Link seen between seizures and migraines in the brain

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Credit: Sasha Wolff/Wikipedia

Seizures and migraines have always been considered separate physiological events in the brain, but now a team of engineers and neuroscientists looking at the brain from a physics viewpoint discovered a link between these and related phenomena.

Scientists believed these two brain events were separate phenomena because they outwardly affect people very differently. Seizures are marked by electrical hyperactivity, but migraine auras—based on an underlying process called spreading depression—are marked by a silencing of electrical activity in part of the brain. Also, seizures spread rapidly, while migraines propagate slowly.

"We wanted to make a more realistic model of what underlies migraines, which we were working on controlling," said Steven J. Schiff, Brush Chair Professor of Engineering and director of the Penn State Center for Neural Engineering. "We realized that no one had ever kept proper track of the neuronal energy being used and all of the ions, the charged atoms, going into and out of brain cells."

Potassium and sodium contribute the ions that control electricity in the brain. The Penn State researchers added fundamental physics principles of conservation of energy, charge and mass to an older theory of this electricity. They kept track of the energy required to run a nerve cell, and kept count of the ions passing into and out of the cells.

The brain needs a constant supply of oxygen to keep everything running because it has to keep pumping the ions back across cell membranes after each electrical spike. The energy supply is directly linked to oxygen concentrations around the cell and the energy required to restore the ions to their proper places is much greater after seizures or migraines.

"We know that some people get both seizures and migraines," said Schiff. "Certainly, the same brain cells produce these different events and we now have increasing numbers of examples of where single gene mutations can produce the presence of both seizure and migraines in the same patients and families. So, in retrospect, the link was obvious—but we did not understand it."

The researchers, who also included Yina Wei, recent Penn State Ph.D. in engineering science and mechanics, currently a postdoctoral fellow at University of California-Riverside, and Ghanim Ullah, former Penn State postdoctoral fellow, now a professor of physics at University of South Florida, explored extending older models of brain cell activity with basic conservation principles. They were motivated by previous Penn State experiments that showed the very sensitive link between oxygen concentration with reliable and rapid changes in nerve cell behavior.

What they found was completely unexpected. Adding basic conservation principles to the older models immediately demonstrated that spikes, seizures and spreading depression were all part of a spectrum of nerve cell behavior. It appeared that decades of observations of different phenomena in the brain could share a common underlying link.

"We have found within a single model of the biophysics of neuronal membranes that we can account for a broad range of experimental observations, from spikes to seizures and spreading depression," the researchers report in a recent issue of the *Journal of Neuroscience*. "We are particularly struck by the apparent unification possible between the dynamics of seizures and spreading depression."

While the initial intent was to better model the biophysics of the brain, the connection and unification of seizures and spreading depression was an emergent property of that model, according to Schiff.

"No one, neither us nor our colleagues anticipated such a finding or we would have done this years ago," said Schiff. "But we immediately recognized what the results were showing and we worked intensively to test the integrity of this result in many ways and we found out how robust it was. Although the mathematics are complex, the linking of these phenomena seems rock solid."

The ability to better understand the difference between normal and pathological activity within the brain may lead to the ability to predict when a seizure might occur.

"We are not only interested in controlling seizures or migraines after they begin, but we are keen to seek ways to stabilize the brain in normal operating regimes and prevent such phenomena from occurring in the first place," said Schiff. "This type of unification framework demonstrates that we can now begin to have a much more fundamental understanding of how normal and pathological brain activities relate to each other. We and our colleagues have a lot on our plate to start exploring over the coming years as we build on this finding."

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