Deep sleep short-circuits brain’s grid of connectivity

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In the human brain, cells talk to one another through the routine exchange of electrical signals. But when people fall into a deep sleep, the higher regions of the brain - regions that during waking hours are a bustling grid of neural dialogue - apparently lose their ability to communicate effectively, causing consciousness to fade.

Writing Friday, Sept. 30, in the journal Science, a team of researchers led by UW-Madison professor of psychiatry Giulio Tononi reports that the fading of consciousness during dreamless sleep seems to occur as the different regions of the cerebral cortex that mediate perception, thought and action become functionally disconnected.

Tononi and his team observed the disconnect when brief, magnetically generated pulses of electricity were directed to specific regions of the brain. The pulses stimulated an electrochemical response from the targeted cells, which, when the subject was awake, rippled across the brain, traveling along networks of nerve fibers to different cerebral destinations. But when the subject was in deep sleep, the same response was quickly extinguished and did not travel beyond the stimulated cells.

When consciousness fades, according to Tononi, "the brain breaks down into little islands that can't talk to one another."

The new findings are important because they provide the first direct clues about how the brain alters the state of consciousness during sleep. Consciousness is a scientifically murky realm as little research has been conducted on how the brain sustains and alters the various states of mind. Tononi, one of the few scientists exploring the frontiers of consciousness, has theorized that conscious thought depends on the brain's ability to integrate information.

"Sleep is the most familiar alteration of consciousness," he says. "It happens every night to all of us. Every night, when you fall into deep sleep, your consciousness usually fades."

Indeed, research subjects woken early in the night frequently report little or no conscious experience. Later in the night, and especially in the morning hours, subjects report vivid dreams, indicating that the later stages of sleep can be associated with conscious experience, Tononi says.

But why does consciousness fade during deep sleep early in the night? "You cannot say that consciousness fades because the brain shuts off. That's not the case. Scientists have long known that the brain remains active while we sleep," Tononi says. "So what could be responsible?"

To explore the breakdown of consciousness during sleep, Tononi and his colleagues capitalized on a new technology - transcranial magnetic stimulation - that permits precise, non-invasive activation of small regions of the brain. Subjects are also equipped with a cap of electrodes to monitor the brain's electrical activity so that the cell signals elicited by the quick bursts of electricity can be tracked.

In subjects who are awake, the pulses elicited a significant response: "The brain reacts in a strong and specific manner," Tononi explains. "There is a very interesting set of activations that occur over great distances in the cortex.

"During deep sleep early in the night," he adds, "the response is short-lived and doesn't propagate at all. Somehow, it doesn't travel anywhere."

The experiments conducted by the Wisconsin team are the first of their kind. The results lend support to the idea that consciousness depends on the ability of the brain to integrate information. In other words, consciousness rests on the ability of the various regions of the brain to talk to one another.

In the brain, messages are relayed along networks of nerve fibers. Cells transmit information along those fibers electrochemically. Anatomically, the fibers are analogous to the cables that computers use to share information. But the network of nerve fibers, like a tangle of computer cables, is not transparent and may not always be in use.

"What we needed to do was stimulate an area of the brain and see if it talks to another part. We have a tool to do that now," says Tononi, referencing one of only a handful of machines in the world capable of stimulating precise regions of the brain from outside the skull while recording the resulting electrical responses.

The paddle-like device is placed over the head of a subject and generates a magnetic field. The magnetic field, in turn, produces pulses of electricity lasting less than a millisecond and that are capable of penetrating the skull to stimulate brain cells.

"Essentially, we activate an area," Tononi says. "We can do this anywhere in the brain. Once an area is activated, it responds by sending signals, waves that travel through the axons (nerve fibers) to other regions of the brain. At the same time, we can record how the rest of the brain is responding."

The new technique promises science a way to see how the different areas of the brain communicate, Tononi says.

Beyond helping illuminate the secrets of consciousness, the new study, which was directed in part by Marcello Massimini, a research associate in the UW Psychiatric Institute and Clinics, may aid in the development of diagnostic and therapeutic tools for neurological and psychiatric disorders that affect consciousness, such as schizophrenia. That work is now being pursued by the Wisconsin group.

In addition to Tononi and Massimini, co-authors of the Science paper include Fabio Ferrarelli, Reto Huber, Steve K. Esser and Harpreet Singh, all of UW-Madison.

Source: University of Wisconsin System