Hertz Fellow Ed Boyden Taking Optogenetics to the Next Level and Wins the $3 Million Breakthrough Prize in Life Sciences

Edward Boyden

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MIT associate professor Ed Boyden, a pioneer in the field of optogenetics, doesn't want to merely learn more about brain disorders; he wants to help cure them, by using light to turn neurons on and off, like a power switch. By perturbing the brain, he aims to both reveal new targets for curing disorders, and perhaps, someday, even use the technology to directly interface to the human brain.

Utilizing gene therapy technology, researchers can insert the DNA of light-sensitive proteins derived from algae into individual neurons or neural groups, allowing them to control the brain's behavior by simply illuminating the neurons with fiber optics. It is hoped that the technology can be used to treat a myriad of disorders, including epilepsy, Parkinson's disease and post-traumatic stress disorder (PTSD).

"If you want to understand the brain, you ideally want a map of the wiring," Boyden said. "In optogenetics, we take natural molecules that sense light, called opsins, and put them into neurons, so that we can activate or silence the neurons with light."

The advantage of optogenetics over other brain manipulation techniques, such as deep brain stimulation (DBS), Boyden said, is that the light can be aimed at a region of the brain, but only the specific cell types expressing the opsins will respond to light, enabling ultra-precise pinpointing of the neurons that result in a desired outcome.

"Only the neurons that you have made sensitive to light are affected," Boyden said. "If you shut down specific neurons in the brain, you can understand what those neurons are necessary for. If you activate certain neurons, you can see what behaviors or disease states they can trigger."

Since Boyden and his colleagues' groundbreaking paper on optogenetics in 2005, thousands of research groups have obtained the technology, with many applying the technology to a broad range of areas – using it to trigger aggression, terminate epileptic seizures, treat anxiety or eating disorders, improve memory recall, and restore sight and hearing, in mice and other animal models.

In November, Boyden was named one of five winners of the highly prestigious $3 million Breakthrough Prize in Life Sciences, the largest scientific prize in the world. Boyden said he wants some of the money to go toward "developing new tools to get ground truth understanding of biology and medicine," although the particulars are still to be determined.

"Over a billion people have some kind of brain disorder," Boyden said. "We need to understand how the brain works if we want to understand the human condition. If we can understand how the brain processes thoughts and feelings, we can find out what makes us unique."

A self-described philosopher-at-heart, Boyden has always had an interest in getting to the heart (or rather the brain) of what makes human beings tick. He started college at the Texas Academy of Mathematics and Science at the tender age of 14, and by 16, he matriculated into MIT. Boyden earned dual bachelor's degrees in both physics, and electrical engineering and computer science. He was 19 by the time he earned his master's degree in electrical engineering and computer science, working on quantum computers and robots.

"I want to understand the nature of humanity, and to do that, we need good neuroscience," Boyden said. "If someone has Alzheimer's or epilepsy, we have a moral imperative to try to help stop their suffering."

After MIT, Boyden went on to Stanford University where he received his PhD in neurosciences. Boyden said the Hertz Fellowship he was awarded in 1999 gave him the freedom to do the research he wanted to do at Stanford, where he analyzed how memory is stored in the brain and discovered that the mechanisms the brain uses are determined by the content to be learned. This work won the Hertz Thesis Prize in 2006.

Boyden said his work on optogenetics was a "side project," as the field of neuroscience was skeptical of neurotechnology in general at the time. In 2004, while working with Stanford colleague Karl Deisseroth, Boyden conducted the first experiment in optogenetics, which was a rousing success.

"It worked on the first try," Boyden said. "It was surreal, almost magical. That moment is very much burned into my brain."

With Boyden as lead author, along with Deisseroth and three other scientists, the group published the breakthrough findings the following year, demonstrating it was possible to reliably control neurons with light, ensuring the technique would gain widespread acceptance.

Boyden, 36, is now recognized as an authority in the field of optogenetics. In 2006, he was named one of the "Top 35 Innovators Under the Age of 35" by Technology Review, and in 2013, he received the Lundbeck Brain Prize, the largest award in the field of brain science. Boyden published other significant papers, followed by a TED talk in

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2011 that generated even more enthusiasm for optogenetics.

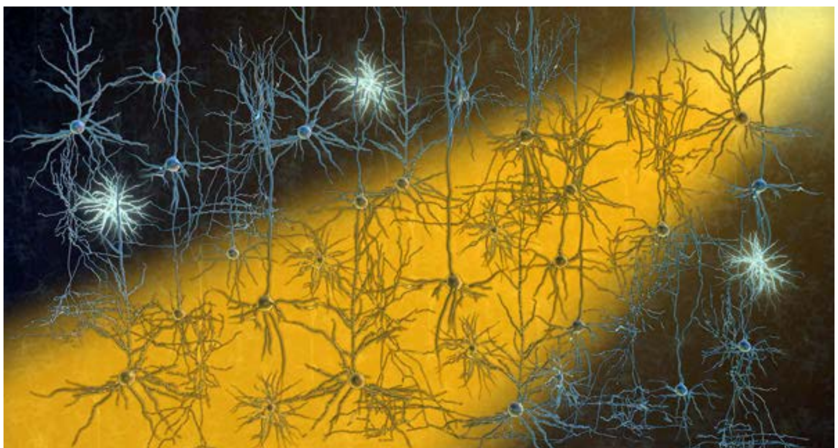
The field has evolved rapidly in recent years, Boyden said. The technology has “matured,” and his group’s research has shown it’s possible to activate neurons with red light, which can go deeper in the brain or body than other colors of light.

At MIT, Boyden leads the Synthetic Neurobiology Group, which seeks to map and repair the brain and other biological systems. Boyden is also co-director of the MIT Center for Neurobiological Engineering, which is developing tools to accelerate neuroscience.

While some key components are in place, over the next ten years, Boyden said scientists will need to fully map out the brain and figure out how to observe high-speed brain activity.

To achieve these ends, Boyden worked with a group at the Georgia Institute of Technology to build a robot that can autonomously record brain activity with single cell resolution, called an autopatcher. His group also is embedding brain circuits in swellable polymers and then causing the polymer to swell, thus causing the brain circuits to become more visible, a technology they call expansion microscopy. Finally, they are collaborating on the development of microscopes that can image the entire nervous system in 3D, to better map out and understand how neural networks compute.

“The technologies should be done in the coming several years, and thousands of groups are already applying the tools,” Boyden said. “In our group, we want to solve the brain completely, and we need all the tools we can get, to help us do that.”



Orange Light Bathing the Brain, Silencing a Cone of Neurons: In optogenetics, light-sensitive ion channels and pumps, known as microbial opsins, are genetically targeted to specific cells, so that upon light delivery, just those cells will be electrically activated or silenced. In this image, the cells of the cortex are expressing the light-driven ion pump halorhodopsin. Upon illumination of the cortex, the cells are electrically quieted. Such technologies could be used to investigate what behaviors or brain functions a given set of cells is necessary for, or alternatively to quiet overactive neurons such as in the context of a seizure. (Science image courtesy of Ed Boyden and MIT McGovern Institute.) (Photo of Ed Boyden by Xue Han.)

2300 First St., Ste 250 | Livermore, CA 94550 | 925.373.1642