Not responding. A new EEG technique (*above*) might one day help doctors assess vegetative-state patients for any glimmer of consciousness.

CREDITS (LEFT TO RIGHT): CAROL GUZY/*THE WASHINGTON POST*/GETTY IMAGES; COURTESY OF STEVEN LAUREYS

NEUROSCIENCE

Feedback From Frontal Cortex May Be a Signature of Consciousness

In recent years, researchers working with people who've suffered massive brain injuries due to accidents, hemorrhages, or other causes have found evidence that some patients who show few outward signs of awareness can experience pain and may even have a degree of consciousness. Better methods for assessing consciousness in these patients might help doctors calibrate pain medication and predict their prognoses, and they might help give comfort or closure to families desperate to know whether a loved one can understand their words or feel their touch.

In this week's issue of *Science* (p. 858), researchers describe a potential step in that direction. By feeding electroencephalographic (EEG) recordings of brain activity into a sophisticated mathematical model, they say they have identified a neural signature of consciousness that is present in healthy people and brain-damaged patients who retain some awareness, but not in people who are truly in a vegetative state. Other researchers say the method is innovative but not ready for clinical use. In the meantime, however, the study may provide insights into the mystery of how consciousness is embodied in the human brain.

Researchers led by Melanie Boly and Steven Laureys of the Coma Science Group at the University of Liège in Belgium collected EEG recordings in 22 healthy volunteers and 21 brain-damaged patients. (Their families gave permission.) Eight patients were diagnosed as being in a vegetative state, characterized by only reflexive responses, and 13 were in a minimally conscious state, a less profound impairment in which patients have occasional flashes of responsiveness, such as following an object with their eyes or squeezing someone's hand on command.

The researchers made the EEG recordings while subjects listened to a series of tones. Previous studies with healthy people have found a characteristic pattern of ups and downs in the EEG trace that lasts several hundred milliseconds after the pitch of the tones suddenly changes—a sign that the brain has noticed. These blips diminish during sleep and under anesthesia, suggesting to some researchers that they may be an indicator of consciousness. Boly and colleagues found that in the vegetative-state patients, the response to changing pitch was diminished and fleeting, lasting less than 100 milliseconds.

To investigate why, the Belgian team collaborated with neuroscientist Karl Friston and colleagues at University College London, who have developed mathematical models that enable researchers to infer the network of brain regions that gives rise to a specific EEG signal. This modeling showed that in all of the study subjects, including those in a vegetative state, the tones stimulated activity in parts of the temporal cortex specialized for processing sounds.

Neuroscientists generally agree that the brain processes sounds and other stimuli in a hierarchical fashion: Signals flow up from the brainstem to areas of the temporal cortex that analyze the frequency, timing, and location of sounds, and then on to "higher" areas of the parietal and frontal cortex thought to contribute to conscious awareness ("That's my cell phone ringing,") and decision-making (a looming deadline or "no time to talk"). In healthy subjects and minimally conscious patients, the modeling indicated, the frontal and parietal cortex send signals back down to the temporal cortex, completing a feedback loop. In vegetative-state patients, this feedback signal was absent, which explains their truncated EEG responses to the changing tones. "What we've shown is that it's this top-down communication from these frontal and parietal networks that is necessary for you to be conscious," Laureys says.

The findings give experimental support to a model of consciousness advocated by Lionel Naccache, a neurologist and cognitive neuroscientist at the French biomedical research agency INSERM in Paris, and colleagues. "We've proposed from a theoretical point of view that the first stages of perception are not conscious, and that conscious perception arises from a long-range conversation across cortical regions," Naccache says. He thinks the new EEG method has "a lot of potential" for improving the clinical diagnoses of unresponsive patients.

One caveat is that the method has only been shown to distinguish groups of people, says Adrian Owen, a neuroscientist at the University of Western Ontario in London, Canada. "In a clinical setting, you want to look at an individual and say whether that person is conscious or not," Owen says. In 2006, Owen and colleagues reported such a method, using functional magnetic resonance imaging (fMRI) to reveal surprisingly robust activity in the brain of one unresponsive subject after she'd been instructed to imagine herself engaging in specific activities such as walking through her house (*Science*, 8 September 2006, p. 1402). His group is working on adapting that method for use with EEG, which is cheaper and more portable than fMRI. "It's obvious that for something to be clinically viable, it's going to have to be EEG-based," Owen says.

It remains to be seen which tool—or more likely, combination of tools—will be most useful for distinguishing vegetative-state patients from those with some level of awareness, says Nicholas Schiff, a neurologist at Weill Cornell Medical College in New York City. But such tools are sorely needed, Schiff says: "What you risk is too great a medical error to be tolerated."

–GREG MILLER

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