Science of time: What makes our internal clock tick?

Neuroscientists are exploring how brain and body make sense of our most ephemeral resource.

By Melissa Healy

In warp-speed modern America, time has become one of our most precious resources. We manage it, and we expend it carefully.

Ironic, then, that a resource as precious as seconds, minutes and hours is so poorly understood and so routinely misestimated by modern humans -- by 15% to 25% in either direction, depending on the individual and the acuity of his or her time perception. But understanding our ability to perceive time -- and to use time to make sense of our world -- is one of the newest and most sweeping frontiers of neuroscience.

Says UCLA neuroscientist Dean Buonomano: "In order to understand the nature of the human mind, we must unravel the mystery of how the brain tells time, in both normal and pathological states."

Against that backdrop, the temporally challenged have become more scientifically relevant than ever. Neuroscientists have come to recognize that patients with devastating brain disorders such as Parkinson's and Huntington's diseases greatly underestimate the passage of time. Poor timing is a hallmark in several psychiatric conditions, including schizophrenia, autism and attention deficit disorder. Many of about 5,500 soldiers returning from Iraq and Afghanistan with traumatic brain injury will find that faulty timing is one of the invisible wounds that follow them into civilian life. And researchers have confirmed that as we reach senior status, our internal clock grows increasingly unreliable.

But to treat these disorders and to understand how we sense time's passage, researchers say they must stand back and see the brain as a complex network of circuits, some interlocking, some whirring away independently.

This "network" approach to brain science "is a much more complicated problem" than asking what tasks are performed in individual regions of the brain, says Catalin Buhusi, a computer scientist-turned-brain scientist who now researches time perception at the Medical University of South Carolina.

Decisions, decisions

We use our grasp of long spans of time -- from hours to weeks -- to apportion our energies: Shall I surf the Internet aimlessly, or knuckle down and finish that report due tomorrow?

Rats rewarded on a regular time schedule will grow more attentive and motivated to learn as treat-time draws near, Buhusi notes. Students, he observes, show the same pattern, both in hourlong experimental situations and in their approach to the academic year: They tend to party and socialize for the first several weeks of a semester and, in the weeks before finals, grow ever more attentive to schoolwork.

This sense of time is probably evolution's way, Buhusi says, of ensuring we mete out our attention and energy efficiently, rather than expending too much too soon and falling short at the end. And it explains why open-ended challenges -- whether it is a mother-in-law's visit, a research paper with no deadline or imprisonment in Guantanamo -- can be deeply disorienting.

At the other end of the time spectrum is the elusive -- but tiny -- stretch of time we call "now."

For most people, researchers have come to define the optimal "now" -- give or take a second or two -- about 2 1/2 seconds long, basically a human's typical span of unconscious attention.

Those whose "now" interval is much shorter than 2 1/2 seconds are readily distracted and thus unlikely to stay on task long enough to make full sense of their surroundings and respond appropriately. If "now" is much longer than that, people's powers of attention may be too rigid to shift when necessary to keep up with changes in their surroundings.

The "now" interval may help explain why attention might be the most important -- and most fragile -- part of our internal clocks.

We see, move and react in tiny increments of this unconscious "now": Motorists make constant calculations of time to avoid collisions. Athletes use split-second estimates of time to connect with an incoming ball. Planting a kiss in the right place requires a precise coordination of movement and time estimation. The person with an off-kilter sense of the "now" will have problems with timing.

Time, interrupted

In a healthy human brain, researchers believe that every second we are conscious, a circuit involving three distinct regions of the brain -- the cerebellum, basal ganglia and prefrontal cortex -- is essentially checking and cross-checking incoming information and its time stamp. In real time, that circuit builds a logical sequence of events out of information coming from different sources at different speeds.

From our earliest days, this circuit helps us to infer relationships of cause and effect, to make sense of the world and to learn. A baby bats at a dangling toy clown, feels its soft covering hit her hand and, less than a second later, hears it jingle: By correctly perceiving the order of those events and the tiny space of time between them, she learns that her action caused the clown to swing and jingle. And in so doing, she learns she can do it again.

When this sense of time is disrupted -- as in several illnesses now under study -- the world can become a chaotic jumble of seemingly unrelated events, or of effects attributed to the wrong cause. Chronically taken by surprise in an illogical world, a patient with what's increasingly known as a "temporal disorder" might respond with irrational anger or fear. Or he may feel helpless to understand how his actions affect things and people around him, and lapse into apathy.

David Eagleman, a neuroscientist at Baylor College of Medicine in Texas, suggests that such dysfunctions of timing may underlie what he calls the "fragmented cognition of schizophrenia." Schizophrenic patients, Eagleman says, are recognized as having spotty powers of time estimation -- sometimes too fast, sometimes too slow.

Patients with traumatic brain injury, including thousands of service members who have suffered concussions from bomb blasts in Iraq and Afghanistan, may also yield important clues to the brain's timing mechanisms, and what happens when they're disrupted.

"These patients can see, move, hear; all their sensory systems are intact, but they can't interact" in expected ways, says Dr. Jamshid Ghajar, a Cornell University neurosurgeon and time-perception researcher who directs the Brain Trauma Foundation. "They regularly tell you, 'I feel out of sync.' They're telling you they can't synchronize when they're trying to interact."

In short, their timing is "off," possibly because their injury has affected the bundle of time they unconsciously define as "now."

Ghajar says that getting time right allows the healthy brain to project a few steps ahead of events happening around us, and to begin setting up to react even before it's necessary. Whether volleying a tennis ball, answering a question or responding to a gesture, this anticipation allows us to respond smoothly to our world. For many brain injury patients, such effortless interaction is subtly and painfully missing. These victims of brain injury may seem awkward, lazy, agitated or slow. But Ghajar thinks many of these patients have sustained damage somewhere in the brain's timing circuits.

The weak link

"You can explain a lot of pathologies," including schizophrenia, autism and ADHD, as problems of time perception, Ghajar says.

These patients may start with faulty perception at the level of a few seconds and below, he says. "But if things start going off-track within that time frame, they're going to stay off-track through longer spans of time."

That may be one explanation for what happens to Parkinson's and Huntington's disease patients.

These patients, whose neurological disorders progressively disrupt motor control, routinely misestimate the passage of time -- both at very short intervals and at spans lasting several minutes.

In both diseases, the brain chemical dopamine becomes progressively less available, or effective, in the basal ganglia's mid-brain neighborhood.

But give a Parkinson's patient his medicine, which mimics the effect of dopamine, "and his sense of time is restored dramatically -- within minutes," marvels brain scientist Buhusi.

Such bits of medical arcana suggest to some researchers that the basal ganglia might be the weak link in the internal clocks of these patients. But the weak link could as easily be flagging attention, others say. The Parkinson's drug L-Dopa also has the effect of goosing activity in these patients' prefrontal cortices, sharpening their attention.

"We've learned a lot from Parkinson's disease patients. But we clearly haven't got it all," Buhusi says.

As the link between time perception and health has grown more visible, the study of time is no longer the sole province of philosophers, physicists and poets.

"There is no National Time Institute," says Richard Ivry, a noted time-perception researcher at UC Berkeley. But as philanthropies and funders such as the National Institute of Mental Health and the Department of Veterans Affairs gain interest, time perception may cease to be what Ivry calls "the stepchild of the sensory system" that it has traditionally been in brain-science circles.

Time's time, in short, may be now.