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SPECIAL REPORT
A Guide to the 21st CENTURY

Rewiring Your Gray Matter

The brain: You can teach an old brain new tricks. Neuroplasticity promises to give a whole new meaning to 'changing your mind.' **By Sharon Begley**

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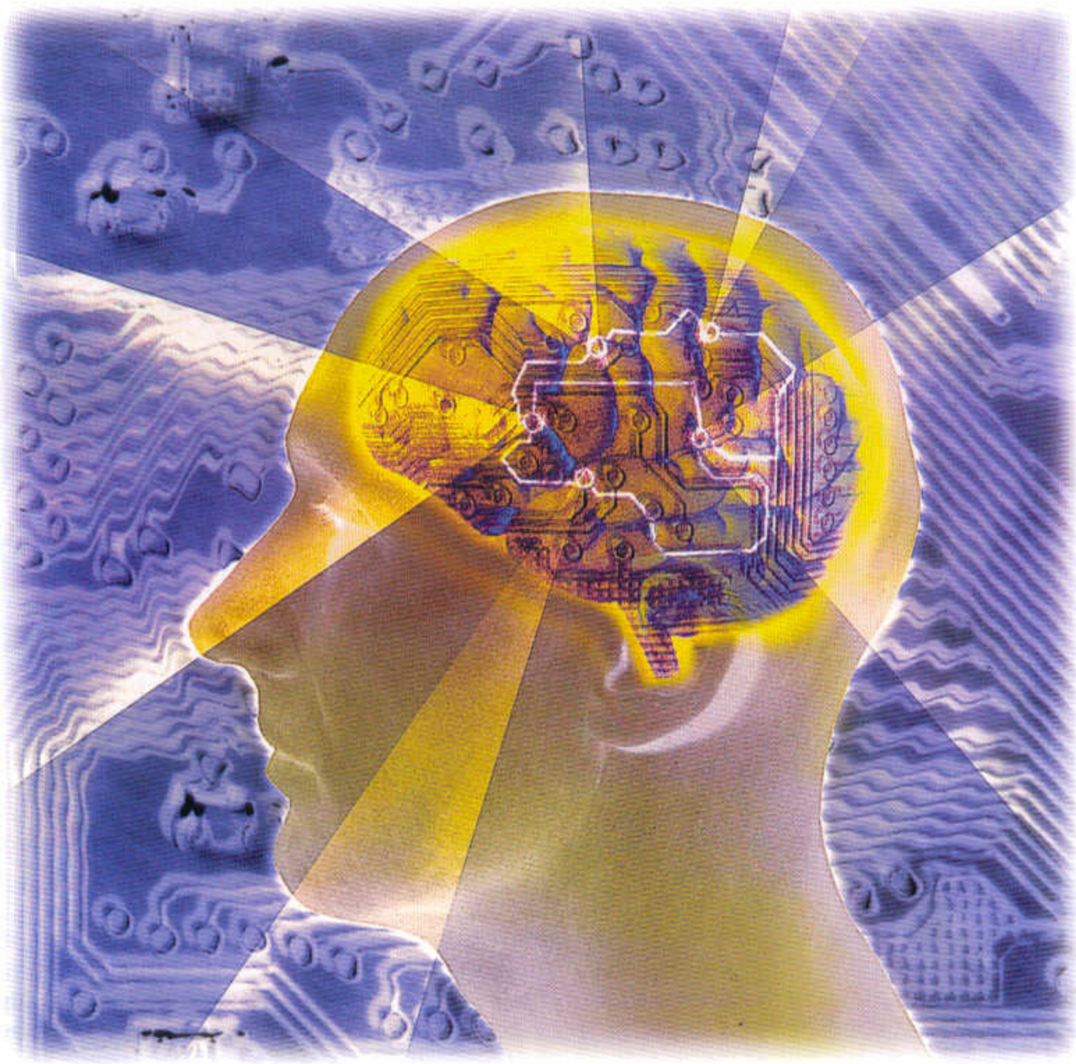

"LADIES AND GENTLEMEN, children of all ages!" booms the cartoonish little ringmaster on the computer screen. "Welcome to the Circus Sequence game!" Although it has all the earmarks of a typical educational CD, once Circus Sequence and the other six games that make up Fast ForWord get past the words of welcome, they sound decidedly odd—and for good reason. The players are otherwise normal children 4 to 14 who cannot distinguish between similar short sounds, like "da" and "ka." They have trouble linking written words with sounds, and therefore with learning to read. So when the computer asks the players to "point to rake" when a picture of a lake is also offered, or to release the cursor over a flying pig when a series of spoken "g's" is interrupted by a "k," it stretches out the target sounds. The usual .003-second difference between "day" and "bay," for instance, lasts several times that long. And with this simple trick, Fast ForWord does something quite a bit more revolutionary than your run-of-the-mill educational CD: it rewires brains.

In 1989 President George Bush signed a resolution declaring the 1990s the Decade of the Brain. Neuroscientists lived up to the advance billing. In the '90s they used neuroimaging to locate regions of the brain associated with everything from recognizing faces to playing Tetris. They linked genes to mental illnesses and to Alzheimer's disease and Parkinson's. They discovered molecular changes that underlie memories. Of all the finds, though, one is rewriting the textbooks. It is the dawning realization that a brain older than three years is not the rigid structure that scientists long thought, but a malleable, "plastic" organ. "Ever since the 1950s one of the great themes in neuroscience had been that neurons in the cortex matured during a critical period in the first few years of life, and that the brain's organization did not change much after that," says neurobiologist Michael Merzenich of the University of California, San Francisco. But a flood of discoveries shows that the brain continually reorganizes itself. It's called "neuroplasticity." And it means that "you create your brain from the input you get," says Paula Tallal, codirector of the Center for Molecular and Behavioral Neuroscience at Rutgers University in Newark, N.J.

Creating brains: neuroscientists are not immune to millennium dreams. They

PHOTO ILLUSTRATION BY PHILIP KAAKE

Aid to education: 'In 10 to 15 years every school ... will be able to deliver help based on brain plasticity'

imagine that in the new century they will master "directed neuroplasticity," that is, they will figure out what sequence of specific inputs changes the brain in desirable ways. Through special brain exercises, they hope, they will be able to untangle our circuits to relieve depression, cure learning disabilities, rehabilitate stroke victims, postpone the worst of Alzheimer's disease—even undo the brain wiring that supports racism. With hardly a glance back at "A Clockwork Orange," they foresee astonishing possibilities for teaching old brains new tricks. Says Jon Kaas of Vanderbilt University: "Once we understand the mechanisms of neuroplasticity, we could give people the tools to maximally alter their brains in ways they want."

Improved learning based on neuroscience may be the first dream to be realized. Educators, for the most part, ignore (or are ignorant of) the mechanisms by which the brain changes so that it is capable of, say, deductive logic. But make no mistake: the brain capable of logic is physically different from the brain that is not. Tallal and Merzenich figured out that a brain that cannot recognize the differences between the sounds of "gee" and "key," or "zip" and "sip," is different from a brain that can. With Fast ForWord, made by Scientific Learning Corp., they set about changing the brain so that it recognizes such lightning-fast phonemes. Some 500 school systems have bought the program, and 25,000 children have been trained on it for 100 minutes a day, five days a week. After six to eight weeks, "90 percent of the kids who complete the program made 1.5 to two years of progress in reading skills," says Tallal.

They hope to exploit brain plasticity for other kinds of learning. "Just as we can now fix the brain's way of connecting oral language with the written word, so I think we will find the keystone that underlies mathematical ability," Merzenich says. "Ultimately, this strategy will lead to neuroscience-based education. In 10 to 15 years this will be everywhere, and every school will be able to deliver help based on brain plasticity."

"Learning" doesn't mean only academics: neuroplasticity might become the latest weapon in a coach's arsenal. Highly precise, patterned movements, whether dribbling a soccer ball or driving a golf ball 200 straight yards, seem to arise from dedicated brain circuits. When researchers led by Leslie Ungerleider at the National Institutes of Health scanned the brains of people who were tapping their fingers in a complicated sequence that they had practiced for weeks, they got a surprise. "A larger area of motor cortex becomes activated than when they perform sequences they haven't practiced," says Ungerleider. In the adult brain, this suggests that "experience does have effects. It leads to expanded representations of skilled movements." These representations—neural circuits—command the body to carry out a sequence of movements, much as the scrolls in a player piano command keys to move. If neuroscientists figure out how to create these circuits, as they have figured out how to create circuits crucial to reading, the hit-or-miss training of today could give way to more efficient, neuro-based techniques.

Just as the brains of the Fast ForWord kids lack the circuitry to distinguish "bay" from "day," so native Japanese speakers lack the circuitry to distinguish "ra" from "la" (though Japanese newborns, like every normal newborn, can tell the difference). The reason is that Japanese makes no distinction between the sounds; a brain born with the ability to hear the difference forgets how. But neuroplasticity can be harnessed to reverse the change. James McClelland of the University of Pittsburgh had Japanese adults listen to a computer repeat two English words over and over in random order: "road, road, load, road, load," etc. The subjects indicated on a keyboard which word they had heard. Their ability to distinguish "r" from "l" "jumped significantly" after training, McClelland reported.

FROM TOP: PHOTO ILLUSTRATION BY PHILIP KAAKE
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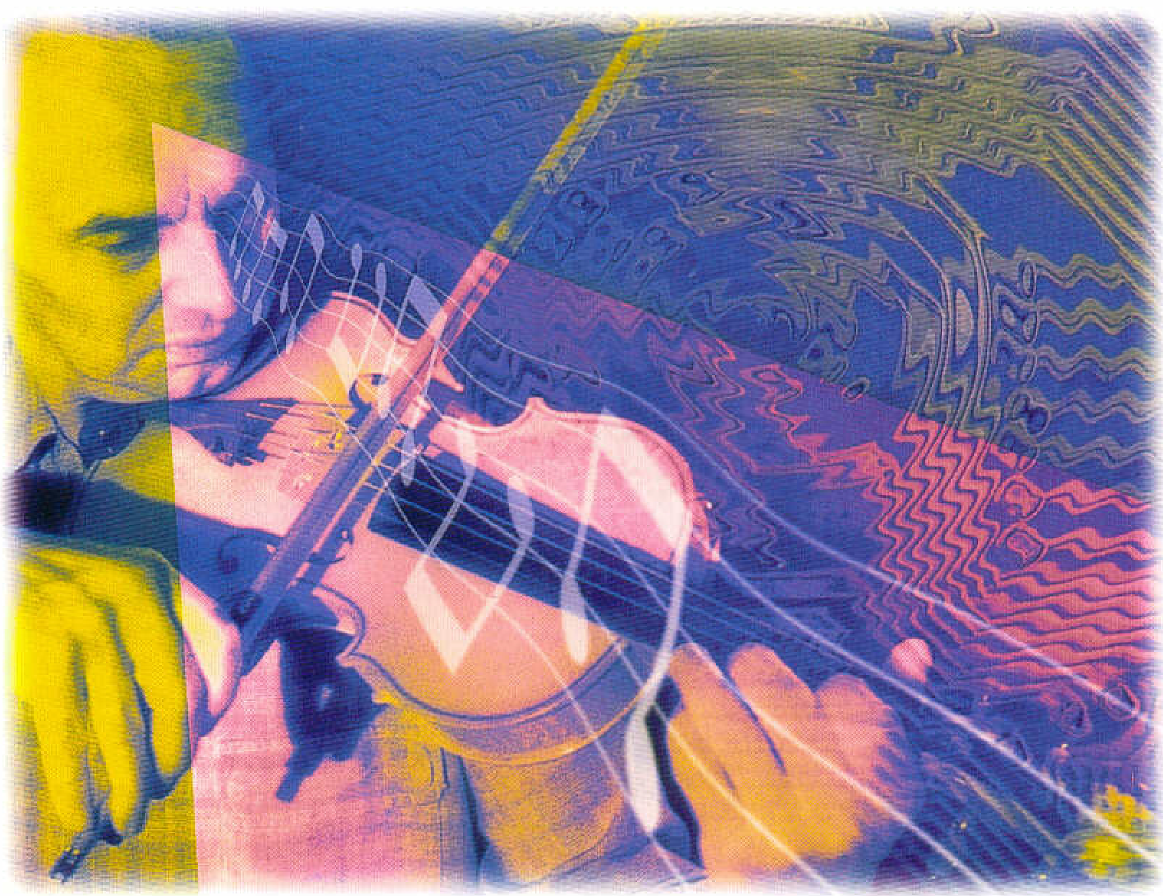
HE HAS GRANDER dreams than eliminating accents. McClelland suggests that neural circuits that bypass conscious awareness might underlie racial and other stereotypes. Perhaps the sight of, say, Asian features triggers in some people a cascade of electrical impulses leading directly to the cluster of neurons that mean fear or hate. "We could think about structuring situations to present a stimulus that originally elicits the fear response, and then train the brain to have a different reaction," McClelland suggests.

No brain book is complete without a diagram showing which regions are zoned for what function. Neuroplasticity acts like a fickle zoning board. A chunk of the brain's real estate may, from birth, have been designated "the region where sensations on the right pinkie register." But experiences can rezone the brain. Learning to read Braille expands what's called the cortical representation of the fingertips. Playing a string instrument increases the area that receives input from the fingering hand. Sometimes this creates problems. Intense piano practice can fool the brain into using a single chunk of neural real estate to process sensation from several fingers, rather than giving each its own bit of cortex. The result is a condition called focal hand dystonia, in which the sufferer cannot raise her forefinger, for instance, without the middle finger's curling or rising up too. After repetitive and near-simultaneous stimulation of the fingers—think "Flight of the Bumblebee"—"the brain begins to interpret signals from one finger as coming from several," says UCSF's Nancy Byl. She is exploiting neuroplasticity to retrain the cortex. By having patients trace designs on first one finger, then another, and handle little objects like buttons or keys, Byl trains their brains to process input from each finger separately once again. Cortical retraining also holds out hope for more common afflictions. "The impact of Alzheimer's disease could be postponed if we used brain plasticity to reroute neurons" around damaged areas, says Kaas. The idea is to perform the neural version of an electrician's wiring a shunt around the damaged part of an electrical circuit.



Plasticity is also the basis for a promising new therapy for stroke. Psychologist Edward Taub of the University of Alabama at Birmingham reasoned that if you constrain the unaffected arm of a patient whose stroke has immobilized the other arm, he would have to stop coddling the affected arm. Instead, in what Taub calls constraint-induced (CI) movement therapy, therapists have patients do exercises like grasping objects and fitting pegs into holes with their bad arms. CI therapy, says Taub, seems to recruit intact areas of the brain to take over from damaged regions—in this case, regions responsible for moving an arm. "The sling that we use to constrain the good arm is not a magic talisman," says Taub. "The only thing it does is induce repetitive use of the affected limb, which in turn induces cortical reorganization. The area responsible for producing movements of the affected arm more than doubles in size." CI therapy has restored function to patients as much as 21 years after their strokes. "With determination and repeated acts of will, some people can change how their brain functions," says Taub.

There are limits to neuroplasticity, of course. It probably can't overcome mental retardation, for instance, or give a klutz the body control of Michael Jordan. But the fact that it exists at all was hardly suspected just a few years ago. Now neuroscientists are on the cusp of the unthinkable: figuring out how people can create the brain they want.

With ERIKA CHECK

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