Is Noise a Neural Necessity?

Nerves can sometimes hear messages better amid babble

By JANET RALOFF

Nerves serve as the body's town criers. Upon receiving a signal, a sensory nerve cell passes it up the line until it reaches the brain, where processing neurons figure out what response is called for. These nerve cells then relay instructions about what to do to the appropriate tissues and organs—again via a network of nerves.

Some of the messages are internally generated, like those that tell the lungs to breathe in air or portions of the brain to relax for sleep. Others convey information about interactions with the outside world, like the image of resplendent fall foliage, the laughter of a child, or the pain of stubbing a toe.

One might think the body would understand those neural messages better if they passed alone through conduits isolated from irrelevant signals. In fact, nerves are constantly exposed to a din of electrical messages (SN: 11/2/96, p. 280) being relayed by neighbors or even other parts of themselves. Overlaid upon these messages can be stimulation from outside the body.

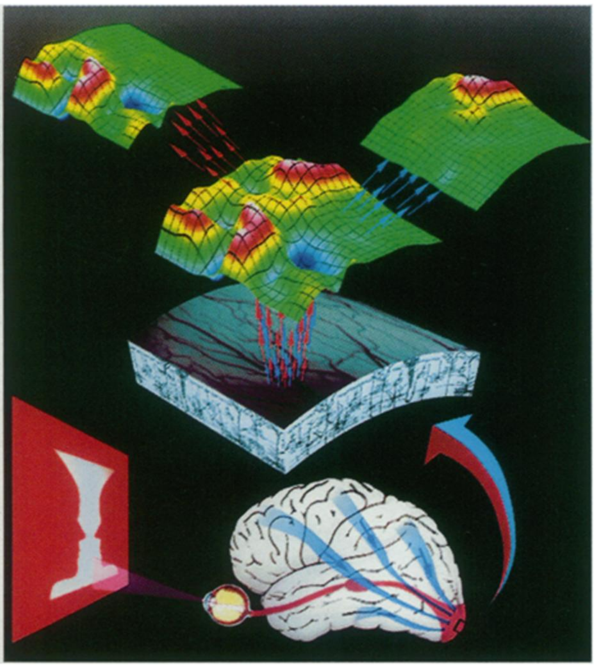
One new study has just shot down a leading theory about how the body might tune out this potentially confusing background of neural noise. Moreover, a group of related studies suggests that noise—or what appears to be noise—may in fact help a nerve recognize the signals to which it should respond.

These latter findings are spurring several investigations aimed at treating a range of disorders, including epilepsy and a potentially dangerous nerve desensitization that can occur in diabetics.

For years, scientists have observed that the brain's response to outside information, such as a visual image, depends on the background of internal signals that pervades the brain. As a result, "if you provided a stimulus to a single neuron, it would not respond the same way each time," notes Amiram Grinvald of the Weizmann Institute in Rehovot, Israel.

Most researchers had assumed that the brain resolved the issue by not relying on any one neuron. The redundancy of the neural system should ensure that if some cells are distracted or confused, many more will be alert and responding appropriately, they reasoned. Grinvald says the brain was envisioned as averaging the output from perhaps hundreds of thousands of individual nerve cells to eliminate the variability due to anything but some common signal—such as the visual image.

It was a good idea, but based on a faulty assumption, Grinvald now observes.



Arieli et al./Weizmann

What looks at first like a gray vase (lower left) quickly resolves into two faces in silhouette. What the eye sees hasn't varied. What changed were waves of electric activity in the brain's vision center, depicted at upper left and upper right in color-coded contour mappings. The perceptual change may reflect a matching of the image to memory.

Such an averaging would help only if each nerve cell is influenced by different sources of noise than those that affect its neighbors. It turns out, however, that all those neurons are listening simultaneously to the same chorus of voices, Grinvald, Amos Arieli, and their Weizmann colleagues report in the Sept. 27 SCIENCE.

Working with anesthetized cats, they tagged brain neurons of the visual system with a dye that turns a fluorescent red as the neurons fire. When the scientists displayed a series of moving lines before the cats' eyes, the cells' hues revealed the reactions of a whole population of sight-activated nerve cells.

If each neuron were starting from a different background activity level, reflecting the whispers of local brain babble that only it could hear, the population of these cells should have lighted up with random flashes of fluorescence. Instead, the Israeli scientists recorded coherent waves of color that rippled over the entire field of vision-activated cells.

This clearly demonstrated, Grinvald told SCIENCE NEWS, that each neuron is listening not to babble but to some common melody that varies with time but produces a coherent reaction across the population.

Nor is this melody an artifact of the animal's drugged stupor, he says. In follow-up studies with an alert monkey, the Weizmann team showed that background brain activity affects how nerve cells respond. The scientists gauge activity by the animal's reaction time—how quickly it reaches out its arm.

"My speculation," Grinvald says, is that the background activity in the visual field shows that it is "looking for a match between the incoming flow of information and the internal representation—or memories—of those things." However, he adds, these waves of coordinated electric activity might also constitute consciousness, emotion, or even the electric representation of thought. "We are performing experiments to test which might be correct."

What's clear, he notes, is that this background activity is not random and so probably not truly noise.

On that, Theodore H. Bullock agrees. "Just because this activity is unstructured or looks random, we shouldn't assume it's noise." Rather, he asserts, "we have evidence that much of the ongoing background activity is not noise for the system but is used by it. It's part of the signal."

For more than 40 years, this neurophysiologist at the University of California, San Diego has been studying background nerve talk in a host of animals. Working on crayfish during the mid-1950s, he showed that the electric firing, or activity, of their stretch receptors—a type of sensory neuron—could be altered by exposing those neurons to an electric field.

What impressed him was how small the effective fields could be—"within the same range as brain waves." The sensitivity of the nerve cells "was much higher than anybody had expected," he recalls, and it led him to speculate that brain waves and other background neural activity might likewise influence nerve cells.

Physicist William L. Ditto of the Georgia Institute of Technology's Applied Chaos Lab in Atlanta believes that this noise of neuronal signaling "is actually being used for a very specific purpose: to detect faint signals."

He bases this idea on the counterintuitive but well-established phenomenon of stochastic resonance, in which the addition of noise sometimes improves the ability of nonlinear systems to respond to previously undetectable signals.

Nonlinear systems include any "in which a very small stimulus provokes a disproportionately large response," Ditto explains, such as when a small addition of water to a bead at the end of a leaky faucet makes the entire droplet fall. Indeed, he notes, most of the world is nonlinear, including virtually all of biology.

Stochastic resonance has been demonstrated in computer circuits (SN: 8/31/91, p. 143), in lasers (SN: 2/23/91, p. 127), even in hairs on the tails of crayfish (SN: 10/23/93, p. 271). However, these systems respond basically as simple on-off switches. Ditto was interested in searching for stochastic resonance in the more complex "thinking tissue"—the brain.

To determine whether the brain would respond as the switches had, he contacted Steven J. Schiff at Children's National Medical Center in Washington, D.C., and proposed that they collaborate with Bruce J. Gluckman and Mark L. Spano, physicists who specialize in nonlinear systems at the Naval Surface Warfare Center in Silver Spring, Md.

A neurosurgeon interested in epilepsy, Schiff decided they should experiment with slices of tissue from a rat's hippocampus. In humans, this part of the brain is an important locale for epileptic seizures—characterized by large patches of intense and uncontrolled neural firing. The scientists decided to try tweaking the tissue's neural firing with electromagnetic fields (EMFs). The conundrum was how to deliver EMFs independently as signal and as noise to a hippocampal slice containing 1,000 to 10,000 neurons.

For hints, they turned to work conducted decades earlier, such as a 1927 report showing that an electric field could influence a nerve in ways that varied according to the field's orientation relative to the nerve's axis. It ultimately took the Navy scientists 2 man-years of effort to figure out how to monitor neural responses accurately while delivering the complex EMFs into a test chamber.

Their experiment confirmed that whether exposed to a weak, periodic EMF signal or to noise (in this case, an EMF that oscillated with a random, broadband frequency), the neurons would fire in a rhythmic pattern of their own choosing.

However, when the researchers superimposed both fields on the brain tissue simultaneously, the neurons began pacing their pattern to that of the periodic EMF signal. Schiff and his colleagues report their findings in the Nov. 4 PHYSICAL REVIEW LETTERS.

Along the way, Schiff's team noted that a nonoscillating field could turn off a pattern of neural firing that resembled seizures or the aberrant spikes in firing that often precede epileptic seizures.

In many patients, seizures trace to irregular spikes that stem from a single focal point. In intractable cases, physicians sometimes target this unstable zone—which Schiff likens to the epicenter of an earthquake—for removal. He wondered if there might be a way to prevent the quakes by applying EMFs to that epicenter.

As a test, the researchers chemically induced spikes in the rat tissue to mimic those preceding a seizure and then exposed the neurons to a steady, direct-current field. As long as the lines of the electric field ran parallel to the orientation of the neurons, their wild, erratic spikes gave way to a pattern of more normal neural activity, Schiff and his colleagues will report in an upcoming JOURNAL OF NEUROPHYSIOLOGY.

Based on the findings, Schiff has obtained approval from his medical center to begin limited testing of steady, direct-current electric fields on humans. The tests, which could begin early next year, would target seizure epicenters "right before we cut them out in the operating room," he observes. If this EMF treatment can shut down the aberrant firing in a patient's brain, he says, "I may have a way to turn off seizures without cutting out a big chunk of the brain."

And down the road? Schiff wonders if it might not be possible to implant electrodes at a patient's seizure epicenter, then run leads to a tiny microprocessor tucked elsewhere in the body. This would "make the epilepsy pacemaker from Michael Crichton's 1972 novel *Terminal Man* more science than fiction," he observes.

In the meantime, James J. Collins of Boston University and his colleagues report a direct demonstration of stochastic resonance in people. In a pair of studies reported in the Oct. 31 NATURE, they show that noise delivered in the form of random physical vibrations can increase the ability of nerves to recognize minute, previously undetectable movements of the wrist or slight compressions of a fingertip.

Each experiment stimulated sensory neurons, which can lose sensitivity as a result of age or certain diseases.

For instance, the neurons stimulated in the wrist belong to a class of proprioceptor sensors that helps individuals identify a limb's position in space. In the elderly, loss of such proprioception in the feet could lead to stumbling and in the hands to a potentially dangerous clumsiness in the kitchen. Similarly, the loss of sensitivity that sometimes accompanies diabetes can prevent people with this disorder from feeling the heat of a pot handle in time to prevent a burn.

To treat these conditions, Collins' team is at work on such aids as "noisy" socks and gloves that might use battery-powered electrodes to deliver vibrations. Small computers might sense when movement is attempted and wait to turn on the devices at that time.

"This is still clearly at the Flash Gordon stage," Collins admits. "We don't have these things built yet. But I don't think they're far off either." Indeed, he hopes to begin engineering prototypes within 6 months.

The EMF fields that Schiff's team used to influence their neurons are relatively large—and would have to be larger still to penetrate the skull and fluids of an intact head. Similarly, though Collins has increased the sensitivity of sensory neurons with vibrational noise, those increases weren't very large.

Neither group is put off by the relatively low sensitivity of the neurons they studied. The reason for their optimism, Collins says, is that they examined only small groups of neurons. Last year, both his team and Ditto's showed that the greater the number of linked stochastic resonators—such as neurons—the greater the signal detection sensitivity of the entire system (SN: 7/22/95, p. 55; 12/9/95, p. 389).

Indeed, Ditto now argues, this potential of the body's billions of linked neurons to act as a signal amplification array may finally offer an explanation for the hotly debated epidemiological link between cancers and the EMFs associated with power lines and household current.

"Until now, nobody's been able to provide any mechanism by which a really small EMF can influence tissue." It's an issue he plans to explore much, much further. □