Equations reveal the rebellious rhythms at the heart of nature

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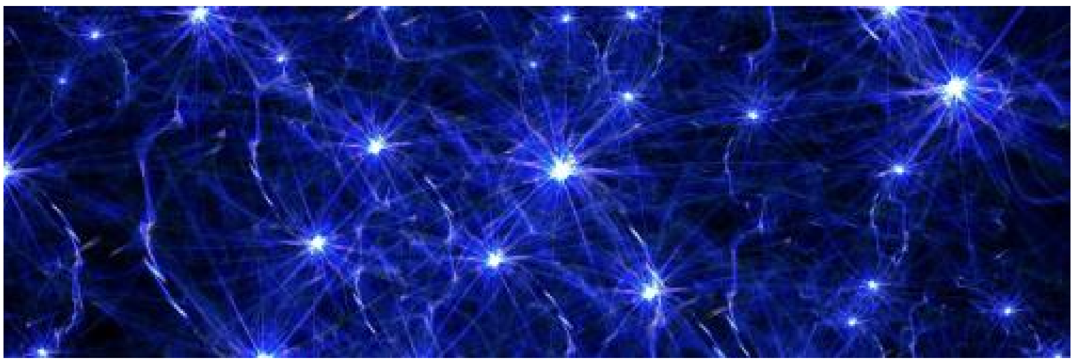

Neurons

Physicists are using equations to reveal the hidden complexities of the human body.

From the beating of our hearts to the proper functioning of our brains, many systems in nature depend on collections of 'oscillators'; perfectly-coordinated, rhythmic systems working together in flux, like the cardiac muscle cells in the heart.

Unless they act together, not much happens. But when they do, powerful changes occur. Cooperation between neurons results in brain waves and cognition, synchronized contractions of cardiac cells cause the whole heart to contract and pump the blood around the body. Lasers would not function without all the atomic oscillators acting in unison. Soldiers even have to break step when they reach a bridge in case oscillations caused by their marching feet cause the bridge to collapse.

But sometimes those oscillations go wrong.

Writing in the journal *Nature Communications* , scientists at Lancaster University report the possibility of "glassy states" and a "super-relaxation" phenomenon, which might appear in the networks of tiny oscillators within the brain, heart and other oscillating entities.

To uncover these phenomena, they took a new approach to the solution of a set of equations proposed by the Japanese scientist Yoshiki Kuramoto in the 1970s. His theory showed it was possible in principle to predict the properties of a system as a whole from a knowledge of how oscillators interacted with each other on an individual basis.

Therefore, by looking at how the microscopic cardiac muscle cells interact we should be able to deduce whether the heart as a whole organ will contract properly and pump the blood round. Similarly, by looking at how the microscopic neurons in the brain interact, we might be able to understand the origins of whole-brain phenomena like thoughts, or dreams, or amnesia, or epileptic fits.

Physicists Dmytro Iatsenko , Professor Peter McClintock, and Professor Aneta Stefanovska, have reported a far more general solution of the Kuramoto equations than anyone has achieved previously, with some quite unexpected results.

One surprise is that the oscillators can form "glassy" states, where they adjust the tempos of their rhythms but otherwise remain uncoordinated with each other, thus giving birth to some kind of "synchronous disorder" rather like the disordered molecular structure of window glass. Furthermore and even more astonishingly, under certain circumstances the oscillators can behave in a totally independent manner despite being tightly coupled together, the phenomenon the authors call "super-relaxation".

These results raise intriguing questions. For example, what does it mean if the neurons of your brain get into a glassy state?

Dmytro Iatsenko, the PhD student who solved the equations, admitted the results posed more questions than they answered.

"It is not fully clear yet what it might mean if, for example, this happened in the human body, but if the neurons in the brain could get into a "glassy state" there might be some strong connection with states of the mind, or possibly with disease."

Lead scientist Professor Aneta Stefanovska said: "With populations of oscillators, the exact moment when something happens is far more important than the strength of the individual event. This new work reveals exotic changes that can happen to large-scale oscillations as a result of alterations in the relationships between the microscopic oscillators. Because oscillations occur in myriads of systems in nature and engineering, these results have broad applicability."

Professor Peter McClintock said: "The outcome of the work opens doors to many new investigations, and will bring enhanced understanding to several seemingly quite different areas of science."

More information: D. Iatsenko, P.V.E. McClintock & A. Stefanovska. "Glassy states and super-relaxation in populations of coupled phase oscillators" *Nature Communications*. Article number: 4118. DOI: 10.1038/ncomms5118

Provided by Lancaster University