Scientists discover mathematics of brain waves

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The human brain is considered by many to be the most complex organ in existence, and Army researchers have developed a technique for its measurement in support of the wellbeing of warfighters. Credit: US Army

A U.S. Army Research Laboratory scientist has collaborated with a team of researchers from the University of North Texas to develop a new data processing technique that uses electroencephalogram, or EEG, time series variability as a measure of the state of the brain.

The researchers say such a technique has the potential to provide measures that facilitate the development of procedures to mitigate stress and the onset of conditions such as Post-Traumatic Stress Disorder in warfighters.

"The human brain is considered by many to be the most complex organ in existence, with over a billion neurons and having in excess of a trillion interconnections," said Dr. Bruce West, senior scientist of mathematics and information science at the U.S. Army Research Office and ARL Fellow.

According to West, it is the operation of this extraordinary complex network of neurons that hosts human thinking, and through the central nervous system, enables the functioning of most, if not all, of the physiologic networks, such as the respiratory, motor control and cardiovascular.

However, according to the researchers, even with this central role the brain plays in enabling our existence, remarkably little is known about how it does what it does.

Consequently, measures for how well the brain carries out its various functions are critical surrogates for understanding, particularly for maintaining the health and wellbeing of military personnel.

A small but measureable electrical signal generated by the mammalian brain was captured in the electrocardiogram of small animals by Caton in 1875 and in human brains by Berger in 1925.

Norbert Wiener, a half century later, provided the mathematical tools believed necessary to penetrate the mysterious relations between the brain waves in EEG time series and the functioning of the brain.

According to West, progress along this path has been slow, and after over a century of data collection and analysis, there is no taxonomy of EEG patterns that delineates the correspondence between those patterns and brain activity....until now!

The technique developed by West and his academic partners generalizes Evolutionary Game Theory, a mathematical technique historically used in the formulation of decision making in war gaming.

Their findings are reported in a paper published in the August edition of *Frontiers in Physiology*.

In the paper, titled "Bridging Waves and Crucial Events in the Dynamics of the Brain," West, along with Gyanendra Bohara and Paolo Grigolini of the University of North Texas, propose and successfully test a new model for the collective behavior within the brain, which bridges the gap between waves and random fluctuations in EEG data.

"The work horse of decision making within the military has historically been Game Theory, in which players cooperate or defect, and with pairwise interactions receive various payoffs so that under given conditions certain strategies always win," West said. "When the game is extended to groups in which individual strategy choices are made sequentially and can change over time, the situation evolves offering a richer variety of outcomes including the formation of collective states in which everyone is a cooperator or a defector, resulting in a collective state."

It turns out, West said, that the technique developed to process EEG data, the self-organized time criticality method, or SOTC method, incorporates a strategy that is an extension of Evolutionary Game Theory directly into the modeling of the brain's dynamics.

"The collective, or critical, state of the neural network is reached spontaneously by the internal dynamics of the brain and as with all critical phenomena its emergent properties are determined by the macroscale independently of the microscale dynamics," West said.

This macroscale can be directly accessed by the EEG spectrum.

The EEG spectrum, obtained by the SOTC method, decays like Brownian motion at high frequencies, has a peak at an intermediate frequency (alpha wave) and at low frequencies has an inverse power law.

In the case of the brain, the inverse power law has revealed that there is a broad range of time scales over which the brain is able to respond to the demands placed on it.

This spectrum suggests a flexibility in response, reflecting a potential range from concentrating on a single task for hours to rapidly countering a physical assault.

"This means that in the foreseeable future the physical training of warriors, along with the necessary monitoring of progress associated with that training, will be expanded to include the brain," West said. "The reliable processing of brain activity, along with the interpretation of the processed EEG signal, will guide the development of reliable techniques to reduce stress, enhance situational awareness and increase the ability to deal with uncertainty, both on and off the battlefield."

West said that the research team even speculates that such understanding of brain dynamics may provide the insight necessary to mitigate the onset of PTSD by early detection and intervention, as is routinely done for more obvious maladies.

According to West, going forward with this research can proceed in at least two ways.

"One way is to apply these promising results to data sets of interest to the Army," West said. "For example, quantify how the EEG records of warriors with PTSD differ from a control group of warriors and how this measure changes under different therapy and medication protocols. The other way is to refine the technique, for example, locate where on the scalp it is the most robust, while retaining sensitivity."

However this research proceeds, these Army scientists are focused on bringing the technology to fruition to help the Soldier of the future succeed in an ever-changing world and battlefield.

More information: Gyanendra Bohara et al, Bridging Waves and Crucial Events in the Dynamics of the Brain, *Frontiers in Physiology* (2018). DOI: 10.3389/fphys.2018.01174

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