Generic dynamics at criticality links brain structure to function

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The relation, influence, and constraints between structure and function of the human brain is not yet well understood even for the widely studied resting state. In the last decade, different topological descriptors, and dynamical models such as neural mass or more complicated coupling models have shown how dynamics produced upon a given structure can map the empirical functional connectivity. In this context, a number of experimental findings seem to support the conjecture that the brain works at (or near) criticality (for review see [1] and references therein). Theoretical approaches have shown that systems operating at this critical regime show multiple functional advantages, such as maximal memory storage, information transfer and dynamic range. Universality –stating that model specific details should not matter at criticality– is inherent to critical phenomena. Instead, only a few key traits such as dimensions, symmetries and conservation laws are relevant. Based on these ideas, we show here how very simple dynamical models running upon a given structural connectivity and tuned to its critical point can reproduce some relevant of brain functioning at its resting state. It will also be shown how modifying some key aspects of the underlying structural connectivity affects the mapping between criticality and empirical functioning.

In order to implement a parsimonious dynamics, we have followed previous studies [2] and considered the Ising model in which the network nodes have been linked by pairwise interactions and performed Monte Carlo simulations using the Metropolis rule, which drives the system to its corresponding equilibrium state at any given temperature [3]. Pairwise interactions were given by the connectivity matrix reported in [4] for the human connectome consisting of 998 regions of interest –the different network nodes–.

After simulating the Ising model at different values of the temperature, we have computed the matrix of pairwise correlations of the Ising dynamics and compare it with the empirically measured rs-fMRI correlations [4]. By comparing these two matrices we are able to measure a temperature-dependent "distance" or "correlation" between the rs-fMRI activity and the Ising results. The similitude between the two correlation matrices is maximal around criticality, indicating that the critical Ising dynamics captures essential correlation aspects of the true dynamics. Based on these findings, we further analyze different aspects of the dynamics of the Ising dynamics and its connection to the rs-fMRI dynamics by using different Information-theroy approaches that has been previously obtained for the Ising model.

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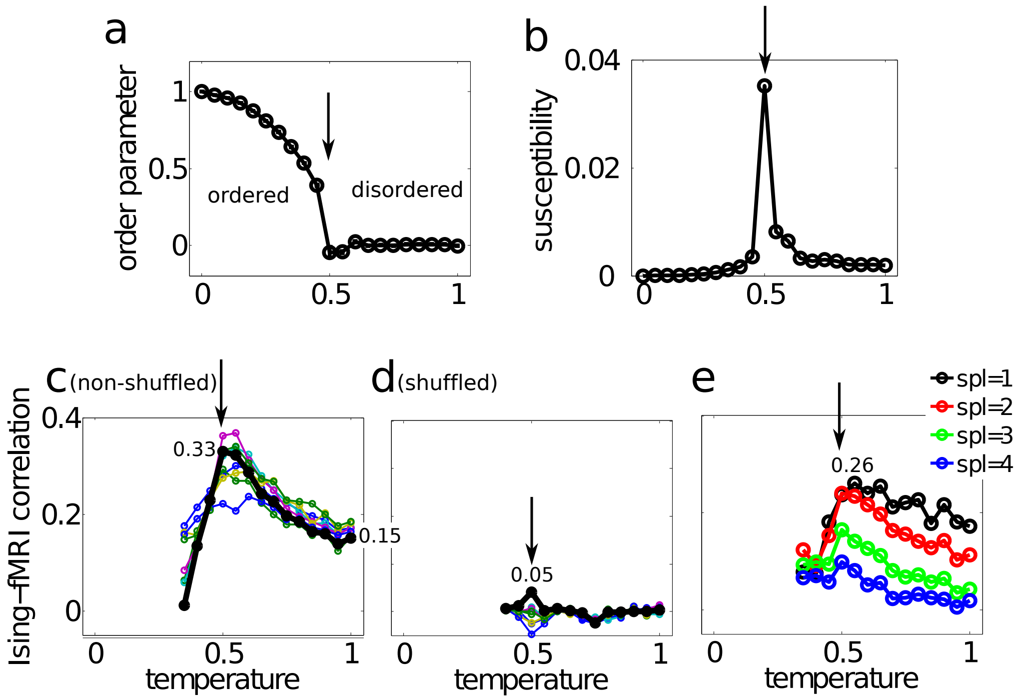

FIG. 1: **Ising model on the connectome**.a: order parameter vs temperature. The order parameter –magnetization– distigueshes two phases, and ordered one with non-zero magnetization and a disordered one in which magnetization is equal to zero. b: susceptibility vs temperature. The peak of the susceptibility –magnetization variance- occurring at $T \approx 0.5$ corresponds to the phase transition (marked in all panels with an arrow). c,d,e: For all values of temperature, point-point correlation between two correlation matrices, one for the activity generated by the Ising model and the other for the rs-fMRI activity. c,d: Different colors correspond to different $N = 10$ subjects. The thick black line is the result for the average rs-fMRI for all the $N = 10$ subjects. c: Original connectome –non-shuffled– of 998 ROIs. d: Shuffled-connectome with a method that preserves the degree in all the 998 ROIs. e: The point-point correlation is calculated only for nodes which have shortest path length (spl) equal to 1,2,3,4 (different colors). Notice that the Ising dynamics relies mainly over nodes with spl=1.