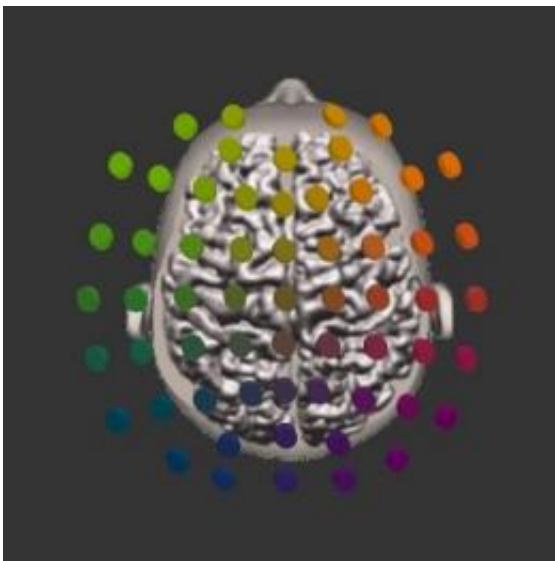


# Dynamical theory and novel 4-D colorimetric method reveal modus operandi of intact living brain

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This image illustrates the new "colorimetric technique" developed by researchers at Florida Atlantic University to map four dimensions (4-D) of brain data using EEG signals at once. This technique was a key element in the findings reported in *Progress in Neurobiology*. Using this fourth dimension will dramatically change the way neuroscientists are able to understand how the brain operates, shedding insight on a number of psychiatric and neurological disorders and opening up new ways to study therapeutic interventions, in particular the effects of drugs. Credit: FAU

For the brain to achieve its intricate functions such as perception, action,

attention and decision making, neural regions have to work together yet still retain their specialized roles. Excess or lack of timely coordination between brain areas lies at the core of a number of psychiatric and neurological disorders such as epilepsy, schizophrenia, autism, Parkinson's disease, sleep disorders and depression. How the brain is coordinated is a complex and difficult problem in need of new theoretical insights as well as new methods of investigation.

In groundbreaking research published in the January 2009 issue and featured on the cover of *Progress in Neurobiology*, researchers at Florida Atlantic University's Center for Complex Systems and Brain Sciences in the Charles E. Schmidt College of Science propose a theoretical model of the brain's coordination dynamics and apply a novel 4D colorimetric method to human neurophysiological data collected in the laboratory.

The article, titled "Brain coordination dynamics: true and false faces of phase synchrony and metastability," is co-authored by Drs. Emmanuelle Tognoli, an expert in neurophysiology and research assistant professor in the Center's Human Brain and Behavior Laboratory, and J. A. Scott Kelso, the Glenwood and Martha Creech Eminent Scholar in Science and founder of the Center. The authors' theory and data show that both tendencies co-occur in the brain and are essential for its normal function. Their research demonstrates that coordination involves a subtle kind of ballet in the brain, and like dancers, cortical areas are capable of coming together as an ensemble (integration) while still exhibiting a tendency to do their own thing (segregation).

"A lot of emphasis in neuroscience these days is on what the parts do," said Kelso. "But understanding the coordination of multiple parts in a complex system such as the brain is a fundamental challenge. Using our approach, key predictions of cortical coordination dynamics can now be tested, thereby revealing the essential *modus operandi* of the intact living brain."

Tognoli and Kelso developed a novel colorimetric technique that simultaneously maps four dimensions of brain data (magnitude, 2D of cortical surface and time) in order to capture true synchronization in electroencephalographic (EEG) signals. Because of the fourth dimension afforded by this colorimetric method, it is possible to observe and interpret oscillatory activity of the entire brain as it evolves in time, millisecond by millisecond. Moreover, the authors' method applies to continuous non-averaged EEG data thereby de-emphasizing the notion of "an average brain." The authors demonstrate that only in continuous EEG can real synchronization be sorted from false synchronization - a kind of synchronization that arises from the spread of electrical fields and volume conduction rather than from genuine interactions between brain areas.

Most of the time, activity from multiple brain areas look coordinated; however, in actuality, there is far less synchrony than what appears to be. With the support of mathematical models that reproduce the biases of real brain records in synthetic data, the authors show how to tell apart real and false episodes of synchronization. For the first time, true episodes of brain coordination can be spotted directly in EEG records and carefully analyzed.

In addition to shedding insight on the way the brain normally operates, Tognoli and Kelso's research provides a much-needed framework to understand the coordination dynamics of brain areas in a variety of pathological conditions. Their approach allows a precise parsing of "brain states" and is likely to open up new ways to study therapeutic interventions, in particular the effects of drugs (pharmaco-dynamics). Their approach will also help improve the design of brain computer interfaces used to help people who are paralyzed.

"In the future, it may be possible to fluently read the processes of the brain from the EEG like one reads notes from a musical score," said

Tognoli. "Our technique is already providing a unique view on brain dynamics. It shows how activity grows and dies in individual brain areas and how multiple areas engage in and disengage from working together as a coordinated team."

In addition to simple linear synchronization between brain areas, the authors describe more subtle modes of coordination during which areas may cooperate (integrate) and at the same time retain their functional specificity (segregation).

"This property of metastability falls out of our theory and is crucial for the brain," said Kelso. "The brain is a complex nonlinear dynamical system, and it needs to coordinate the activity of diverse and remotely connected parts in order to extract and communicate meaningful information."

Tognoli points out that subtle regimes of coordination are advantageous for the brain and are faster, more powerful and less energetically costly, thereby creating rich modes of interaction that surpass those of simple linear modes of coordination.

For a long time, scientists have strictly emphasized one kind of synchronization called 'inphase' or 'zero-lag synchrony' looking only at who is coordinated with whom and not observing the details of how they are coordinated. Through their research, Tognoli and Kelso have shown that the brain uses a much wider repertoire of synchronization patterns than just inphase. For example, brain areas may lock their oscillations together but keep a different phase.

This characteristic is also a key to the brain's dynamic complexity. Areas may encode distinct information when they coordinate with one phase difference or another, and the brain may finely tune itself, such as in learning, by altering the lag at which its areas coordinate rather than just

switching synchrony on and off. Such a brain would have a far greater combinatorial and computational power than the old model of the 'inphase brain'. But to understand the principals at work, the lag or 'relative phase' between coupled oscillations in the brain needs to be systematically studied.

"This work lies at the intersection of neuroscience and complexity science," said Dr. Gary Perry, dean of the Charles E. Schmidt College of Science. "Drs. Kelso and Tognoli have successfully developed the specific conceptual and methodological tools needed to capture and observe these important features in empirical data. Their unique approach and findings will help to shed light on some of world's most debilitating and costly health disorders."

Source: Florida Atlantic University

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