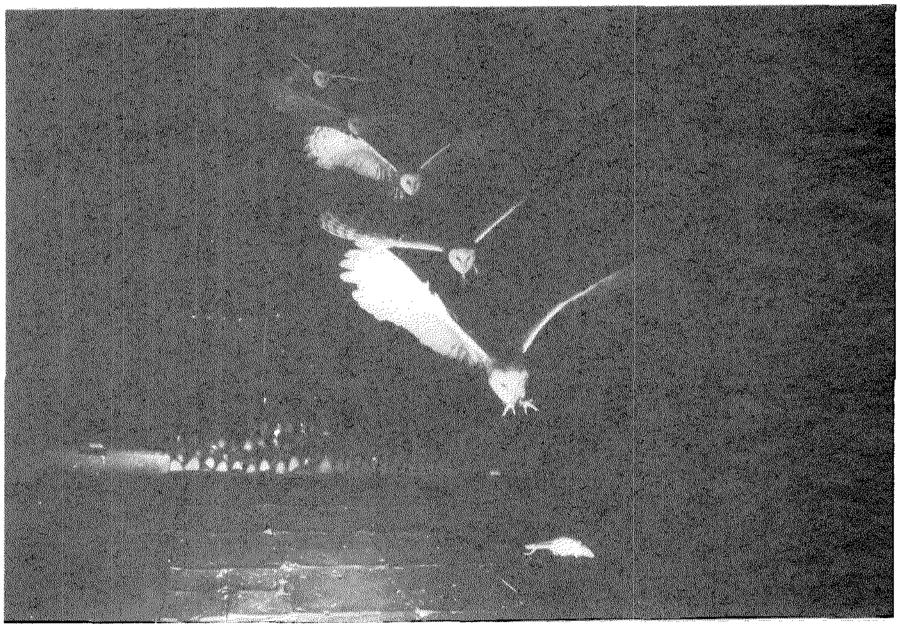
Research in Progress

Birdbrains

MASAKAZU (Mark) Konishi, who studies owls, is often asked whether owls can see in the daytime. Yes, they can see fine in the daytime, he answers; what they can't do is see in the dark. But they can hear, and the nocturnal owls that hunt at night can find their prey purely by sound.

Konishi, the Bing Professor of Behavioral Biology, has been doing research on barn owls for more than a decade. Initially he conducted behavioral studies but in recent years has concentrated more on neurophysiology — how the owl's brain analyzes sound. He still finds it useful, however, to do both behavioral and neurophysiological experiments, because one field can generate ideas of what to do in the other. In sound localization, Konishi says, what you see in behavior and in the brain turns out to be tightly correlated.



In total darkness the noises made by the tethered mouse provide an accurate auditory map for the barn owl, who arrives at the precise location with talons spread out in an oval shape aligned with the axis of the mouse's body. The experiment was photographed with light from an infrared strobe (the five images over one second), which the owl can't see.

Barn owls can pinpoint the source of a sound more accurately than any other terrestrial animal studied so far — as accurate as 1.5° in both the vertical and horizontal dimensions. But they exploit a different sound cue in each of those dimensions. To localize a sound in the horizontal, the owl makes use of interaural time difference, that is, the time between the arrival of a sound at one ear and at the other. For example, if a sound is coming from the right, it will reach the right ear sooner than the left ear. In man, with about 19 cm between the ears, this is a maximum difference of 570 microseconds (millionths of a second).

But a barn owl's head is five times smaller than man's, and the time span is correspondingly shorter. To determine whether the barn owl indeed responds to time in the microsecond range, Konishi and Research Fellow Andrew Moiseff outfitted their owls with tiny earphones that present sounds to the right and left ears with time differences of 10-30 microseconds. Since the owl conveniently turns its head in the direction of the perceived sound, its response can be monitored; when the owl is perched in an electromagnetic field, the slightest movement induces current in a coil placed on its head. Measurement of this current showed that the amount of head movement was proportional to the magnitude of time differences in the microsecond range.

To track sound in the vertical dimension the owl uses a different set of cues — from interaural intensity differences. (The ear nearer the sound hears it not only sooner but louder.) Humans use both time and intensity differences to localize sound on the horizontal but can't come close to the owl's sensitivity on the vertical. The barn owl is more than twice as sensitive as man to the loudness of a sound. The heart-shaped ruff of feathers that looks like an Elizabethan collar and that distinguishes the faces of all nocturnal owls is a collector, which focuses sound into the ears.

The owl's face is also conspicuously lopsided; its ears are asymmetric. Although its skull is symmetric, the skin forming the left ear opening is higher and tilted downward for increased sensitivity to sounds from below, while the right ear flap is lower and aimed upward. This amplifies the intensity differences from varying elevations.

The interaural intensity difference (vertical) and the time difference (horizontal) provide a set of unique cues for each particular point in a two-dimensional space. These correspond to a neural map in the owl's brain, which he can translate immediately into the precise site of his potential meal. Konishi and former postdoc Eric Knudsen have determined how these mechanisms work by inserting fine electrical probes in an anesthetized owl's brain to record activity of the auditory nerve cells by picking up the electrical field created by each cell. They have found that each specialized cell responds only to sound from a particular point. Perhaps the most striking finding of the Konishi group's research is that each of the systematically arranged nerve cells is tuned to a particular narrow range of *both* interaural time differences and intensity differences simultaneously.

Konishi's research group has five breeding pairs of barn owls, who produce some 50 hatchlings per year. These are raised individually so that they become extremely tame. His aviary also includes finches and sparrows. Konishi's work on finches with former grad student Mark Gurney has determined the sex-hormone link to the brain cells that control singing, and in his current work with sparrows he and grad student Dan Margoliash are studying the auditory brain cells that enable the bird to recognize the song of its own species. ☐ – *JD*

Infusion

CALTECH'S ENCORE tokamak is not so named because it's a repeat performance of the first tokamak on campus, built seven years ago by Roy Gould, chairman of the division of engineering and applied science. Nor is the name an acronym, although Paul Bellan, who designed it, is pretty sure he could think one up. Rather, Bellan, who is assistant professor of applied physics, named the device for its high repetition rate, a unique design feature that facilitates study of some of the basic physics of tokamaks.

The tokamak is the most successful device in the quest for fusion energy — the largest tokamaks under construction should be close to achieving controlled fusion. Inside a working tokamak reactor, deuterium and tritium, two isotopes of hydrogen, would be ionized to form a plasma and then would be heated to 100 million degrees C. The fusion reaction occurring on impact between the two ions would release energy greater than that used to generate the reaction and so provide net power.

A tokamak is basically an electrical transformer, in which the very hot, doughnut-shaped plasma is a one-turn secondary. (A transformer has two coils, a primary and a secondary; driving a current pulse in the primary causes an equal and opposite current pulse to flow in the secondary.) The magnetic fields associated with the current flowing in the plasma confine the plasma to keep the ions and electrons from colliding with the walls.

ENCORE is not large, as tokamaks go. About three feet across, it's not a "parameter-pushing" tokamak like the 25-foot-diameter machine being built at Princeton. It was designed, instead, to provide access for measuring some of the fundamental physics of a magnetically confined plasma. ENCORE's temperature of 100 thousand degrees C is much colder than what other tokamaks attain, but this relative "coldness" enables researchers to put in probes to see what's going on. And the high repetition rate, which allows 15 plasma pulses per second, is almost a thousand times faster than conventional tokamaks, which generate one plasma pulse per minute. Bellan compares it to the difference between a muzzle-loading rifle and a machine gun. With this capability Bellan and his colleagues can construct complicated spatial profiles of various plasma parameters by simply moving a probe to a different position for each plasma pulse.

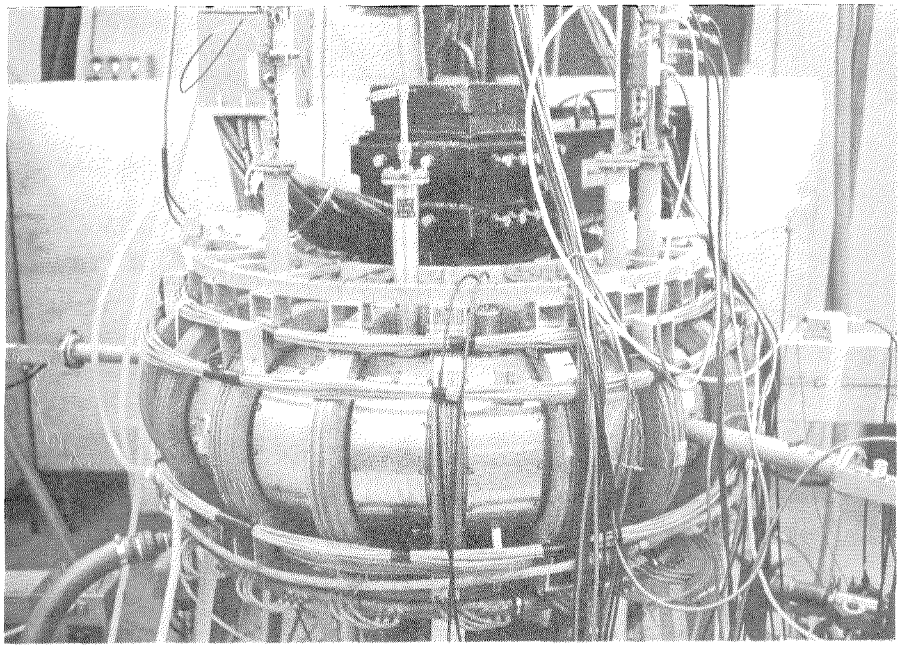
Bellan achieved this high repetition rate in ENCORE with an unusual power supply (which he admits he was initially not sure would work). Where other tokamaks use capacitor banks to generate the plasma, ENCORE uses a 48-kilowatt rms amplifier with peak power output of almost one megawatt. The surplus amplifier, originally used to test rocket and satellite parts for withstanding takeoff vibrations, weighs five tons and had to be hoisted by a crane onto the roof of Steele Laboratory where it now resides.

Among the phenomena Bellan is studying are lower hybrid waves, which propagate in a microwave frequency regime where large power oscillators are readily available. These waves could be used to heat the plasma to fusion ignition. They can also be used to generate large DC currents in the plasma, which is of enormous practicality since it would allow dispensing with the tokamak's transformer and running the tokamak as a steady-state rather than a pulsed machine.

Although these complicated waves are easy to create, they are essentially impossible to observe in other tokamaks. ENCORE's high repetition rate allows Bellan and his students to measure them easily and to study how they propagate. Graduate student Larry Sverdrup is now setting up an experiment in which lower hybrid waves will generate large DC currents in ENCORE.

Another topic being actively pursued on ENCORE is the study of magnetic islands. This phenomenon has a detrimental effect on the tokamak's efficiency and is caused by fluctuation of the magnetic field confining the plasma. Grad student Eric Fredrickson is studying these islands and has developed a computerized plot of the cross section of the torus that shows up the magnetic islands very clearly — looking like extra cores in the concentric rings of an onion. He is now trying to find a coupling between islands and another mode in the plasma — a density fluctuation called a drift wave. Originally the two appeared unrelated, but experimentally a connection is showing up.

Bellan thinks that fusion is starting to look feasible, although it's not clear when it will be competitive economically. But first it's important to make it work, he believes, and the economics can come later. And ENCORE is doing its best to discover how to make fusion work — again and again and again. . . ☐ *-JD*



The ENCORE tokamak fusion reactor is essentially a transformer. The black iron core in its center has a primary winding of copper wires that induces current in the one-turn, doughnut-shaped plasma secondary; magnetic fields associated with the current confine the plasma electrons and ions. Probes (the cylinders sticking out of the top of the doughnut) enable researchers to study some of the fundamental physics of a magnetically confined plasma.