Time-resolved functional brain networks: Dynamics of human brain connectivity at rest

Andrew Zalesky

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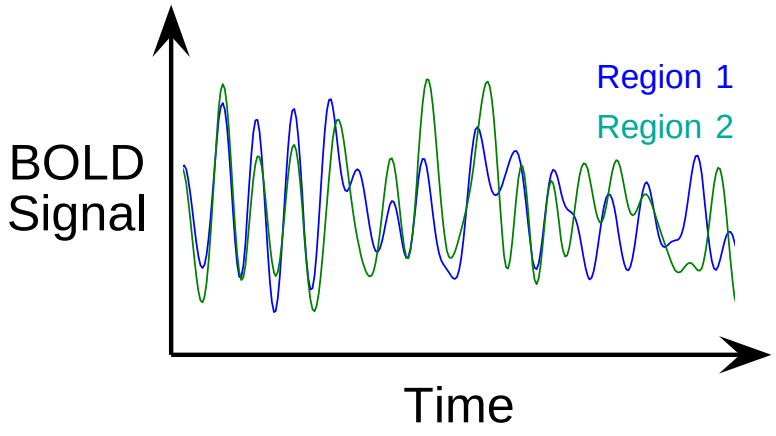
ICON 2014

Background

Resting-state functional connectivity is dynamic



Theoretical:

- Breakspear, 2004
- Deco et al, 2008
- Friston, 1997
- Honey et al, 2007

Empirical:

- Chang & Glover, 2010
- Hutchison et al, 2013
- Kitzbichler et al, 2009
- Smith et al, 2012

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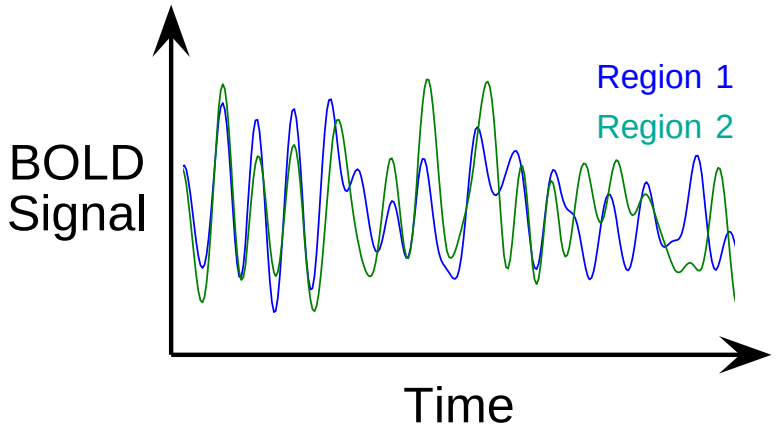

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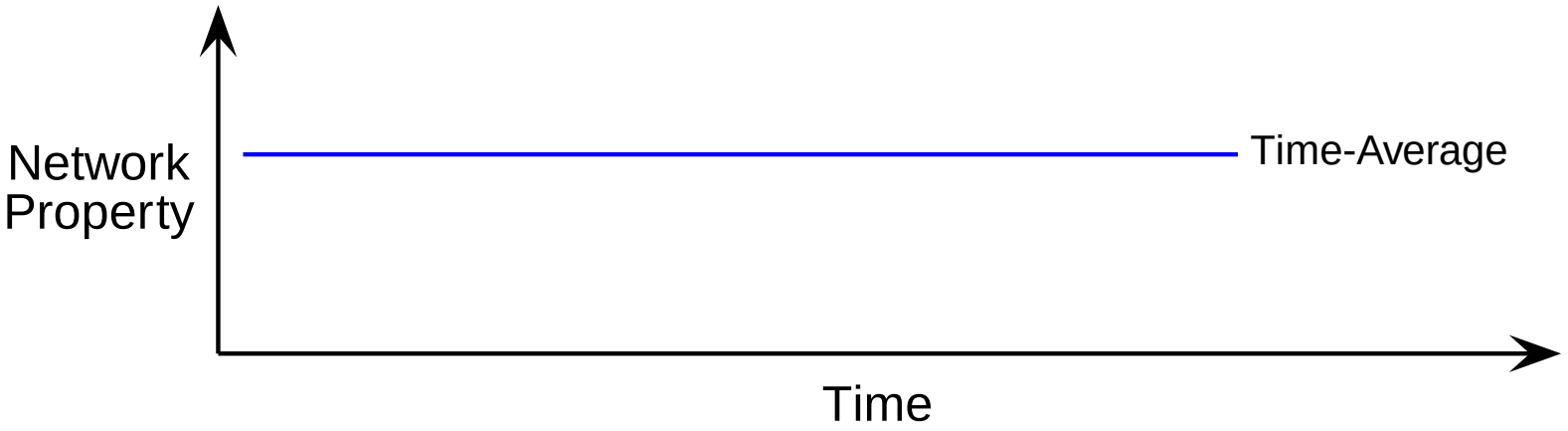
However, resting-state networks are studied as static networks...

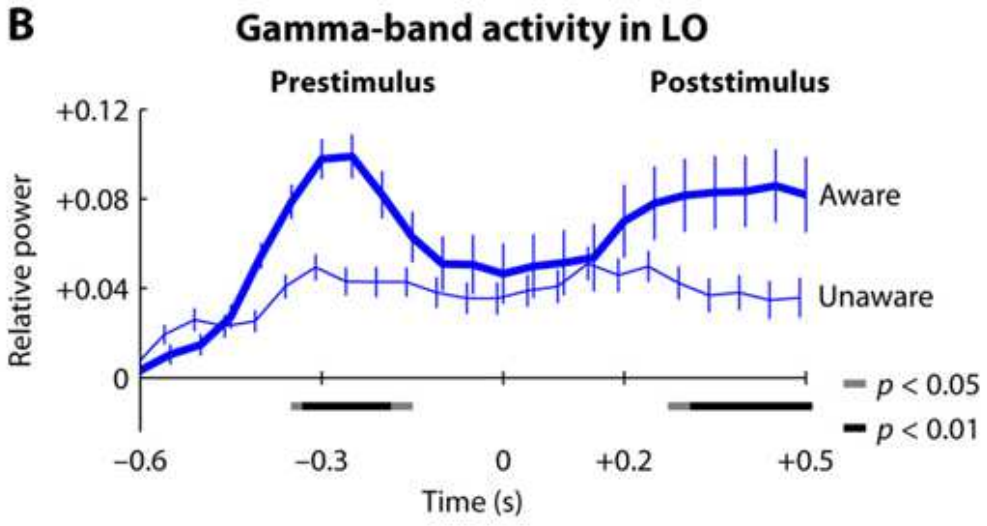


Motivation for studying time-resolved brain connectivity

- Test predictions from global workspace theory

(Dehaene et al, 2014)

Inattentional Blindness

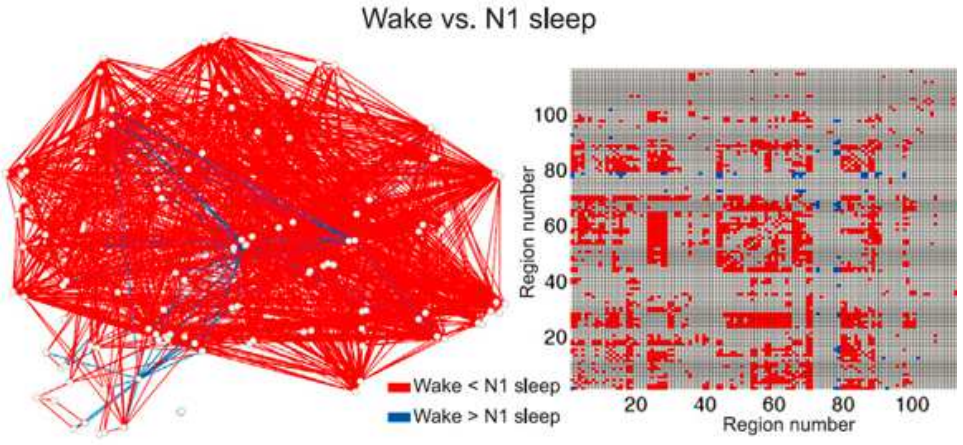


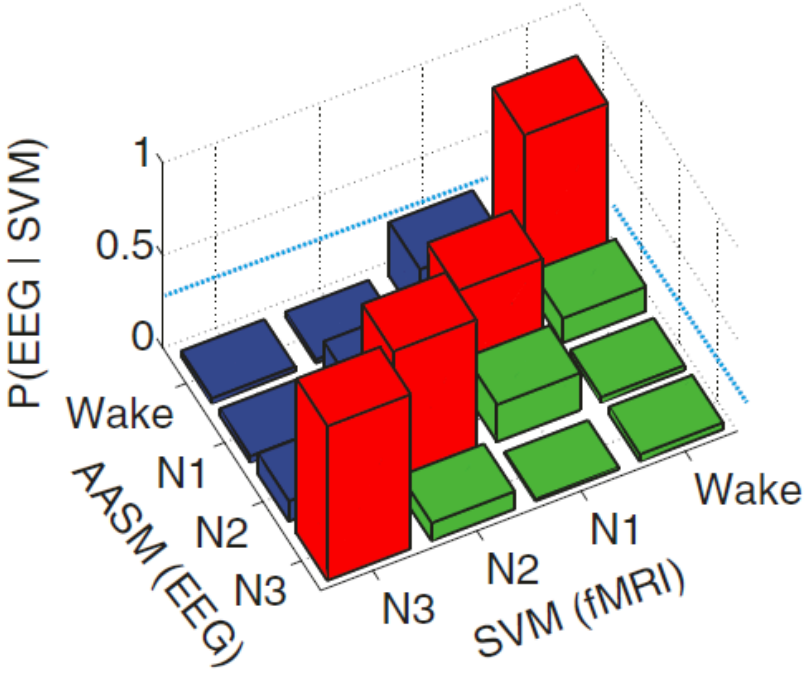
Wyart & Tallon-Baudry, 2009

Motivation for studying time-resolved brain connectivity

- Better characterize the “resting-state”

50% of participants are asleep for some interval during data acquisition





Tagliazucchi & Laufs, 2014

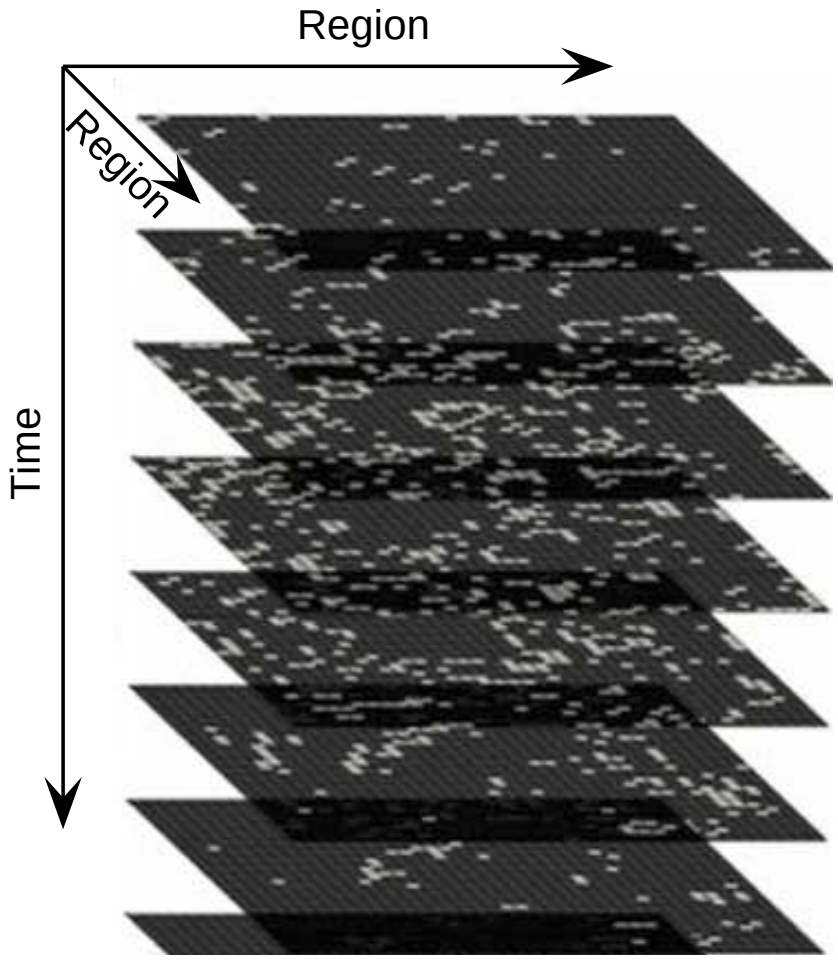
Methods

- 10+10 healthy, young adults analysed
- 15 mins rsfMRI with 0.72 s TR

Methods

HUMAN Connectome PROJECT

- 10+10 healthy, young adults analysed
- 15 mins rsfMRI with 0.72 s TR



Ghosh et al, 2008

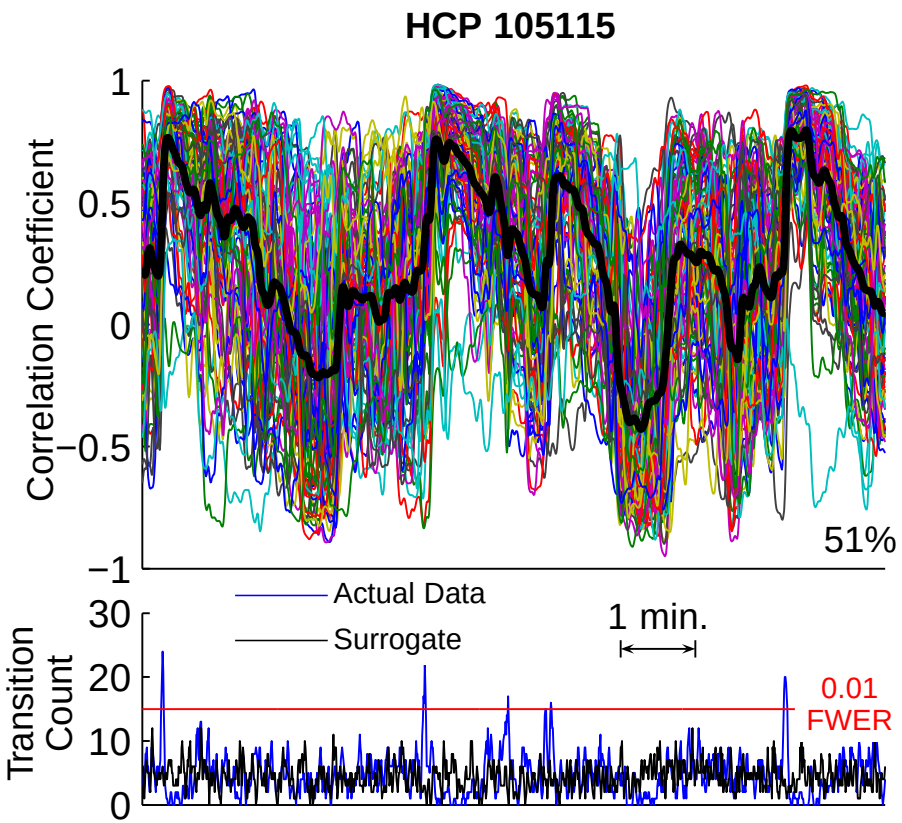
Sliding Window

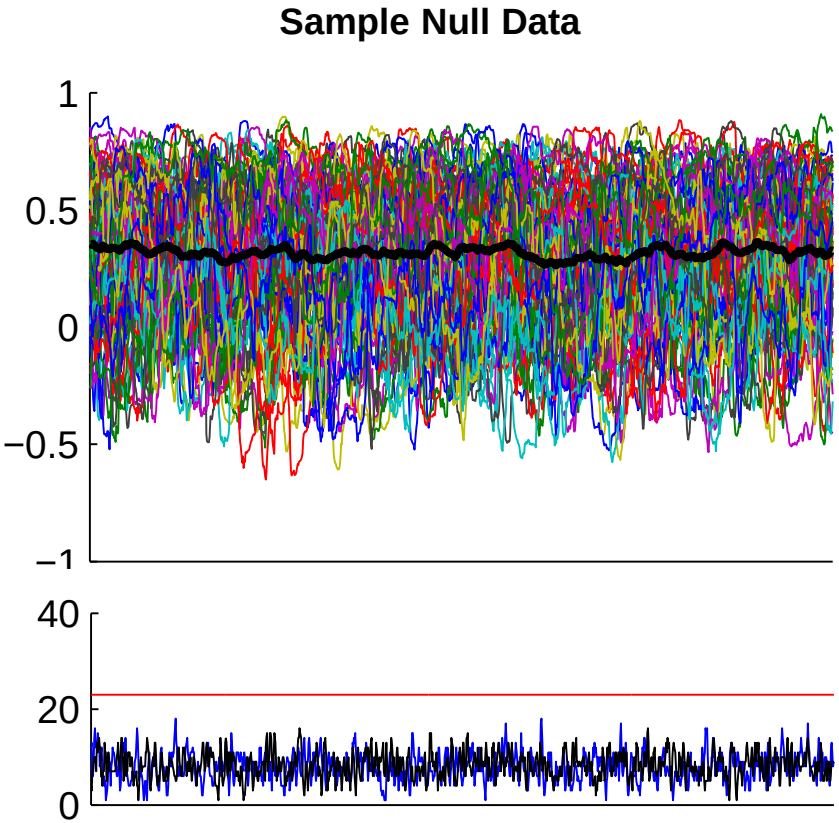
Connectivity estimated using correlation in regionally averaged rsfMRI time series data falling within tapered windows of length 60 seconds (83 TRs).

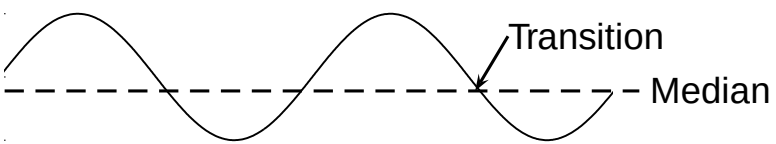
Thresholding

Connectivity matrices thresholded to ensure a fixed connection density for all time points.

Fluctuations in connectivity are coordinated among the most dynamic connections



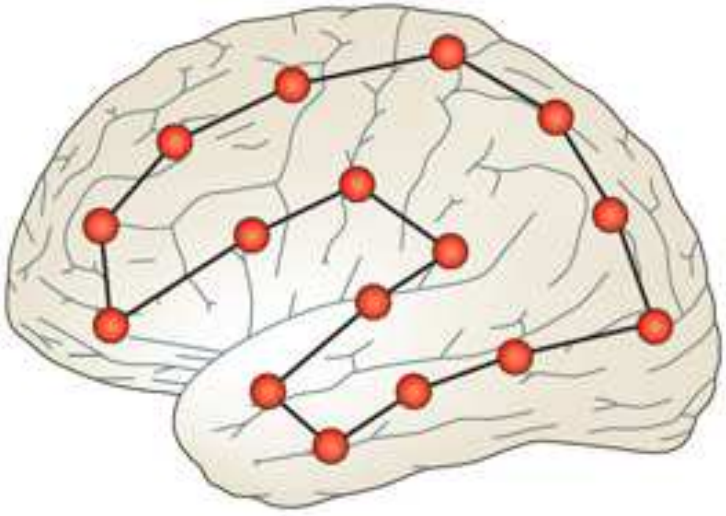




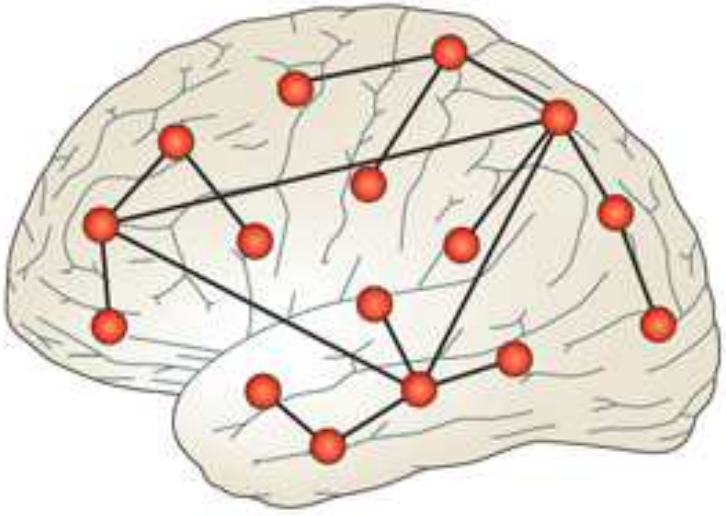
- Null data was *stationary*, but otherwise matched to statistical properties of BOLD (i.e. auto- & cross-spectrum).

Network Efficiency

Low Efficiency (Low Cost)

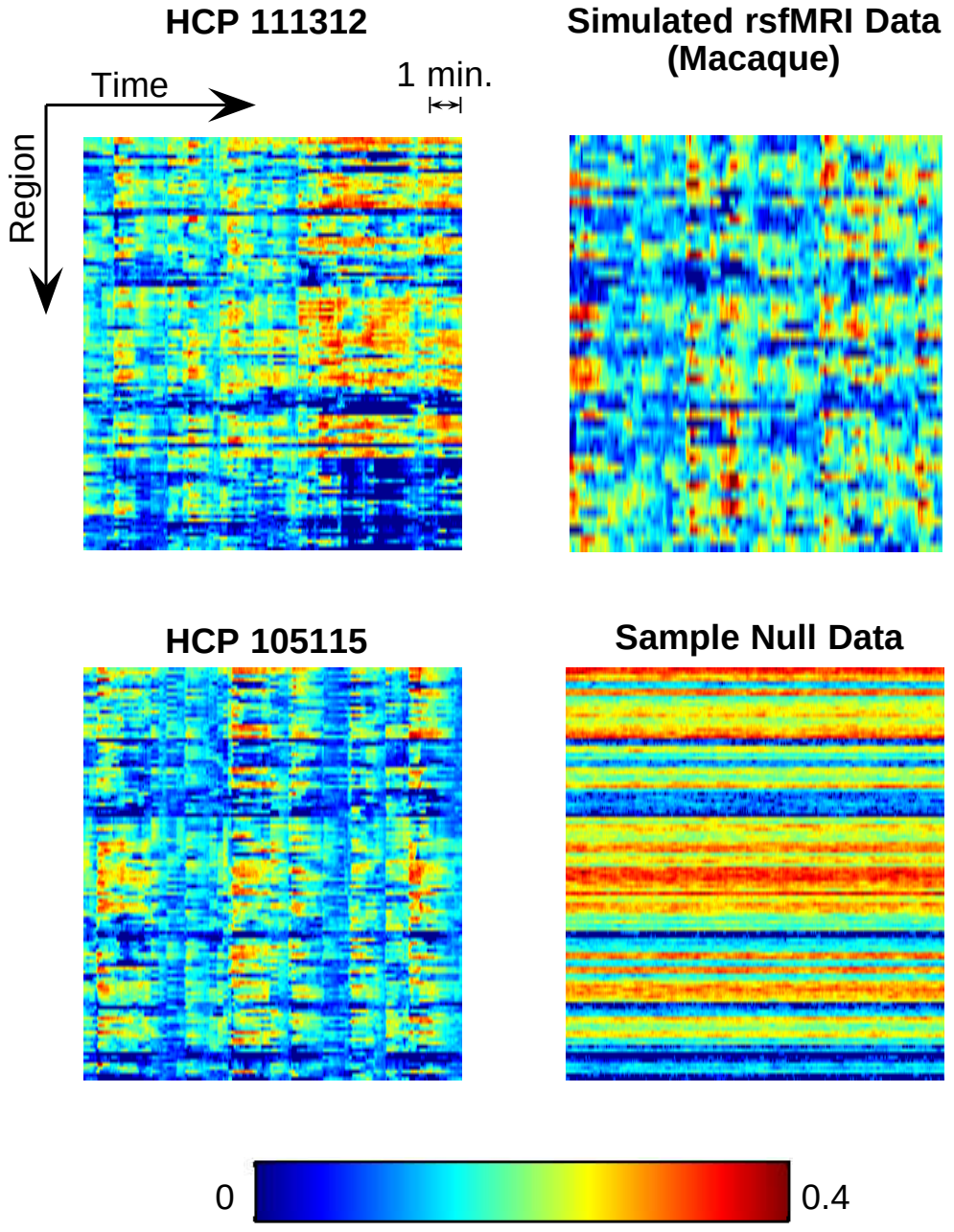


High Efficiency (High Cost)



Bullmore & Sporns, 2012

Sporadic emergence of brief, high efficiency states



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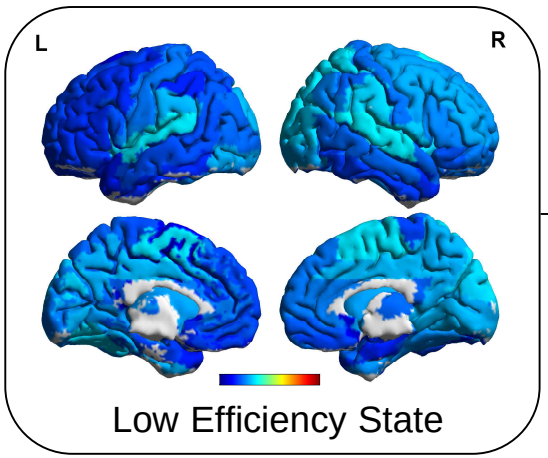
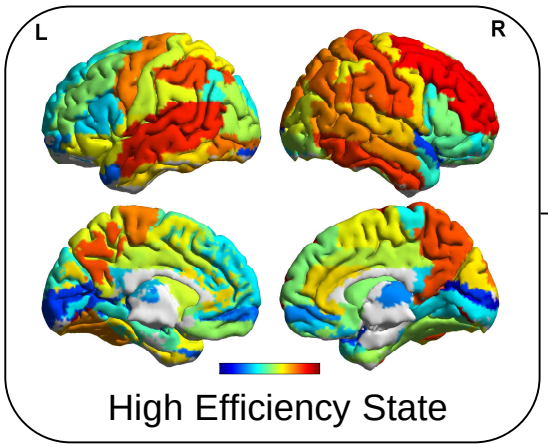
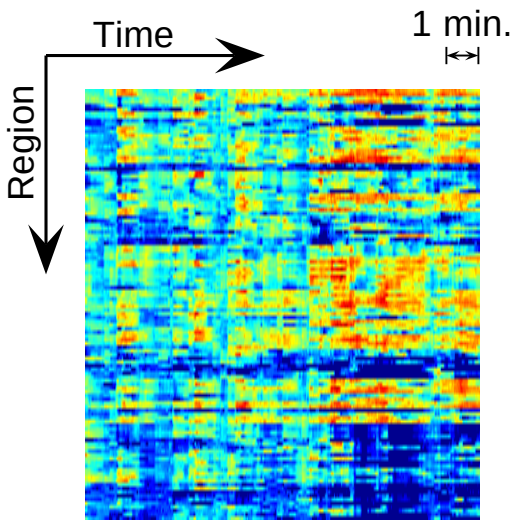
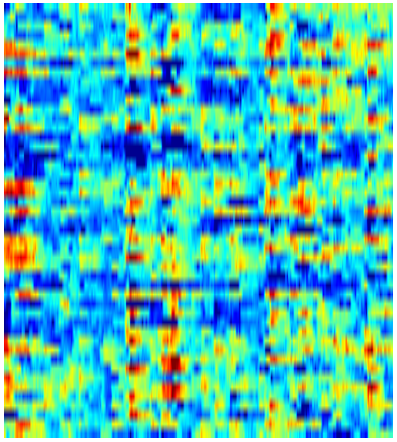




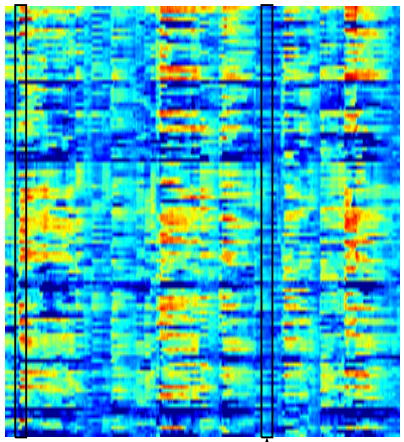
HCP 111312



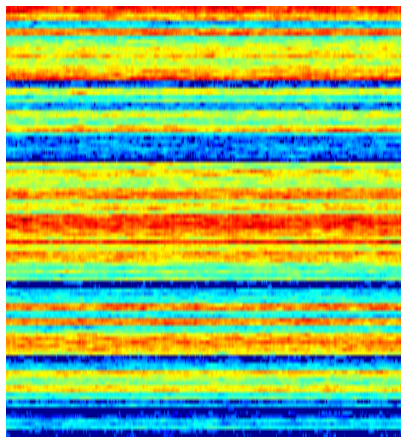
Simulated rsfMRI Data (Macaque)

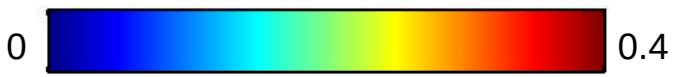


HCP 105115



Sample Null Data





High efficiency states are metabolically costly

• High efficiency states comprise longer connections than low efficiency states ($p < 0.01$).

State	*Average Connection Length*
Low Efficiency	67.1 ± 2.1 mm
High Efficiency	73.0 ± 1.9 mm

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Low Efficiency	67.1 ± 2.1 mm
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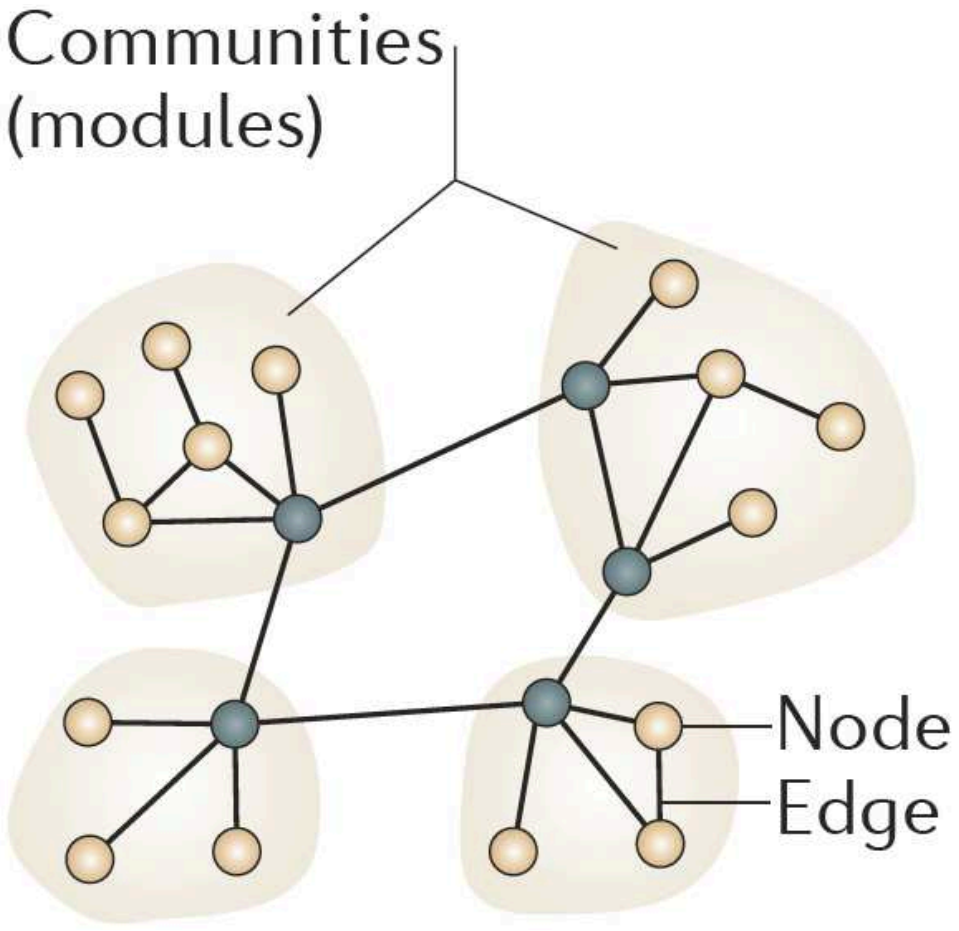
• Long connections are metabolically costly (Liang et al, 2013).

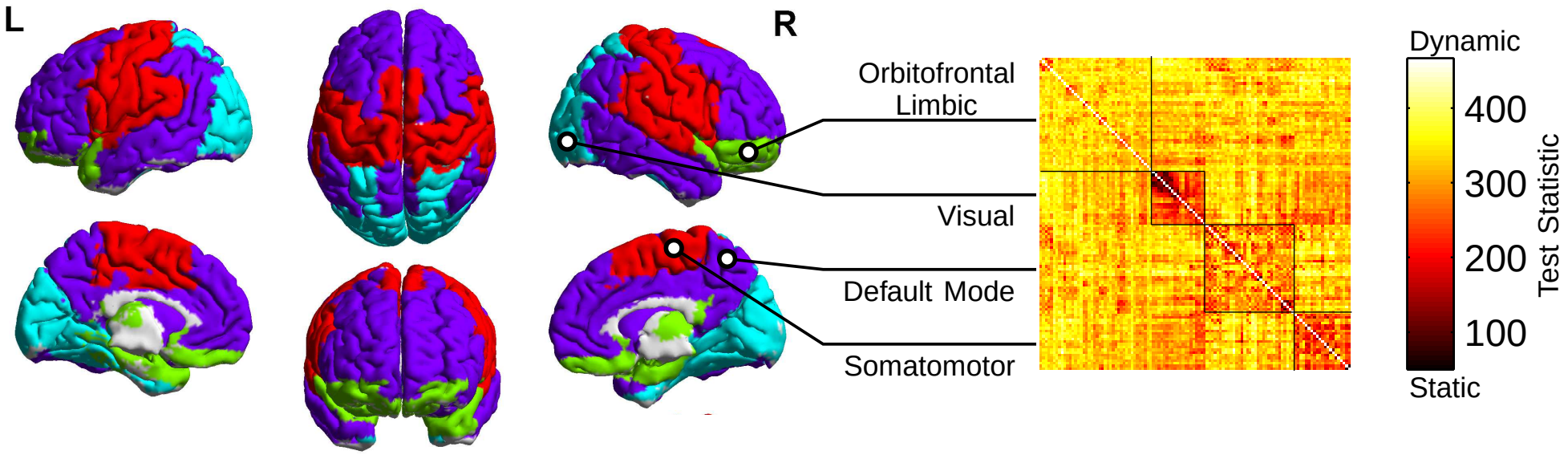
• **Hypothesis:** Intermittent periods of high efficiency may be a dynamic strategy that has evolved to minimize metabolic requirements, while maintaining the connectome in a responsive state.

Network Modules

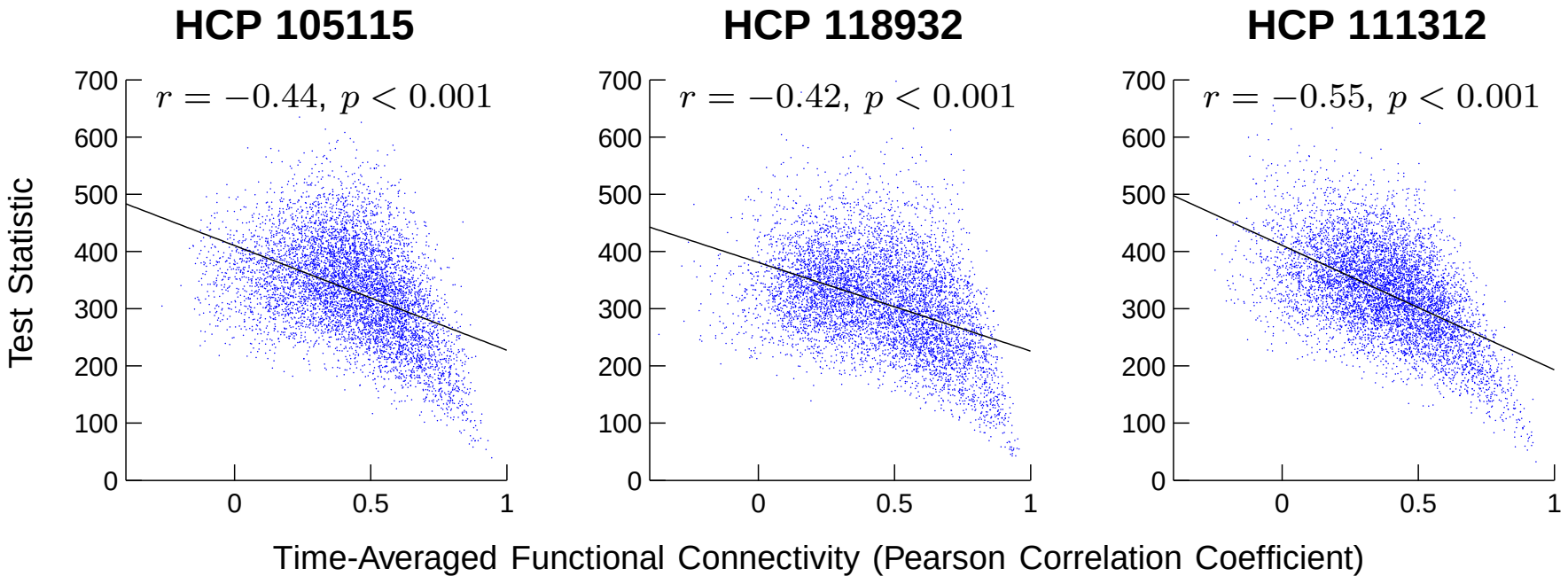


Bullmore & Sporns, 2012

Dynamic connections interconnect distinct modules, whereas static connections are intra-modular



Dynamic connections have time-averaged correlations near zero



- **Hypothesis:** Modular decomposition algorithms are effectively delineating communities of regions that are interconnected by *static* connections.

Summary

- Multiple regions briefly increase their topological efficiency, and by inference, their capacity to transfer information.
- **But** these intervals of high efficiency are supported by long anatomical connections and thus likely carry an extra metabolic cost.
- **Therefore**, intermittent periods of high efficiency may be a dynamic strategy that has evolved to minimize metabolic requirements.
  - Food foraging in animals
  - Eye tracking

Summary

- Multiple regions briefly increase their topological efficiency, and by inference, their capacity to transfer information.
- **But** these intervals of high efficiency are supported by long anatomical connections and thus likely carry an extra metabolic cost.
- **Therefore**, intermittent periods of high efficiency may be a dynamic strategy that has evolved to minimize metabolic requirements.
  - Food foraging in animals
  - Eye tracking
- Time-averaged modular decompositions can be explained by the layout of static and dynamic connections.

Reproducibility

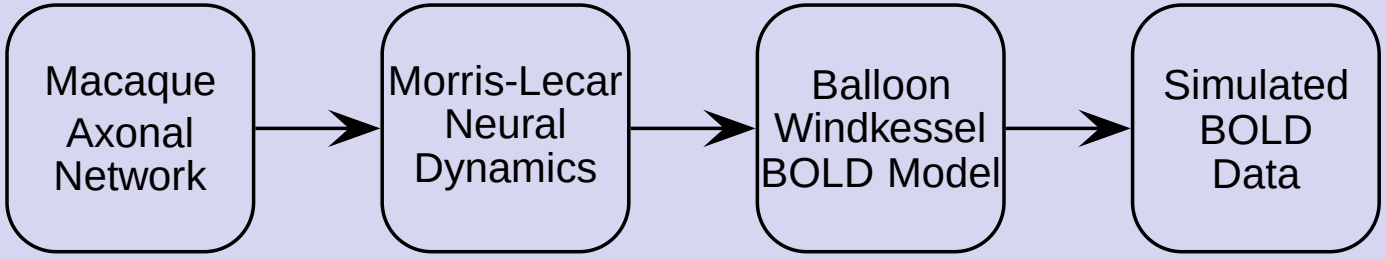
Regional Definitions

- AAL-116
- Random-90
- Craddock-200

Confound Cleanup

- CompCor
- CompCor + Scrubbing
- ICA-based X-Noiseifier

Simulated BOLD Data



- No motion or physiological confounds in simulated BOLD

Honey et al, 2009

Further details:

Zalesky A, Fornito A, Cocchi L, Gollo L, Breakspear M.
Time-resolved functional brain networks reveal dynamics of human brain connectivity at rest.
Proc Natl Acad Sci U S A. In Press.