Self Driving & Self Diagnosing

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Mike McKenna was tired of epilepsy controlling his life. For years, he tried different medications and therapies to no avail; his seizures, which occurred every three to six days, dictated what he could do and where he could live. Then, about ten years ago, he joined a clinical trial for a new, implantable medical device from a company called NeuroPace. The RNS System monitors brain activity, detects patterns that indicate an imminent seizure, and responds by sending brief electrical pulses to disrupt the abnormal brain activity, stopping seizures in their tracks.

"By that time in my life, I had tried so many different seizure treatments that had failed," says McKenna. "I didn't know what to expect from the RNS System." For McKenna, the results were
life-changing. Gradually, the device was able to prevent his seizures altogether. McKenna went to college and then graduate school. He was able to move away from the Mayo Clinic in Arizona where he had been treated. Today, he’s been seizure-free for over four-and-a-half years. “I look back at all those early years of being stuck and living under the label of epilepsy, thinking this was as far as I could go and assuming I’d be disabled for the rest of my life,” says McKenna. “When the RNS System came into my treatment, it was amazing.”

Over the last few decades, researchers have developed a variety of methods to detect and predict seizures. These include electroencephalography, heart-rate monitors, accelerometry and motion sensors, and electrodermal activity sensors. Devices currently on the market can detect seizure activity in real time, and studies are underway to develop technologies that can predict when a seizure might happen well in advance. The goal of all these options is to improve the lives of patients with epilepsy.

Approximately 65 million people worldwide suffer from epilepsy, a neurological disorder in which abnormal brain activity causes seizures. For roughly one-third of these people, the condition is not controlled with medication. Seizures can be incredibly disruptive to a person’s life, limiting everyday activities like driving a car, performing certain jobs, or socializing. A major issue is the unpredictable nature of seizures. Not knowing when a seizure could occur causes a great deal of anxiety, stress, and uncertainty.

If seizures could be predicted, people with epilepsy would have the opportunity to lead more normal lives. Patients could avoid potentially dangerous activities like driving, administer medications only when needed, or alert caregivers before a seizure starts. Essentially, patients would get back a degree of control in their lives.

**Turning Smartwatches into Seizure Detectors**

Often, patients do not know that they have had a major seizure until waking up in an ambulance or emergency room. Being unconscious during the seizure, they can’t tell doctors anything about what the seizure was like or how long it lasted. Smartwatches may be one way to address this problem. Already in development, these wearables can detect movements that may indicate a person is having a seizure and then sound an alarm or message a patient’s caretaker.

A team at Johns Hopkins University in Baltimore is planning to soon release its EpiWatch seizure detector for use on the Apple Watch. The app has been in development for two years and has collected information from users around the country. “We have been gathering data with Apple Watch’s sensors to detect seizures and measure their duration and severity,” says Gregory Krauss, professor of neurology at the Johns Hopkins University School of Medicine and leader of the EpiWatch team (Figure 1).

The app makes use of the Apple Watch’s heart-rate sensor, accelerometer, and gyroscope to detect seizure activity and measure and record movements during seizures. It can also send a notification to a doctor or caregiver. In addition, the app monitors patient responsiveness with a specialized memory test every minute during a seizure. Krauss claims EpiWatch is the first medical research app to include a cognitive test such as this.

EpiWatch also helps patients keep track of their seizures, medication use, and drug side effects—all of which contribute to better management of epilepsy. Krauss says that, technologically, we are at a good stage. “In a few years, there will probably be multiple smartwatches with the ability to support seizure-detector algorithms, and some of the novel devices will be miniaturized and perfected,” he explains. “I think these devices will eventually be essential for patients with uncontrolled major seizures.”
Stopping Seizures at Their Source

Systems like EpiWatch can help patients detect and track their seizures. But what if seizures could be detected almost immediately and then zapped away before they began? “What is state of the art right now is the RNS System from NeuroPace, which is a responsive neurostimulator that triggers brain stimulation when it detects seizure events,” according to Tay Netoff, a biomedical engineer at the University of Minnesota, who studies epilepsy. “This system constantly monitors the patient, watching brain activity, and when it detects certain electrical activity, it triggers a stimulation with the hopes of avoiding the seizure.”

“The RNS System is a small, implantable device connected to leads that are placed in up to two seizure onset areas in the brain,” says Martha Morrell, chief medical officer at NeuroPace and a neurologist at Stanford University, California (Figure 2). Approved by the U.S. Food and Drug Administration in 2013, it is the first and only medical device that can monitor and respond to the brain’s electrical activity. The system is personalized to recognize the electrical patterns specific to an individual’s brain. Within milliseconds of detecting unusual brain activity—and often before patients even feel seizure symptoms—it sends brief, imperceptible electrical pulses to treat the seizure.

Morrell explains that more than 1,300 patients have received the RNS System so far. Data from clinical trials show most patients experienced significant, long-term seizure reduction as well as improvements in their quality of life. “The RNS System is the only epilepsy therapy that also provides physicians with clinically meaningful, ongoing data about their patients’ seizure frequency and electrocorticographic activity,” Morrell continues. “The patient uses a simple remote monitor at home to wirelessly collect and upload data from the neurostimulator. The data is made available to the patient’s doctor to review and analyze to personalize and improve patient care.”

For Mike McKenna, the RNS System has been a true life changer. He says he receives roughly 800 stimulations every day, and these stop seizure potentials from growing into full-blown seizures. “Eventually, I was just living my life and not thinking about seizures,” says McKenna. “Plus, being able to see my own seizure data helped remove that mystery and some of the worry about seizures,” says McKenna. “Plus, being able to see my own seizures.” Eventually, I was just living my life and not thinking about seizures, McKenna. “Plus, being able to see my own seizures.” Eventually, I was just living my life and not thinking about seizures.

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Personalized Seizure Forecasting

Predicting seizures well before they happen, rather than detecting seizure activity in real time, has proven to be a more difficult venture. But researchers are making progress toward this goal. “For this type of information to be useful, seizure prediction has to be more than a few seconds ahead of a seizure; that’s more like seizure detection,” says Mark Cook, a neurologist at the University of Melbourne and St. Vincent’s Hospital. “On the other hand, a time window that is too large, like the next 48 hours, is not very useful, either.”

Teaming up with IBM Research Australia, Cook and his colleagues have outlined a new framework that paves the way for a daily seizure forecast app. The team foresees that such an app will allow users to enter information about their seizure activity, medication, and other lifestyle factors, which can then be combined with environmental data and brain recordings. The app will then aggregate this information and report to the user his or her likelihood of having a seizure that day.

To date, most research on seizure prediction has used classical machine-learning algorithms. In these approaches, researchers hand-select brain activity patterns that might preempt seizures, which are then used to train prediction algorithms (Figure 3). However, classical machine learning does not work efficiently across different patients or over long periods of time. A major reason is that brain activity patterns indicating an upcoming seizure are not only individually specific but also change over a person’s lifetime.

Cook and his colleagues took a new approach, a state-of-the-art type of machine learning called deep learning. Deep learning can automatically identify seizure patterns for individual patients and adapt to changes in these brain signals over time. “The most striking advantage of deep learning over classical machine learning is that you do not need to hand pick search features and train the algorithm on them,” notes Stefan Harrer, IBM Research Australia’s Brain-Inspired Computing manager (Figure 4). “You essentially let the algorithm automatically roam through the data and find patterns of interest for itself.”

**FIGURE 3** An example of brain activity data collected from an individual patient before and during a seizure. (Images courtesy of Stefan Harrer.)
Cook, Harrer, and their colleagues applied deep learning to data recorded from the surface of the brain during a previous trial for an implantable seizure warning device, which ran for three years and involved 15 epilepsy patients. “In this proof-of-concept study, we showed that our deep-learning algorithm worked across the entire patient cohort as well as over time for individual patients,” says Harrer.

Seizure Prediction on a Chip

Next, the IBM Research Australia and University of Melbourne research team demonstrated that their deep-learning algorithms could be deployed on IBM’s neuromorphic computing chip. Previous seizure prediction research has been achieved on high-power computers, but this chip is the size of a postage stamp and operates on the power budget of a hearing aid. It is still in the proof-of-concept stage and has not yet been tested on humans. But in a simulation study using previously collected brain activity data, the researchers showed the feasibility of using this technology as part of an intelligent, wearable system. The algorithm on the chip successfully predicted an average of 69% of seizures across patients. “We show, for the first time, that seizure prediction is feasible,” says Cook. “We hope the proof-of-concept work that we have done might in the future be used for patients.”

Epilepsy patients consistently report wanting some sort of gauge that will warn them when a seizure is coming. As Cook explains, “If you could reliably predict seizures, patients might be able to drive or hold jobs they didn’t think were possible. You might also be able to provide treatment only when it is required.”

According to Netoff, an important next step will be demonstrating that seizure prediction algorithms can work in real time on low-power devices implanted in patients’ brains. “That’s where we need to go,” says University of Minnesota researcher Netoff. “We’ve shown proof of concept; now can we do it efficiently and practically in real patients?”

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Further Reading


