THE SCIENCE OF SLEEP AND DAILY RHYTHMS

Living Clocks

by

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TEAMING WITH BENEFITS

by **Jeffrey P. Sutton, M.D., Ph.D.**, Director, National Space Biomedical Research Institute (NSBRI)

Dr. Jeffrey P. Sutton

Space is a challenging environment for the human body. With long-duration missions, the physical and psychological stresses and risks to astronauts are significant. Finding answers to these health concerns is at the heart of the National Space Biomedical Research Institute's program. In turn, the Institute's research is helping to enhance medical care on Earth.

The NSBRI, a unique partnership between NASA and the academic and industrial communities, is advancing biomedical research with the goal of ensuring a safe and productive long-term human presence in space. By developing new approaches and countermeasures to prevent, minimize and reverse critical risks to health, the Institute plays an essential, enabling role for NASA. The NSBRI bridges the research, technological and clinical expertise of the biomedical community with the scientific, engineering and operational expertise of NASA.

With nearly 60 science, technology and education projects, the NSBRI engages investigators at leading institutions across the nation to conduct goal-directed, peer-reviewed research in a team approach. Key working relationships have been established with end users, including astronauts and flight surgeons at Johnson Space Center, NASA scientists and engineers, other federal agencies, industry and international partners. The value of these collaborations and revolutionary research advances that result from them is enormous and unprecedented, with substantial benefits for both the space program and the American people.

Through our strategic plan, the NSBRI takes a leadership role in countermeasure development and space life sciences education. The results-oriented research and development program is integrated and implemented using focused teams, with scientific and management directives that are innovative and dynamic. An active Board of Directors, External Advisory Council, Board of Scientific Counselors, User Panel, Industry Forum and academic Consortium help guide the Institute in achieving its goals and objectives.

It will become necessary to perform more investigations in the unique environment of space. The vision of using extended exposure to microgravity as a laboratory for discovery and exploration builds upon the legacy of NASA and our quest to push the frontier of human understanding about nature and ourselves.

The NSBRI is maturing in an era of unparalleled scientific and technological advancement and opportunity. We are excited by the challenges confronting us, and by our collective ability to enhance human health and well-being in space, and on Earth.

NSBRI RESEARCH AREAS

CARDIOVASCULAR PROBLEMS
The amount of blood in the body is reduced when astronauts are in microgravity. The heart grows smaller and weaker, which makes astronauts feel dizzy and weak when they return to Earth. Heart failure and diabetes, experienced by many people on Earth, lead to similar problems.

HUMAN FACTORS AND PERFORMANCE
Many factors can impact an astronaut's ability to work well in space or on the lunar surface. NSBRI is studying ways to improve daily living and keep crewmembers healthy, productive and safe during exploration missions. Efforts focus on reducing performance errors, improving nutrition, examining ways to improve sleep and scheduling of work shifts, and studying how specific types of lighting in the craft and habitat can improve alertness and performance.

MUSCLE AND BONE LOSS
When muscles and bones do not have to work against gravity, they weaken and begin to waste away. Special exercises and other strategies to help astronauts' bones and muscles stay strong in space also may help older and bedridden people, who experience similar problems on Earth, as well as people whose work requires intense physical exertion, like firefighters and construction workers.

NEUROBEHAVIORAL AND STRESS FACTORS
To ensure astronaut readiness for space flight, preflight prevention programs are being developed to avoid as many risks as possible to individual and group behavioral health during flight and post flight. People on Earth can benefit from relevant assessment tests, monitoring and intervention.

RADIATION EFFECTS AND CANCER
Exploration missions will expose astronauts to greater levels and more varied types of radiation. Radiation exposure can lead to many health problems, including acute effects such as nausea, vomiting, fatigue, skin injury and changes to white blood cell counts and the immune system. Longer-term effects include damage to the eyes, gastrointestinal system, lungs and central nervous system, and increased cancer risk. Learning how to keep astronauts safe from radiation may improve cancer treatments for people on Earth.

SENSORIMOTOR AND BALANCE ISSUES
During their first days in space, astronauts can become dizzy and nauseous. Eventually they adjust, but once they return to Earth, they have a hard time walking and standing upright. Finding ways to counteract these effects could benefit millions of Americans with balance disorders.

SMART MEDICAL SYSTEMS AND TECHNOLOGY
Since astronauts on long-duration missions will not be able to return quickly to Earth, new methods of remote medical diagnosis and treatment are necessary. These systems must be small, low-power, noninvasive and versatile. Portable medical care systems that monitor, diagnose and treat major illness and trauma during flight will have immediate benefits to medical care on Earth.

For current, in-depth information on NSBRI's cutting-edge research and innovative technologies, visit www.nsbri.org.

OVERVIEW

Students observe that some behaviors and functions of living organisms vary predictably every 24 hours. Many regular functions are governed by internal "clocks," which run independently but are cued or reset by the environment.

ACTIVITY

Living Clocks

Most living things behave predictably in cycles of about 24 hours, the period required for Earth to complete one full rotation. These cycles are called circadian, from the Latin words for "about" (*circa*) and "day" (*dies*). In this activity, students will explore circadian patterns in humans, animals and plants.

There are many familiar circadian rhythms in nature. Well-known examples include the flowering of morning glories at dawn and the nighttime hunting routines of owls. These behaviors are governed by internal mechanisms, often called "biological clocks," within the cells of living organisms. Biological clocks that run on a 24-hour cycle also are known as "circadian clocks."

SCIENCE EDUCATION CONTENT STANDARDS*
GRADES 6-12

LIFE SCIENCE

- Regulation of an organism's internal environment involves sensing the internal environment and changing physiological activities to keep conditions within the range required to survive.
- Behavior is one kind of response an organism can make to an internal or environmental stimulus.

EARTH AND SPACE SCIENCE

- Most objects in the solar system are in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the moon and eclipses.

SCIENCE, HEALTH & MATH SKILLS

- Measuring
- Observing
- Drawing conclusions

* National Research Council. 1996. National Science Education Standards. Washington, D.C., National Academies Press.

The circadian timing system is complex and operates throughout the body. In fact, circadian clocks are part of our genetic code, and they govern virtually all functions of the human body. Examples include alertness, waking and sleeping, body temperature (lower in the morning just after waking, and higher in the afternoon), physical performance and hand/eye coordination, secretion of some hormones, and urine production. These cycles occur regularly over intervals of approximately 24 hours. Without cues from the environment, the human circadian clock eventually drifts into a cycle that is slightly longer than 24 hours.

TIME

Several 30-minute sessions, depending on the options selected

MATERIALS

Materials required for each student group will vary, depending on the investigation(s) being conducted.

Each group will need:

Body Temperature Investigation

- Digital thermometer with several sterile covers (and access to a fever thermometers at home)
- Copy of student sheet

Bean Leaf Investigation

- Source of natural sunlight, or fluorescent "grow light" with timer
- 4 bean plants per group (purchase or grow in small pots from seed)

Continued

Discovery: Biological Clocks

In 1729, French scientist, Jean-Jacques de Mairan, was the first to notice that daily movements of certain plants' leaves continued even when the plants were kept in constant dim light. Other plant activities that occur at specific times of day include the opening of flowers, the release of fragrances, and the opening and closing of pores in the leaves.

The Tiniest Clocks

A group of nerve cells, which acts as a biological clock, was first identified in the brains of house sparrows. Biological clocks now have been identified in vertebrates, such as mammals, reptiles and some amphibians—and even invertebrates, such as fruit flies, cockroaches, crickets and mollusks. "Clocks" also have been found in single-celled organisms, including mold and bacteria.

Animal Behavior Investigation

- Study animals that can be observed in the classroom throughout the day (gerbils, birds, crickets, etc.)
- Science journal or graph paper

Alertness, Heart Rate (or other student selected investigation)

- Stopwatch or timer (if necessary)
- Science journal or graph paper
- Other materials as needed

BODY CLOCK INVESTIGATIONS

BODY TEMPERATURE INVESTIGATION

Have students measure their body temperature at three different times per day and repeat the process over three days. Times should be selected in advance and temperatures taken at the same time each day. Suggested times: immediately after waking in the morning, eight hours after waking (about 2:00 p.m.), and just before going to bed in the evening. Measurements should be recorded as degrees F, and should be made no less than 15 minutes after students eat, drink or brush their teeth. Have each student calculate and graph the average temperature of his or her group for each time of day (see p. 20).

Note: For class, use a digital thermometer and provide a sterile cover for each student.

What students will observe: Body temperature can be as much as one to two degrees lower in the very early morning than in the mid to late afternoon. This pattern is relatively consistent across individuals. Depending on levels of activity during the day, and the particular activities undertaken, student results may vary. Results also will be affected by the specific times at which temperature is measured.

ANIMAL BEHAVIOR INVESTIGATION

If you have a hamster or gerbil with an exercise wheel in your classroom, your students can observe and record the times of day when the rodent is active. Or, have students observe and record the daily behaviors of other classroom animals, such as fish, crickets (will chirp at approximately the same time each day) or birds. Students should record eating, resting and active times over several days to determine if the animals' activities follow a predictable pattern. The best results will be obtained if student observations do not disturb the animal subjects, and if the animals are exposed to a consistent cycle of light and darkness each day.

What students will observe: Animals may show a variety of predictable behaviors. For example, most animals are active at certain times of the day and more inclined to rest at others; birds and crickets will sing or chirp at similar times each day; and most animals tend to feed at particular times of the day.

BEAN LEAF INVESTIGATION

Grow young bean plants from seed, or purchase them from a greenhouse. Before using plants grown from seed, be sure they have at least two leaves in addition to the cotyledons (fleshy seed leaves). Place the plants in a sunny window or a growth chamber with a light timer. Have students note the orientation of the larger leaves as early as possible in the morning and again later in the afternoon. In particular, students should notice whether the leaves are extended outward or folded downward toward the stem. Have students repeat their observations over several days. Then, place the plants in a darkened corner of the room or cupboard, and have students observe and record the position of the leaves at the same times as before.

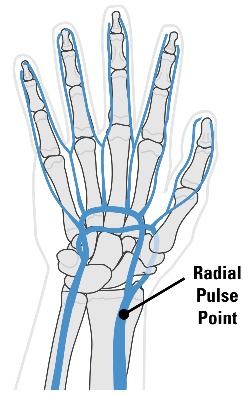
What students will observe: Leaves will be dropped toward the stem very early in the day and fully extended (horizontal) later in the day, whether the plants are exposed to the sun or artificial light. These patterns will continue when the plants are kept in the dark (see "Bean Leaf Movement," sidebar, right).

Note. Students may notice that their plants' stems curve toward the source of light. This movement is governed by chemicals inside the plant that cause cells on the side away from the light to lengthen more than cells on the side facing the light. This phenomenon is different from daily leaf movements, because it produces a permanent change in the shape of the stems.

ALERTNESS, HEART RATE (OR OTHER STUDENT SELECTED INVESTIGATION)

Many physical activities and abilities—among humans and non-human organisms—vary predictably by time of day. For example, students may choose to observe and chart whether they feel alert (wide-awake; fully aware and attentive) or drowsy (sleepy) on an hourly basis over the course of several days; measure and record their resting heart rate at different times of day (see "Radial Pulse Point," sidebar, upper right); or observe their "brain power" by timing how long it takes to mentally add columns of 50 single-digit numbers at different times of day.

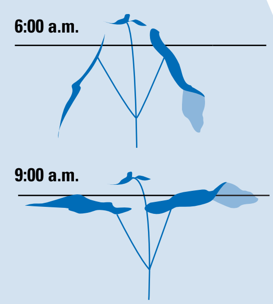
Radial Pulse Point



The safest and most common site to check pulse is on the thumb-side of the wrist (radial pulse).* Use the middle finger and ring finger together to apply slight pressure at the location shown above.

* Pulse site recommended for the general public by the National Heart, Lung, and Blood Institute, National Institutes of Health.

Bean Leaf Movement



Circadian Advantage

Because many variables related to athletic performance—respiration, heart rate, strength, flexibility and reaction time—peak late in the day, some coaches have concluded that well-trained athletes may derive a "circadian advantage" from competing at certain times of day.

Resetting the Clock

Bright light, particularly blue enriched light, can help to set the human body's internal clock. This spectrum of light is used to help regulate the sleep schedules of astronauts in space, and to aid people on Earth who have insomnia.

External Triggers

Natural changes in day length require animals' circadian clocks to "reprogram" themselves over the course of the year, to stay in sync with the external environment.

Cycle Length

Some cycles in living organisms are longer or shorter than 24 hours. Longer cycles include monthly hormone fluctuations in humans, once-yearly flowering periods of many plants, and the multi-year dormancy of insects known as cicadas. Shorter cycles include the cardiac cycle (heartbeat) and the internal stages of sleep (sleep cycle).

SAFETY

Follow proper care guidelines for any animals in the classroom.[1] Always follow district and school laboratory safety procedures. It is a good idea for students to wash their hands with soap and water before and after any science activity.

SETUP & MANAGEMENT

Read "Body Clock Investigations." Students should work in groups of 2–4. Conduct discussions as a class.

PROCEDURE

1. To prompt students' thinking about daily rhythms in themselves and other organisms, ask, *What are some animal behaviors that follow the same pattern every day?* (Rooster crowing, birds singing in the morning, bats coming out at night, etc.) *Are you more alert or sleepy at certain times each day? Have you observed flowers that are open only in the morning?*
2. Discuss as a class how behaviors of living organisms are tied to the 24-hour cycle of night and day on Earth.
3. Tell students that they will be investigating different daily cycles in plants, animals or themselves. You may assign each group an investigation from the list of activities given in "Body Clock Investigations," or allow groups to devise their own topics for investigation.
4. Have the members of each group decide upon a central question that will guide their "research." For example, students conducting the body temperature investigation might ask, *Is body temperature constant throughout the day?*
5. Students should plan the times of day at which they will conduct their measurements, the instrument(s) needed (thermometer, stopwatch, "grow light," etc.), and the recorded units of measurement (degrees F, seconds, etc.).

   A sample data sheet for the body temperature investigation is included at the end of this activity. Students will need to create their own data-recording tables for other investigations.
6. Have students work in collaborative groups to conduct their investigations over several days.
7. After students have concluded their investigations, have each group present its question and observations to the class. Students should be able to describe the behaviors or body functions observed, methods used to measure the behaviors or functions (recording leaf movement, checking temperature, observing active times, etc.), and the pattern or patterns they discerned.
8. Discuss the results of the different investigations with the class. Ask questions to prompt students' thinking: *What did all of the cycles you observed have in common? Did any of the patterns occur without the presence of normal sunlight? Do you think something other than sunlight controls the patterns you observed?* Help students to reach the conclusion that something inside each organism controls plant and animal behaviors. Point out that most organisms have internal "timers" that regulate many aspects of their lives, and that these "timers" have a genetic basis.

EXTENSION

Indiana University's "Plants-In-Motion Theater" website offers time-lapse video of circadian movements of plant leaves (http://plantsinmotion.bio.indiana.edu). Have students compare the behaviors shown on the website with those observed in their own plants.

1 See National Science Teachers Association, Position Statement on Responsible Use of Live Animals and Dissection in the Science Classroom, www.nsta.org/about/positions/animals.aspx .

ACTIVITY

Body Temperature Investigation

1. You will need to take your temperature (in °F) three times per day, over the course of several days. For best results, take the first reading just after waking in the morning, the second reading around 2:00 p.m., and the third reading just before going to sleep at night. Wait at least 15 minutes after eating or drinking anything to take a measurement.

2. Record the body temperature (Temp.) and the time the temperature was taken for each member of your group in the chart below. Repeat the process over the next three days.

3. On a separate sheet of paper, calculate the average temperature for each person in your group at each time of day. Graph your results. Write a paragraph describing your findings.

	Morning: Just after waking		Time during the day		Evening: Just before bed	
Name ______________	**Time**	**Temp.**	**Time**	**Temp.**	**Time**	**Temp.**
Date ______________						
Date ______________						
Date ______________						
Date ______________						

	Morning: Just after waking		Time during the day		Evening: Just before bed	
Name ______________	**Time**	**Temp.**	**Time**	**Temp.**	**Time**	**Temp.**
Date ______________						
Date ______________						
Date ______________						
Date ______________						

	Morning: Just after waking		Time during the day		Evening: Just before bed	
Name ______________	**Time**	**Temp.**	**Time**	**Temp.**	**Time**	**Temp.**
Date ______________						
Date ______________						
Date ______________						
Date ______________						

	Morning: Just after waking		Time during the day		Evening: Just before bed	
Name ______________	**Time**	**Temp.**	**Time**	**Temp.**	**Time**	**Temp.**
Date ______________						
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