

Communicating via Brain Waves

One of the most horrifying of medical conditions is the “locked in” state that may occur in brainstem stroke, severe cerebral palsy, or late-stage amyotrophic lateral sclerosis, sometimes called Lou Gehrig’s disease. A locked-in patient is paralyzed and unable to control any muscle, but can still see, hear, feel, and think. Such patients may be unable to communicate by any means, even by blinking or moving their eyes.

Neurobiology at the University of Tübingen in Germany, reported in *Nature* that it had enabled two completely locked-in patients to write letters by spelling them out on a computer that interpreted the patients’ brain waves. Birbaumer’s approach trains patients to control their slow cortical potentials (SCPs), the slowest-changing components of the EEG (which extends from dc to 50–60 Hz). The patients, who could hear and understand instructions,

were trained over about 50 hours to voluntarily increase the SCP (as measured between two scalp electrodes). They received visual feedback on a computer screen from a ball that moved up or down in response to the SCP.

Once the patients achieved about 75% accuracy in generating the SCP signal, they could use it to start spelling out messages. Half the alphabet appeared on the bottom of the

screen. If the patient produced no SCP, the other half of the alphabet was presented. If the patient did produce the SCP, the letters were split into two groups again and presented separately, and the process repeated until a single letter was selected. This letter was then added to the message on the top of the screen. Although the process is slow—about two letters per minute or 20 to 30 words per hour—it does offer a means of communication.

Another approach—pioneered by Jonathan Wolpaw and Dennis J. McFarland of the Wadsworth Center–New York State Department of Health and the State University of New York, Albany—trains people to alter the mu rhythm, the EEG frequency component from 8 to 12 Hz. Trainees, initially healthy volunteers but more recently disabled patients as well, had separate electrode pairs placed

on each side of their head. This pattern yielded two sets of EEGs, filtered to measure the amplitude of the mu rhythm. A cursor on a computer screen, which was divided into four quadrants, moved in response to the EEG as the subject tried to get the cursor to hit a series of “targets” located around the edge of the screen. If the cursor moved off the screen onto the target, it was a “hit,” and if it moved off anywhere else, it was a “miss.” Several algorithms were tried. The most successful moved the cursor up with large sums of the mu rhythm in both hemispheres, down with small sums, left for large differences in amplitude between the two hemispheres’ amplitudes, and right for smaller differences.

Over six- to eight-week training periods, most subjects can gain control of the cursor by learning to control their mu rhythms. Well-trained individuals can select between two targets with 80% to 90% accuracy (50% expected by chance) and between four targets with 60% to 70% accuracy (25% expected by chance). Initially, subjects reported using imagery (running to move the cursor down and floating to move it up), but as training progressed, moving the cursor became similar to other motor tasks. The subject could simply “will” the cursor in the right direction, and normally it obeyed.

Analysis showed that subjects were actually controlling narrow frequency bands, sometimes one frequency for up-down and another nearby for left-right movements. Most recently, the team trained some subjects to stop the cursor along a line, paving the way for a possibly faster means of selecting letters.

Although the large-scale electrical fields detected in the EEG are generated by millions of neurons acting together, another team uses a more invasive technique, one that monitors the firing of only a few cells. At Emory University, Philip Kennedy and Roy Bakay, an Atlanta neurosurgeon, insert a tiny glass cone containing two gold wires into a patient’s brain. In a few weeks, nerve cell fibers grow into the cone, touching the gold wires. This connection allows the neurons’ firings to be recorded. Again, a patient can be trained to control the neurons’ firing so as to guide a cursor on a computer screen. The



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“Locked in” patients who cannot control any muscles can now communicate via computers that interpret their brain waves.

But several research teams are developing new ways for these patients to communicate directly through their brain waves, the electrical fields produced by the brain and recorded as electroencephalograms (EEGs). Such communication might benefit several thousand new patients each year in the United States alone, and the techniques under study may open a new window on the functioning of the brain in healthy individuals.

“Even the most antisocial of us is a pretty social animal, and the inability to move and the loss of voice control are major depersonalizing disabilities,” says neurologist Daniel F. Hanley of the Johns Hopkins School of Medicine. “Making your feelings known to other people is central to maintaining your human characteristics.”


In March, a team led by N. Birbaumer of the Institute of Medical Psychology and Behavioral

major point of such work, Dr. Hanley notes, “may well be that people can control their electrical impulses in the brain, can be trained to modulate how they do that, and that there is value to many individuals with impairment to do this.”

Not all approaches train people to control their own brain waves. Several research groups are trying to use computers to recognize the natural EEG patterns produced by the brain that correlate with certain mental states. These states include individual words or simple phrases, or the intention to move a limb. At the Technical University of Graz in Austria, G. Pfurtscheller used multiple electrodes attached to the scalp to measure the responses of the sensorimotor cortex in several frequency bands of the EEG as a healthy subject moved a joystick to the left or right. A neural network was trained to recognize the pattern associated with either movement and then recognize the EEG pattern when the subject only thought about moving the joystick. (Neural networks are computer programs that automatically adjust the strengths of connections among three layers of circuits in response to training. They are useful in many pattern-recognition applications and are broadly modeled on neural connections.) The system has about 90% accuracy, allowing normal subjects to move cursors in one dimension merely by thinking about moving it with their hand. If the patterns are found to be consistent from subject to subject, such systems could be used for locked-in patients.

At Stanford University’s Center for the Study of Language and Information, Patrick Suppe and Zhong-Lin Lu of the University of Southern California, and Stanford graduate student Bing Han, have used 1-second patterns of EEGs, filtered within certain frequency bands, as templates to recognize the words that a person has just heard or read. An average of 50 EEG patterns is used as the prototype for each word or simple three-word sentence, which the subject sees on a screen or hears. Suppe then has the computer compare a new test pattern, generated in response to one of the words, to the prototypes. The computer simply cal-

culates the “sum of the squares” difference between the new pattern and each of the prototypes, and selects as a match the prototype with the least difference. If the prototype that the computer selects corresponds to the word actually heard or read, the match is correct. For some people, the computer achieves correct matches as high as 90%, although accuracy varies widely from person to person. It is noteworthy that the patterns for different people are similar, and a given word has similar patterns whether it is heard or read.

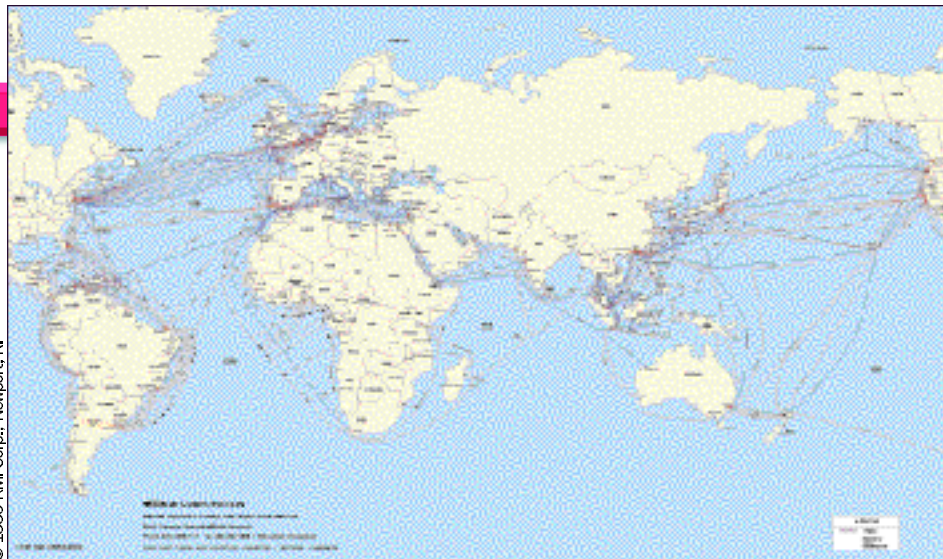
Suppe’s work aims more at understanding how the brain uses electrical fields to generate and process thought than at any clinical applications. However, such research may eventually lead to a means of recognizing words just as a locked-in patient thinks them, which would allow more rapid and flexible communication. 

Fiber-optic cable

The length of undersea fiber-optic cable should more than double by 2003 to nearly 890,000 km, according to KMI Corp. (Newport, RI), a market-research firm. Driven by the apparently insatiable demand for inexpensive intercontinental links, telecommunication companies plan to spend \$27.5 billion for fiber-optic cables over the next three to four years, KMI says in its report, 1999 Worldwide Summary of Fiberoptic Undersea Systems.

In the past, estimates of planned cable projects have proven too conservative. In 1989, long-term predictions called for only 115,000 km of cable to be laid by 2003, about one-eighth of the total now expected and one-quarter of that already laid by the beginning of 1999. KMI’s forecast itself may be too conservative, says David Bain of Lucent Technologies’ Atlanta Works, a leading fiber-optic cable maker. “Up to 2002, you are going to see a number of transatlantic cable systems put in place,” he says. “Following that, two years behind, are the transpacific networks.”


However, an overestimate is also possible. Current plans call for \$10.6 billion, nearly 40% of the investment, to go for



Worldwide undersea fiber-optic cable routes planned and in place.

cables in the Pacific region. With Japan and most of Asia in deep economic recession or outright depression, companies may cut back or delay some projects. However, says Bain, “Asia is starting to recover; we’re seeing signs of that.”

The capacity of the fiber-optic global network is growing faster than the length of cable laid, because new and existing cables are being fitted with systems that carry data at higher rates. Wavelength division multiplexing, which uses multiple wavelengths of light over the same fiber, is in widespread use, and field tests are under way for the next level of technology. This system uses solitons—pulses that maintain their shape over long distances without dispersion—and has proven capable of data rates above 40 Gb/s over transmission lengths of 1,000 km. A continued rapid increase in data rates, combined with the growing web of fiber-optic cables, should keep pace with demand over the next few years.

“You’re getting more wavelengths, faster speed, on more fiber,” Bain says. “People ask: where is the demand? The demand is being driven by data—e-mail, the Internet, video.” 

Magnetic surgery

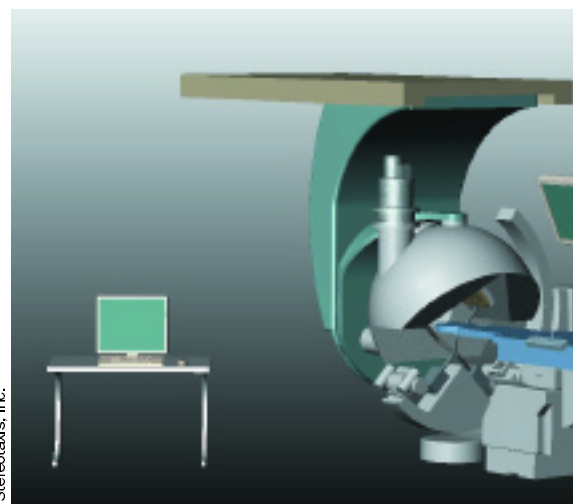
When the brain requires surgery, say for a tumor, the operation itself can do a lot of damage because a surgeon may have to destroy some healthy tissue to get to the disease site. One way to minimize such damage has moved a step closer to commercial reality with the agreement of Oxford Instruments (Abingdon, England) to help bring a magnetic surgery system developed by Stereotaxis, Inc. (St. Louis,

MO) to market. In magnetic surgery, a magnetized tip attached to a flexible wire inside a hollow catheter is directed by a strong and precise magnetic field along a curving path to the affected area of the brain, thus minimizing damage to vital regions.

“This new system is a fundamentally new approach to guiding surgical instruments during brain surgery,” says Ralph G. Dacey, professor of neurological surgery at Washington University School of Medicine in St. Louis.

The Stereotaxis system, whose development started in the mid-1980s, uses three superconducting magnets placed around a patient’s head, with their field axes mutually perpendicular. The 5-T, 40-cm-diameter coils generate a precise, computer-controlled field that orients the magnet tip in the correct direction in three-dimensional space. An external electric motor is then used to drive the tip forward, cutting a narrow path through the brain.

The catheter is inserted through a dime-size hole cut in the skull. Then the surgeon




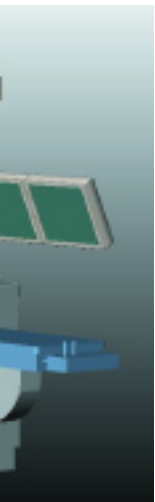
uses a computer mouse to chart a circuitous path on a preoperative magnetic resonance image, which enables the cutting tip to avoid sensitive regions of the brain. The computer changes the magnetic field of the superconducting magnets surrounding the patient's head to guide the tip along the pre-determined route.

"Not only does this system allow us to follow a curved path through the brain, but for the first time, a computer is able to steer a catheter using externally applied magnetic fields acting on the catheter tip, giving us greater navigational control," Dr. Dacey says.

The magnets are powerful enough to guide a 3-mm³ tip through the brain and accurate enough to locate the tip with a precision of less than 1 mm. Once the tip arrives at its target, it is withdrawn through the catheter. Then, medication can be delivered precisely through the catheter to the area; brain tissue can be removed for biopsy; or the surgeon can excise part of the brain, as in cancer surgery.

Oxford's efforts focus on ensuring that the magnets are rigid enough to withstand the high sweep rates and changes of magnetic field that are required, and making them compact and portable enough to assure easy use.

Two patients have been operated on successfully in the first human test of the system. Stereotaxis expects to seek approval from the U.S. Food and Drug Administration before the end of the year to conduct a larger study. The company also envisions its system as eventually applicable to the diagnosis and treatment of several cardiovascular conditions, including coronary heart disease and aneurysms. 



In the operational position, the three-coil magnet system covers the X-ray system on a C-arm positioner at the head of the patient table. The X-ray monitors and workstation are also shown.