# Dynamical properties of fMRI functional connectivity in neuronal networks mediating consciousness

Raphaël Liégeois[1], Mohamed Bahri[2], Mattia Zorzi[1,3], Steven Laureys[2] and Rodolphe Sepulchre[1,3]
[1] Department of Electrical Engineering and Computer Science, University of Liège, Belgium
[2] Coma Science Group, Cyclotron Research Centre, University of Liège, Belgium
[3] Department of Engineering, Trumpington Street, University of Cambridge, United Kingdom
Email : {R.Liegeois, M.Bahri, MZorzi, Steven.Laureys}@ulg.ac.be, R.Sepulchre@eng.cam.ac.uk

## 1 Introduction

Induced loss of consciousness is commonly used in order to investigate the neural correlates of consciousness. Even if it has been observed in different studies that deep sedation is characterized by a global drop in cerebral activity, the neuronal mechanisms underlying this process are still actively explored. Recently, it has been shown in [2] that the static (i.e. considered as constant during the entire time course) *functional connectivity (FC)* of some neuronal networks are affected by the change of state of consciousness whereas other networks remain unchanged. Meanwhile, the interest of considering FC as evolving in time (i.e. *dynamic* FC) has been highlighted and reviewed in [3].
In this work we use an autoregressive model adapted from [1] of the fMRI time courses resulting in a dynamic interpretation of FC. We analyze resting-state fMRI data in four different states of consciousness and show how the *static* interpretation of FC and its changes across stages of consciousness presented in [2] can be enriched when a *dynamical* framework is used.

## 2 Methods

fMRI data was collected from 18 healthy subjects undergoing four different states of consciousness: wakefulness (W), mild sedation (MS), deep sedation or unconsciousness (U) and subsequent recovery of consciousness (R). The same preprocessing as in [2] was performed including 0.007-0.1Hz bandpass filtering and global signal regression. The dynamical interpretation of FC is based on an autoregressive model of the fMRI time courses:

$$x(t) = \sum_{j=1}^{n} A_j * x(t-j) + \varepsilon(t) \qquad (1)$$

where x(t) is the fMRI volume at time $t$, the $A_j$ characterize the model, $\varepsilon(t)$ is a white noise process and $n$ is the order of the autoregressive model, denoted AR$(n)$. This autoregressive model results in an extended version of the static functional connectivity matrix, the matrix-valued spectral density:

$$\bar{\Phi}(e^{i\theta}) = \sum_{k=-n}^{n} \bar{R}_k e^{-ik\theta} \qquad (2)$$

where $\bar{R}_k = \bar{R}^*_{-k}$ are the k-lagged connectivity matrices of the AR(n) model (1) encoding dynamical properties of FC.

## 3 Results

Using an AR(1) model of the fMRI time courses we represent in the next figure the static and dynamic connectivities in one node (the superior frontal sulcus) of the default mode network (DMN) and across the four states of consciousness.

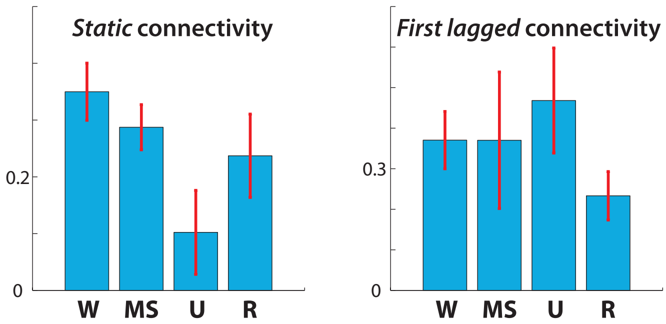


**Figure 1:** Mean and StD of static (l) and dynamic (r) connectivities of the DMN in the four states of consciousness

The static connectivity is computed from $\bar{R}_0$ corresponding to the AR(1) model and follows the level of consciousness of the subjects, as presented in [2]. However, the trend is almost opposite for the dynamical connectivity extracted from $\bar{R}_1$. In this case, the first lagged connectivity is higher during unconsciousness. A possible interpretation is that the overall connectivity between the regions considered here does not drop during unconsciousness but is *delayed*.
As a conclusion, we show here the utility of considering *dynamical* models of fMRI time courses in order to characterize the properties of FC in a more comprehensive way and reveal features that are not captured by a static analysis.

## References

[1] E. Avventi et al. (2013), 'ARMA Identification of Graphical Models', IEEE Trans. Automat. Contr. 58(5), pp. 1167-78.

[2] P. Boveroux et al. (2010), 'Breakdown of within- and between-network Resting State Functional Magnetic Resonance Imaging Connectivity during Propofol-induced Loss of Consciousness'. Anesthesiology 113(5), pp.1038-53.

[3] R.M. Hutchison et al. (2013), 'Dynamic functional connectivity: Promise, issues, and interpretations', Neuroimage 80, pp.360-78.