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Ultrasound directed to the human brain can boost sensory performance

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William "Jamie" Tyler, an assistant professor at the Virginia Tech Carilion Research Institute, studied the effects of ultrasound on the region of the brain responsible for processing tactile sensory inputs. Credit: Jim Stroup/Virginia Tech

Whales, bats, and even praying mantises use ultrasound as a sensory guidance system—and now a new study has found that ultrasound can modulate brain activity to heighten sensory perception in humans.

Virginia Tech Carilion Research Institute scientists have demonstrated that ultrasound directed to a specific region of the brain can boost performance in sensory discrimination. The study, published online Jan. 12 in *Nature Neuroscience*, provides the first demonstration that low-intensity, transcranial-focused ultrasound can modulate human brain activity to enhance perception.

"Ultrasound has great potential for bringing unprecedented resolution to the growing trend of mapping the human brain's connectivity," said William "Jamie" Tyler, an assistant professor at the Virginia Tech Carilion Research Institute, who led the study. "So we decided to look at the effects of ultrasound on the region of the brain responsible for processing tactile sensory inputs."

The scientists delivered focused ultrasound to an area of the cerebral cortex that processes sensory information received from the hand. To stimulate the median nerve—a major nerve that runs down the arm and the only one that passes through the carpal tunnel—they placed a small electrode on the wrist of human volunteers and recorded their brain responses using electroencephalography, or EEG. Then, just before stimulating the nerve, they began delivering ultrasound to the targeted brain region.

The scientists found that the ultrasound both decreased the EEG signal and weakened the brain waves responsible for encoding tactile stimulation.

The scientists then administered two classic neurological tests: the two-point discrimination test, which measures a subject's ability to distinguish whether two nearby objects touching the skin are truly two distinct points, rather than one; and the frequency discrimination task, a test that measures sensitivity to the frequency of a chain of air puffs.

What the scientists found was unexpected.

The subjects receiving ultrasound showed significant improvements in their ability to distinguish pins at closer distances and to discriminate small frequency differences between successive air puffs.

"Our observations surprised us," said Tyler. "Even though the brain waves associated with the tactile stimulation had weakened, people actually got better at detecting differences in sensations."

Why would suppression of brain responses to sensory stimulation heighten perception? Tyler speculates that the ultrasound affected an important neurological balance.

"It seems paradoxical, but we suspect that the particular ultrasound waveform we used in the study alters the balance of synaptic inhibition and excitation between neighboring neurons within the cerebral cortex," Tyler said. "We believe focused ultrasound changed the balance of ongoing excitation and inhibition processing sensory stimuli in the brain region targeted and that this shift prevented the spatial spread of excitation in response to stimuli resulting in a functional improvement in perception."

To understand how well they could pinpoint the effect, the research team moved the acoustic beam one centimeter in either direction of the original site of brain stimulation – and the effect disappeared.

"That means we can use ultrasound to target an area of the brain as small as the size of an M&M," Tyler said. "This finding represents a new way of noninvasively modulating human brain activity with a better spatial resolution than anything currently available."

Based on the findings of the current study and an earlier one, the researchers concluded that ultrasound has a greater spatial resolution than two other leading noninvasive brain stimulation technologies—transcranial magnetic stimulation, which uses magnets to activate the brain, and transcranial direct current stimulation, which uses weak electrical currents delivered directly to the brain through electrodes placed on the head.

"Gaining a better understanding of how pulsed ultrasound affects the balance of synaptic inhibition and excitation in targeted brain regions—as well as how it influences the activity of local circuits versus long-range connections—will help us make more precise maps of the richly interconnected synaptic circuits in the human brain," said Wynn Legon, the study's first author and a postdoctoral scholar at the Virginia Tech Carilion Research Institute. "We hope to continue to extend the capabilities of ultrasound for noninvasively tweaking brain circuits to help us understand how the human brain works."

"The work by Jamie Tyler and his colleagues is at the forefront of the coming tsunami of developing new safe yet effective noninvasive ways to modulate the flow of information in cellular circuits within the living human brain," said Michael Friedlander, executive director of the Virginia Tech Carilion Research Institute and a neuroscientist who specializes in brain plasticity. "This approach is providing the technology and proof of principle for precise activation of neural circuits for a range of important uses, including potential treatments for neurodegenerative disorders, psychiatric diseases, and behavioral disorders. Moreover, it arms the neuroscientific community with a powerful new tool to explore the function of the healthy human brain, helping us understand cognition, decision-making, and thought. This is just the type of breakthrough called for in President Obama's BRAIN Initiative to enable dramatic new approaches for exploring the functional circuitry of the living human brain and for treating Alzheimer's disease and other disorders."

A team of Virginia Tech Carilion Research Institute scientists—including Tomokazu Sato, Alexander Opitz, Aaron Barbour, and Amanda Williams, along with Virginia Tech graduate student Jerel Mueller of Raleigh, N.C.—joined Tyler and Legon in conducting the research.

In addition to his position at the institute, Tyler is an assistant professor of biomedical engineering and sciences at the Virginia Tech-Wake Forest University School of Biomedical Engineering and Sciences. In 2012, he shared a Technological Innovation Award from the McKnight Endowment for Neuroscience to work on developing ultrasound as a noninvasive tool for modulating brain activity.

"In neuroscience, it's easy to disrupt things," said Tyler. "We can distract you, make you feel numb, trick you with optical illusions. It's easy to make things worse, but it's hard to make them better. These findings make us believe we're on the right path."

More information: Transcranial focused ultrasound modulates the activity of the primary somatosensory cortex in humans, *Nature Neuroscience*, DOI: 10.1038/nn.3620

Provided by Virginia Tech

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