Modelling low-dimensional interacting brain networks reveals organising principle in human cognition

Yonatan Sanz Perl[1,2,3*], Sebastian Geli[1], Eider Pérez-Ordoyo[1], Lou Zonca[1], Sebastian Idesis[1], Jakub Vohryzek[1], Viktor K. Jirsa[4], Morten L. Kringelbach[5,6,7,8], Enzo Tagliazucchi[2,9] & Gustavo Deco[1,10,11*]

1 Center for Brain and Cognition, Computational Neuroscience Group, Universitat Pompeu Fabra, Barcelona, Spain
2 National Scientific and Technical Research Council (CONICET), CABA, Buenos Aires, Argentina
3 Paris Brain Institute (ICM), Paris, France
4 Institut de Neurosciences des Systèmes, Aix Marseille Université, Marseille, France
5 Department of Psychiatry, University of Oxford, Oxford, United Kingdom
6 Center for Music in the Brain, Department of Clinical Medicine, Aarhus University, Århus, Denmark
7 Life and Health Sciences Research Institute (ICVS), School of Medicine, University of Minho, Braga Portugal
8 Centre for Eudaimonia and Human Flourishing, University of Oxford, Oxford, United Kingdom
9 Latin American Brain Health Institute (BrainLat), Universidad Adolfo Ibáñez, Santiago, Chile
10 Department of Information and Communication Technologies, Universitat Pompeu Fabra, Barcelona, Spain
11 Institució Catalana de la Recerca i Estudis Avancats (ICREA), Barcelona, Spain

Abstract

The revolutionary discovery of resting state networks radically shifted the focus from the role of local regions in cognitive tasks to the ongoing spontaneous dynamics in global networks. In recent years, considerable efforts have been invested to reduce the complexity of brain activity recordings through the application of nonlinear dimensionality reduction algorithms leveraging the fact that brain activity can be embedded into a small number of networks. Here, we investigate how the interaction between these networks emerge as an organising principle in human cognition. To do so, we combine deep variational auto-encoders with computational modelling to construct a dynamical model of brain networks fitted to the whole-brain dynamics measured with functional magnetic resonance imaging (fMRI). Crucially, this allows us to infer the interaction between these networks in resting state and 7 different cognitive tasks by determining the effective functional connectivity between them. We found a high flexible reconfiguration of task-driven network interaction patterns and we demonstrate that can be used to classify different cognitive tasks. Importantly, compared to using all the nodes in a parcellation, we obtain better results by modelling the dynamics of interacting networks in both model and classification performance. These findings show the key causal role of manifolds as a fundamental organising principle of brain function at the whole-brain scale, providing evidence that interacting networks of brain regions are the key computational engines brain during cognitive tasks.