

Spatial Orientation and Visuo-motor Performance

Lessons and Activities

GRADES 5–12

Section III



Spatial Orientation and Visuo-motor Performance

TOPIC

Gravity is an important component that enables organisms to establish frames of reference and maintain a sense of orientation with respect to objects in the environment.

How did the Neurolab astronauts maintain their sense of spatial orientation in a microgravity environment?

INTRODUCTION

Perception of where one is located with respect to certain landmarks in the environment (**self-orientation**), and where specific objects are located with respect to each other (**object-orientation**), are interdependent. Our abilities to recognize and interact with objects in the environment depend on proper perception of self-orientation as well as object-orientation.

Our perception of self-orientation depends on input from our external sensory organs (**exteroceptors**), such as our eyes, ears, and nose. It also depends on input from our internal sensory systems (**interoceptors**). These include **proprioception**, which is a system of specialized receptors and nerves in our bodies that monitor the positions of our muscles and joints. Another example is the **vestibular system** located inside the head near each ear. This system responds to rotations and accelerations of the head as well as to gravity. Under ordinary conditions, the input to the brain from all of these sensory systems are consistent with one another. However, in microgravity conditions, the vestibular information that the brain receives changes, and this sometimes leads to motion sickness, as well as to illusory perceptions.

Things to Know

RELATIVE POSITION AND PATH ANALYSIS

The term **frame of reference** refers to a coordinated system for specifying the locations and movements of objects. For example, map makers use the North and South poles, and the equator, to establish a frame of reference for the Earth. This allows us to specify locations in terms of their latitude and longitude.

Similarly, the brain uses its sensory organs to establish and maintain a frame of reference to specify locations of objects with respect to the body.



For example, in the Northern Hemisphere, vision can be used to establish “East,” the direction from which the sun is seen to rise in the morning, and “West,” the direction where the sun sets in the evening. Locations and movements of the body and other objects can then be specified within this frame of reference. For example, one may think, “To go home, I must travel eastward.”

Vision can also potentially provide a frame of reference for “up.” For example, we know that to see the sky we look “up,” or that to determine the direction of the ground on which our feet rest we look “down.” Information about “up” and “down” is also provided independently by the **otolith organs**, a component of the vestibular system that responds directly to gravity.

NAVIGATION

When you travel from a location in the environment to which you later want to return, your brain is confronted with the problem of how to navigate back home. One way your brain might accomplish this task is to use some form of **Path Integration**. This is an automatic process performed by

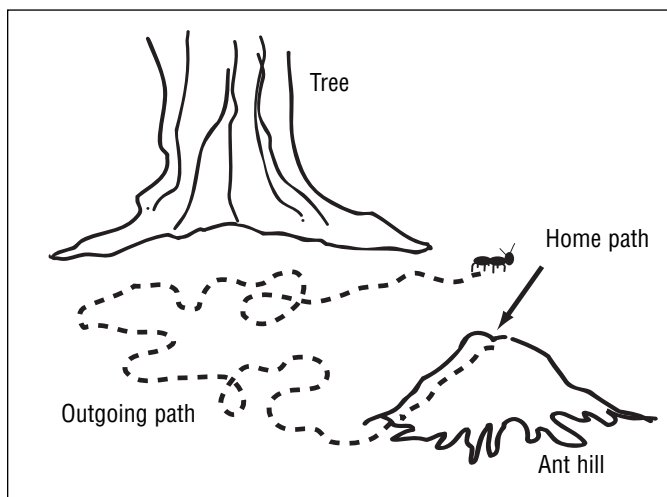


Figure 52 Diagram of path integration.

the brain to try to continuously keep track of how far you have traveled, and in what direction, over each segment of your path, and then use this information to compute your current position relative to your starting point. Many animal species, even those with very simple nervous systems, are able to utilize some form of path integration to navigate. For example, ants can navigate their way back home after foraging in search of food (Figure 52).

Our brains are able to construct and store spatial maps that specify our current location with respect to important landmarks.

These maps are formed by combining information from interoceptors with **corollary discharge**. A corollary discharge is a copy of the motor commands that the brain sends to the muscles. For example, if the brain is trying to figure out how far the body has walked since leaving home, it has two obvious sources of information. One is to examine the corollary discharge of the signals that were sent to the leg muscles. In other words, the brain knows how many steps you have walked because it was the brain itself that sent the commands to the leg muscles that caused you to walk.

An independent source of this same information comes from proprioception which supplies the brain with detailed information about positions and movements of the muscles and joints in the legs. Similarly, the

vestibular system sends information to the brain every time you accelerate or decelerate in speed, or rotate to turn a corner.

Finally, this information about your current location is augmented by vision, olfaction, and audition. For example, through **vision**, you can tell that you are in your classroom by looking around, through **olfaction**, you can tell that you are near the cafeteria by the way it smells, and through **audition**, you can know that you are near your classroom because you can hear the sound of your students talking.

Under ordinary circumstances, the information supplied to the brain from these various sources is consistent and thus the spatial maps that are formed by the brain are accurate. In mammals, there is a specialized structure called the **hippocampus** that appears to play a major role in storing these maps (Figure 53). The hippocampus is a seahorse-shaped structure located deep in each hemisphere of the brain. Self-orientation is coded in the hippocampus in the neural firing patterns of specialized neurons called **place cells**. These place cells buzz with electrical activity whenever an animal knows it is located in a certain place. Different place cells are active in different locations. By recording the activity from many place cells at the same time, scientists essentially can read an animal's mind and tell where the animal thinks it is located.

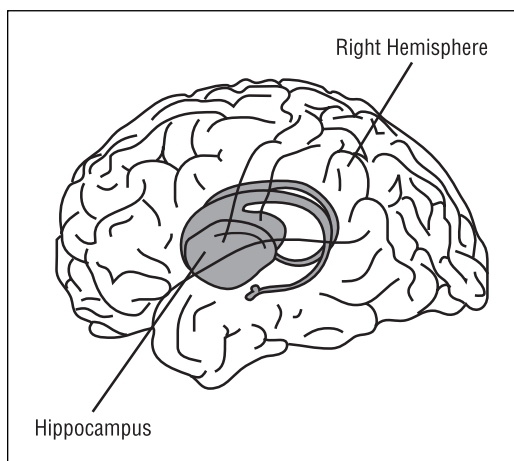


Figure 53 Diagram of the hippocampus within the brain.

SPATIAL ORIENTATION IN MICROGRAVITY

In microgravity conditions, the vestibular information that the brain receives is changed. In order to understand why this is so, we need to understand how the vestibular system operates. The vestibular system is composed of two subsystems called the **semicircular canals** and the **otolith organs**. There are three semicircular canals and they signal to the brain whenever the head is rotated. One responds to **yaw** motions (motion that occurs when you shake your head side-to-side), a second to **pitch** motions (motion that occurs when you do a back flip), and a third to roll motions (motion that occurs when you turn cartwheels). The otolith organs send two kinds of information to the brain. First, they signal whenever you accelerate or decelerate (the feeling of being sucked into the back of the car seat when you press on the gas pedal to pass another car). Second, they respond to gravity to tell you which end of your body is “up,” and which is “down.”

Imagine that you are performing a cartwheel to your left. As you first start the motion, your semicircular canal signals that your head is starting to rotate to the left, and simultaneously your otolith organs are signaling that the “up” direction is shifting from the top of your head towards your right ear. Halfway into the cartwheel, your semicircular canal continues to signal that your head is rotating to the left, and now your otolith organs signal that the top of your head is in the “down” position. If you have your eyes open, the input to your brain will be consistent with the input from your vestibular system because the world will look “upside-down.”

Similarly, the proprioceptive inputs from your muscles will indicate that the force from the floor shifted from your feet to your hands. If you were to turn the same cartwheel under the condition of microgravity, the input from your semicircular canals and from vision would be identical, but the input from the otolith organs would be inconsistent because it would not signal that the direction “up” shifted during your cartwheel. Also the force exhibited by the floor on your muscles would be less in microgravity.

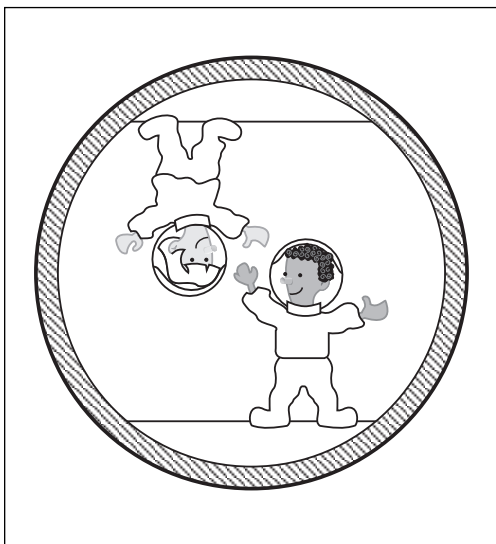


Figure 54 Diagram of free floating.

This kind of inconsistent input is a regular occurrence in the brains of astronauts during a space flight. Astronauts experience the spacecraft and Earth from their bodily attitudes. Because the “down cue” that Earth’s gravity provides to the otolith organs, as well as to the proprioceptive receptors in the muscles and joints are not present in microgravity, the crew must rely on vision to become oriented and figure out where they are located in relation to the space they occupy. In daily life on Earth, the “floor” is always beneath our feet and people are upright. However, in weightlessness, free floating crews view the cabin interior, and each other, from many orientations. For example, when floating in symmetrical cabin interiors, the surface beneath their feet feels like “the floor,” even if they are floating upside-down with their feet touching the ceiling (Figure 54). As a result,

space flight often causes altered spatial orientation, illusions of body orientation, changes in visuo-motor performance, and space motion sickness.

TRICK MAZE EXPERIMENTS ON NEUROLAB

One Neurolab animal experiment tried to determine whether or not spatial maps in the hippocampus are disrupted by the inconsistent information provided to the brain under conditions of microgravity. Neurolab scientists used a unique set of trick mazes designed to fool the animals into thinking they were in one place, based on corollary discharge and proprioception (where the animals thought their legs should have taken them), when in reality they were in another place (which they were able

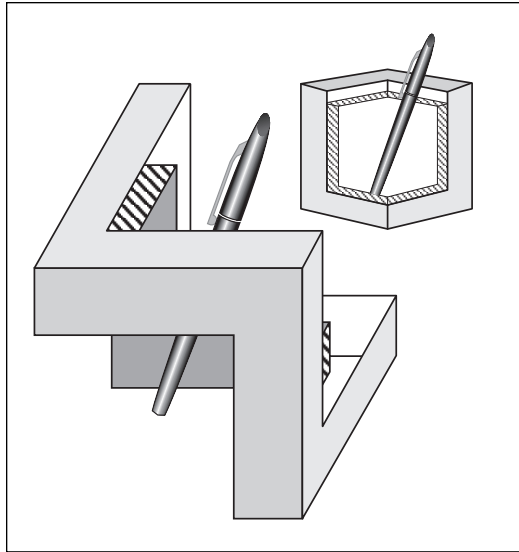


Figure 55 Diagram of an Escher Staircase.

to see from what their eyes told them). One maze was called the Escher Staircase (Figure 55) and another was called the Magic Carpet (Figure 56). Scientists wanted to see whether the animals' hippocampi were telling them they were "home" or not by measuring the activity of the place cells in the hippocampi.

In the **Escher Staircase**, there was a route around three inner walls of a corner of a cube. In the presence of gravity, you could not walk around the staircase because you cannot walk along the sides of walls. However, in the absence of gravity's effect, it was possible to follow a route that combined three 90 degree "yaw" turns with three 90 degree "pitches" and end up back home at the starting point. The animal did not have any input from its otolith organs

informing it that it had been walking on the wall instead of the floor during part of the route. It had been predicted that even though the animal was back to where it started, it would be confused. The visual system would tell the brain that all the visual landmark cues indicated that the animal was back where it started the maze, but the path analysis performed by the brain would probably think the animal needed to turn one more corner to return home (as would be the case if the animal had not been able to walk on the walls).

The **Magic Carpet** maze played a similar trick that was possible only in the absence of gravity's effect. It was a plus-shaped maze that could pitch and roll the animal so they ended up facing 180 degrees in the opposite direction to where it had started without ever turning around. Again, the visual cues told the animal it had turned around, but path analysis would not. It was believed that the hippocampal place cells would put more emphasis on path analysis computations than on visual information. Thus, the prediction was that when the animal returned to its starting position, the hippocampus would underestimate the animal's true position by 90 degrees on the Escher Staircase and by 180 degrees on the Magic Carpet.

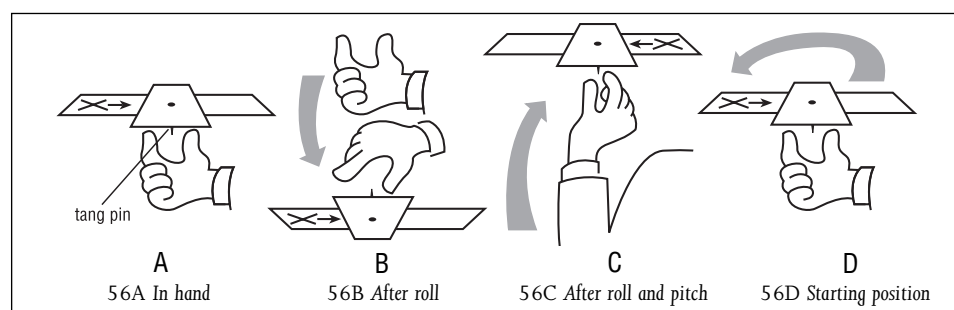


Figure 56 Diagram of the Magic Carpet.

LEARNING ACTIVITY I:

Finding Your Way Around Without Visual or Sound Cues

OVERVIEW

In this activity, students will play a series of simple games to investigate navigation without visual and sound cues.

SCIENCE & MATHEMATICS SKILLS

Observing, collecting quantitative data, creating graphs, interpreting data, drawing conclusions, communicating

PREPARATION TIME

15 minutes

CLASS TIME

45 minutes

MATERIALS

- Access to an open area
- Measuring tape
- Timer (watch or clock with second hand)
- Graph paper, one sheet per student
- Pencil (pen or chalk is acceptable), one per student
- Bell
- Blindfold, one per student
- Candy to reward for foraging
- Statistical calculator

BACKGROUND

The brain is able to interpret information from several different body systems to estimate position. Visual cues, information from the otolith organs in the inner ear, sound cues, and information from the motor system are used to determine spatial orientation.

MAJOR CONCEPTS

- The brain combines information from several different sources to estimate position.
- Inertial navigation (navigation based on motion-related cues) can provide direction without visual or auditory cues.
- The environment can be navigated with some success by solely using feedback received by the brain from self-motion sensors in the body.

This activity allows students to investigate how well the central nervous system is able to estimate position based on information other than visual and sound cues.



PROCEDURE 1

Navigating Without Visual or Sound Cues

1. Have each student take a partner and a blindfold to an open area.
2. Designate an area as “home” base by placing a piece of paper on the ground where the students are, or mark the spot with tape forming an “X” on the ground or on the floor.
3. Have one member (subject) of each student team tie the blindfold over his/her eyes so he/she cannot see anything. This is a test to see if the student can navigate without visual cues. Encourage the students not to cheat.
4. Once blindfolded, each subject should walk around continuously for 30 seconds, like an ant foraging for food, and then try to return to the same spot where he/she started (Figure 57). Have the students make at least four turns as part of the path. They may go anywhere, as long as they try to end up at the starting place after 30 seconds. Each student’s partner should let him/her know how much time has elapsed every 10 seconds. Have the partners move around so that the subjects cannot use the sound of their partners’ voices as the cues for “home.”

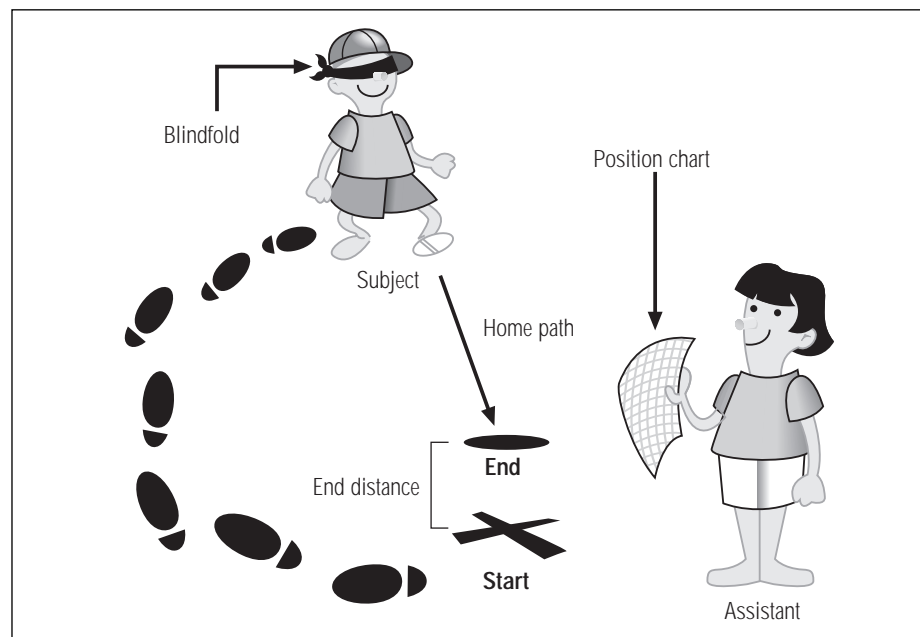


Figure 57 Diagram of student walking blindfolded to show how inertial navigation can provide direction without sight or sound.

5. Make sure that the partners do not give the blindfolded students any hints. The environment should be as quiet as possible so that students receive no sound cues. Once each blindfolded student believes he/she has returned to home base (or, after the 30 second time limit is

reached), instruct him/her to remove the blindfold and measure how far he/she is from the starting mark. This distance should be recorded. Instruct the students not to worry if they end up far away from “home” after their first try.

- To add excitement, distribute little packets of candy at random and have the students forage on hands and knees blindfolded, starting from a location called home, marking the floor (or pavement, if you are outdoors) with something they cannot feel, such as chalk. Then ring a bell and have them try to get back to home base within five seconds. The students might pretend that they are foraging ants and that the bell is a danger signal. Thus, they would try to get back “home” quickly.

Each student should have the opportunity to try this experiment at least once.

PROCEDURE 2

Using Quantitative Information to Assist Navigation Without Visual or Sound Cues

Note to Teacher: Encourage students not to make any audible clues that might alter results. The environment should be quiet.

- Have your students repeat the previous activity, again blindfolded. But this time, instead of having the blindfolded students wander around randomly, have them count the number of steps they take in each direction.

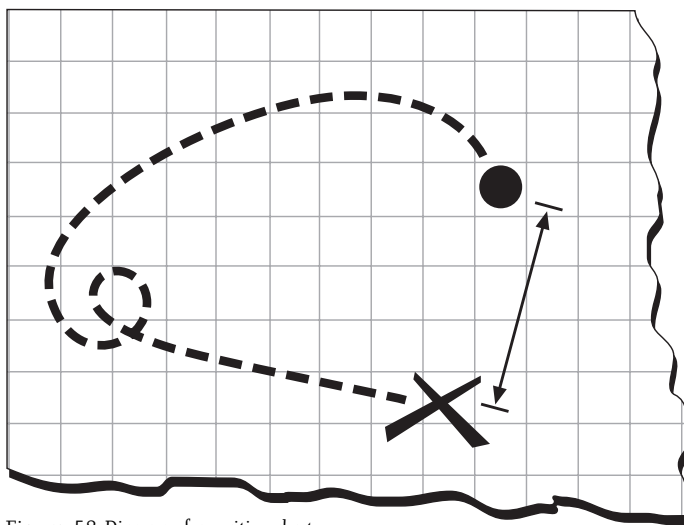


Figure 58 Diagram of a position chart.

- The partner should help the blindfolded student by writing down the number and direction of steps taken by the blindfolded student. Partners can try to chart the student’s course by drawing the student’s position at each step on a sheet of graph paper (Figure 58).
- At 30 seconds, the blindfolded students should try to find their way “home” by guessing where they are, using how far they have gone in each direction as a cue. Direct each blindfolded student to tell his/her partner how far, and in which

direction(s) he/she thinks he/she needs to travel in order to reach home. (It is acceptable if the partner looks at the chart to see if the blindfolded student is correct, but the partner should not give any hints.)

- The student should now try to find home. Once the blindfolded students reach the place they believe to be “home,” have their partners measure the distance from where the students ended to the actual starting place, or “home.” Have students compare their estimates of the distance to home with the actual measurements. Each student should try the experiment.

PROCEDURE 3

Using a Pre-established Pattern to Navigate Without Sound or Visual Cues

- All students should be blindfolded for this exercise. As many students can participate at one time as available space will allow.

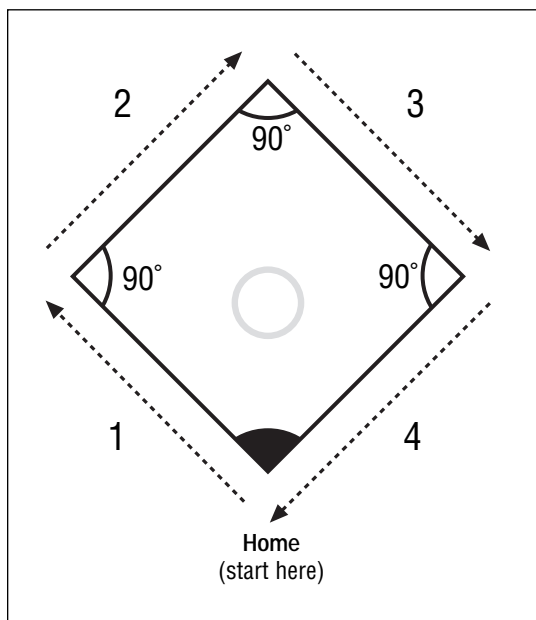


Figure 59 Diagram of a pre-established pattern.

- Students should blindfold themselves and try taking 10 steps forward from their “home” mark. They should then turn 90° to the right, take 10 more steps, turn 90° to the right again, take 10 more steps, and stop (Figure 59). Ask the students if they think they are back to where they started yet.
- Have the blindfolded students turn 90° to the right and take 10 more steps. Have the students add all their 90 degree turns to determine how many degrees they have rotated in total.
- Ask the students where their brains tell them they are. Direct them to lift their blindfolds and see if they are “home.” The students should measure how far they are from their mark and record the measurement. If the students counted accurately, they should be close to the place where they started.

- Have students compare measurements from the three trials. Have them identify the trial in which they navigated most accurately and the trial in which they were least accurate in returning to home. Why do they think the results varied from one trial to another?

Evaluation

REVIEW

QUESTIONS

1. What types of information does the brain use for navigation and determining position?
The brain receives and utilizes sensory information from the eyes, ear, and nose to determine position.
2. Is it possible to estimate position using information from only one or two sources?
Yes. It is possible.

THINKING CRITICALLY

1. What is the minimum amount of sensory information needed for navigation?
A minimum of two sensory information is needed for navigation.
2. Was navigation successful without visual cues?
3. How much error occurred when using each of the tactics?
4. Which tactic produced the least error? Why?
5. How much more or less difficult would the task have been if one could walk up and down walls?

SKILL BUILDING

1. Have students pool the class data from each of the trials, compute the mean distance from “home” for each trial and, using a statistical calculator, find the standard deviations (averages) of each of the trials. Have them use this information to decide whether the results of each trial are different or not.
2. Have student teams devise their own experiments to further investigate navigation without visual cues.



LEARNING ACTIVITY II:

Pitch, Roll and Yaw: The Three Axes of Rotation

OVERVIEW	This exercise will help students understand how the visual and vestibular systems work with the hippocampus to determine location and direction.
SCIENCE & MATHEMATICS SKILLS	Observing, measuring, visualizing objects in three dimensions, drawing conclusions
PREPARATION TIME	None
CLASS TIME	45 minutes
MATERIALS	No materials needed
BACKGROUND	The body is capable of rotating in three different ways (roll, pitch, and yaw). This activity will help students understand the three axes of rotation.

MAJOR CONCEPTS

- Without gravity's effect as a reference, it is difficult to detect the body's orientation.
- In microgravity, astronauts' brains will rely on place cells within the hippocampus for information about position.
- Place cells are more strongly influenced by computations based on path integration than by visual cues.

Body in Rolling Motion

The sideways motion of a body doing a cartwheel (Figure 60) is called a **roll**.

Body and Head Pitching

The motions of the body when somersaulting (Figure 61) are called a head over heels **pitch**. The head is up, then down, then up, then down. Throwing a football or a baseball is also a pitch motion.

Yaw

When you stand up and turn left and right, the motion you have made is called a **yaw** axis motion (Figure 62). One "yaws" when spinning around in a rotating chair, or when doing a pirouette.



HEAD DIRECTION CELLS

There are cells deep within the brain that tell the hippocampus in which direction the head is facing in the yaw axis. These are called **head-direction cells**. The head direction cells always specify direction relative to some important landmark. In the classroom, the front of the classroom might provide a landmark to form a frame of reference labeled by the brain as “forward” (facing the front of the classroom) and “backward” (facing the back of the classroom). When facing the front of the classroom, the head-direction cells tell the hippocampus that the head is facing forward.

When the head is turned to face the back of the room, another set of head-direction cells becomes active and tells the hippocampus that the head is facing backward. Yaw motions are sensed by the vestibular system even if the eyes are closed. They are not influenced by gravity and can be sensed even when upside-down. Unlike yaw motions, the pitch and roll motions usually have gravity for a reference. This is because the otolith organs that respond to gravity are activated along with the semicircular canals during these motions. Thus, the responses of the vestibular system to “pitch” and “roll” will be altered in microgravity conditions compared to these responses in Earth’s gravity.

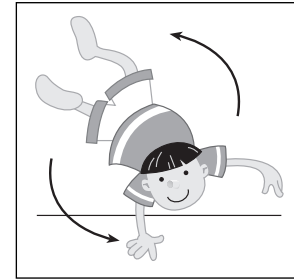


Figure 60 Diagram of rolling motion.

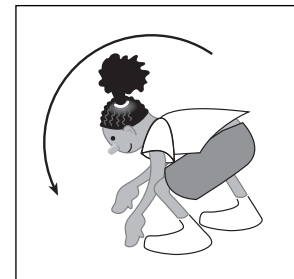


Figure 61 Diagram of body pitching.

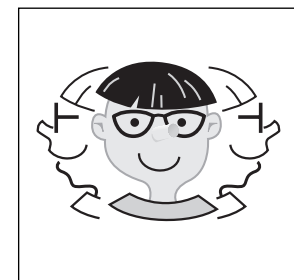


Figure 62 Diagram of yaw axis motion.

PROCEDURE

1. The roll, pitch and yaw motion diagrams to the right can be emulated by your students outdoors or in a large area such as a hallway.
2. Demonstrate each of the movements or show the figures on an over-head chart. Then let all of the students attempt each of the different rotations.
3. To begin the rolling cartwheel motion (Figure 60), have the students lead with their right hands, with their left ears facing up to the sky. As they roll along or rotate in the correct direction, their right ears will face upward, while their left ears are down, and so on.
4. For pitch (Figure 61), have students attempt both a head-over-heels pitch (summersault) and a pitching motion with the arm. Students can also shake their heads “yes.”
5. For yaw (Figure 62), have students stand and turn left, then right. Students also should try spinning in a pirouette. They can also shake their heads side-to-side as if gesturing “no.”

6. Explain to students that the body has different systems to sense yaw, pitch, and roll movements. Introduce the concept of **head direction cells**, which tell the hippocampus whether the head is facing forward or turned toward the back. Ask them to identify which type of rotation the head direction cells would be detecting. Mention that the head direction cells are not influenced by gravity, whereas the pitch and roll motions usually have gravity for a reference.

LEARNING ACTIVITY III: Building a Magic Carpet

OVERVIEW

Students will compare and contrast pitch and roll motions by using a Magic Carpet maze similar to one that was used for Neurolab investigations.

SCIENCE & MATHEMATICS SKILLS

Observing, measuring, visualizing objects in three dimensions, drawing conclusions

PREPARATION TIME

None

CLASS TIME

45 minutes

MATERIALS

Each student or team of students will need:

- Scissors
- Two strips of cardboard or posterboard (2.5 inches wide and 18 inches long)
- Metal paper fasteners (tang pins)

BACKGROUND

The Neurolab Magic Carpet experiment was designed to investigate “pitch” and “roll” in microgravity. The Magic Carpet is a maze shaped like a plus symbol that can work only in a weightless environment. This maze allowed the astronauts to pitch and roll animals in space, so that without making any yaw turns, the animals ended up facing the opposite direction from where they started.

MAJOR CONCEPTS

- Roll is a sideways motion.
- Pitch is a head-over-heels movement.



Neurolab scientists used this trick maze to fool animals into thinking they were in one place based on their self-motion cues, while their visual systems gave them conflicting information about their locations. The scientists wanted to know whether rats' hippocampi told them they were "home," or not, by measuring the activity of place cells.

PROCEDURE

1. Tell students they will be creating another puzzle that was used by Neurolab scientists to investigate navigation and spatial orientation in space.
2. Have the students follow the four steps for building a Magic Carpet.

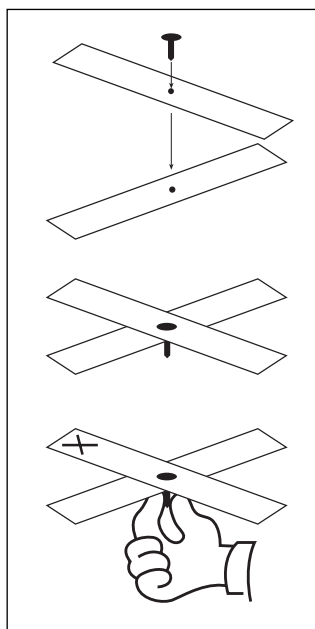


Figure 63 Diagram of construction of a Magic Carpet.

How to Build a Magic Carpet

- I. Cut two strips of cardboard 2.5 inches wide and 18 inches long.
- II. Put a hole in the center of each strip and fix the two together, perpendicular to one another, with a bent tan pin. Do not split the tangs of the pin when attaching the strips.
- III. Hold the tang pin in the hand (palm up), with the head of the tang pin pointing up and the tangs pointing down.
- IV. Mark the end of the Magic Carpet that is farthest away from you with an "X" to represent an animal, as if the animal were facing you.

3. The Magic Carpet will allow the students to perform the following roll and pitch maneuvers, as shown in Figures 64A and 64B.
4. To perform roll maneuvers, the Magic Carpet should be turned so the head of the tang is pointing down and the student's hand is on top. Explain to the students that if an animal were on Earth, it would have fallen to the ground. When this experiment is performed in space, the animal will remain on the Magic Carpet, even when it is turned upside down, because there is little gravity.

5. To examine pitch maneuvers, have the students turn their wrists and elbows upward so the head of the tang is on top again. Ask them if they see how the “X” is now on the end of the maze closest to them, as if the animal were facing away from them. The students should note that the animal did not have to make any yaw axis motion, yet it ended up facing 180° away from where it started (Figures 64C & 64D).
6. Now rotate the Magic Carpet 180° in a yaw motion so that the “X” ends up where it started as if the animal were facing you.

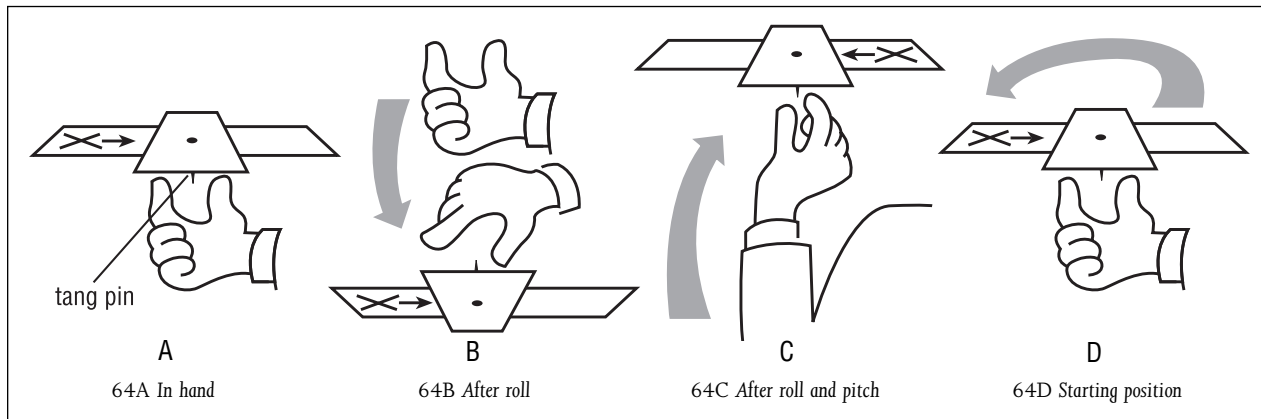


Figure 64 Diagram of the Magic Carpet.

Evaluation

REVIEW QUESTIONS

1. Which two types of rotation does the Magic Carpet use?
Pitch and roll.
2. How does the brain track movements and position?
The hippocampus gets information from many different parts of the brain, and integrates it to assess where the animal is in space. The hippocampus uses self-motion cues (vestibular, muscular, body position senses), visual (sight) and auditory (sound) cues.

THINKING CRITICALLY

1. If the animal's brain is not properly encoding pitch and roll motions, what will its hippocampus tell it about where it is?
If the animal has not moved, except for a 180° roll, then the hippocampus will not indicate that the animal has moved, and the hippocampal map should indicate that the animal is in the same place.



2. Will its vestibular system indicate that it has moved at all?

The vestibular system should indicate some disturbance, but it cannot give the hippocampus accurate pitch and roll information without gravity.

3. What will its visual cues tell it?

No visual cues have been removed, therefore, the animal will receive accurate information regarding its position.

4. What will its place cells do?

If the hippocampus has not yet learned how to use this new set of visual cues, then it will rely on the self-motion cues from the vestibular system and we think it will tell the animal that it has not moved.

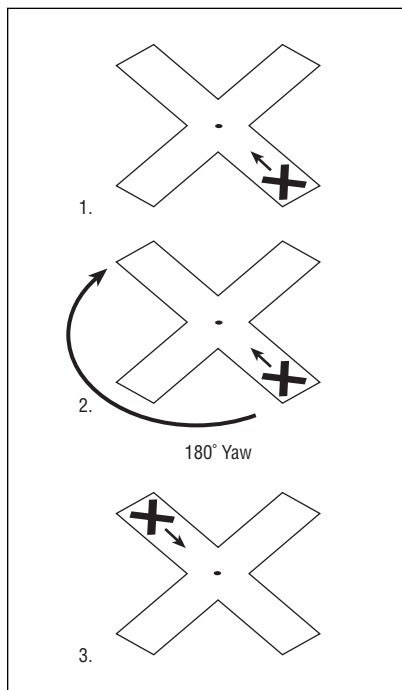


Figure 65 Diagram of a helicopter blade movement.

5. What if the animal was turned 180 degrees in the yaw axis (a movement like helicopter blades)? Have the students demonstrate (Figure 65).

Since the yaw movements don't depend on gravity, the vestibular system should accurately inform the hippocampus that the animal has moved 180° and is now facing in the opposite direction.

6. Where does the "X" end up?

Where it started.

Note to teacher: If the animal is sensing motion with its vestibular system, it will not accurately sense that it has motion. It will only detect that it has undergone a 180 degree "yaw," and this would indicate that it is 180 degrees from where it started. Vision will indicate that the animal is back where it started. It is predicted that the animal will think it has rotated 180 degrees because the place cells are influenced more by the vestibular system than by the inertial navigation system.

STUDENT ACTIVITY SHEET

How to Build a Magic Carpet

Name _____ Date _____

OBJECTIVE To compare and contrast pitch and roll motions by using a Magic Carpet similar to one that was used for Neurolab investigations.

MATERIALS

- Scissors
- Two strips of cardboard or poster board (2.5 inches wide and 18 inches long)
- Metal paper fasteners (tang pin)

DIRECTIONS You will be creating another puzzle that was used by Neurolab scientists to investigate navigation and spatial orientation in space. Follow the four steps to building a Magic Carpet (Figure 66).

PROCEDURES

1. Cut two strips of cardboard 2.5 inches wide and 18 inches long.
2. Put a hole in the center of each strip and fix the two together, perpendicular to one another, with a bent tang pin. Do not split the tangs of the pin when attaching the strips.
3. Hold the tang pin in the hand (palm up), with the head of the tang pin pointing up and the tangs pointing down.
4. Mark the end of the Magic Carpet that is farthest from you with an "X" to represent an animal, as if the animal were facing you.

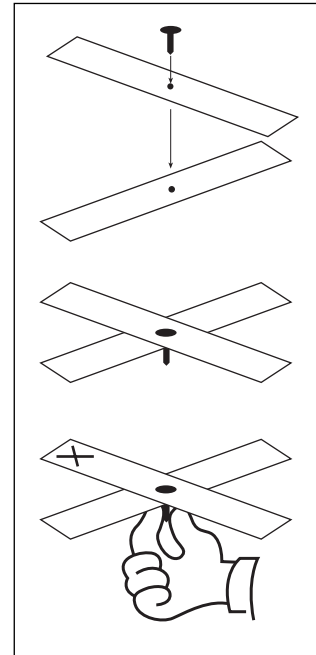


Figure 66 Diagram of construction of a Magic Carpet.



Name _____ Date _____

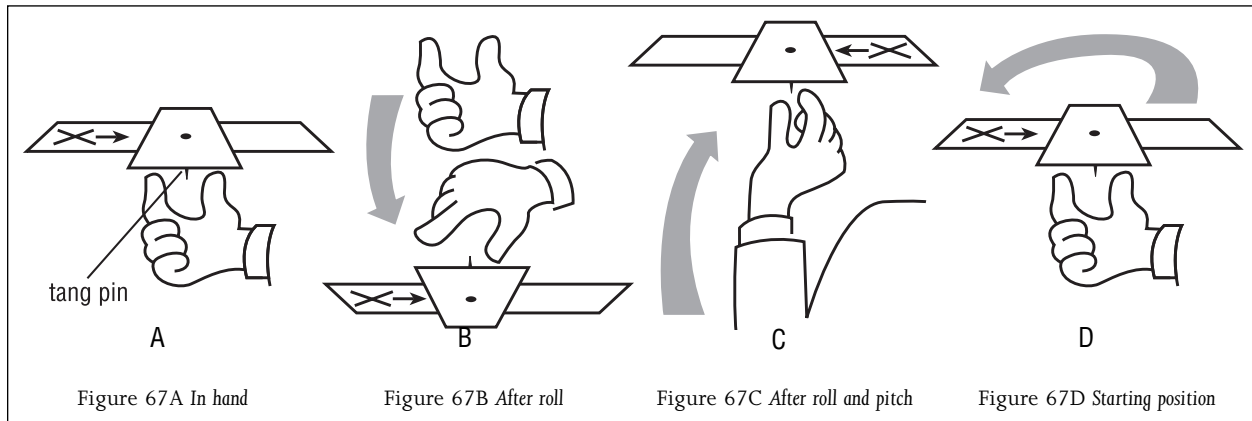


Figure 67 Diagram of the Magic Carpet.

5. The Magic Carpet will allow you to perform the following roll and pitch maneuvers, as shown above.
6. To perform roll maneuvers, the Magic Carpet should be turned so the head of the tang is pointing down and your hand is on top (Figure 67B).
7. To examine pitch maneuvers, turn your wrists and elbows upward so the head of the tang is on top again (Figure 67C).

LEARNING ACTIVITY IV:

Building a 3-D Space Maze: Escher Staircase

OVERVIEW	Students will create Escher Staircase models similar to those that were used by the Spatial Orientation Team to investigate the processing of information about pitch, roll, and yaw.
SCIENCE & MATHEMATICS SKILLS	Observing, measuring, visualizing objects in three dimensions, drawing conclusions
PREPARATION TIME	None
CLASS TIME	45 minutes
MATERIALS	Each student or team of students will need: <ul style="list-style-type: none"> • Scissors • Three strips of cardboard or posterboard (two inches wide and two feet long) • Three metal paper fasteners (tang pins) • Light-weight ball (ping-pong) • Magic marker

BACKGROUND The Neurolab Escher Staircase experiment was designed to investigate whether, within microgravity, the hippocampus received inaccurate information about pitch and roll motions, but still had a fully functional yaw motion detection system. On board Neurolab, investigators used the weightless environment to pit the vestibular and proprioceptive (which is hampered by the microgravity environment) against the visual cues of position.

The Escher Staircase is a maze that can be run only in microgravity, because it requires movement up and down and sideways along three of the walls that make up the inside of the cube. There is no distinction between horizontal and lateral movements in a microgravity environment. Rats running

MAJOR CONCEPTS

- Without gravity as a reference, the information provided to the brain about “pitch” and “roll” motions will be distorted.
- In microgravity, astronauts’ brains will rely on place cells in the hippocampus for information about position.
- Place cells are more strongly influenced by vestibular and proprioceptive systems visual cues.



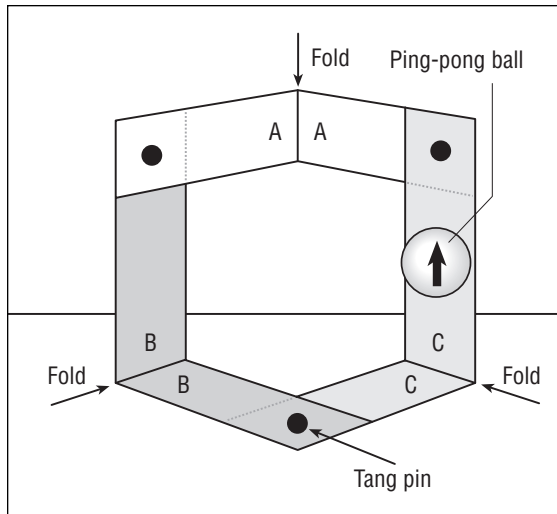


Figure 68 Diagram of a student model of an Escher Staircase.

the maze in microgravity made three 90° pitches and three 90° yaws to end up where they started. The maze is named after the artwork created by **M.C. Escher**. Escher, an artist, incorporated optical illusions into his work.

PROCEDURE

1. Discuss the trick maze experiment that the astronauts conducted during the Neurolab mission (this experiment is described in the “Things to Know” section). Tell students that they will be constructing an Escher Staircase similar to the one that was used for the experiment.
2. Have each student or pair of students follow the five steps below to build an Escher Staircase.

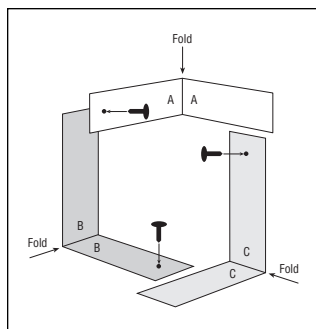


Figure 69 Diagram of the construction of an Escher Staircase.

How to Build an Escher Staircase

- I. Cut cardboard into three strips (A, B and C) that are two inches wide and two feet long.
- II. Punch holes near the top and bottom of each strip.
- III. Bend the center of each strip to a 90° angle.
- IV. Use the tang pins to connect strip A to strip B, and strip B to strip C at the holes.
- V. Orient the strips at the tang joints so that they are 90° degrees relative to each other, and then connect strip C to strip A.
- VI. Draw an arrow on the ping-pong ball.

3. After students have built the Escher Staircase model, have them move the light weight ball along the maze for one full circuit with the arrow pointing in the direction of travel (Figure 68). Have them think about whether it would be possible to walk along the maze in the presence of gravity. What about in space? What types of information would the brain need to remain oriented while walking along the staircase?

Evaluation

REVIEW QUESTIONS

1. Describe yaw, pitch, and roll.

Yaw motions are in the horizontal plane relative to your body, for example, shaking your head “no.”

Pitches are turns in the vertical plane, for example, bending over forward to touch your toes.

Rolls are turns along the long axis of your body, for example, when you accidentally roll off the bed when you are sleeping.

2. For which of these rotational movements does the brain depend on gravity to process information about the movement?

Pitches and rolls.

THINKING CRITICALLY

1. How many yaw axis turns did the students’ hands make?

Three 90° yaw axis turns complete one full circuit on the Escher Staircase.

2. How many pitches? If an animal has no way of encoding the pitch turns, what will the inertial navigation tell the animal’s hippocampus after it has made one full circuit? What will the visual cues tell it?

Three 90° pitches complete one full circuit on the Escher Staircase. Inertial navigation calculations should tell the animal that it has only made 270° worth of turns and it needs to move forward and make one more 90° yaw turn before completing the circuit. Visual cues are accurate. If the animal uses the visual cues quickly, it would accurately indicate that animal’s true position in the environment.

3. Which system will the hippocampus rely on the first time the animal is exposed to the maze, having not yet learned the visual relationships between landmarks?

Scientists hypothesize that the animal will rely on selfmotion cues (inertial navigation) at first, because it has not spent enough time in the environment to have learned how the visual cues map out.

4. What about the second day it runs the maze?

The animal will have spent enough time looking at the environment to be able to rely on its placement to tell where it is.

5. Can you make only three 90 degree turns in the yaw axis in space, yet end up right back where you started?

Not if you are also moving forward.



6. Without gravity as a reference for sensing the pitch and roll motions, how can you tell if you are back where you started?

Using yaw and translational movement cues along, you can keep fairly good track of where you are relative to where you started, only if you have not moved up or down. Without gravity to help your vestibular system keep track of pitches and rolls, if you make translational movements after a pitch, your map calculation of your position will be inaccurate.

SKILL BUILDING

1. The artist M.C. Escher created a number of paintings that present gravity-defying optical illusions. Have students find more examples of his work using resources at the library or on the internet.
2. Have students create their own artworks that present paradoxes or illusions in their design.



STUDENT ACTIVITY SHEET

How to Build an Escher Staircase

Name _____ Date _____

OBJECTIVE

To understand how the brain processes information about pitch, roll, and yaw.

MATERIALS

- Scissors
- Three strips of cardboard or poster board (two inches wide and two feet long)
- Three metal paper fasteners (tang pins)
- Light-weight ball (ping-pong)

DIRECTIONS

You will be constructing an Escher Staircase similar to the ones that were used for the experiment. Follow the five steps below to build an Escher Staircase.

PROCEDURES

1. Cut cardboard into three strips (A, B, and C) that are two inches wide and two feet long.
2. Punch holes near the top and bottom of each strip.
3. Bend the center of each strip to a 90 degree angle.
4. Use the tang pins to connect strip A to strip B, and strip B to strip C at the holes.
5. Orient the strips at the tang joints so that they are 90 degrees relative to each other, and then connect strip C to strip A.

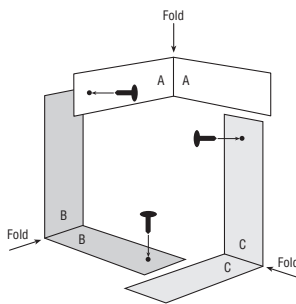


Figure 70 Diagram of construction of an Escher Staircase.

After you have built the Escher Staircase (Figure 71), move your hands or a light weight ball along the maze for one full circuit. Think about whether it would be possible to walk along the maze in the presence of gravity. What about in space? What types of information would the brain need to remain oriented while walking along the staircase?

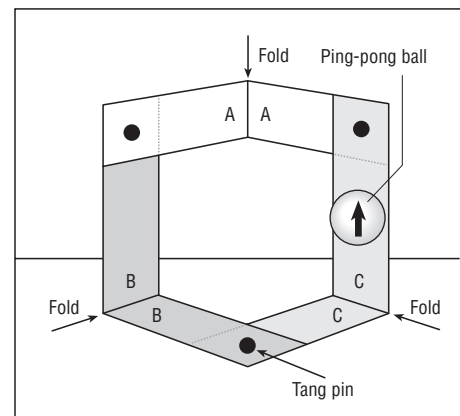


Figure 71 Diagram of an Escher Staircase.

