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Amping Up Brain Function: Transcranial Stimulation Shows Promise in Speeding Up Learning

Electrical stimulation of subjects' brains is found to accelerate learning in military and civilian subjects, although researchers are yet wary of drawing larger conclusions about the mechanism

By R. Douglas Fields | Friday, November 25, 2011 | 23 comments

WASHINGTON, D.C.—One of the most difficult tasks to teach Air Force pilots who guide unmanned attack drones is how to pick out targets in complex radar images. Pilot training is currently one of the biggest bottlenecks in deploying these new, deadly weapons.

So Air Force researchers were delighted recently to learn that they could cut training time in half by delivering a mild electrical current (two milliamperes of direct current for 30 minutes) to pilot's brains during training sessions on video simulators. The current is delivered through EEG (electroencephalographic) electrodes placed on the scalp. Biomedical engineer Andy McKinley and colleagues at the Air Force Research Laboratory at Wright–Patterson Air Force Base, reported their finding on this so-called transcranial direct current stimulation (TDCS) here at the Society for Neuroscience annual meeting on November 13.

"I don't know of anything that would be comparable," McKinley said, contrasting the cognitive boost of TDCS with, for example, caffeine or other stimulants that have been tested as enhancements to learning. TDCS not only accelerated learning, pilot accuracy was sustained in trials lasting up to 40 minutes. Typically accuracy in identifying threats declines steadily after 20 minutes. Beyond accelerating pilot training, TDCS could have many medical applications in the military and beyond by accelerating retraining and recovery after brain injury or disease.

The question for the Air Force and others interested in transcranial stimulation is whether these findings will hold up over time or will land in the dustbin of pseudoscience.

"There is so much pop science out there on this right now," says neurobiologist Rex Jung of the University of New Mexico Health Sciences Center in Albuquerque, referring to sensational media reports, the widely varying protocols and sometimes lax controls used in different studies of brain stimulation to power learning or elevate mood.

Indeed, electrical stimulation for therapeutic effect has a long and checkered history extending back to the 19th century when "electrotherapy" was the rage among adventurous medical doctors as well as quacks. Pulses of electric current were applied to treat a wide range of conditions from insomnia to uterine cancer. The placebo effect might have been at work in the case of those historical results, and although the experiments were carefully controlled, it is unclear to skeptics if it is a factor in the case of the Air Force's research on transcranial stimulation and learning.

Subjects definitely register the stimulation, but it is not unpleasant. "It feels like a mild tickling or slight burning," says undergraduate student Lauren Bullard, who was one of the subjects in another study on TDCS and learning reported at the meeting, along with her mentors Jung and Michael Weisend and colleagues of the Mind Research Network in Albuquerque. "Afterward I feel more alert," she says. But why?

Bullard and her co-authors sought to determine if they could measure any tangible changes in the brain after TDCS, which could explain how the treatment accelerates learning. The researchers looked for both functional changes in the brain (altered brain-wave activity) and physical changes (by examining MRI brain scans) after TDCS.

They used magnetoencephalography (MEG) to record magnetic fields (brain waves) produced by sensory stimulation (sound, touch and light, for example), while test subjects received TDCS. The researchers reported that TDCS gave a six-times baseline boost to the amplitude of a brain wave generated in response to stimulating a sensory nerve in the arm. The boost was not seen when mock TDCS was used, which produced a similar sensation on the scalp, but was ineffective in exciting brain tissue. The effect also persisted long after TDCS was stopped. The sensory-evoked brain wave remained 2.5 times greater than normal 50 minutes after TDCS. These results suggest that TDCS increases cerebral cortex excitability, thereby heightening arousal, increasing responses to sensory input, and accelerating information processing in cortical circuits.

Remarkably, MRI brain scans revealed clear structural changes in the brain as soon as five days after TDCS. Neurons in the cerebral cortex connect with one another to form circuits via massive bundles of nerve fibers (axons) buried deep below the brain's surface in "white matter tracts." The fiber bundles were found to be more robust and more highly organized after TDCS. No changes were seen on the opposite side of the brain that was not stimulated by the scalp electrodes.

The structural changes in white matter detected by the MRI technique, called diffusion tensor imaging (DTI), could be caused by a number of microscopic physical or cellular alterations in brain tissue, but identifying those is impossible without obtaining samples of the tissue for analysis under a microscope.

An expert on brain imaging, Robert Turner of the Department of Neurophysics at the Max Planck Institute for Human Cognitive and Brain Sciences, in Leipzig, Germany, who was not involved in the study, speculated that the changes detected by DTI could represent an increase in insulation on the fibers (myelin) that would speed transmission of information through the fibers. "In my present view, the leading hypothesis for the observed rapid changes…is that previously unmyelinated axonal fibers within white matter become rapidly myelinated when they start to carry frequent action potentials," he says. There are, however, several other possible explanations, he cautions.

Matthias Witkowski, now at the Institute for Medicine, Psychology and Behavioral Neurobiology at the University of Tübingen in Germany, described the rapid changes in white matter in these experiments as "incredible." "That [white matter changes] would not have been my first guess," he said. "It will be very interesting to see if there are cellular changes." This is the next step in research planned by Jung and colleagues. They hope to obtain brain tissue from patients who would be willing to participate in TDCS studies prior to undergoing necessary brain surgery in which tissue would be removed as a required part of their treatment.

Witkowski is convinced by these new studies and his own research that transcranial stimulation can accelerate many kinds of learning, and research on brain–machine interfacing, which he presented at the meeting, demonstrates the potential for TDCS in speeding patient rehabilitation after injury. People with paralyzed limbs can be taught to control a robotic glovelike device that will move their fingers in response to the patient's own thoughts. Electrodes on the person's scalp pick up brain waves as the person imagines moving his or her hand. The brain waves are analyzed by a computer to control the robotic artificial hand. But learning to generate the proper brain waves to control the artificial hand through thought alone requires considerable training. Witkowski found that if patients received 20 minutes of TDCS stimulation once during five days of training, they learned to control the hand with their thoughts much more rapidly.

The new studies reported at this meeting suggest that there is far more to speed learning produced by TDCS than can be explained by the placebo effect. And the evidence now shows that TDCS produces physical changes in the brain's structure as well as physiological changes in its response. TDCS increases cortical excitability, which can be measured in recordings of brain waves, and it also causes changes in the structure of the brain's connections that can be observed on an MRI. By using electricity to energize neural circuits in the cerebral cortex, researchers are hopeful that they have found a harmless and drug-free way to double the speed of learning.