the nucleus accumbens. The implication is that the brain builds more glutamate receptors in that region as cocaine addiction takes hold.

Whether the same happens in amphetamine addiction is less clear, because Wolf and her colleagues found large decreases in the proteins forming the AMPA glutamate receptor in nucleus accumbens neurons in rats sensitized to amphetamine. Still, says Wolf, the data do show "that there are adaptations in glutamate transmission in response to chronic exposure to [both] drugs."

Sensitized animals are thought to be especially valuable models of addiction to cocaine and amphetamine—stimulants whose rewarding properties seem to be the main impetus for cravings and repeated drug use. But for other drugs, such as opiates, avoiding withdrawal symptoms is thought to be at least as strong a driver for continued use as is seeking a high. Inhibitor studies have implicated glutamate's brain-sculpting effects in this kind of addiction as well. It seems to play a role in both opiate dependence, in which withdrawal symptoms develop when the drugs are taken away, and tolerance, in which an individual needs more of the drug with continued use to experience the desired effects.

In 1991, for instance, Keith Trujillo and Huda Akil at the University of Michigan, Ann Arbor, showed that the NMDA antagonist MK-801 could prevent rats from becoming either tolerant to morphine or dependent on it. And in 1993, neuropharmacologist Charles Inturrisi of Cornell University Medical College in New York City, with then-postdoc Paul Tiseo, discovered that another NMDA antagonist, called LY274614, could even reverse tolerance to morphine in rats. This suggested that such antagonists might help addicts or people with chronic pain who have developed opiate dependence or tolerance.

Although many of the molecular and cellular details of glutamate's influence on addiction remain to be worked out, it's now clear that glutamate does mediate many of the lessons taught by drugs. In doing so, it creates lasting memories by changing the nature of the conversations between neurons—a phenomenon neuroscientists call neuronal plasticity. Says Pulvirenti: "The plasticity that occurs during drug addiction most likely depends on glutamate transmission."

Of course, plasticity is also the basis of everyday learning and memory. Thus, the same neurotransmitter may hold the key to both preserving the good memories and erasing those planted by the tutors of addiction.

–Ingrid Wickelgren

Additional Reading

S. Grant *et al.*, "Activation of memory circuits during cue-elicited cocaine craving," *Proceedings of the National Academy of Sciences* **93**, 12040 (1996).

B. H. Herman and C. P. O'Brien, "Clinical medications development for opiate addiction: Focus on nonopioids and opioid antagonists for the amelioration of opiate withdrawal symptoms and relapse prevention," *Seminars in Neuroscience* **9**, 158 (1997).

R. C. Pierce *et al.*, "Repeated cocaine augments excitatory amino acid transmission in the nucleus accumbens only in rats having developed behavioral sensitization," *The Journal of Neuroscience* **16**, 1550 (1996).

R. Spanagel and W. Zieglgänsberger, "Anti-craving compounds for ethanol: New pharmacological tools to study addictive processes," *Trends in Pharmacological Sciences* **18**, 54 (1997).

ASTRONOMY

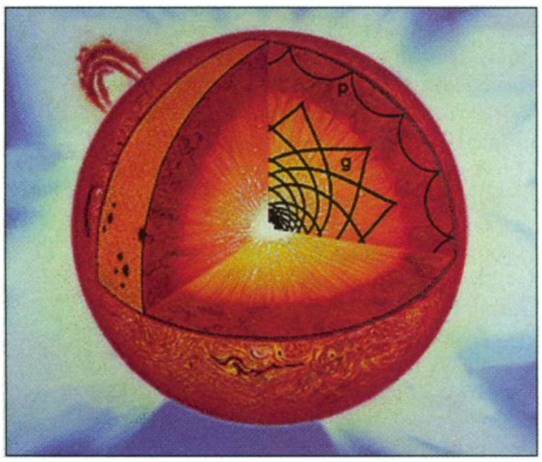
Seeking the Sun's Deepest Notes

The sun plays a silent symphony. It reverberates with oscillations that shake its surface and cause subtle frequency shifts in light from the glowing gases. These oscillations carry clues to the sun's interior, and astronomers have been watching them avidly with a network of telescopes called the Global Oscillation Network Group (GONG) and a space-based observatory called SOHO (*Science*, 31 May 1996, p. 1264). But so far, the sun's deepest notes—slow pulsations that stir its very core—have eluded them. At a workshop early this month in Boston, researchers discussed new strategies for identifying these deep undulations and weighed one claim of a candidate detection.

The solar oscillations studied so far are acoustic modes, which resemble sound waves. Generated by turbulence near the surface of the sun, they penetrate the interior and are deflected back toward the surface by the increase in density with depth. These so-called p-modes, which cause patches of the sun's surface to rise and fall over periods of from three to several dozen minutes, have helped solar physicists map the sun's density structure and interior flows (*Science*, 5 September 1997, p. 1438).

But p-modes don't penetrate to the core, where the sun's fusion power plant seethes. To probe those depths, astronomers need to pick up gravity or g-modes, in which large masses of gas heave up and down, driven by buoyancy. Such waves should have longer periods than the p-modes. "Thirty-six minutes … divides g-modes from p-modes," says Richard Bogart of Stanford University.

The exact frequencies and patterns of g-modes would help astronomers answer such questions as the rotation rate of the sun's core, which would affect deep mixing and the sun's nuclear processes. But the g-modes are thought to be weak and hard to pick out of the noise. "There are so many peaks in the power spectrum, and to tell which peak is real or just noise is almost impossible at this stage," says Jørgen Christensen-Dalsgaard of Århus University in Denmark.



SOURCE: SOHO

Plumbing the depths. G-modes stir the sun's core.

Alan Gabriel of France's Institute of Space Astrophysics near Paris reported at the meeting, however, that he may have caught a glimpse of g-modes in SOHO data. "I daringly announced two possible g-mode candidate frequencies. Emphasis is on the word candidate," he adds. Most astronomers *Science* talked to are not convinced that the reported signal—two peaks with periods of 66 and 75 minutes—is the real thing, however. "It's far too early to say whether those are really detections or just random peaks," says Bogart, who adds that it would take at least three or four peaks satisfying the expected frequency relationships to convince him.

Thierry Appourchaux of the European Space Research and Technology Centre in Noordwijk, the Netherlands, thinks he has a way to find stronger, more convincing peaks: Look at the limb of the sun—its visible edge—rather than the center of the disk. "At the solar limb, the same perturbation can give a three to four times stronger signal," he says, explaining that at the limb one can track the motions of higher layers of gas, where the density falls and the amplitude of the waves grows.

Because of instrument limitations, SOHO can't track motions at the solar limb. But Appourchaux is part of a group that will try this strategy for picking up the sun's low notes with PICARD, a small solar observatory that France will launch in 2002.

–Alexander Hellemans

Alexander Hellemans is a science writer in Naples.