Unlocking the brain's secrets using sound

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(Phys.org) —The brain is a reclusive organ. Neurons the cells that make up the brain, nerves, and spinal cord communicate with each other using electrical pulses known as action potentials, but their interactions are complicated and hard to understand. Just getting access to the brain itself is difficult: inserting devices through the skull into the brain requires surgery. But work by Technion Professors Eitan Kimmel and Shy Shoham, and Ph.D. student Misha Plaksin, may advance our ability to unlock the brain's secrets noninvasively using sound, and perhaps create new treatments for illnesses. The findings were published today (January 21, 2014) in *Physical Review X*.

Scientists have known for a while that ultrasonic waves can affect cells in many ways. For instance, physicians use ultrasound to stimulate the production of blood vessels and bone; it's also used in heat therapy. When applied to neurons, ultrasonic waves can change how the neurons generate and transmit electrical signals. "Ultrasound is known to do all kinds of things in cells," says Prof. Kimmel, "but how it works in many cases isn't clear, particularly when it comes to neural stimulation."

A new model may help clarify much of this behavior. This new way of understanding the interaction of sound waves and cells relies on the cellular membrane. This microscopic structure is the skin that surrounds a cell, keeping the organelles – like the nucleus and the DNA it contains – in, and the rest of the world out. The molecules that form the membrane are arranged in such a way that there are two layers, with a space between them. According to Kimmel's model, when the ultrasonic waves encounter a cell, the two layers of the cellular membrane begin to vibrate (much like how a person's vocal cords vibrate when air passes through the larynx). Cell membranes also act as capacitors, storing electrical charge. As the layers vibrate, the membrane's electrical charge also moves, creating an alternating current that leads to a charge accumulation. The longer the vibrations continue, the more charge builds up in the membrane. Eventually, enough charge builds up that an action potential is created.

The Technion team was able to use the model to predict experimental results that were then verified using brain stimulation experiments performed in mice by a team at Stanford University. According to Prof. Shoham, this is "the first predictive theory of ultrasound stimulation." All of these results mean that scientists might be on the verge of finally understanding how ultrasound affects nerve cells.

And this new understanding could lead to important new medical advances. For example, scientists could use ultrasonic waves to probe the brain's internal structure, a non-invasive technique that would be safer than implanting electrodes and complement the information produced by MRI scans. Physicians could also conceivably use ultrasound to treat epileptic seizures. And Shoham has begun studying the ways in which ultrasonic waves could stimulate cells in the retina, possibly creating images and letting people see without light. "There is great potential for additional applications," says Kimmel.

The Technion team's findings also illustrate how important it is to get a theoretical understanding of things in nature. After all, says Shoham, "there's only so much you can do with effects you don't understand."

More information: Michael Plaksin, Shy Shoham, and Eitan Kimmel. "Intramembrane Cavitation as a Predictive Bio-Piezoelectric Mechanism for Ultrasonic Brain Stimulation." *Phys. Rev. X* 4, 011004 (2014) [10 pages]

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