3 Bright Ideas

“ **The frogs were so loud I couldn't sleep.**

How Good Is Your Biological Clock?

1. A TRAVELER experiences jet lag when his or her internal clock becomes out-of-synch with the environment. Seasonal Affective Disorder, some types of depression, sleep disorders, and problems adjusting to changes in work cycles all can occur when an individual's biological clocks act up. Recent studies have even found links between these molecular timepieces and cancer.

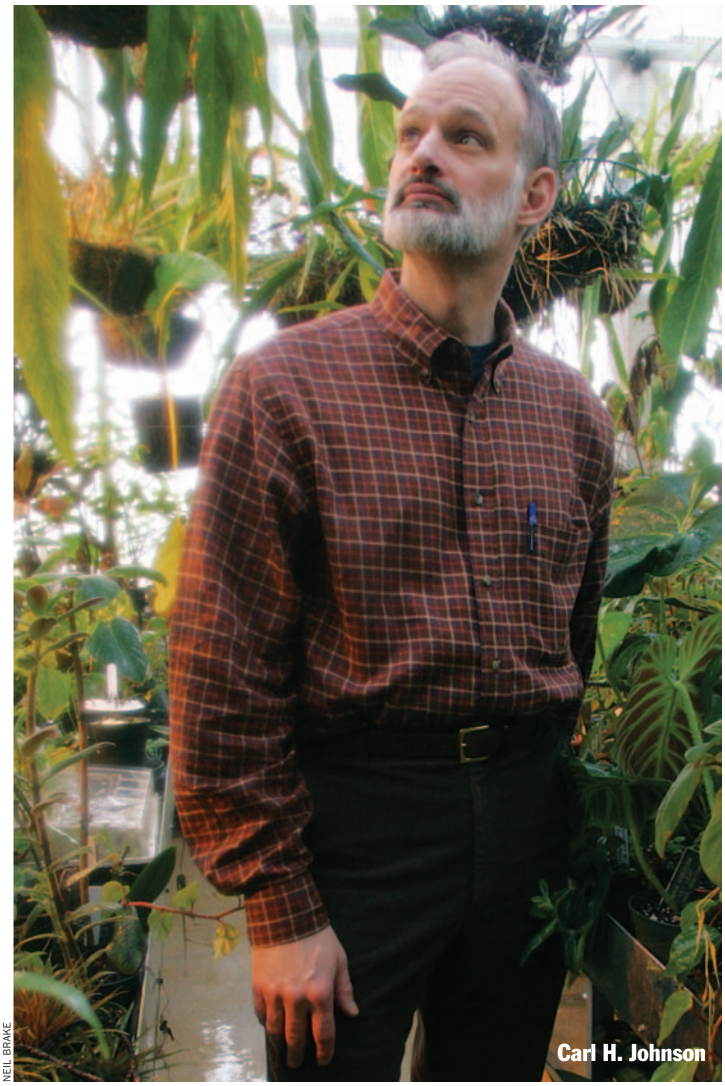
Microscopic pacemakers—also known as circadian clocks—are found in everything from pond scum to human beings and appear to help organize a dizzying array of biochemical processes. Despite the important role they play, scientists are just beginning to understand the benefits that these internal pacemakers provide when they work and the problems they cause when they malfunction.

A study performed by researchers at Vanderbilt University and published in the Aug. 24 issue of the journal *Current Biology* sheds new light on this issue. Using blue-green algae—the simplest organism known to possess these mechanisms—the researchers report that the benefits of biological clocks are directly linked to environments with regular day/night cycle and totally disappear in conditions of constant illumination.

"Circadian clocks are so widespread that we think they must enhance the fitness of organisms by improving their ability to adapt to environmental influences, specifically daily changes in light, temperature and humidity," says Carl H. Johnson, professor of biological sciences and Vanderbilt Kennedy Center investigator, who directed the study. "Some people have even suggested that, once invented, these clocks are such a powerful organizational tool that their benefits go beyond responding to external cycles. However, there have been practically no rigorous tests of either proposition."

To test these ideas directly, Johnson's research team used genetic engineering techniques to completely disrupt the biological clocks in one group of algae and to damp the frequency of the clocks in a second group. The researchers were careful to employ "point" mutations in the clock genes that didn't stunt the growth of the microscopic plants.

They then mixed the algae possessing disrupted clocks with algae possessing normally functioning clocks. When the mixture was placed in an environment with a 24-hour



NEIL BRAKE

Carl H. Johnson

day/night cycle, the normal algae grew dramatically faster than those that lacked functional internal timers. The normal algae also outperformed the algae with the damped clocks, but by a smaller margin.

The result was presaged by a series of experiments Johnson conducted in 1998 with Susan S. Golden from Texas A&M University and Takao Kondo from Nagoya University. In the previous experiments the researchers created two new algae strains with clocks of 22 hours and 30 hours. (The frequency of the biological clocks in normal blue-green algae is 25 hours.) They created mixed colonies by combining the strains in pairs: wild type and

I was fascinated by how the synchronized calling moved around. " —KENNETH D. FRAMPTON

22 hour; wild type and 30 hour; 22 hour and 30 hour. Then they put these mixed cultures into incubators with three different light-dark cycles—22 hours, 24 hours and 30 hours—and monitored them for about a month.

When they pulled the cultures out, the researchers found that the strain whose internal clock most closely matched the light-dark cycle invariably outgrew the competing strain. In fact, they found that the selective advantage of having the correctly tuned biological clock was surprisingly strong: The strains with matching frequencies grew 20 to 30 percent faster than the out-of-synch strains.

The second part of the current experiment was designed to test whether the biological clocks also provide an intrinsic advantage, a hypothesis advanced by the late Colin Pittendrigh of Stanford. He suggested that circadian clocks might be beneficial even in an unchanging environment. There was some indirect support for this proposition. In one experiment, for example, populations of the fruit fly *(Drosophila melanogaster)* were raised in constant illumination for hundreds of generations. Nevertheless, their biological clocks continued to function, suggesting that they continued to have adaptive value.

When the algae strains were placed in a chamber with constant light, however, the researchers were surprised to discover that the shoe was on the other foot: The algae with the disrupted internal clock divided and grew at a slightly faster rate than their clock-watching cousins, both those with natural biological clocks and those whose clocks were damped.

"This was the most surprising result of our study," says Johnson. "Under constant conditions, the circadian clock system is of no benefit and, in fact, might even be bad for the algae."

The scientist doesn't know for certain why this happens, but he has some ideas. The microscopic plants use their biological clocks to turn their photosynthesis system on and off. In a normal 24-hour day/night cycle, this allows the microscopic plant to maximize the amount of chemical energy it can extract during daylight.

"In constant illumination, however, the biological clocks may keep shutting down photosynthesis in expectation of the darkness that never comes," says Johnson.

Co-authors of the study are post-doctoral fellows Mark A. Woelfle and Yan Ouyang and graduate student Kittiporn Phanvijhitsiri. The research was supported by the National Institutes of Health.

Sensor Network Mimics the Synchronized Calling of Frogs, Cicadas

2. The modern world resonates with the uncoordinated beeping and buzzing of countless electronic devices, so it was only a matter of time before someone designed an electronic network with the ability to synchronize dozens of tiny buzzers in much the same way that frogs and cicadas coordinate their nighttime choruses.

"Several years ago I was on a camping trip, and we pitched our tent in an area that was filled with hundreds of tree frogs," says Vanderbilt's Kenneth D. Frampton, assistant professor of mechanical engineering, who dreamed up the project. "The frogs were so loud that I couldn't get to sleep. So I began listening to the chorus and was fascinated by how the pattern of synchronized calling moved around: Frogs in one area would croak all together for a while, then gradually one group would develop a different rhythm and drift off on its own."

Last summer's emergence of cicada brood X brought back that memory and prompted Frampton to assign undergraduates Efosa Ojomo and Praveen Mudindi—working under the supervision of graduate student Isaac Amundson—with the task of simulating this complex natural behavior using a wireless distributed sensor network. They presented the results of their project Nov. 16, 2004, at the annual meeting of the American Acoustical Society in San Diego.

Consulting literature about animal vocalizations, the engineers discovered that a number of different theories have been advanced to explain such naturally occurring synchronized behaviors. They may have evolved cooperatively in order to maximize signal loudness, to confuse predators, or to improve call features that attract potential mates. Or they may have evolved competitively in order to mask or jam the calls of nearby animals.

"Whichever theory is true, it is clear that these behavior patterns are complex and offer an interesting inspiration for group behaviors," says Frampton.

Kenneth D. Frampton

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One thing these behaviors have in common is that they are produced by groups of animals who are in communication with each other but who are acting on their own. Networks consisting of nodes that communicate with each other but act independently according to simple rules are becoming increasingly popular and were the obvious system to use.

"There is a great deal that we do not yet know about the group behavior of such systems," says Frampton. "So, in addition to being a lot of fun, the synchronized calling experiment is adding to our understanding of the behavior of this kind of network."

The engineers began with a wireless network of 15 to 20 "Motes," a wireless network designed by computer scientists at the University of California–Berkeley and manufactured commercially by Crossbow Inc. These are small microprocessors equipped with wireless communications. The researchers added a microphone and a buzzer to each node.

To mimic synchronized calling behaviors, the researchers first programmed a single leader, dubbed the "alpha node," to begin calling (buzzing) with an arbitrary duration and frequency. The alpha node was set so it called at this rate regardless of any other calling in its vicinity. The remainder of the devices, referred to as "beta nodes," were programmed differently. They were instructed to listen with their microphones for a call that was sufficiently loud, to estimate its duration and frequency, and then begin calling in synch with the detected call.

"Although this behavioral algorithm is quite simple, it produces some interesting group behaviors," Frampton reports.

When all is quiet and an alpha node begins calling, at first only those beta nodes nearby hear the call and respond. Then, as more betas swell the chorus, nodes farther away hear the call and join in. In this fashion, synchronized calling gradually spreads concentrically out from the alpha node until all the nodes are synchronized.

A second interesting behavior occurs when a beta node "hiccups" and starts buzzing out of synch with its neighbors. Such hiccups can be caused by measurement noise, operating-system jitter and other factors. Occasionally, when such a hiccup occurs, neighboring nodes resynchronize to the errant node. Normally, these transients quickly disappear as the wayward group resynchronizes with the larger group.

The most interesting behavior pattern appeared when the researchers introduced a third kind of node that they labeled "omega." This node was programmed identically to an alpha node but set to a different duration and frequency. When introduced into the array, an omega node begins to attract neighboring nodes to its call cycle. Unlike the hiccup case, however, the omega group does not resynchronize with the original group. Rather, the omega node eventually recruits a growing number of nodes to its calling cycle until a "balance of power" is reached with the alpha node. The eventual balance between the two groups depends strongly on the initial arrangement of the sensors.

"While this is a rather whimsical application of a sensor network, it demonstrates the unique system behaviors that can arise in truly distributed processing," says Frampton. Even when nodes follow very simple rules, the behavior of the group can be quite complex. Although this project is not likely to improve knowledge about synchronized calling in nature, Frampton says it does demonstrate the types of complex behavior patterns that will be important for future developments in sensor networks.

A Nose for Fast Food

3. THE STAR-NOSED mole gives a whole new meaning to the term "fast food." A study published in the Feb. 3 issue of the scientific journal *Nature* reveals that this energetic burrower can detect prey and gulp them down with a speed too fast for the human eye to follow.

It takes a driver about 650 milliseconds to hit the brake after seeing the traffic light ahead turn red. In half that time, the star-nosed mole, in the Stygian darkness of its burrow, can detect the presence of a tasty tidbit, determine that it is edible and gulp it down.

For more information

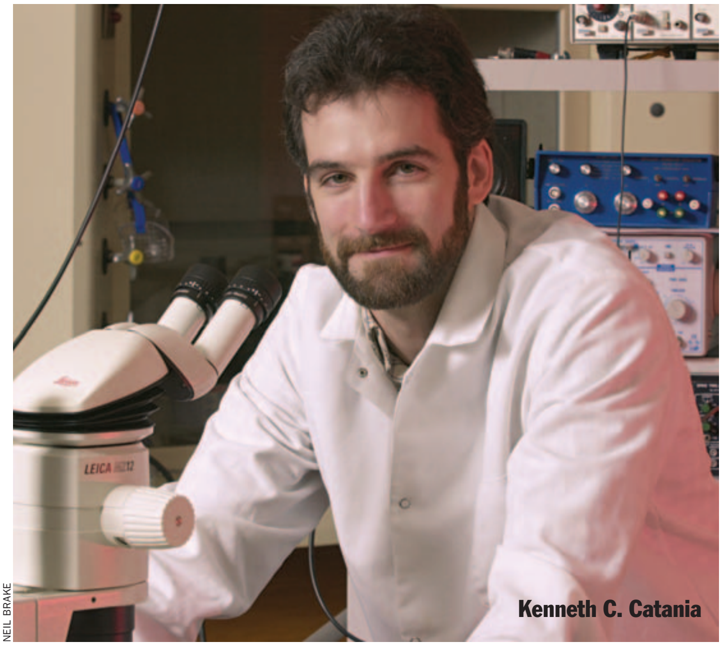
"Most predators take times ranging from minutes to seconds to handle their prey," says Kenneth C. Catania, assistant professor of biological sciences, who directed the study of the mole's foraging speed. "The only things I've found that even come close are some species of fish."

The secret to the star-nosed mole's impressive ability is the star-shaped set of appendages that ring its nose. Its fleshy star makes the mole one of the oddest looking members of the mammal kingdom.

Star-nosed moles range from Canada, down through the Eastern United States as far as Georgia, but are rarely seen because they live in marshes and wetlands. Because they live in darkness, the moles have very poor eyesight. They continually survey their environment by touching their surroundings with their star appendages.

Catania, working with laboratory assistant Fiona E. Remple, captured the moles' feeding behavior with a high-speed video. After touching a small piece of food, it took the moles only 230 milliseconds to identify and eat it. The researchers discovered that the unusual mole is moving almost at the speed limit set by its brain and nervous system. The star-nosed mole takes about 25 milliseconds to decide whether an object is edible, then about 12 milliseconds for a signal to travel from the mole's star appendages to its brain, and another five milliseconds for the muscles to respond to signals from the brain. This leaves only eight milliseconds for the mole's brain to make an identification. Given the split millisecond timing, it is not surprising that it frequently makes mistakes. When researchers set out worm sushi for the moles, they found that one-third of the time moles started to move in the wrong direction and had to suddenly reverse themselves.

Researchers in behavioral ecology invest considerable time and thought studying how different animals eat. The ability to handle prey so quickly and efficiently appears to provide the star-nosed mole with a real competitive advantage. By reducing its handling time to a fraction of a second, the star-nosed mole gains energy from chowing down small insect larvae, tiny worms and other food. Predators that take a few seconds to handle each prey animal, on the other hand, use more energy catching and eating small prey than they gain from eating it.



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Kenneth C. Catania

The insight that the star-nosed mole has specialized in minimizing handling time for small prey helps clear up a number of the mysteries that have surrounded this unusual mammal, Catania says. For years, scientists advanced different theories about the mole's star-shaped appendages. It wasn't until 1995 that studies performed by Catania and others led scientists to agree that the star appendages were super-sensitive touch organs.

Now Catania thinks he knows why the star appendages are so large: The 22 appendages that ring its nose have a surface area eight times greater than the nose of its close cousin, the eastern mole. Its flexible fingers also allow the star-nose to tap objects at a faster rate. Taken together, these advantages mean the star-nosed mole can find 14 times the number of small snacks its close cousin can in a given amount of time.

KENNETH CATANIA

The unusual star-nosed mole eats its prey at lightning-fast speed.

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