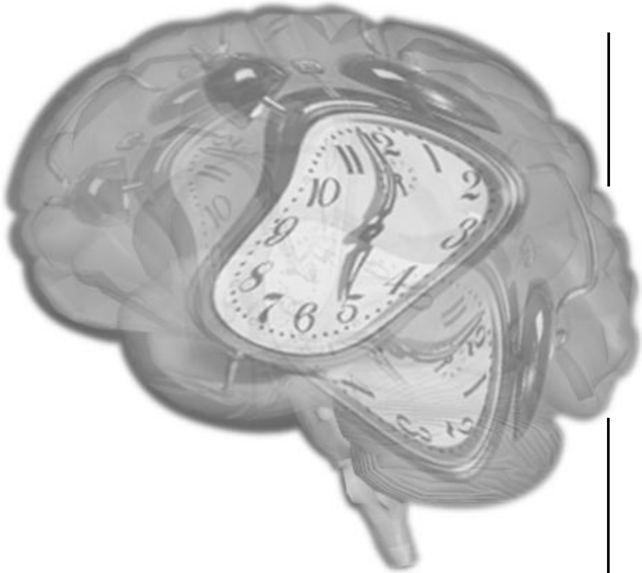

Sleep and Circadian Rhythms

Lessons and Activities

GRADES 5–12

Section V

Sleep and Circadian Rhythms

TOPIC

How did the Neurolab astronauts' sleep patterns change in microgravity?

Did these changes affect the astronauts' reaction times and/or performances?

INTRODUCTION

Human sleep occurs in a daily circadian rhythm. The periods spent between sleep and wakefulness (or rest and activity) are coordinated with the environmental light/dark cycle. The circadian timing system (CTS) acts as a master control to ensure that the various physiological "systems" of the body (including the nervous system, the respiratory system, the cardiovascular system, and others) work together in a synchronized and coordinated fashion. If the CTS is not working properly, an organism's health and performance will be negatively affected.

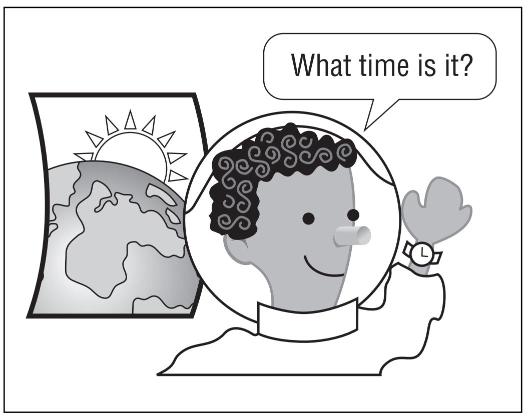

Figure 95 *Diagram illustrating an astronaut's CTS having no normal "day" or "night" cycle.*

When astronauts fly in space, there is a sunrise and sunset every 90 minutes (one each orbit). Considering that the Space Shuttle is flying at 17,000 miles per hour and that the astronauts need to control the Shuttle for landing and maintaining orbit, we can begin to understand why it is important that astronauts remain alert and focused. However, since the astronauts' circadian timing systems have no normal "days" or "nights" (Figure 95), the astronauts' rhythms must rely on the light schedule of the Space Shuttle and their internal clocks.

Things To Know

CIRCADIAN TIMING SYSTEM

The Circadian Timing System (CTS) contains a "clock" located within the hypothalamus of the brain. This "clock" helps to synchronize bodily functions with the external environment. Through its connections with the retina of the eye, it receives and monitors information about the external light/dark cycle. Based on this information, the clock organizes an animal's physiology, biochemistry, and behavior. The CTS ensures that the body's internal environment is appropriate for the tasks that the body has to perform. By coordinating the body's internal clock with sunrise and sunset, the body synchronizes the daily rhythms that help optimize the body for daily living.

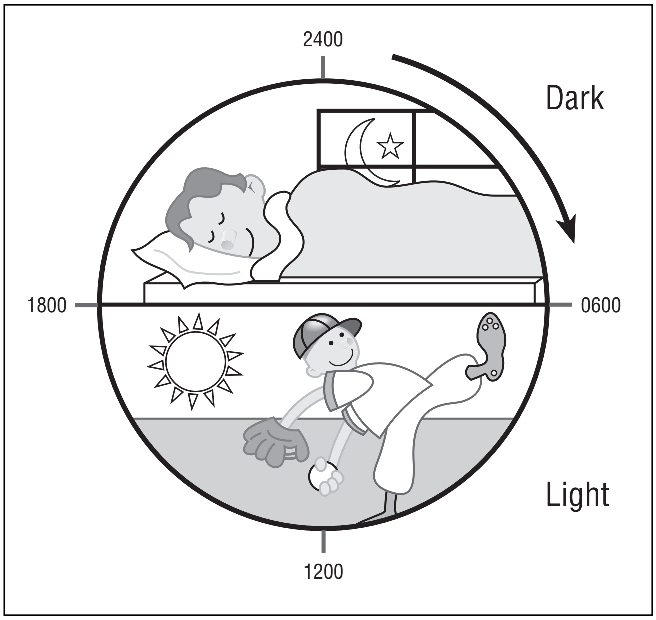

Figure 96 *Diagram illustrating the 24-hour light/dark cycle.*

Our circadian clocks tell our bodies when it is time to go to sleep and when it is time to wake (Figure 96). For example, in humans, our body temperatures rise before we awaken, remain high during the day when we are active, and drop as we sleep at night. People whose rhythms are not working properly may fall asleep at the wrong time, or may not be able to sleep when they should. This can be dangerous, since certain activities, such as driving, learning in school, working, or even playing, require us to be alert.

The CTS influences sleep and wakefulness through its connections with various brainstem nuclei. These nuclei use several neurotransmitters to determine the degree or level of sleep or wakefulness (alertness). This is accomplished through brainstem projections to the thalamus and cerebral cortex. In turn, the CTS modulates this neuronal circuitry to appropriately adjust the durations of sleep and wakefulness, as well as the levels of consciousness during the 24-hour light/dark cycle.

Experiments in which individuals have been deprived of environmental time clues (for example, the light of day) have shown that the body's daily cycles are driven by the CTS clock. For example, the subjects in these experiments continue to eat and sleep on a daily cycle, but the timing of that cycle is determined by the internal clock, which is close, but not equal to, the 24-hour day. Without the CTS or daily light/dark cues, individuals would generally wake up and go to sleep later each day. However, the length of time spent in sleep and/or wakefulness would remain relatively the same during a typical 24-hour cycle. The importance of proper CTS function is illustrated by the fact that conditions such as jet-lag, problems resulting from working night shifts, and some sleep and mental disorders are associated with dysfunction of the CTS.

During space missions, astronauts may have disrupted sleep and work schedules. This can produce physical symptoms, such as fatigue and general feelings of discomfort (malaise). This could affect the ability of crews to perform their tasks during a mission. The Neurolab Sleep and Circadian Rhythms Team examined nervous system regulation of sleep and wakefulness during the mission and examined how alterations in sleep patterns affected astronauts' abilities to carry out certain tasks in space.

The Neurolab experiments examined the physiology of the Circadian Timing System (CTS) and homeostatic control (equilibrium in the body with respect to various functions) of animals exposed to space flight. This data was compared to those of animals kept in similar environments on Earth. Some of the animals were exposed to a light-dark cycle and some were exposed to constant light. The constant light environment did not provide any time cues to the animals, allowing the scientists to examine the innate characteristics of these animals' CTS clocks.

SLEEP AND RESPIRATION

Scientists also believed that astronauts' sleep patterns and quality of sleep would be affected by other factors as well. For example, they hypothesized that, during sleep, the relationship between respiration and heart rate would change in microgravity. They also believed that, during sleep, there would be less oxygen in the arterial blood. Therefore, the astronauts would awaken more easily. The scientists also tested the hypothesis that, when the astronauts were awake, breathing responses to carbon dioxide and low oxygen (hypoxia) levels were increased in microgravity. They believed this would also disrupt sleep. The scientists expected to find that in microgravity, the chest and abdomen do not move in synchrony during sleep, thereby adding to sleep disruption.

LEARNING ACTIVITY I:
The Geophysical Light/Dark Cycle

OVERVIEW

Students will discover how the light/dark cycle is dictated by the rotation of Earth. In addition, they will examine the annual changes in the duration of light each day as the planet orbits the sun.

MAJOR CONCEPTS

- The light/dark cycle is accelerated for astronauts orbiting Earth.
- Changes in the light/dark cycle may lead to disruptions of sleep and other bodily cycles.

SCIENCE & MATHEMATICS SKILLS

Observing, communicating, modeling, drawing conclusions

PREPARATION TIME

None needed

CLASS TIME

50 minutes

MATERIALS

- Globe
- Flashlight
- Pencil

BACKGROUND

Astronauts do not experience the 24 hour light/dark cycle that is normal for Earth. Instead, while they are orbiting the planet, they experience sunrise and sunset every 90 minutes. Thus, their Circadian Timing Systems (CTS) cannot use external light cues to reset their internal clocks. In general, body functions that occur rhythmically every 24 hours are called circadian rhythms. The body's primary biological clock is the suprachiasmatic nucleus located in the hypothalamus. It regulates many of the body's internal, or endogenous (produced within the organism), rhythms.

The external light/dark cycle, in other words, the hours of daylight (diurnal cycle) and hours of darkness (nocturnal cycle), is particularly important in maintaining regularity of the CTS. The sleep/wake cycle is particularly susceptible to becoming disrupted by changes in external light-dark cues. The sleep/wake cycle is one of the endogenous rhythms of the body.

The CTS maintains coordination of the organism by monitoring the environment and resetting an internal clock to match the external environment. Disruptions in this process can affect alertness and performance. When astronauts fly in space, their CTSs have nothing (no normal "days" or "nights") by which to set themselves. Thus, the astronauts' rhythms must rely on the light schedule of the Space Shuttle and their internal clocks, which may also be altered by the absence of the force of gravity during space flight. This activity will help students understand the changes that occur in the light/dark cycle experienced by astronauts while they orbit Earth.

PROCEDURE

1. Have students mount a flashlight (Figure 97) so that it is stationary and directed at a globe.

2. Instruct students to rotate the globe slowly from west to east (or left to right) to mimic the daily rotation of Earth.

Figure 97 *Diagram of the geographical light/dark cycle.*

3. Direct students to change the angle of the tilt of Earth as it faces the sun. The students should observe how the tilt of Earth's axis alters where the sun shines upon the surface. Have them identify when a particular part of Earth is experiencing "day" and when it is experiencing "night."

4. Help students visualize the accelerated light/dark cycle that occurs during orbit by having one student rotate a pencil or other object around the globe as it continues to spin on its axis.

5. Discuss the implications of changes in the light/dark cycle for astronauts aboard an orbiting space craft.

Evaluation

REVIEW QUESTIONS

1. **What causes light/dark cycles on Earth?**
   The sun and the rotation of Earth.

2. **How do these cycles change for astronauts aboard a spacecraft in orbit?**
   The Shuttle orbits once every 90 minutes, which provides a "sunrise" and "sunset" every 90 minutes. (Of course, if the astronauts are not near a window, this is not seen.)

THINKING CRITICALLY

1. Ask students what happens if the Circadian Timing System is not working properly.
The sleep/wake cycle will be interrupted and other functions in the body will no longer be properly coordinated.

2. Ask students to think about what might happen to people whose rhythms are not working properly?
How might these problems affect certain types of jobs here on Earth?
They might become sleepy at inappropriate times (e.g., on the job); excessive tiredness; decrease in motor performance (e.g., driving, riding a bike, catching a ball), etc.

SKILL BUILDING

1. Have students construct a list of types of jobs that might cause problems with the Circadian Timing System, or that might work against the body's natural sleep/wake cycles.

2. Have students use the Internet or library resources to learn about recently discovered ways to reset the body's internal clock to reduce or eliminate jet lag. How is this related to problems experienced by astronauts?

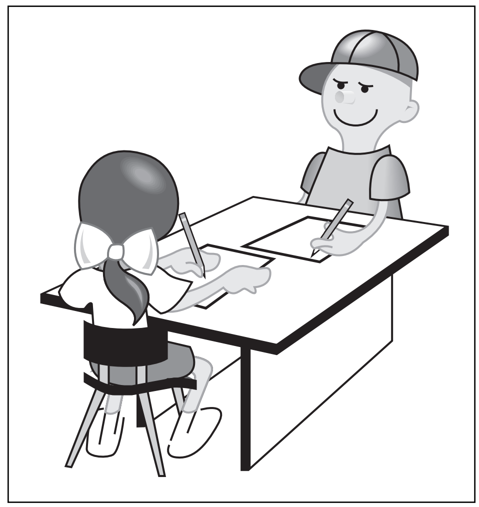

Figure 98 *Diagram of students constructing job lists.*

LEARNING ACTIVITY II:
How Quick Are Your Responses?

OVERVIEW

In this activity, students will learn what reaction time is and how it is measured.

SCIENCE & MATHEMATICS SKILLS

Observing, collecting and recording quantitative data, calculating averages, drawing conclusions

PREPARATION TIME

10 minutes

CLASS TIME

50 minutes for each of two parts

MATERIALS

Each group of students will need:

- Ruler
- Scissors
- Pen or pencil
- Meter stick
- Note pad

MAJOR CONCEPTS

- Reaction time can vary even for the same individual.
- When subjects are tired, reaction time can be slower.

BACKGROUND

When the sleep/wake cycle is disrupted, people can become fatigued and may not perform as well as they usually do in a variety of situations. This activity will allow students to learn about reaction time (the time interval between the presentation of a stimulus and the body's voluntary reaction to that stimulus) and how reaction time might be affected by lack of sleep.

A Reaction Time Test will be used as a means of determining the time it takes to react or respond to a given/presented stimulus. Usually, such tests are performed multiple times to account for the normal range of variation in measurements. In Neurolab, a computerized test determined astronauts' reaction times accurately. The corresponding test to be used on Earth depends on gravity and will not work in the weightless environment of space.

Reaction times can vary even for the same individual, because when subjects are tired, reaction times can be longer. This lesson focuses on the normal range of reaction time, how it is measured, and how it varies with alertness level.

PROCEDURE

Part One: Learning to Measure Reaction Times

Have students work in pairs to do the following activity:

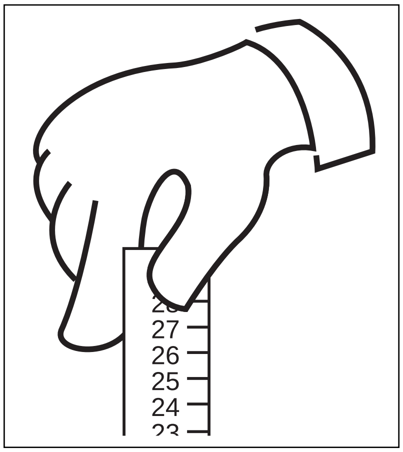

Figure 99 *Diagram of the forefinger and thumb position.*

1. Before beginning, have each student assess, on a scale of one to ten, how sleepy they are—with "1" being not at all sleepy, "5" being somewhat sleepy and "10" being ready to fall asleep instantly.
2. Within each team, have one student hold a ruler with centimeters (between the thumb and forefinger) vertically at the 30 cm mark with the 0 mark toward the floor (Figure 99).
3. Instruct the student's partner to position his/her forefinger and thumb at the 0 cm end of the ruler without touching it, so that he/she will be able to grab the ruler easily by closing his/her finger and thumb together (Figure 99).
4. Tell the partner to observe the ruler carefully and then have the first student release the ruler.
5. Direct the partner to close his/her thumb onto the ruler to stop it as soon as the ruler moves.
6. Have the student mark the place where the partner's fingers were when he/she stopped the ruler. The student should discard the first result if the ruler moved less than five centimeters.
7. Have the students repeat the release/catch process 20 times and record and average the results on a chart (Figure 100).
8. Have the students change places so that all will have an opportunity to do this activity.
9. As a class, plot the average values of each student's reaction times as a histogram, as shown in Figure 101. Have students think about what really is being measured in the activity, and how distance in centimeters reflects reaction times.
10. Have students calculate the average value of their reaction times and the average value of their sleepiness scores. To do so, add the values together and divide the sum by the number of values.
11. Ask the students to identify the normal range of reaction times in their class population. Example: If sleepiness score is a "3" and the average reaction time is ___, add 3 + ___ and divide the sum by ___ (number

Reaction Times

Release #	Result
1	______
2	______
3	______
4	______
5	______
6	______
7	______
8	______
9	______
10	______
11	______
12	______
13	______
14	______
15	______
16	______
17	______
18	______
19	______
20	______
Average	______

Figure 100 *Example of chart for recording reaction times.*

of values.) Discuss reaction time variance and alertness level. Ask the students about the times when distances less than 5 cm occurred during the trials. Why was it important to discard these results?

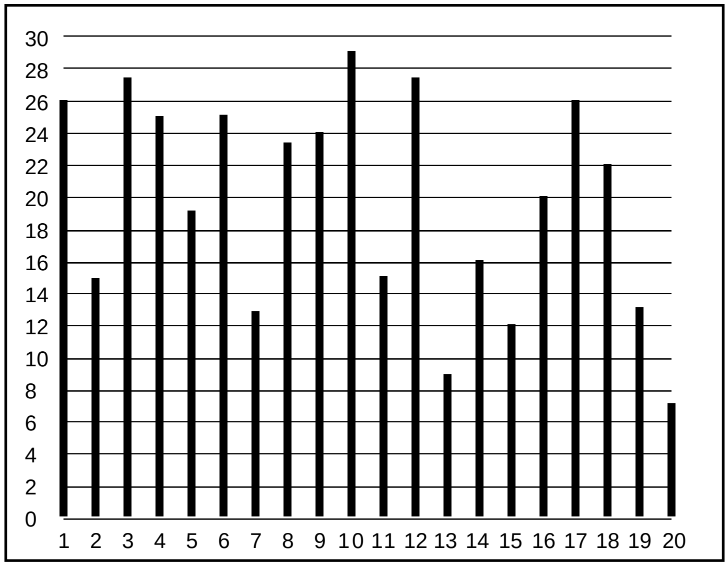

Figure 101 *Example of histogram of the values of students' reaction times.*

Part Two: The Effects of Being Tired on Reaction Times

This exercise is designed to test the students' reaction times after they are feeling tired. Have students follow the steps below in order to obtain accurate results.

1. Have each student take a ruler home.

2. Inform students that they will need to ask someone at home to help them with this activity, and suggest that the students perform this activity on a Friday or Saturday night so as not to disrupt their weekly routines.

3. Have students ask their parent(s)/guardian(s) for permission to stay up one or two hours beyond their normal bed time. (Remind the students that their partners also will have to stay up.)

4. Instruct students to perform 20 trials of reaction times tests before they go to bed. Inform them that they must be feeling tired and ready to go to bed before doing this exercise. (Ask students to evaluate how sleepy they feel using the same scale as in the previous activity.)

5. Direct the students to repeat the activity after they have each had a good night's sleep. (Again, ask them to evaluate how sleepy they feel using the same scale as in the previous activity.)

6. Have students calculate their average reaction times during each trial (night and morning).

7. Compile another set of class averages and a histogram (Figure 101) as before. Have students discuss the results. Have them think about and discuss the physical and mental symptoms of being tired and how these might have affected their reaction times.

Evaluation

Students should now have some understanding of how lack of sleep or fatigue can influence their abilities to respond quickly.

REVIEW QUESTIONS

1. **What happens to reaction time when one is sleepy or tired?**
   Reaction time is slower.

2. **What are physical signs of being tired?**
   What are mental signs of being tired?
   One physical sign of being tired is inaccurate motor coordination.
   A mental sign of being tired is lack of concentration.

THINKING CRITICALLY

1. Ask the students whether or not the sleepiness scores were greater just before going to bed or in the morning.

2. Ask the students whether or not reaction times were longer in their tests performed just before going to sleep or in their tests done in the morning at school.

3. **Discuss with the students what would happen if one was not allowed to sleep for the whole night, and then performed the reaction time test. (Make sure students understand they should NOT do this!)**
   The reaction time would become slower if there were no sleep during the whole night.

SKILL BUILDING

1. Have students conduct a survey of family and friends by asking them to report their sleepiness scores throughout a 24-hour cycle. Are any general trends obvious among all persons surveyed. When are most people alert? When are most people sleepy? How could this information be used to design job or school schedules?

LEARNING ACTIVITY III:
Measuring Your Breathing Frequency at Rest

OVERVIEW Students will learn to measure their resting breathing rates.

SCIENCE & MATHEMATICS SKILLS Observing, collecting and recording quantitative data, charting data, drawing conclusions

PREPARATION TIME None needed

CLASS TIME 50 minutes

MATERIALS *Each team of students will need:*

- Watch or access to a clock with a second hand
- Chair
- Pen or pencil
- Note pad

MAJOR CONCEPTS

- Breathing rate is controlled by the interaction of special pacemaker cells in the brain.
- Breathing frequencies are different for each person.

BACKGROUND Breathing involves the movement of air in and out of the lungs. This facilitates the exchange of O_2 (oxygen) and CO_2 (carbon dioxide) between the blood and the external environment, a process known as **respiration**. The levels of O_2 and CO_2 are tightly regulated and help to determine the rate of breathing frequency. Changes in the control of breathing can lead to altered levels of O_2 and CO_2 in the blood. During space flight, the respiratory patterns and motions of the chest and abdominal wall are altered. Neurolab scientists used an array of measurements to correlate the changes in respiratory patterns and oxygen levels in the blood that occur during sleep and with sleep disturbances.

The number of breaths taken per minute is referred to as breathing frequency or respiratory rate. In a resting person, the average is around 15 breaths per minute, although there are large variations from person to person. Breathing frequency is usually altered while exercising or doing other activities in order to provide the body's cells and tissues with a continuous and adequate oxygen supply. The name given to the amount of air that is inhaled or exhaled in a single normal breath is "tidal volume," because breathing occurs cyclically—"in" then "out," "in" then "out"—rather like the tides in the ocean.

Special receptor cells (ventilatory chemoreceptors) near major blood vessels and on the ventral surface of the brainstem (medulla oblongata) are designed to detect levels of oxygen or carbon dioxide in the blood (often referred to as “blood gases”) and cerebrospinal fluid (CSF), respectively. These receptors utilize neuronal pathways to send messages to other centers in the brain which adjust ventilation according to the levels of blood gases detected. Scientists now believe that the microgravity environment in space affects the regulation of ventilation and that this may also affect sleep cycles in space.

Oxygen is essential for many processes within the body, especially cellular respiration. The air we breathe contains about 21% oxygen and 0.05% carbon dioxide. Carbon dioxide is produced as waste during cellular respiration and must be released out of the body through the lungs. Exhaled gas normally contains about 5% carbon dioxide. Both oxygen and carbon dioxide combine with components of the blood in reversible biochemical reactions.

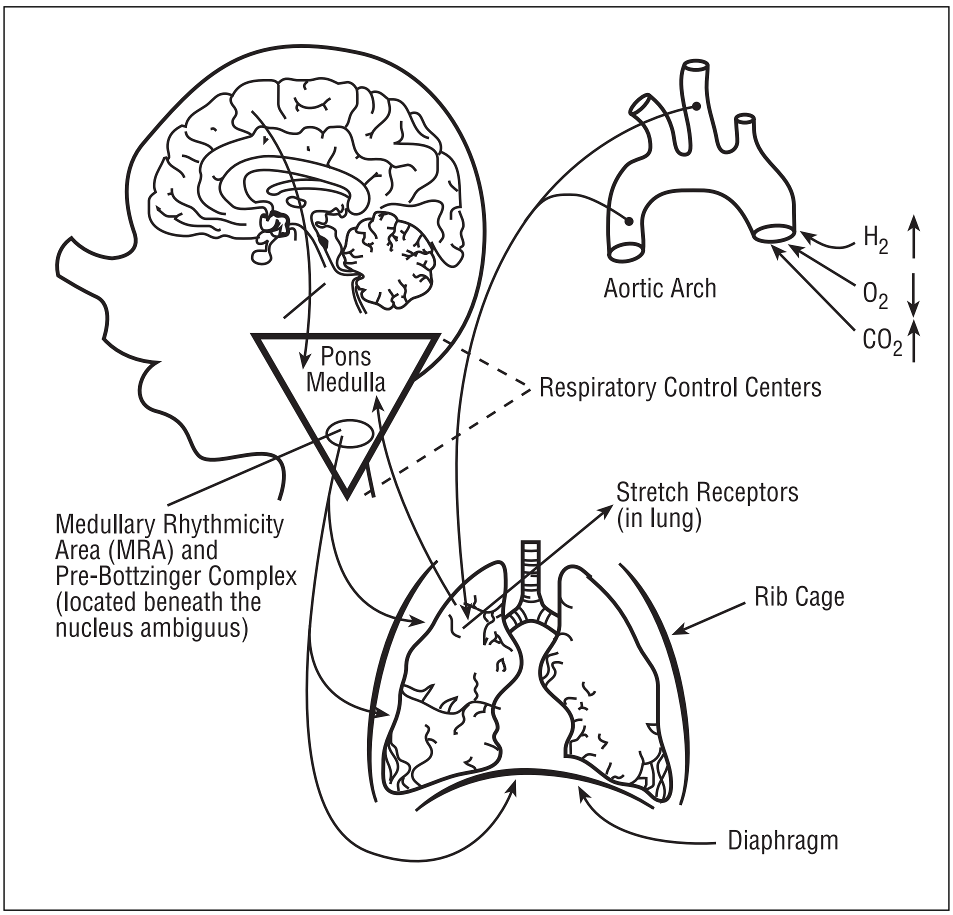

Figure 102 *Diagram of the centers in the brain.*

Centers in the brain (Figure 102) control breathing rate. Although there are several respiratory control regions in the nervous system, two main sites are primarily responsible for regulating breathing and the supply of oxygen to the lungs as well as the rest of the body. One site is the ventral surface of the medulla in the brainstem. This site detects only pH or carbon dioxide levels in the blood. The other main site is the carotid bodies, found in the neck. These sites are sensitive to carbon dioxide, oxygen and pH, although their principle purpose is to detect low blood oxygen levels. These receptors are known as chemoreceptors because they sense and respond to specific dissolved chemicals in plasma. These ventilatory chemoreceptors send signals to the nervous system whenever blood gases deviate from the desired set point (e.g., low oxygen or high carbon dioxide).

PROCEDURE

1. Have students work in pairs. Direct one student of each pair to sit quietly with his/her eyes closed.

2. Instruct the partner to observe the student's breathing carefully by watching the rise and fall of the chest, counting the number of complete breaths that the student makes over the course of one minute using the watch or clock. Have the partner record the number of breaths per minute.

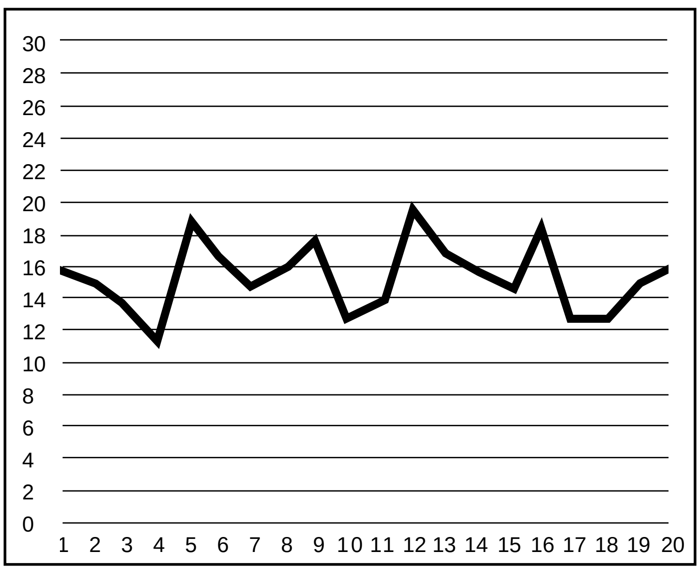

Figure 103 *Example of a line chart used to plot values of students' breathing frequencies.*

3. Direct the students to change places with their partners, so all students can find their breathing rate at rest.

4. Have the class plot the values of breathing frequencies as a line chart. It should look something like the diagram in Figure 103. Have the students calculate the mean (average) value or breathing frequency for the entire class.

5. To calculate a mean value, add the values together and divide the sum by the number of values.

6. Discuss the results with the class. Have students identify the range of breathing frequencies in the class.

Evaluation

REVIEW QUESTIONS

1. **What is breathing rate?**
   Number of breaths per minute.

2. **What regulates breathing rate?**
   A large number of things contribute—the blood levels of CO_2, O_2, limb motion, e.g., running. The main influence is blood CO_2.

THINKING CRITICALLY

1. Is the class mean (average) resting breathing rate close to 15 breaths per minute? Why do most people have similar resting breathing rates?

2. The results farthest from the mean should be considered. Is this normal? (The answer is probably "yes," because there is some range in breathing frequencies in any given population.)

SKILL BUILDING

1. Survey the class about exercise habits and physical activities. Are students able to detect any relationship between physical activity and resting breathing rate?

2. Have students use resources on the Internet and in the library to investigate the effects of certain respiratory disorders on breathing rate and ventilation in general.

LEARNING ACTIVITY IV:
How Long Can You Hold Your Breath?

OVERVIEW

Students will learn how reduced carbon dioxide levels in the blood lower the need to breathe by comparing breathing rates before and after hyperventilation.

SCIENCE & MATHEMATICS SKILLS

Observing, collecting and recording quantitative data, drawing conclusions

PREPARATION TIME

None needed

CLASS TIME

50 minutes

MATERIALS

Each team of students will need:

- Pen or pencil
- Watch or access to a clock with second hand
- Chair
- Note pad

MAJOR CONCEPTS

- The brain acts as a central collection agent of information about breathing from carbon dioxide sensors, the oxygen sensor, mechanical sensors of breathing movements, and the cerebral cortex.
- Amounts of carbon dioxide in the blood affect breathing.

BACKGROUND

Carbon dioxide, produced from cellular respiration, is carried in the blood in three main forms:

1. dissolved as CO_2 (5%)
2. bicarbonate ions (HCO_3) (75%)
3. bound to hemoglobin and other blood proteins (Carbamino compounds) (20%)

Carbon dioxide levels are monitored by cells on the ventral medulla in the brainstem and by the carotid bodies in the neck, which respond to changes in CO_2 levels and pH levels. Unlike the brainstem, the carotid bodies also respond to plasma O_2 levels.

A raising of the arterial blood carbon dioxide levels above normal is called **hypercapnia**. Hypercapnia can result from insufficient ventilation to clear carbon dioxide from the lungs. This might occur with a lung disease that impairs carbon dioxide removal from the blood, even when ventilation is adequate. In general, increases in blood carbon dioxide levels lead to increases in ventilation. Conversely, hyperventilation (rapid shallow breathing) may drastically lower carbon dioxide levels in blood and will trigger a slowdown in ventilation.

Oxygen levels also affect ventilation. Hypoxia results from insufficient fresh air reaching the lungs, the blood, and tissues.

The Neurolab team investigated the changes that space conditions cause in ventilation and the regulation of blood gases. Under microgravity conditions, changes in cerebral blood flow may affect the chemoreceptors in the brain. Sleep may be affected because ventilation, or lack of ventilation, is a powerful wakening stimulus. If there are alterations in the control of ventilation in weightlessness, then these may contribute significantly to the poor quality of sleep that Shuttle crews sometime experience.

PROCEDURE

Note to teacher: *encourage the students not to cheat by changing their normal breathing patterns before starting this activity. Students with respiratory ailments, such as asthma or allergies, should not participate in the breath-holding part of this activity.*

1. Have students conduct this activity in pairs: one student will be the "subject," and the other will be the "observer." Make sure that the observer has a pen and a watch with a second hand.

2. Have the subject student sit quietly (no talking or moving) in a chair.

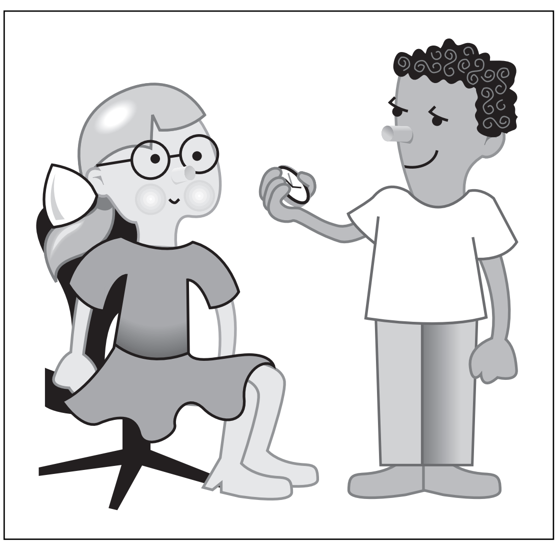

Figure 104 *Diagram of student recording how long student can hold her breath.*

3. Instruct each subject to inhale normally, then tell him/her to stop breathing and signal the observing student by raising his/her finger.
   The observer should note the starting time.

4. Each subject should hold his or her breath as long as he/she possibly can (Figure 104). Tell each student to force himself or herself to continue holding his/her breath even if he/she feels like he/she has to breathe.

5. Instruct each observer to record how long his/her subjects held their breaths.

6. Ask the subject to take a short rest, then to breathe rapidly and deeply for 30 seconds (this is called hyperventilation). Immediately after hyperventilating and at the end of an expiration (outward breath), have each subject hold his/her breath, and signal the observing student as before.

7. Again, instruct the subject to hold his/her breath as long as possible.

8. Have the observer record how long the subject held his/her breath.

9. Have the students switch roles, so that each student has an opportunity to do the activity.

10. Have the members of the class compare the breath-holding times with and without prior hyperventilation.

11. Check to see if there is any difference. Hyperventilation reduces the level of carbon dioxide in the lungs by blowing it off. The resultant reduction in blood carbon dioxide lowers the need to breathe.

12. Ask your students if, at the point they thought they really had to breathe, they could talk themselves out of it, even if only for a few seconds. (There is a strong voluntary component to ventilation.)

13. Have your students compare the individual results of breathing frequency from Activity One and breath-holding time for this activity. Is there a correlation? Although it may be hard to see, in general, people with a lower response to inhaled carbon dioxide can hold their breath for a longer period of time than those with a higher response.

14. Ask the students to describe what finally forced them to breathe. (The answer is, their brain.) The brain acts as a central collection agent of information from a lot of places—carbon dioxide sensors, the oxygen sensor, mechanical receptors that sense the absence of breathing movements, and the cerebral cortex. The complex interaction of all these inputs will finally make the students react by breathing.

Evaluation

REVIEW QUESTIONS

1. **What limits how long one can hold his/her breath?**
   Many things—CO_2, O_2, pulmonary stretch receptors, voluntary control. CO_2 is the most important in normal people.

2. **Where are carbon dioxide levels detected in the body?**
   They are located on the ventral surface of the medulla—the base of the brain (Figure 105).

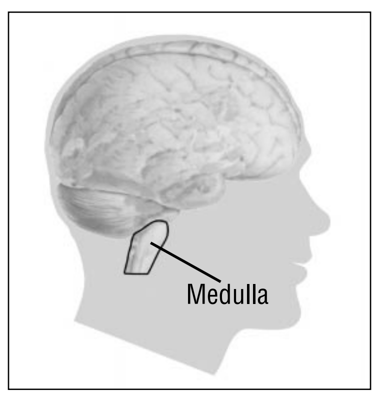

Figure 105 *Diagram of the location of the medulla.*

3. **How can levels of carbon dioxide in the body be changed by breathing patterns?**
If you breathe less, CO_2 increases, if you breathe more, CO_2 decreases. Exercise produces more CO_2, which means we must breathe more to eliminate it.

THINKING CRITICALLY

1. **What factors, other than high carbon dioxide, might cause breathlessness?**
Low levels of oxygen, or hypoxia. If you have skied at high altitudes, you may have experienced this. The factors that contribute to increased breathing during exercise are many, complex, and still not completely understood. Nevertheless, we have all experienced the sensation of being short of breath and of breathing more when we exercise.

2. **Why might the control of ventilation change in weightlessness?**
The major reasons are: (1) changes in cerebral blood flow alters the central CO_2 response; and (2) changes in carotid chemoreceptor responses in the neck that senses O_2. (Evidence suggests reason #2 may be more important in weightlessness.)

3. **What effect might the change in the control of ventilation have on sleep in weightlessness?**
It may alter the "sleep architecture," which will increase arousals (awakenings) and reduce the quality of sleep.

SKILL BUILDING

1. **What represents the fizz in bottled or canned soda (Figure 106)? Why can't we see the bubbles unless the bottle or can is opened?**
CO_2. Under pressure, the CO_2 remains dissolved in the soda liquid. The reduction in pressure brings it out of the solution.

Use resources on the Internet or in the library to learn more about the relationship between pressure and dissolved gases.

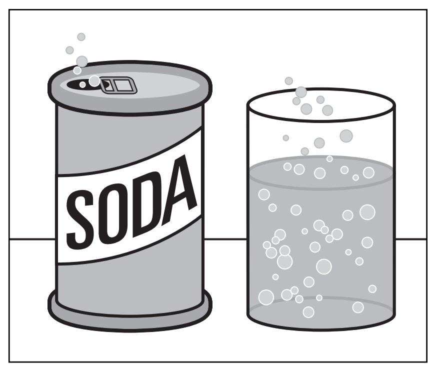

Figure 106 *Diagram of carbonated soft drinks.*

LEARNING ACTIVITY V:
Raising the Level of Carbon Dioxide in Your Blood

OVERVIEW

In this activity, students will learn about the effects of increased carbon dioxide in the bloodstream.

SCIENCE & MATHEMATICS SKILLS

Observing, collecting and recording quantitative data, drawing conclusions

PREPARATION TIME

None needed

CLASS TIME

50 minutes

MATERIALS

Each team of students will need:

- Large paper bag
- Pen or pencil
- Watch or access to a clock with a second hand
- Note pad
- Chair

BACKGROUND

When carbon dioxide levels increase in arterial blood, receptors in the medulla within the brainstem trigger an increase in breathing frequency. In this activity, blood carbon dioxide levels are increased by having students cover their mouths and noses with a paper bag as they breathe. Within the bag carbon dioxide levels will increase because of the higher concentration of carbon dioxide in exhaled air. Because the carbon-dioxide rich air is "rebreathed," it leads to increases in the carbon dioxide in arterial blood or hypercapnia.

PROCEDURE

1. Have students work in pairs to conduct this activity.

   Note to teacher: *Some students may find this exercise uncomfortable. Students with respiratory ailments should not participate as subjects). As in previous activity, one student within each pair should be the "subject," and the other should be the "observer."*

MAJOR CONCEPTS

- Breathing can be involuntarily modified by raising the level of carbon dioxide in the blood.
- Increasing the CO_2 in the blood will stimulate ventilation.
- Unlike some other rhythms in the body, breathing can readily be modified by will. One can, given some thought, breathe more slowly and with larger breaths. If a person is distracted, however, breathing will return to his/her personal "normal" frequency.

2. Within each team, have the student "subject" sit quietly (no talking or moving). Have the observing student count the number of breaths taken by the subject over each 15-second segment of a two minute total time period and record the results.

3. After two minutes, have each subject place a paper bag over his/her nose and mouth, and continue to breathe in and out, as in the diagram in Figure 107.

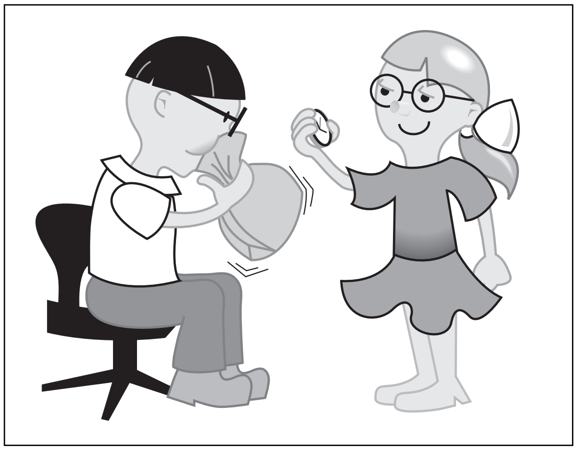

Figure 107 *Diagram of student breathing in and out of paper bag.*

4. Tell the subject to try to keep a good seal against the face and nose to ensure that only air from within the bag is breathed. Encourage the subject to relax as much as possible and breathe normally.

5. Direct each observing student to watch the bag and write down the number of breaths taken by the subject every 15 seconds. The observing student should record the number of breaths for two minutes or until the subject removes the bag (if students feel faint they should remove the bag and breathe normally).

6. After the subject removes the bag, have the observing student ask the subject to rate how breathless he/she feels on a scale of one to ten. (One is "not breathless at all," five is "moderately breathless" and ten is "as short of breath as one could possibly be.") The observing student should record this data.

7. Have the students exchange places and repeat the activity.

Evaluation

REVIEW QUESTIONS

1. **What type of breathing response occurs when blood levels of carbon dioxide occur?**
   Breathing frequency and tidal volume (size of breaths) increase and total ventilation increases.

2. **Where are the changes in arterial blood concentrations of carbon dioxide detected?**
   On the ventral surface of the medulla in the base of the brain. This is termed a "central" response.

THINKING CRITICALLY

1. **Why did breathing frequency increase when the mouth and nose were covered with the paper bag?**
   As carbon dioxide began to build up in the bag, this "re-breathing experiment" served to increase the carbon dioxide in the arterial blood. This condition of hypercapnia stimulates the central ventilatory chemoreceptor in the ventral medulla, causing an increased breathing frequency.

2. **What happened to the tidal volume over the course of the re-breathing experiment?**
   An increase in both breathing frequency and tidal volume results in a large increase in total ventilation.

3. **What might happen to a person if the levels of arterial carbon dioxide increased while they were sleeping?**
   Breathing might increase and they could be awaken.

SKILL BUILDING

1. Have students pool their observations and create a class chart of breathing rates.