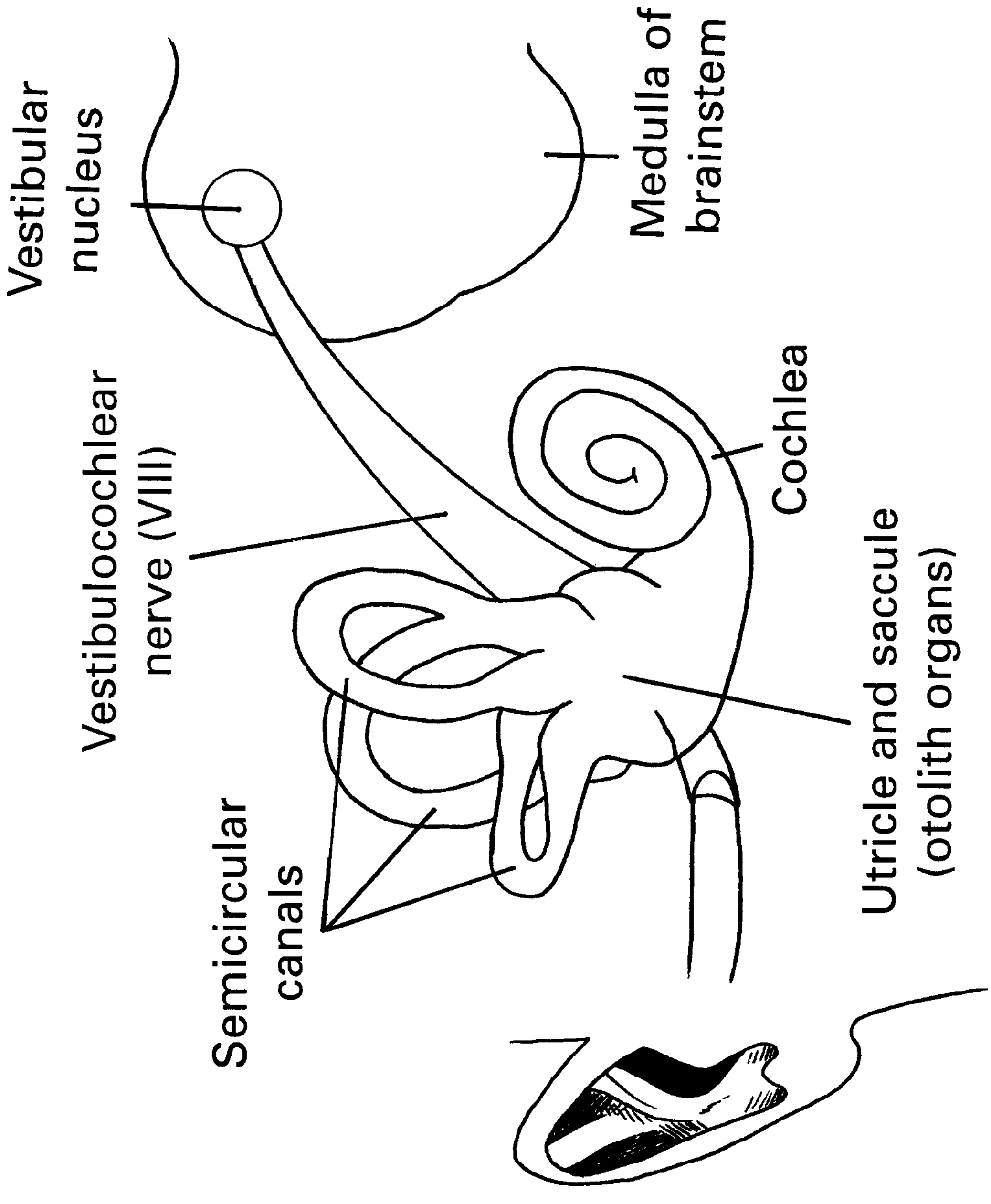


Figure 1. The vestibular system.

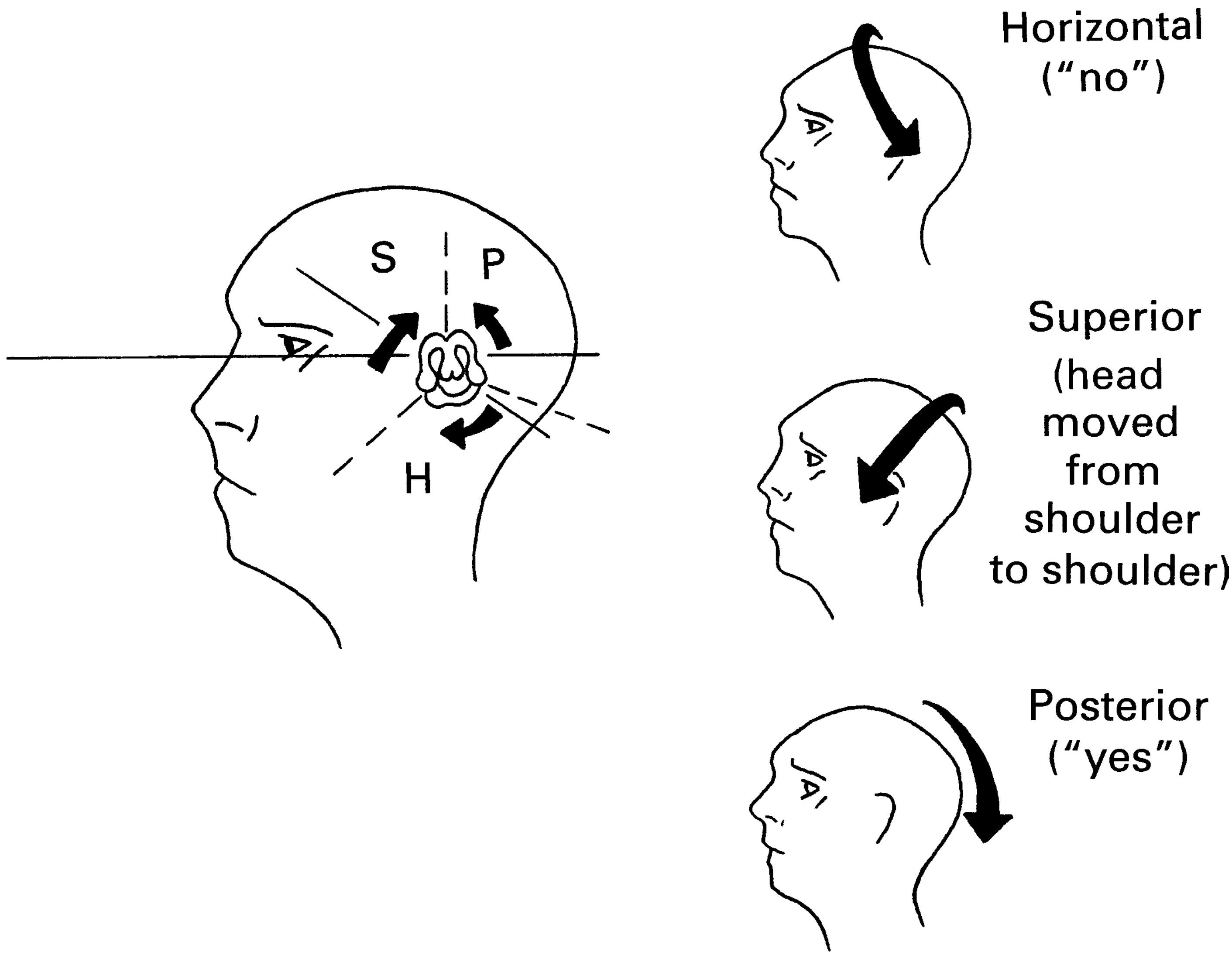
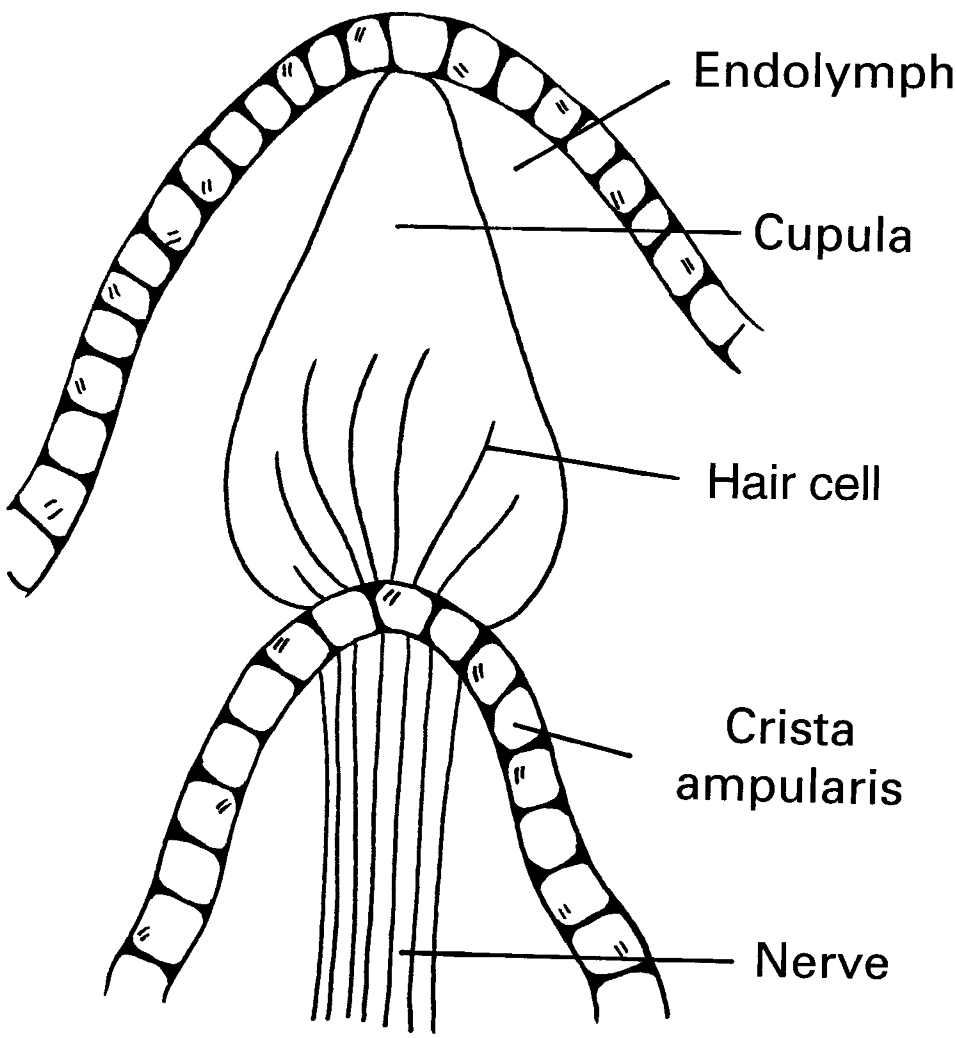
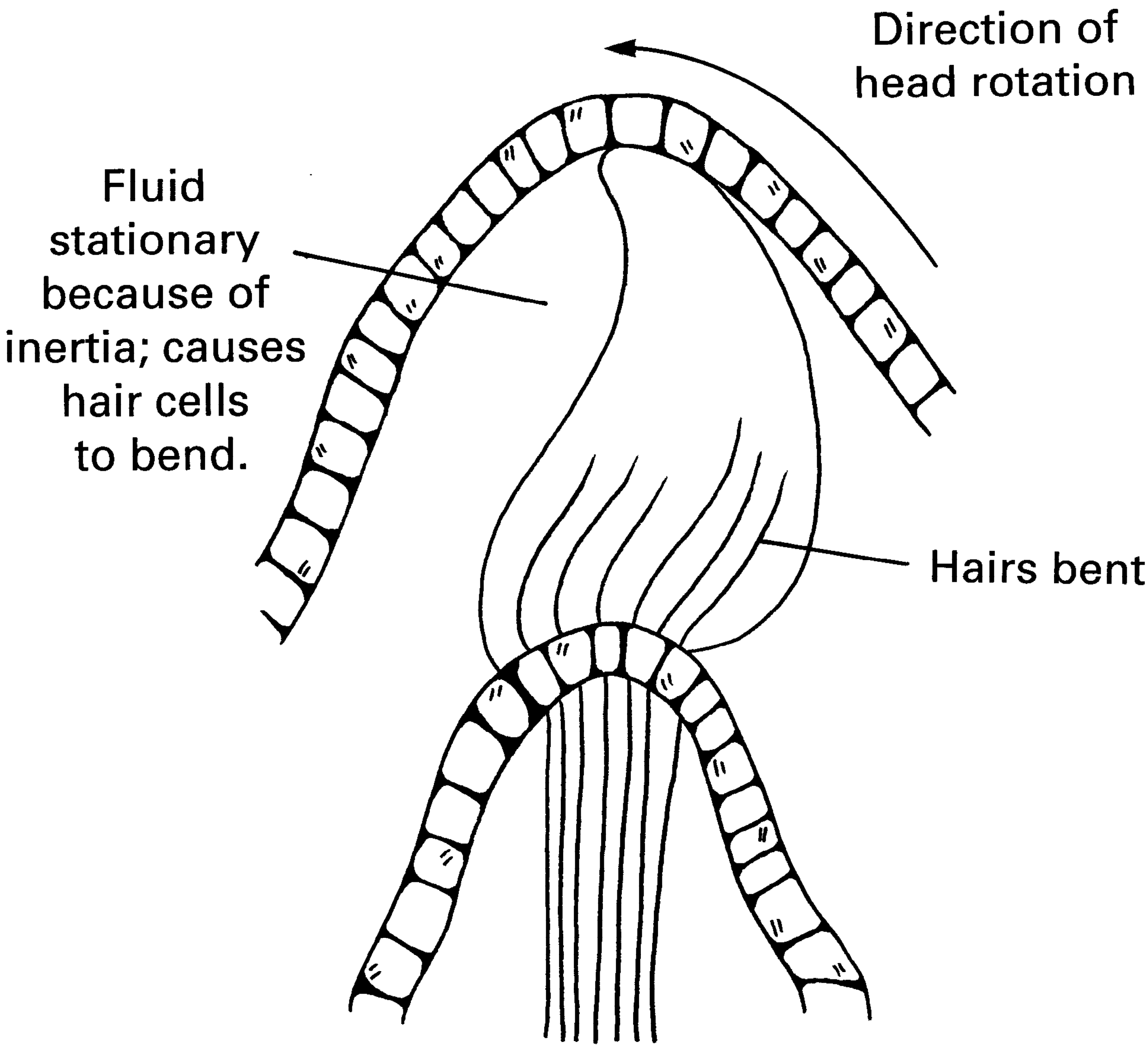


Figure 2. Planes of rotation of semicircular canals.



a. At rest (before spinning)

Figure 3. Motion of hairs in semicircular canals before, during, and after spinning.



b. Spinning begins

Figure 3. Motion of hairs in semicircular canals before, during, and after spinning.

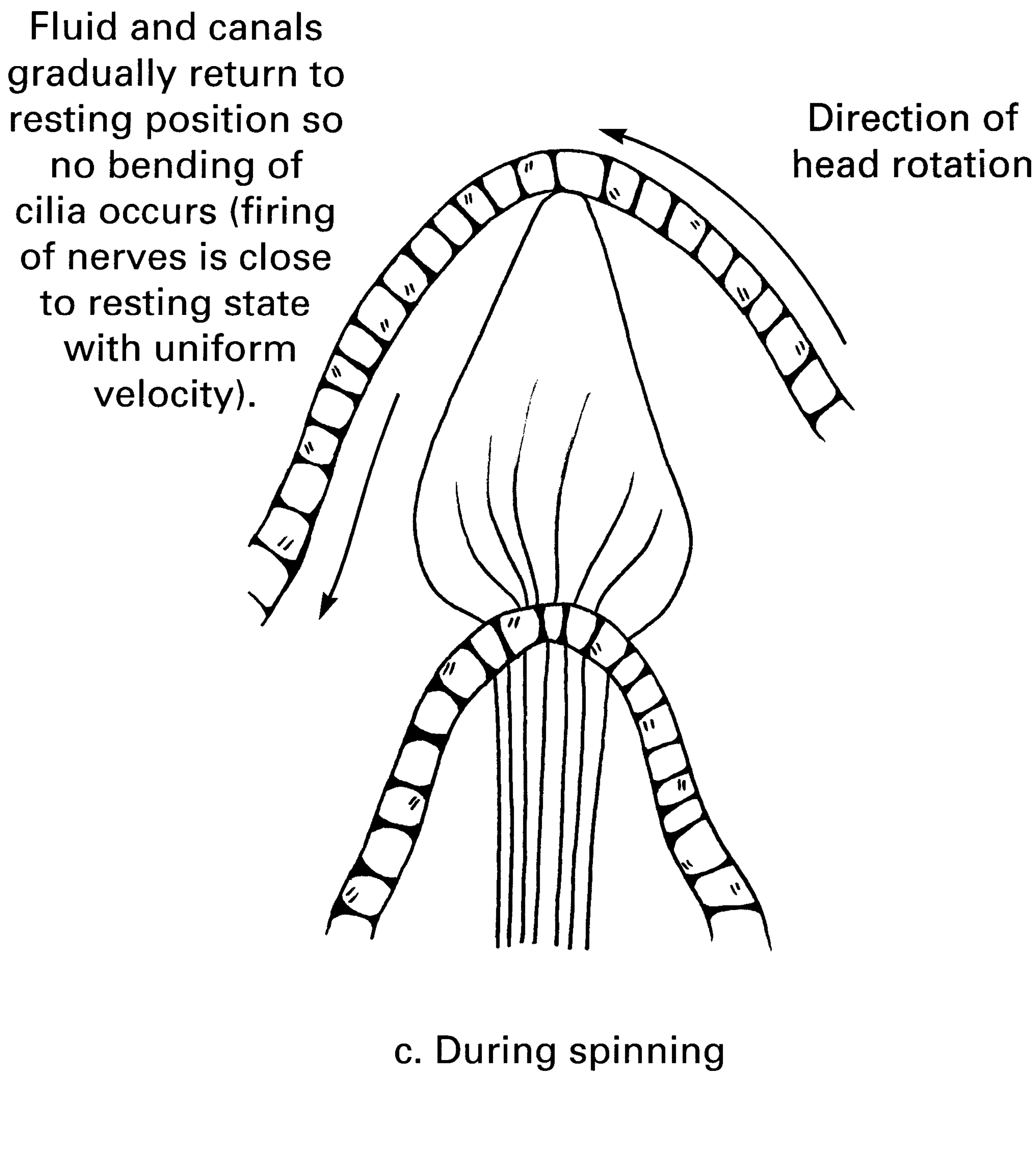


Figure 3. Motion of hairs in semicircular canals before, during, and after spinning.

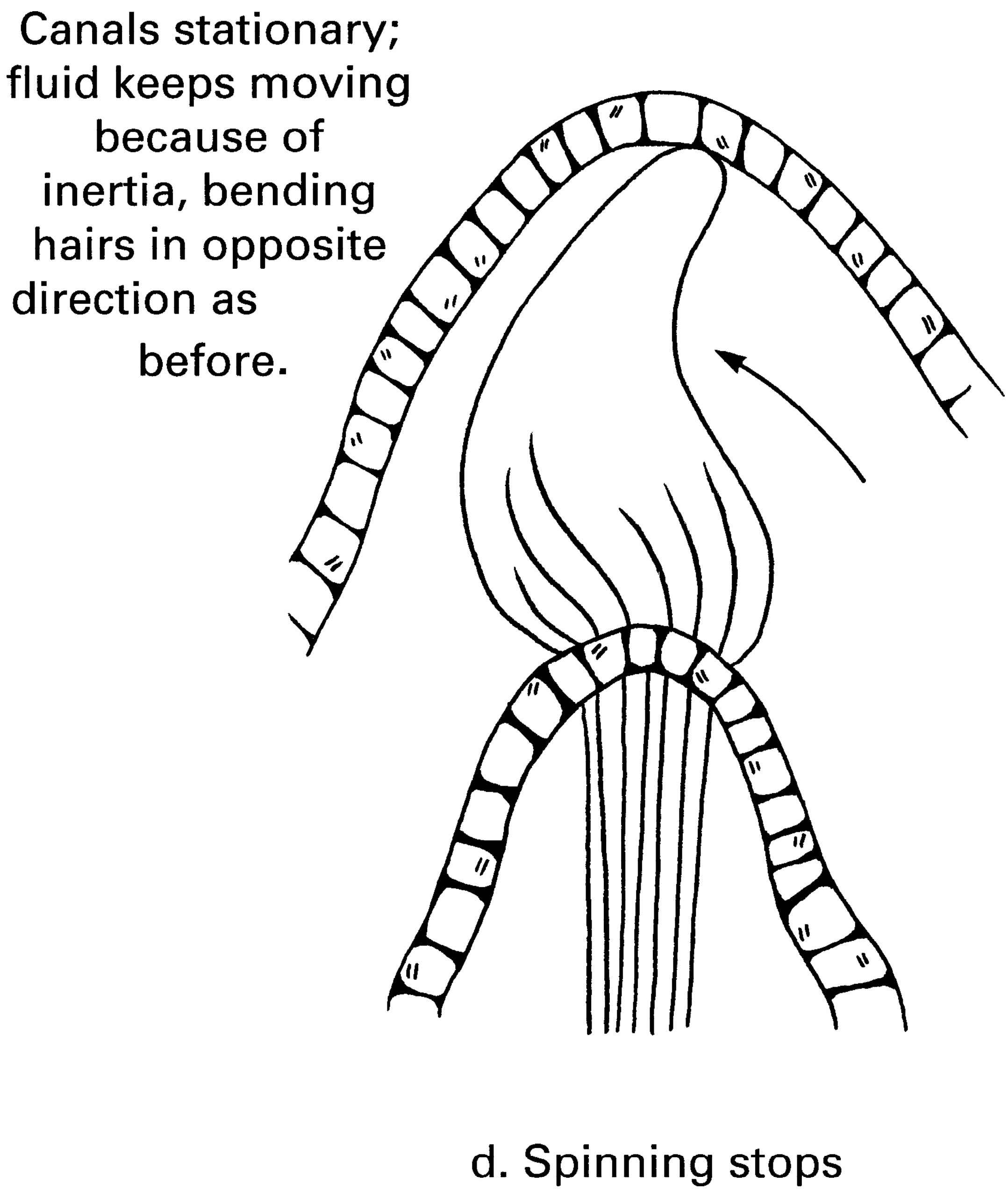


Figure 3. Motion of hairs in semicircular canals before, during, and after spinning.

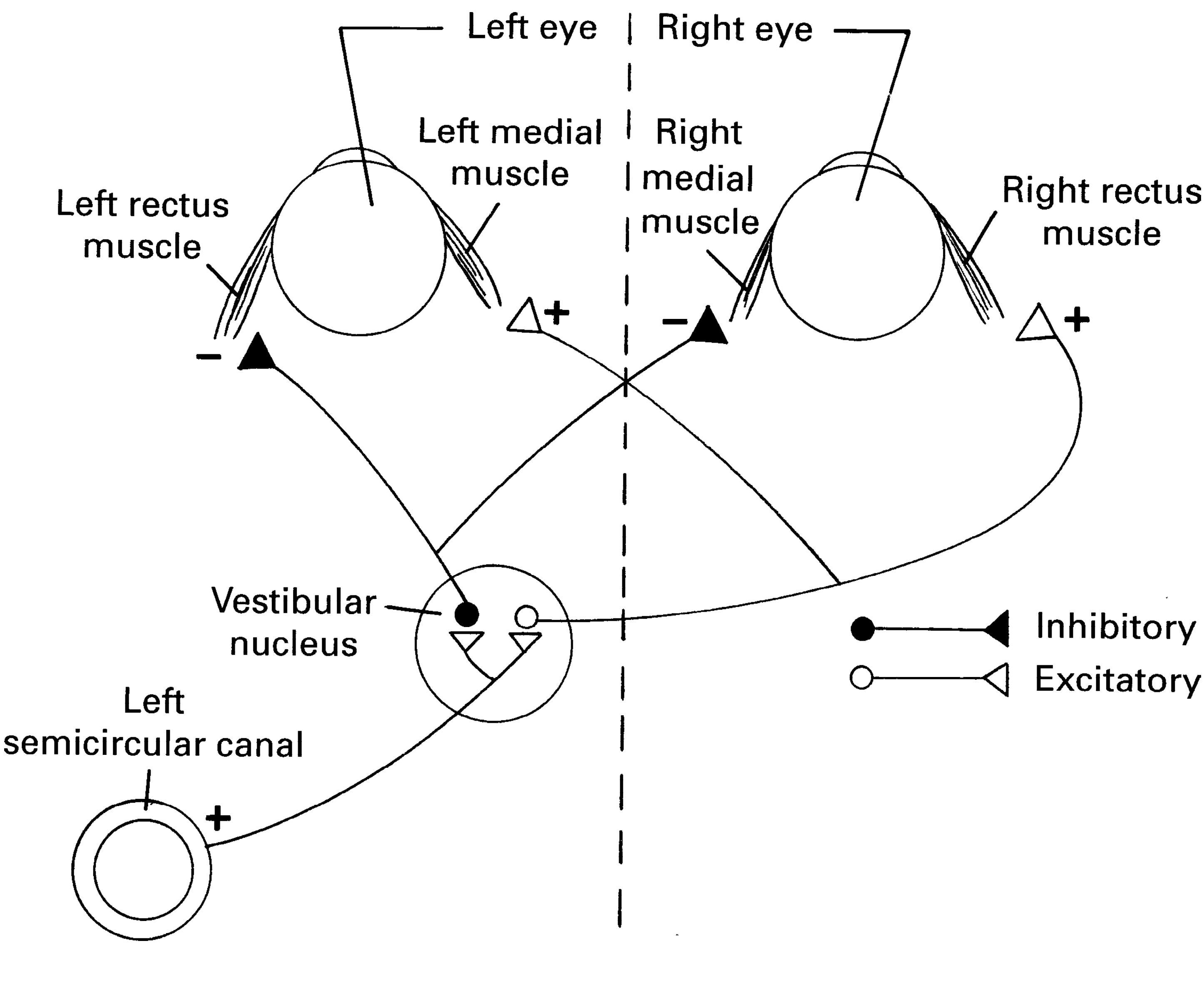


Figure 4. The vestibular-oculomotor connection.

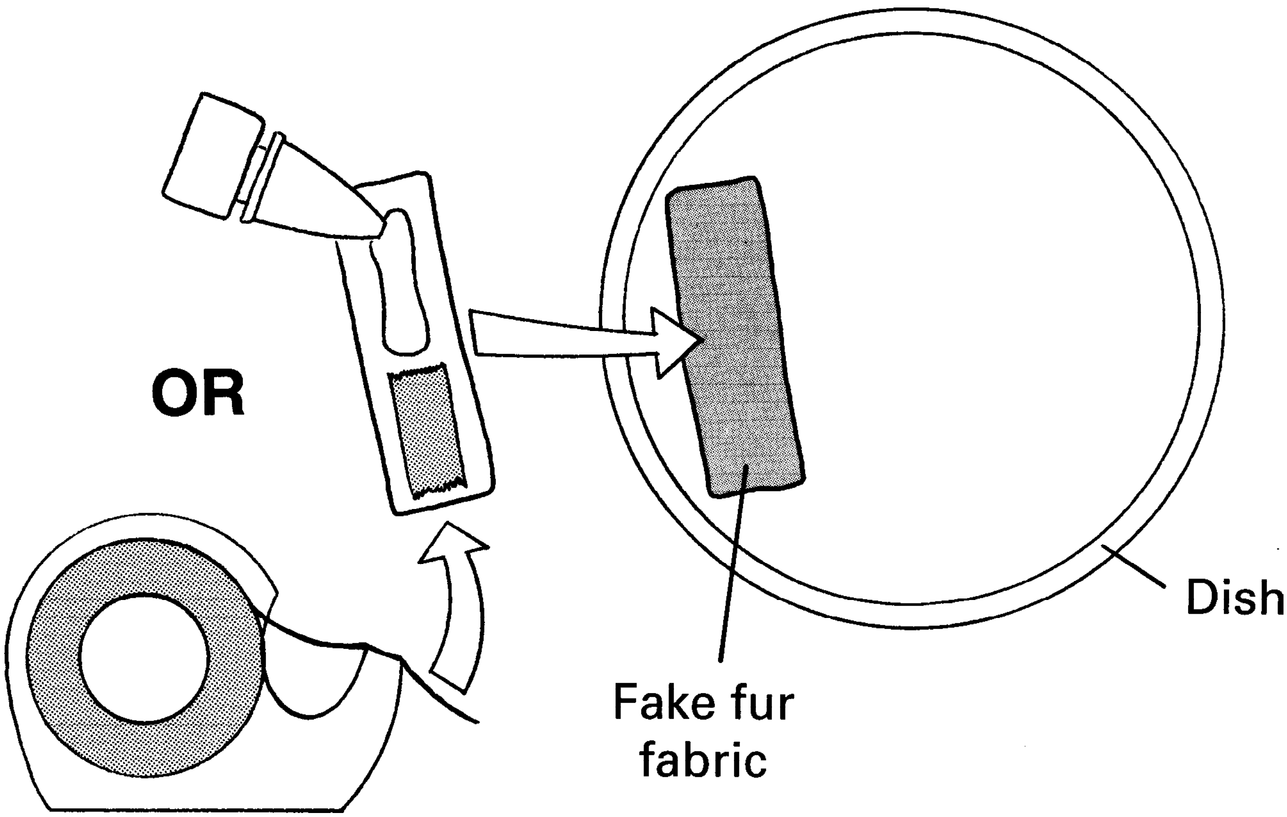


Figure 6. Gluing fake fur on the bottom of glass dish.

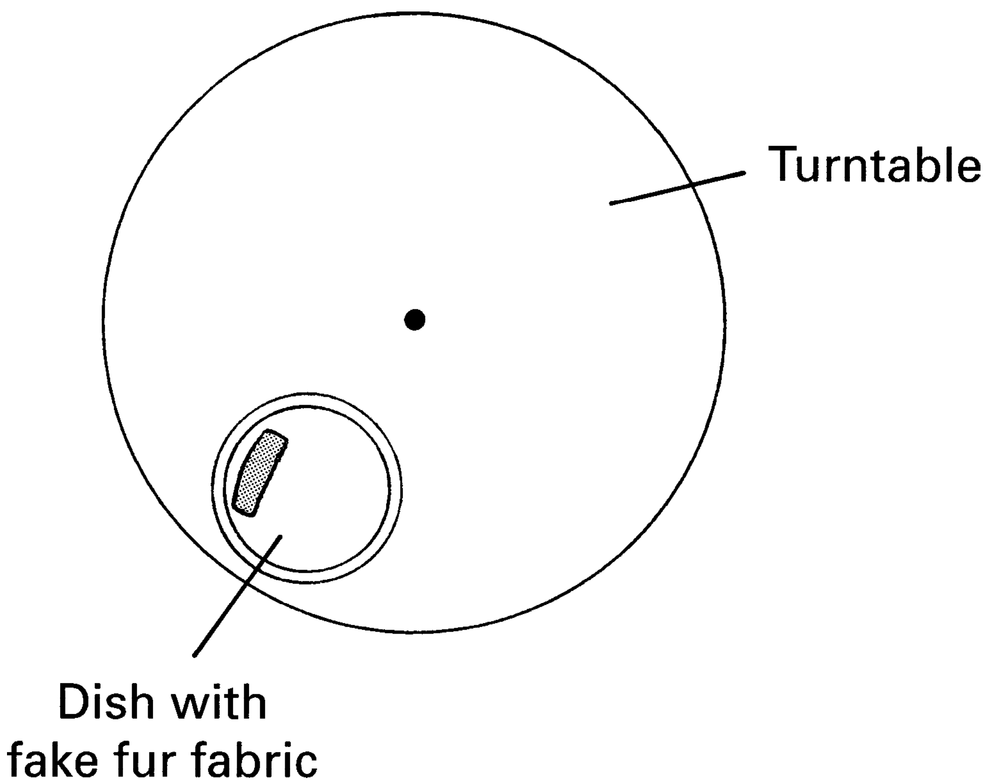


Figure 7. Attaching the glass dish to the turntable.