All Fired Up

Perception may dance to the beat of collective neuronal rhythms

By BRUCE BOWER

Even for the most adventurous among us, daily life bursts with mundane mental events. A paper clip gleams amid haphazard stacks of documents, a friend's face shines like a beacon out of a clutch of pedestrians on a city sidewalk, the smell of freshly baked bread evokes a stomach-rumbling anticipation of lunch mingled with childhood memories of a neighborhood bakery—thoughts and perceptions such as these flow by with monotonous ease.

So it seems, anyway. Yet given what scientists know about how brains work, even the ability to perceive a paper clip on a messy desk represents an extraordinary and mysterious achievement.

Researchers have successfully identified neurons in different regions of the brain that preferentially respond to form, color, motion, and other sensory elements. At the same time, they know that animals of all stripes perceive whole objects and organisms without stopping to contemplate their many separate features. Investigators refer to the brain's puzzling adeptness at weaving unified scenes and meanings out of diverse sensory threads as the binding problem.

Although the binding problem has yet to be resolved, numerous studies in the last several years have suggested that widely scattered neural clusters build a foundation for perceptual binding by synchronizing their electric discharges. This explanation requires millions of nerve cells to switch on and off at roughly the same time, hitting a series of corresponding electric peaks and valleys along the way. Such common rhythmic pulsing, which lasts for fractions of a second, generates the so-called brain waves picked up by electrodes placed on the scalp.

More important, proponents argue, synchronized neural firing—observed most frequently in monkeys and cats, but also detected in people and other animals—sparks the anatomical connections and chemical processes necessary for perception, memory, language, and even consciousness.

"Neural synchronization is so prevalent in mammalian brains, it's hard to imagine that it's not important," says neuroscientist Charles M. Gray of the University of California, Davis. "Still, this is difficult and controversial research."

Synchronized firing by neurons has attracted widespread scientific attention only in the last decade. Researchers have traditionally focused on the rate at which single brain cells fire off electric discharges as an animal encounters various sensations or performs experimental tasks. Their studies inspired an influential theory which holds that certain brain cells respond to basic perceptual elements and then report to powerful, well-connected cells capable of combining the elements in meaningful ways.

A stubborn minority of researchers has elevated collective neural responses to a position of prime importance. Over the past 40 years, as rabbits and cats sniffed and explored experimental settings, these scientists recorded what they called gamma waves in areas of the brain devoted to smell (SN: 11/2/96, p. 280). These gamma waves are produced by several thousand or more neurons emitting synchronized electric signals at a rate of 20 to 100 times a second.

In 1987, Gray and neuroscientist Wolf Singer of the Max Planck Institute for Brain Research in Frankfurt, Germany, reported using implanted electrodes to detect gamma waves in a specific part of the visual cortex of cats. Several instances of synchronized firing, each lasting about one-third of a second, took place in this area as the animals looked at a familiar object. Coordinated outbursts plummeted when the same cats viewed novel items.

Since then, Singer has become a leading advocate of the view that rhythmic electric output among far-flung neurons lies at the heart of visual perception and perhaps other aspects of thought.

Many studies in the past decade have documented synchronized cell firing in visual, auditory, and motor areas of the brain's outer layer, or cortex. Rhythmic activity also appears in structures beneath the cortex that influence memory and attention.

The challenge is to show that the ability to discern a paper clip on a desk or to perform any other cognitive task depends on the rhythmic beat of particular brain cells. According to skeptics, the brain's complex electric system may generate synchronized activity as a useless byproduct, comparable to the droning hum of a computer's processing unit.

Several recent experiments aim to demonstrate that synchronized neural firing is essential to certain types of thought.

In macaque monkeys, selected groups of motor cortex neurons emit precisely timed electric discharges, with corresponding peaks and valleys, during both the planning and the execution of voluntary movements, asserts a research team directed by Alexa Riehle of the National Center for Scientific Research in Marseilles, France.

Synchronized electric activity allows cortical regions involved in movement to form different functional networks, each attuned to the nature of a particular task, Riehle and her coworkers theorize.

Their experiment involved two macaques that learned to perform a delayed-pointing task. The monkeys first saw a small, open circle on a video screen; the open circle indicated the upcoming position of a second, solid circle. Upon seeing the second circle, which appeared at intervals ranging from around 1/2 second to 1 1/2 seconds after the first one vanished, each animal reached out and touched it.

Extremely thin microelectrodes surgically implanted in the motor cortex of both animals recorded the ongoing responses of hundreds of neurons.

Synchronized cell activity grew more pronounced as the monkeys waited longer to see the second circle, a trend that apparently reflected intensifying mental preparation for making a move. In contrast, the number of electric signals generated by motor cortex neurons remained unchanged as monkeys planned their responses, Riehle's group reported in the Dec. 12, 1997 SCIENCE.

Arm movements evoked double-barreled action—motor cortex neurons synchronized their activity and fired off a greater number of electric bursts to boot.

Another group of researchers suggests that gamma waves generated by groups of brain cells help honeybees distinguish between similar smells. In the wild, a honeybee extends its tonguelike proboscis when it happens upon preferred flower types, which it learns to identify by smell.

The scientists, directed by Gilles Laurent of the California Institute of Technology in Pasadena, caught honeybees in molded wax and trained them to stick out their proboscis in response to certain smells. Cells in an olfactory section of the insects' brains synchronized their activity in response to familiar scents, the group reported in the Nov. 6, 1997 NATURE. Earlier, this same group had shown that distinctive sets of neurons in locust brains synchronize their signals as the insects encounter various scents.

Administration of a drug called picrotoxin breaks down these rhythmic pulses in bee brains, the investigators report. At the same time, specific odors continue to elicit increased firing from smell cells. The drugged bees avoided odors that clearly differed from those they were trained to prefer, but they mistakenly extended their tongues upon whiffing chemically similar scents.

Synchronized neural assemblies provide an additional source of information that the brain can use to sort out related smells and other sensations, Laurent and his coworkers propose.

"Laurent's study is a spectacular step in the right direction," comments Gray. Drug-induced desynchronization of densely connected visual, motor, and association areas in mammalian brains, in contrast, would disturb all sorts of functions. This would greatly complicate the interpretation of such studies, he says.

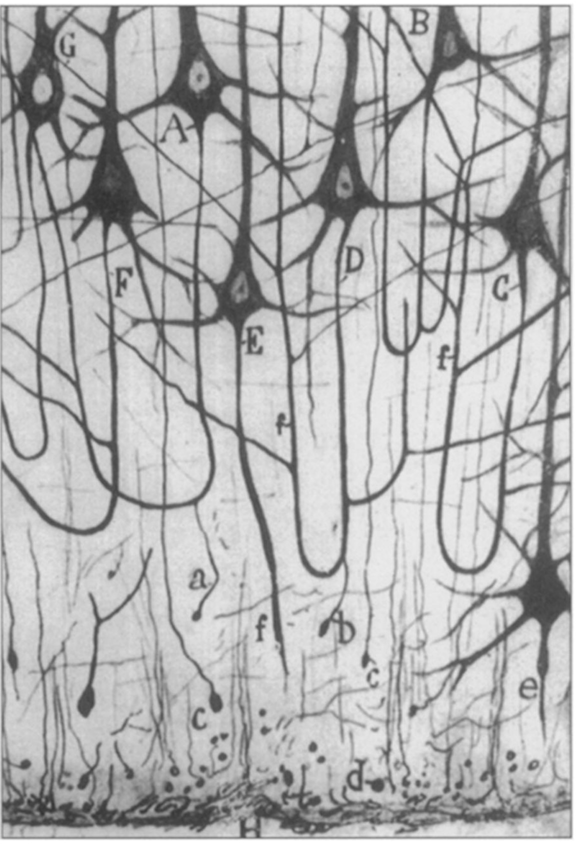

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Illustration of cells in the cerebral cortex rendered by Spanish neuroanatomist Santiago Ramón y Cajal in 1923.

Rhythmic alignments of brain cells in widely separated areas nonetheless appear to foster an integrated view of scenes and objects, contend Singer and his colleagues. In fact, they say, synchronized neural activity makes it possible to become conscious of what one sees.

In a study described in the Jan. 9, 1997 NATURE, five cats learned first to watch a circle of horizontal grates and then, upon seeing it change its orientation, to press a lever for food.

After completing this training, the animals displayed coinciding bursts of gamma-wave activity in areas of the visual cortex and the association cortex as they eyed the grating and waited for it to rotate. These synchronized discharges switched to other parts of the association cortex and to the motor cortex when the grating shifted and the animals prepared to press the lever. Rhythmic firing, which occurred on both the left and right sides of the brain, dissolved once the cats obtained a reward.

As in Riehle's study, neural synchrony shifted its boundaries in order to unite appropriate brain regions while an animal either waited for or responded to a visual stimulus, Singer says.

Coordinated nerve firing also shows signs of freeing up visual information for access to awareness, he adds. To test this theory, Singer's team studied three cats that had undergone an operation to cut off the neural communication needed to combine input from both eyes into a single image. As a result, one eye becomes dominant and its visual signals are fully processed in the brain, while information from the other eye reaches the brain but lies dormant.

The researchers simultaneously presented visual patterns moving in opposite directions to the left and right eyes of each cat.

Before surgery, a specific set of cells in each cat's visual cortex displayed comparable firing rates and moderately synchronous activity during this test. After surgery, only visual neurons with connections to the dominant eye exhibited increased synchrony when stimuli came into view.

At the same time, neurons displayed roughly equal firing rates, regardless of whether they were linked to the dominant or the suppressed eye, Singer's team reported in the Nov. 11, 1997 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES.

Scientific reaction to such findings varies greatly.

Antti Revonsuo of the University of Turku in Finland proposes, much as Singer does, that precisely timed cell activity in the brain seems to lay the groundwork for visual awareness. In a study slated to appear in NEUROREPORT, electrodes placed on the scalp recorded a rush of gamma-wave activity in the visual cortex and the association cortex just before human volunteers reported discerning a three-dimensional object in a field of dots on a computer screen.

This indicates that synchronized areas construct images and scenes out of various features, readying the perceptions for possible entry into awareness, Revonsuo and his colleagues maintain.

Experiments by Singer and others support the notion that synchronized cell activity enables animals to discriminate between related sensations, say Francis Crick of the Salk Institute in La Jolla, Calif., and the California Institute of Technology's Christof Koch. However, consciousness probably requires a flexible shuttling of information back and forth through visual networks that link to distant areas responsible for planning, they theorize in the Jan. 15 NATURE.

The rhythmic activity of neurons may act instead as an information gate in the brain, remarks Anthony A. Grace of the University of Pittsburgh. In his view, the focusing of attention may boost neural activity and yield synchronized zones that collect and pass on relevant sensory information.

It seems more likely that synchronized activity in the cortex occurs as a meaningless by-product of sensory processing by neurons enmeshed in a thick web of connections, asserts J. Anthony Movshon of New York University. Parts of the monkey visual cortex that lie outside initial processing centers appear to be capable of comparing sensory signals from great distances and integrating perceptions without any synchronized activity, he says.

Gray suspects that scientists will continue to explore the meaning of neural synchronization for some time.

"There's a lot of scientific work on this issue that's happened in a short time," he remarks. "It's gratifying to see." □