

Review

Quantifying conscious level by means of intrinsic brain connectivity

**1st Summer School
Interdisciplinary Research on Brain Network Dynamics**

June 24 2019, Terzolas ITALY

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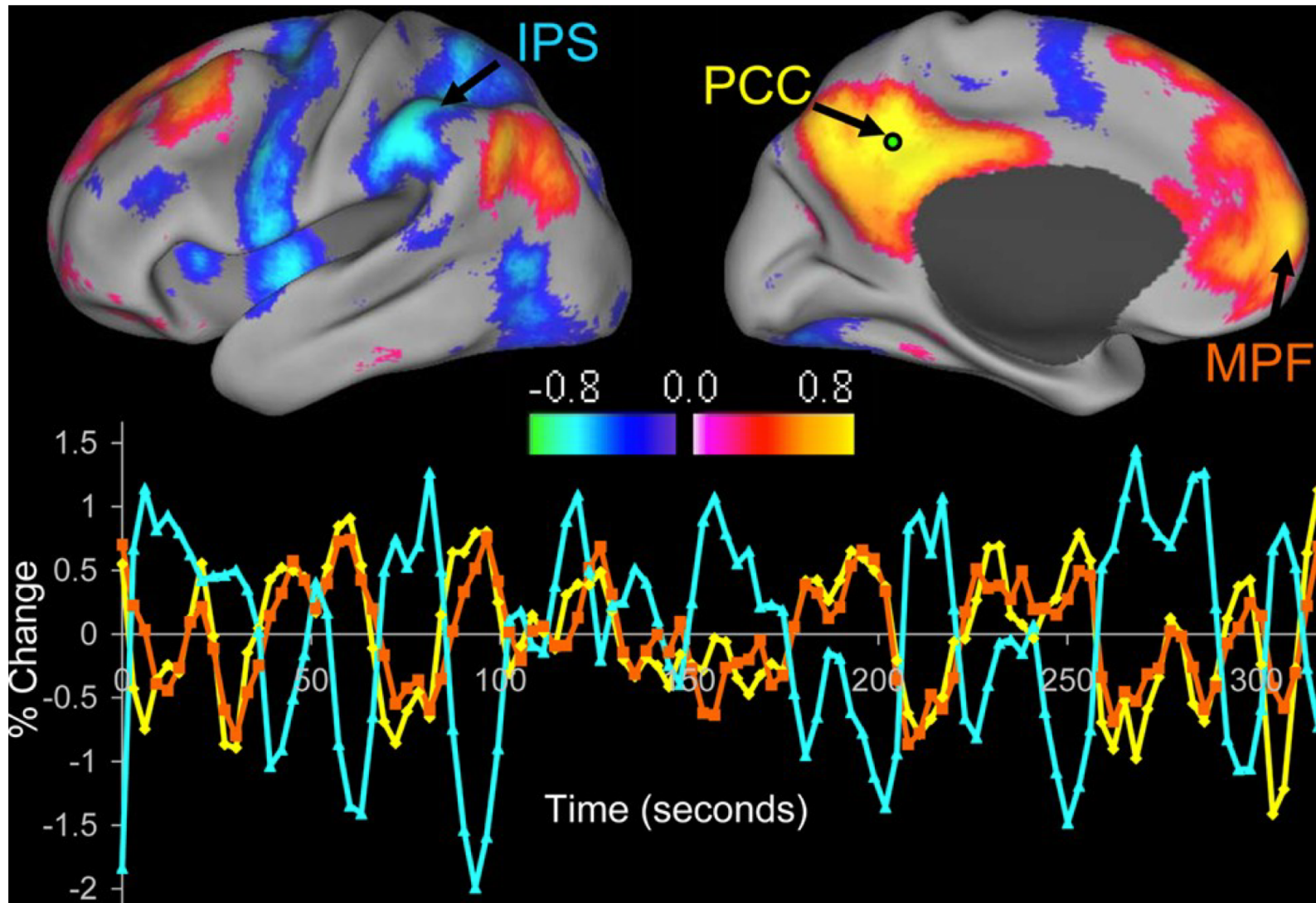


What is Consciousness?



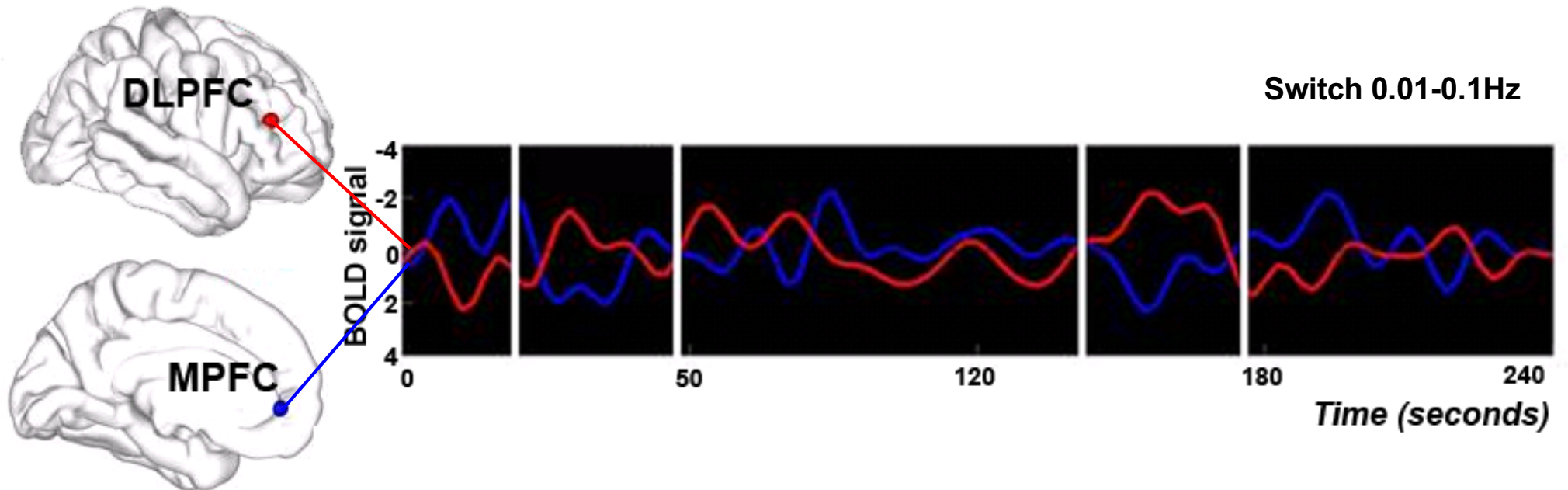


Anticorrelated brain systems



A mode of awareness?

External awareness or anticorrelated network



Internal awareness or Default mode network

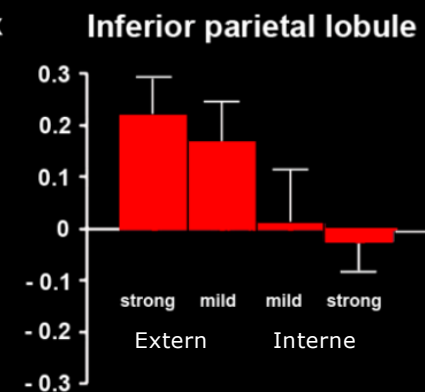
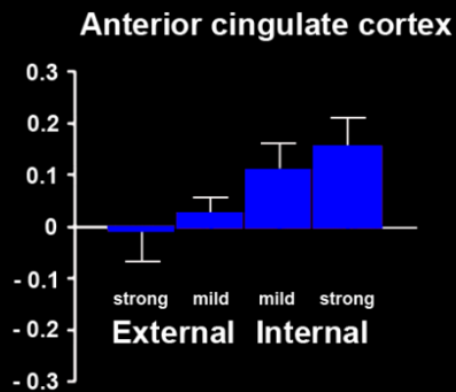
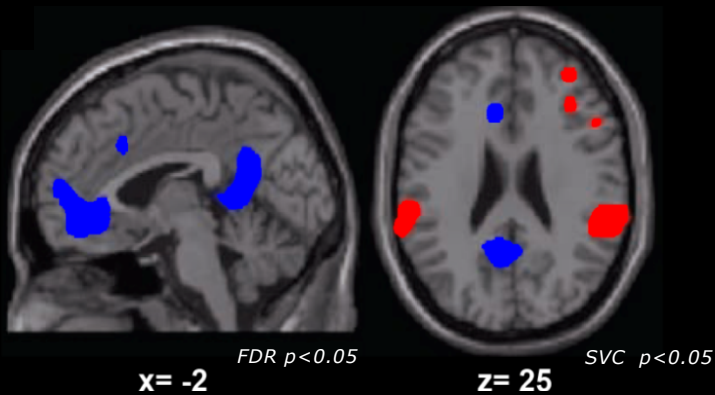
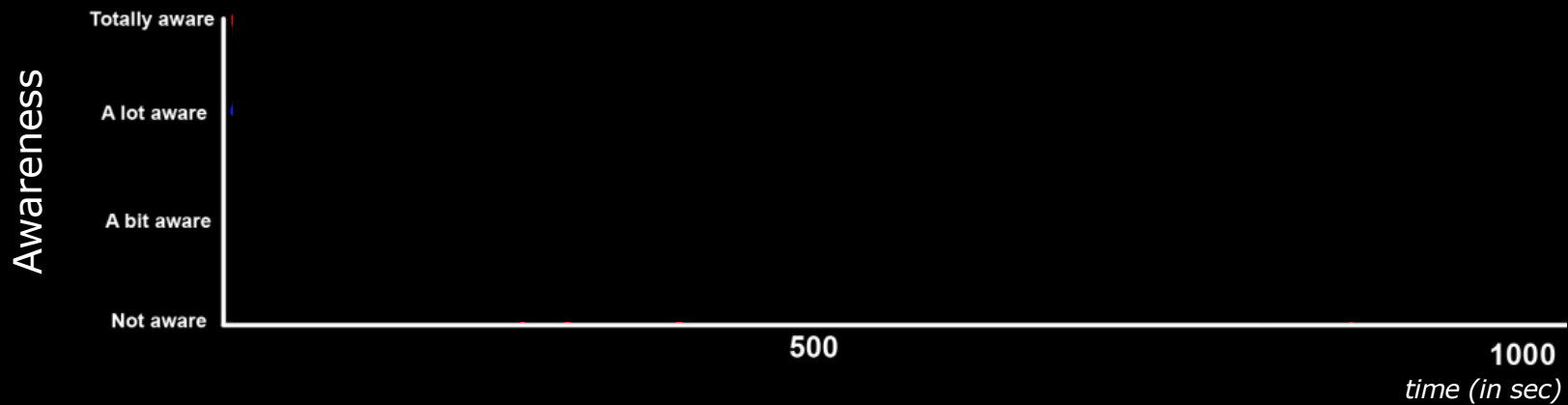
Demertzi, Soddu, Laureys, Curr Opin Neurobiology 2013
Demertzi & Whitfield-Gabrieli, in: *Neurology of Consciousness* 2nd ed. 2015
Demertzi et al, Front Hum Neurosci 2013
Laureys, Scientific American 2007

Neurobehavioral relevance of the anticorrelations



■ Internal awareness
■ External awareness

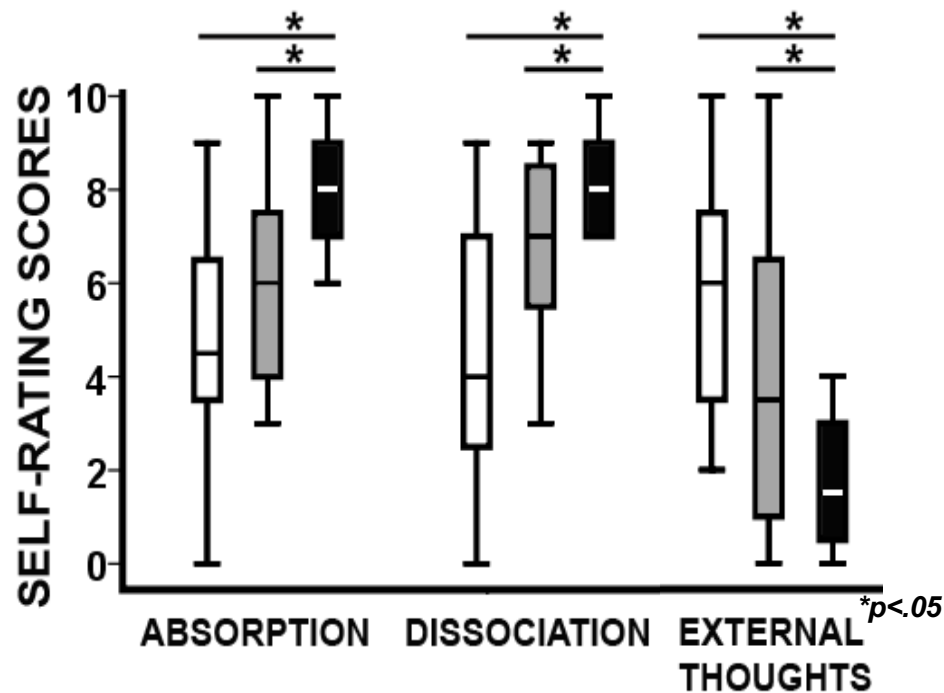
External-internal: $r = -0.44$, $p < .02$
 Mean switch: 0.05Hz (range: 0.01-0.1)



Anticorrelated connectivity is modified in hypnosis-Brain

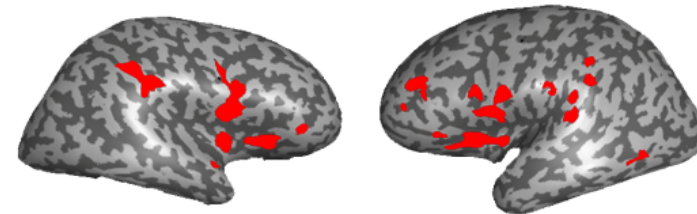


- Normal consciousness
- ▒ Autobiographical mental imagery
- Hypnosis

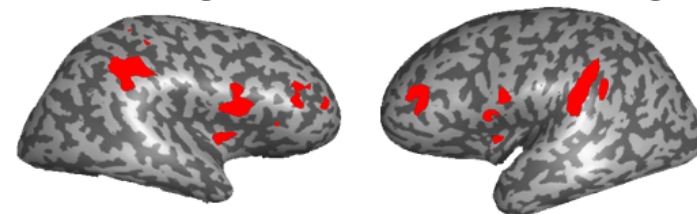


EXTRINSIC SYSTEM

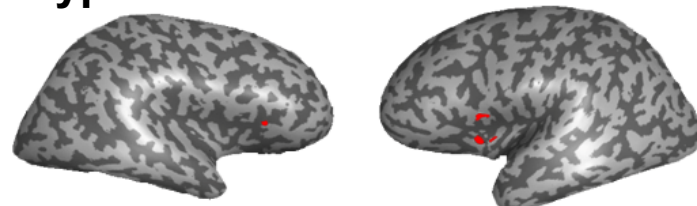
Normal consciousness



Autobiographical mental imagery

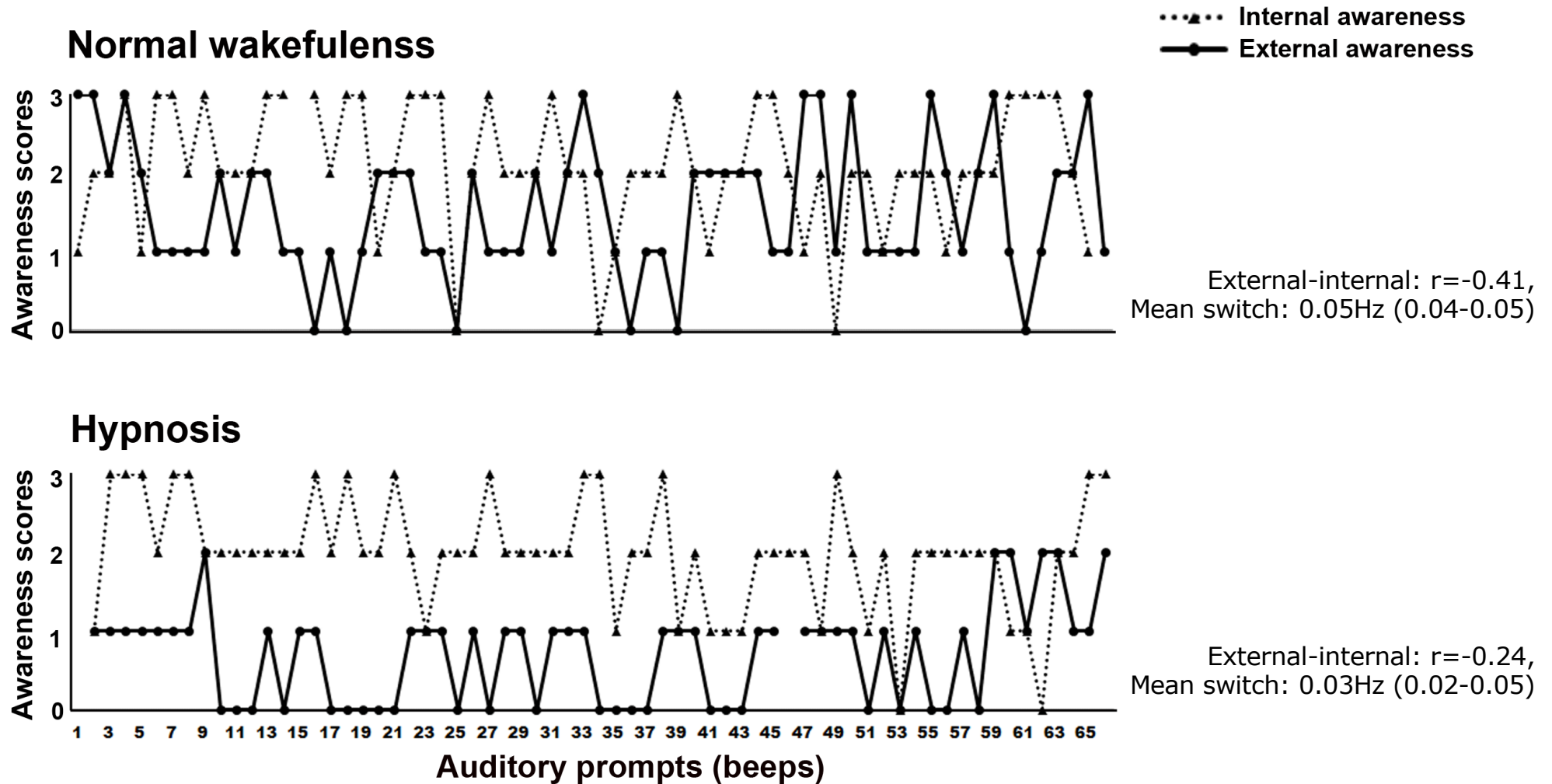


Hypnosis

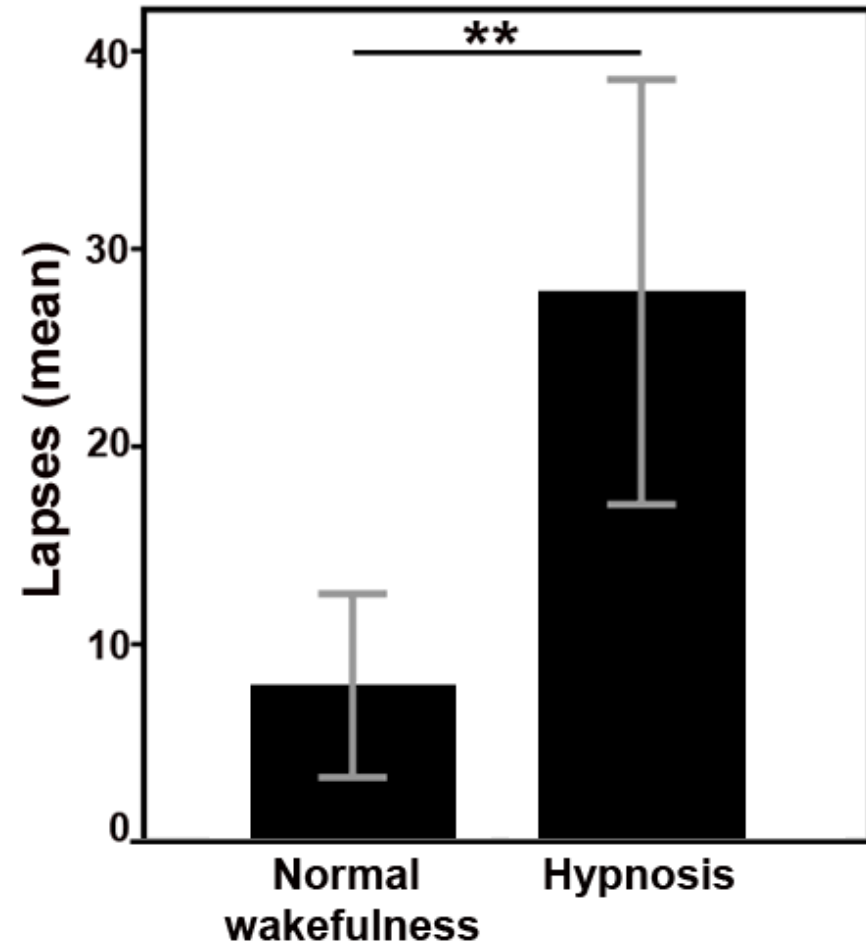
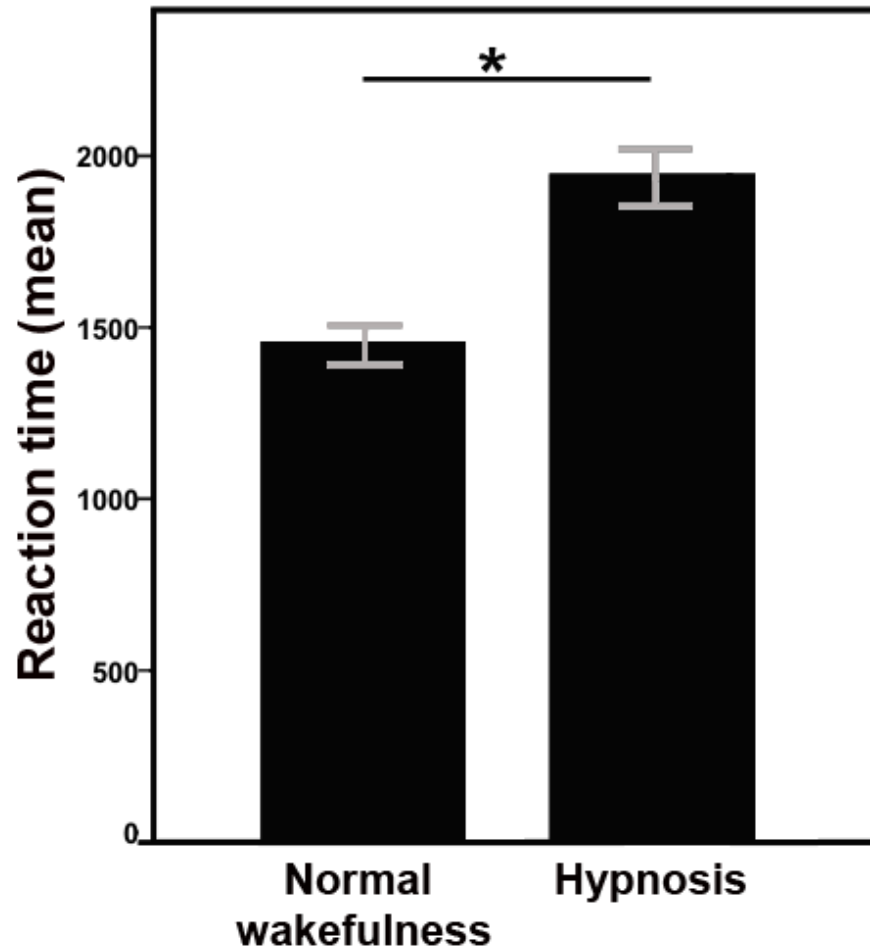


p<0.05 corrected for multiple comparisons

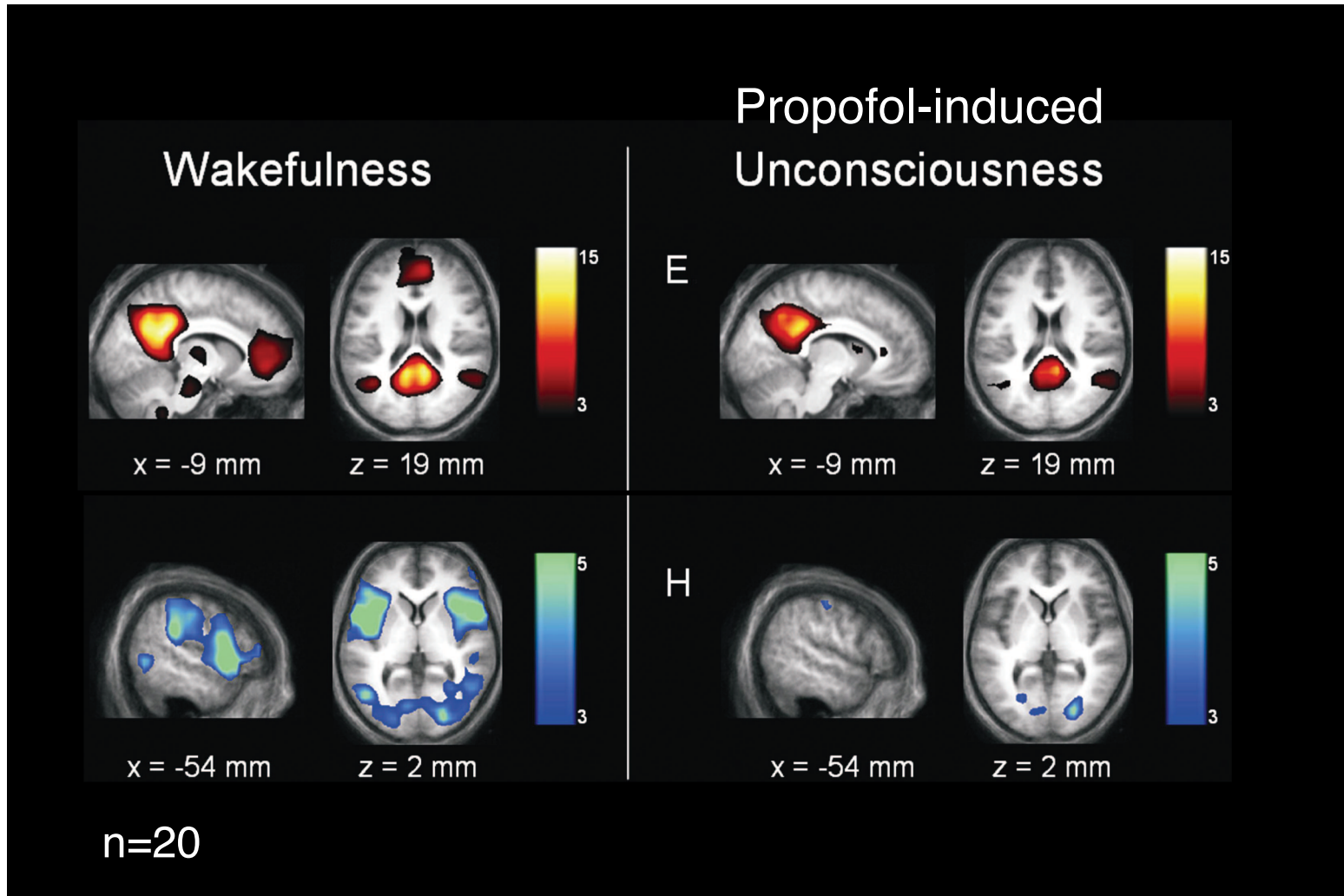
Anticorrelated connectivity is modified in hypnosis-Behavior



Anticorrelated connectivity is modified in hypnosis-Behavior



Anticorrelations reduce in anesthesia





Effect of environment

SCIENTIFIC REPORTS

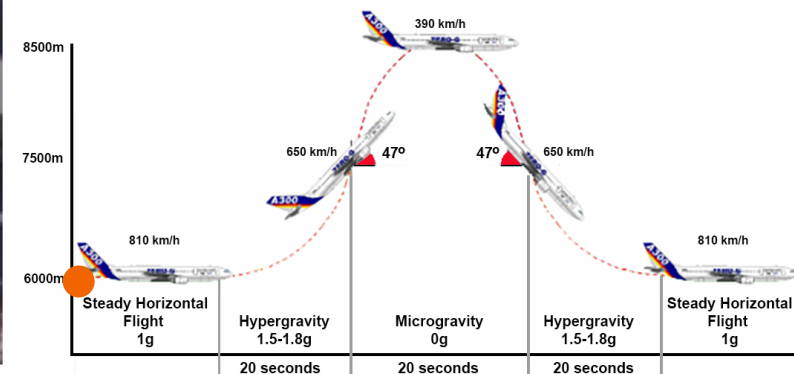
www.nature.com/scientificreports/



Parabolic flight



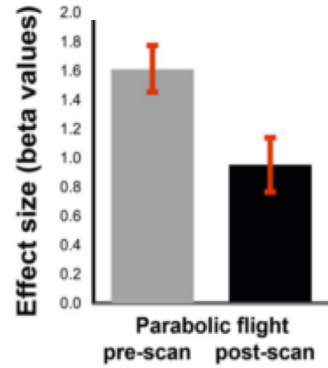
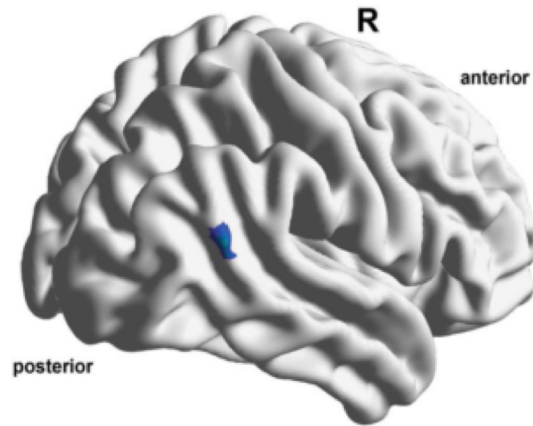
European Space Agency



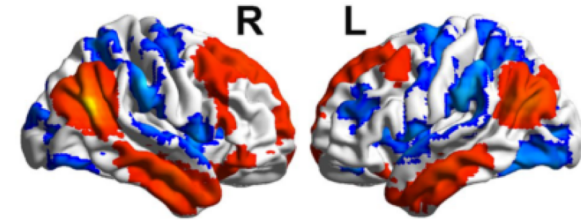
Parabolic flight trajectory

Angelique Van Ombergen¹, Floris L. Wuyts¹, Ben Jeurissen², Jan Sijbers², Floris Vanhevel³, Steven Jillings¹, Paul M. Parizel³, Stefan Sunaert⁴, Paul H. Van de Heyning¹, Vincent Dousset⁵, Steven Laureys⁶ & Athena Demertzi^{6,7}

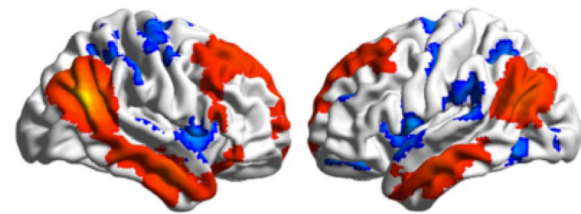
Anticorrelations reduce in extreme environments



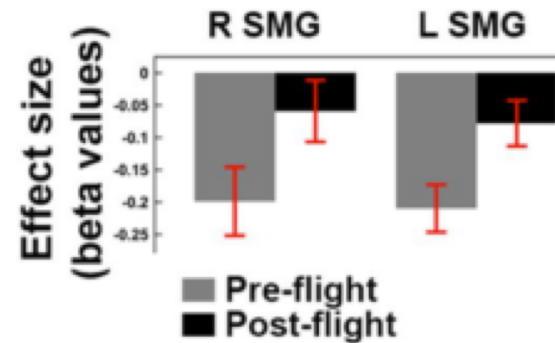
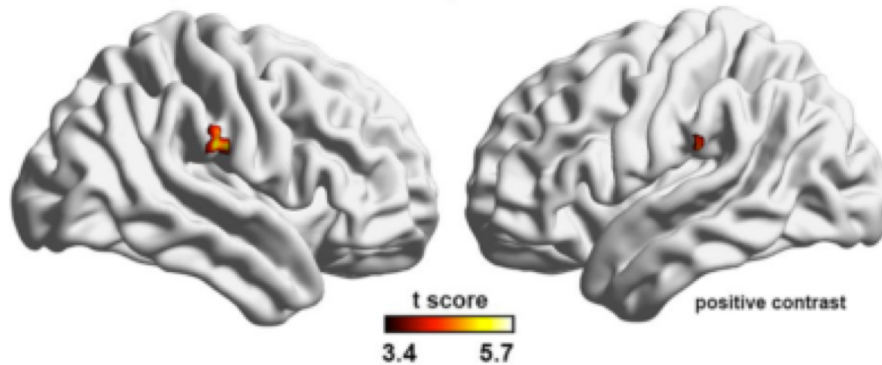
Pre-flight



Post-flight



Post – Pre flight





Interim conclusions

RS functional connectivity :

- is linked to behavior and task performance (*Laird et al, J Cogn Neurosci. 2011*)
- reflects physiological & pathological unconsciousness (*Heine et al, Front Psychol 2012*)
- permits single-patient automatic diagnosis (*Demertzi & Antonopoulos et al, Brain 2015*)

But

it remains unclear to what extent it provides a
representative estimate of cognition

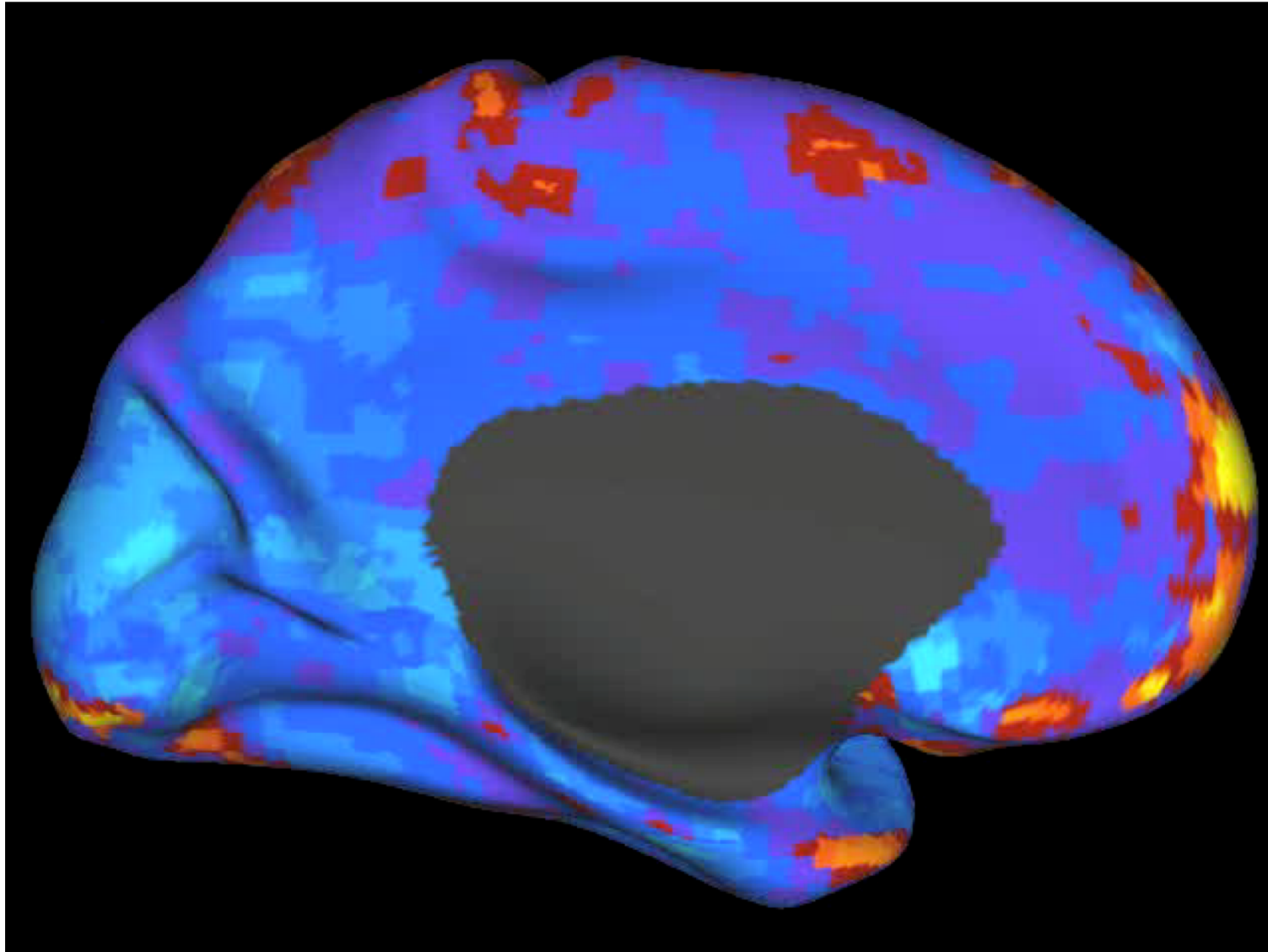
(*Peterson et al, NeuroImage Clin. 2015*)



Ongoing interactions among distinct brain regions

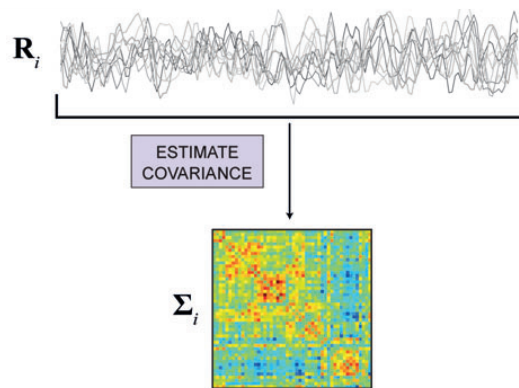
(*Hutchison et al, NeuroImage 2013*)

The brain is dynamic

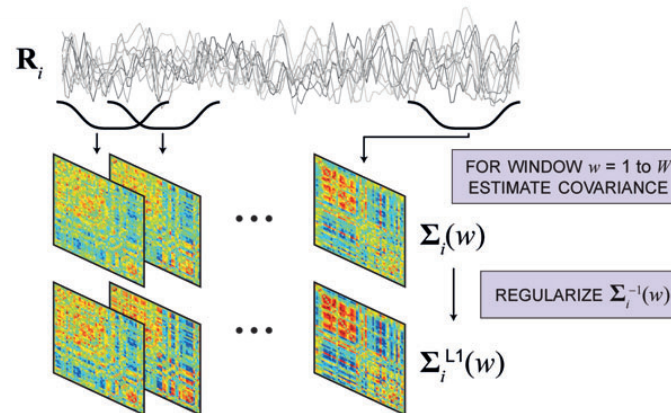


From stationarity to dynamics

Stationary fc



Time-varying fc



Dynamic

$$x_t = A \cdot x_{t-1} + \epsilon_t$$



Brain dynamics and cognition

Typical wakefulness: significance for performance, emotion and cognition

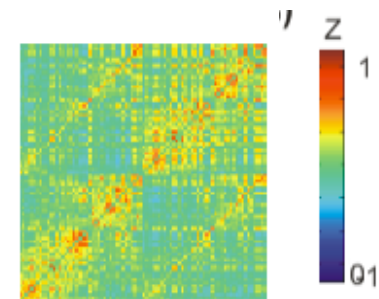
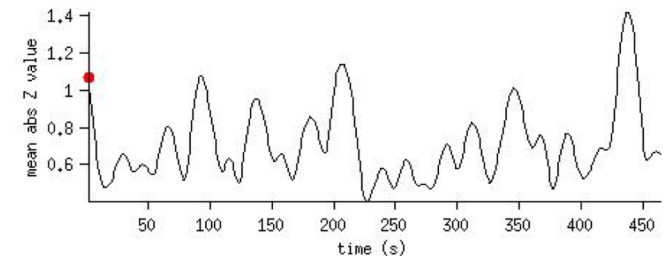
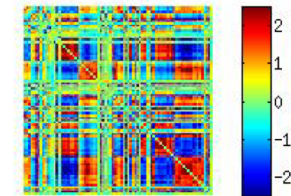
(Alavash, et al, *Neuroimage*, 2016; Shine et al., *Neuron*, 2016; Friston, *Neuroimage*, 1997; Thompson et al., *Hum. Brain Mapp*, 2013)

Unconsciousness: rigid spatiotemporal organization, less metastable dynamics

- **sleep** (Tagliazucchi et al., *PNAS* 2013; Wang, et al, *PNAS* (2016; Wilson et al., *Neuroimage* 2015; Chow et al., *PNAS* 2013)
- **anesthesia**
 - **in humans** (Tagliazucchi et al, *J. R. Soc. Interface.* 2016; Kafashan, et al, *Front. Neural Circuits*, 2016; Amico et al., *PLoS One* 2014)
 - **in animals** (Barttfeld *PNAS* . 2014); Grandjean et al., *Neuroimage.* 2017; Liang, et al, *Neuroimage* 2015).



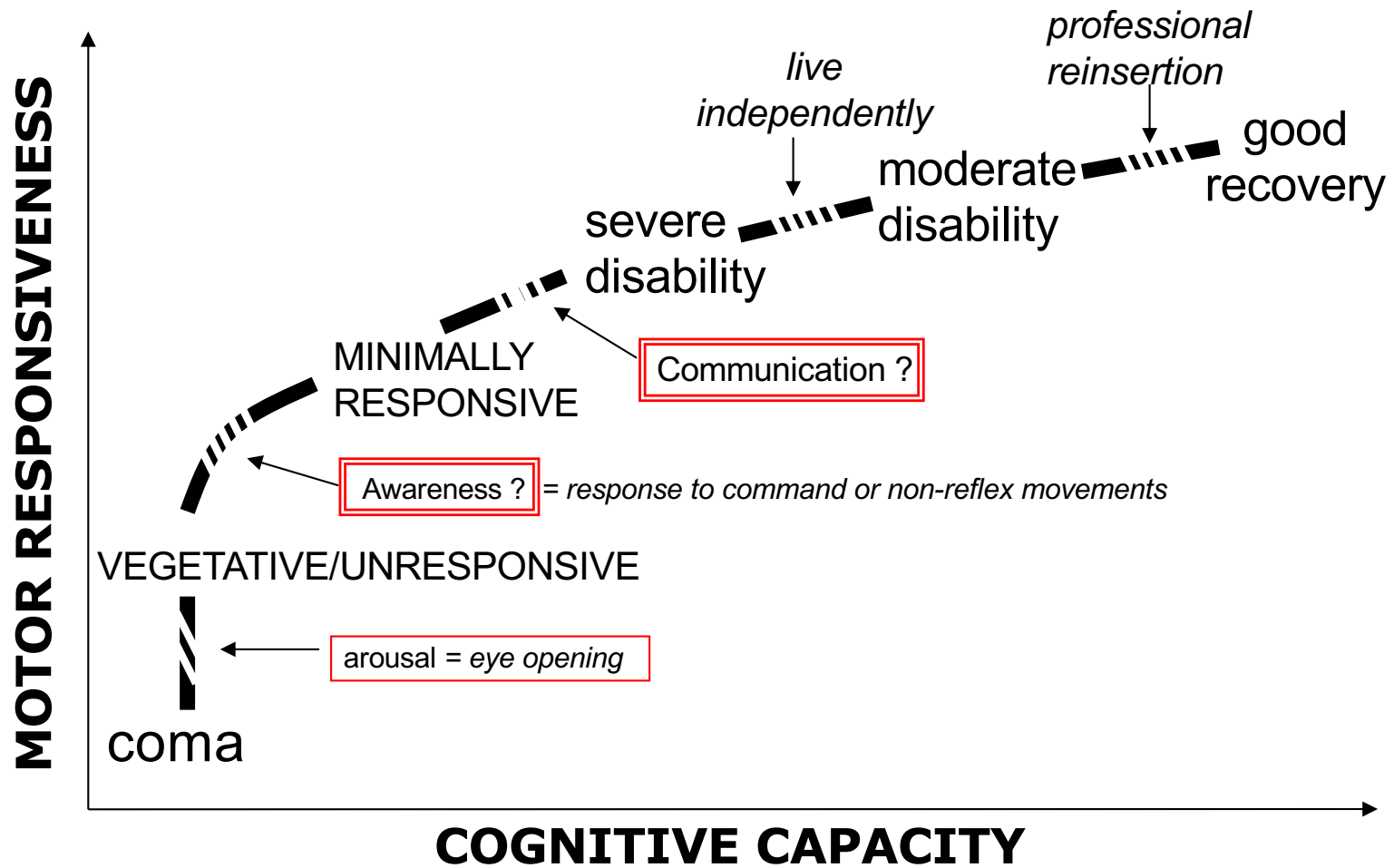
The brain cannot map the complexity of the internal and external world
(Dehaene, et al *Trends Cogn. Sci.* 2006; Tononi et al, *Nat. Rev. Neurosci.* 2016)



Barttfeld*, Ulhig*, Sitt*, et al, *PNAS* 2015



Disorders of Consciousness





Study cohort (N=159)

James S. McDonnell Foundation



Grant Type: Collaborative Activity Award, Phase I & II (2008-2017)

Main dataset

awake

	VS/UWS	MCS	CTR
LIEGE	17	23	21
PARIS	13	9	15
NY	6	10	11
Total	36	42	47

n = 125

Validation datasets

sedated

CMD

LIEGE	
EMCS	3
MCS	14
UWS	6

n = 23

ONTARIO	
VS/UWS-	6
VS/UWS+	5

n = 11



Methods



EPI acquisition

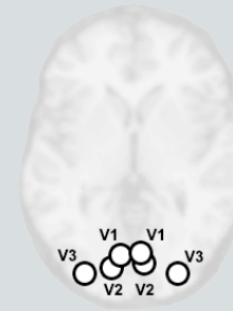


Preprocessing

Slice-time correction
Realignment
Segmentation
Normalization
Smoothing
Motion outliers (ART)
aCompCor
Regressing out realignment parameters and ART outliers
Bandpass filtering [0.008-0.09Hz]

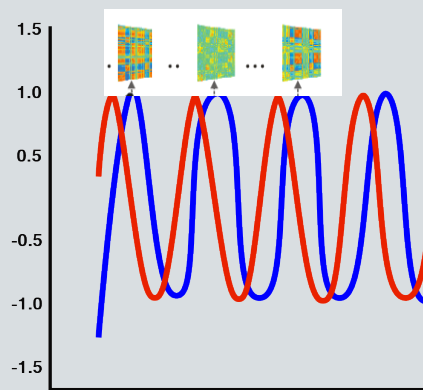
Brain parcellation

(Sphere ROIs)

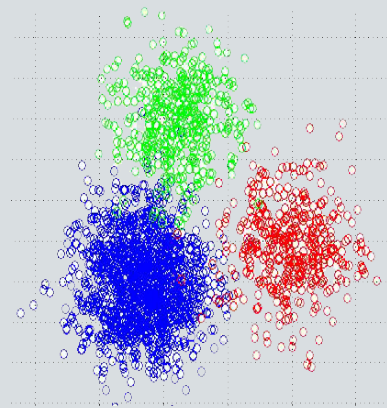


ROI timeseries extraction

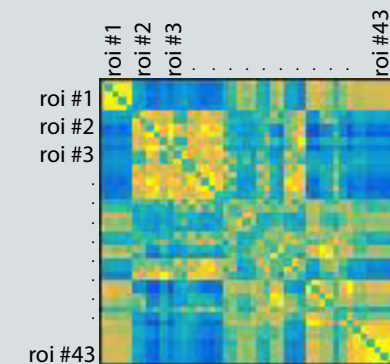
Phase analysis (Hilbert transform)



Unsupervised clustering (k-means)

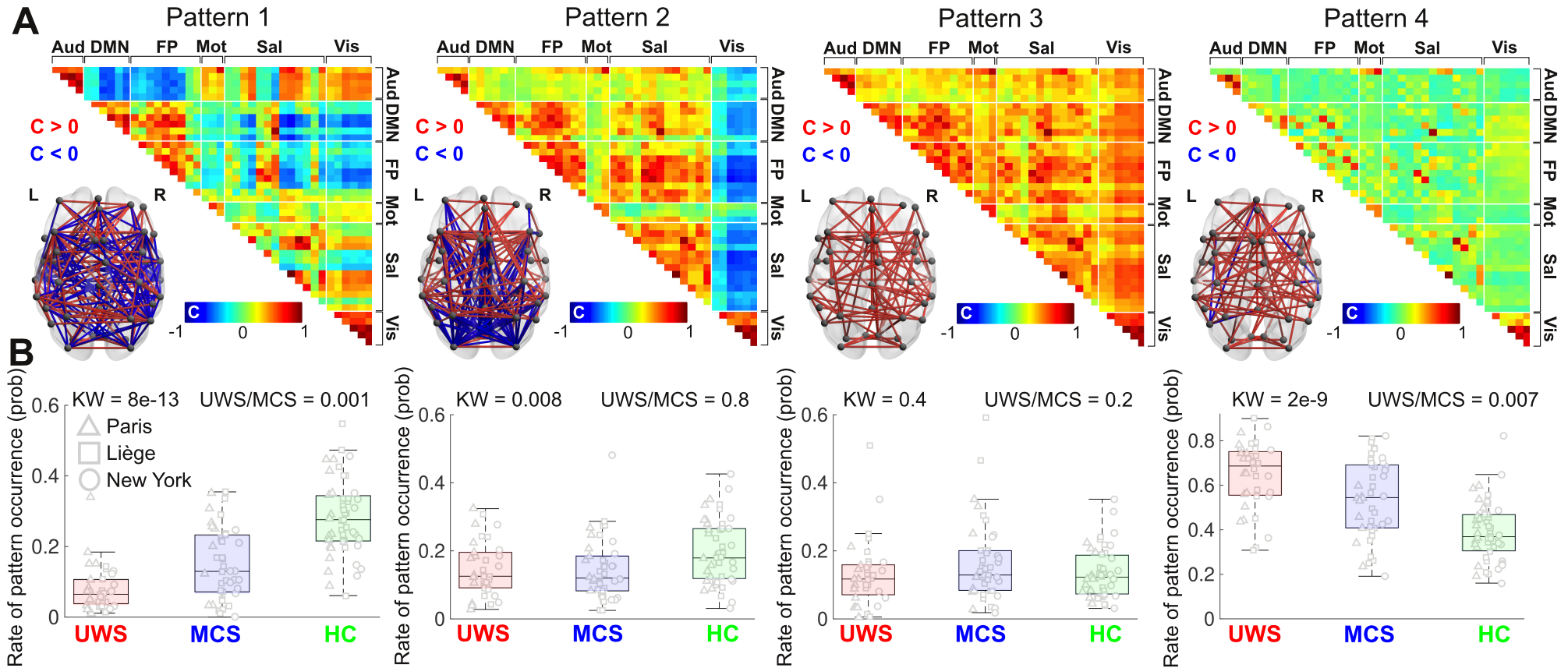


State identification (cluster centroids)



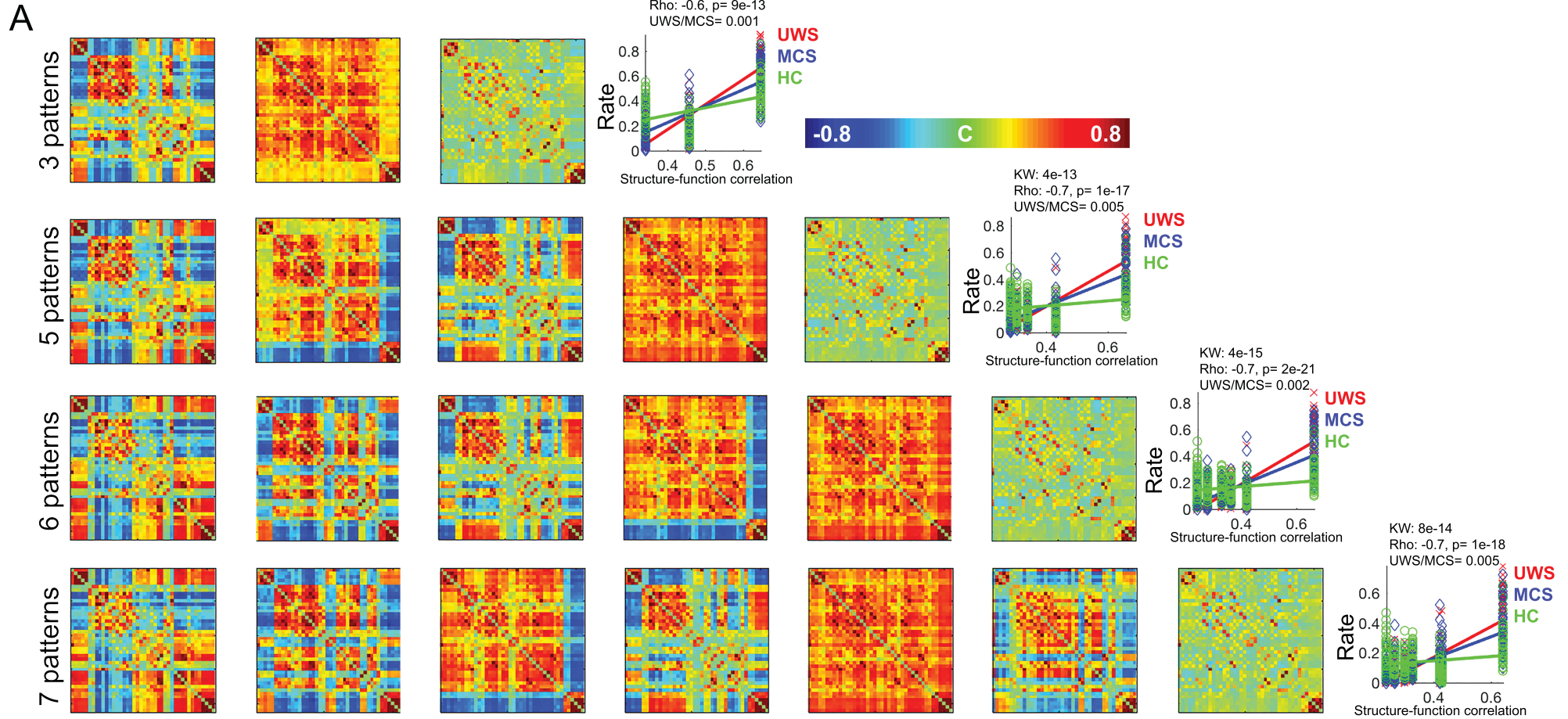


Four brain patterns



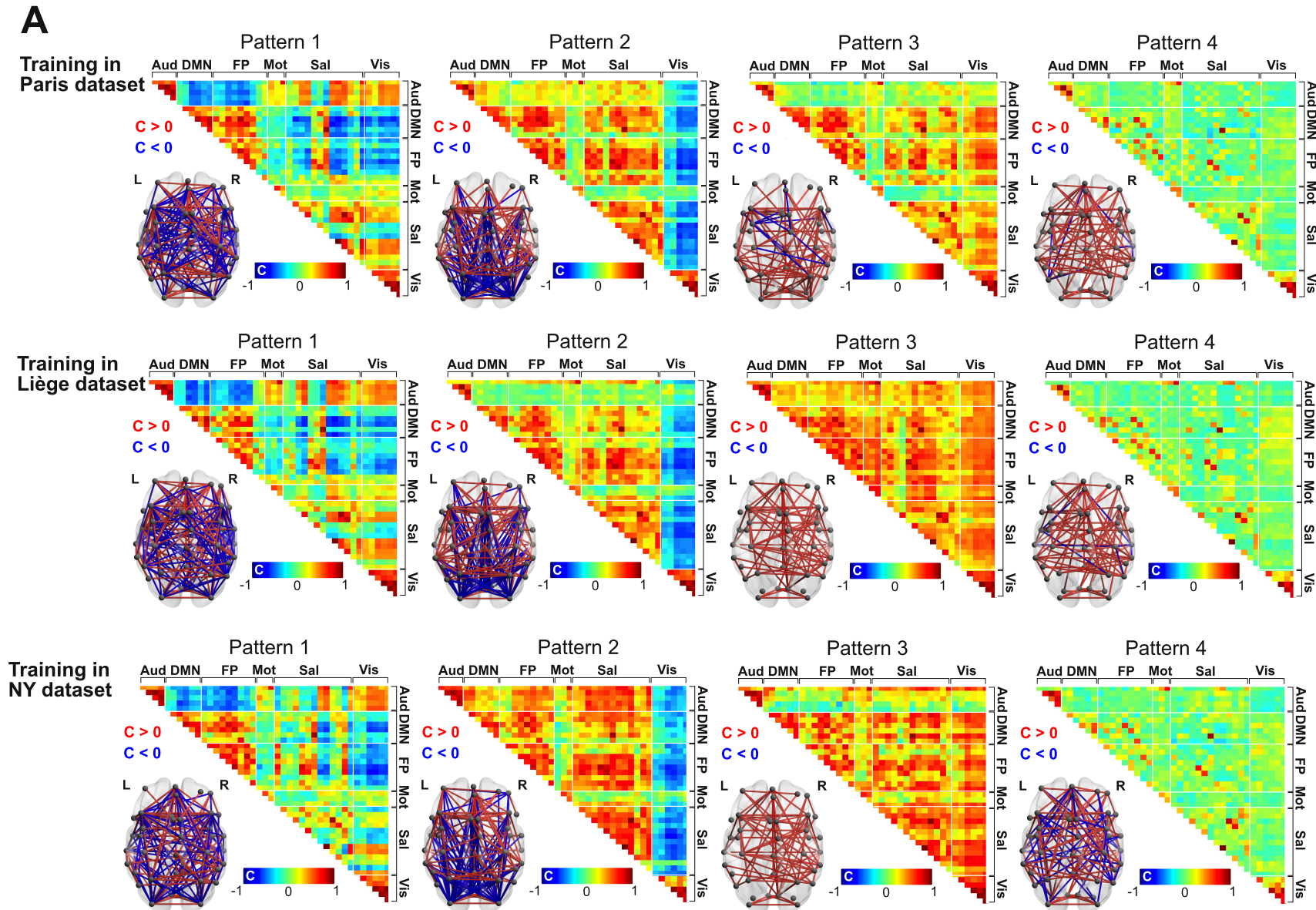


Patterns (different k)



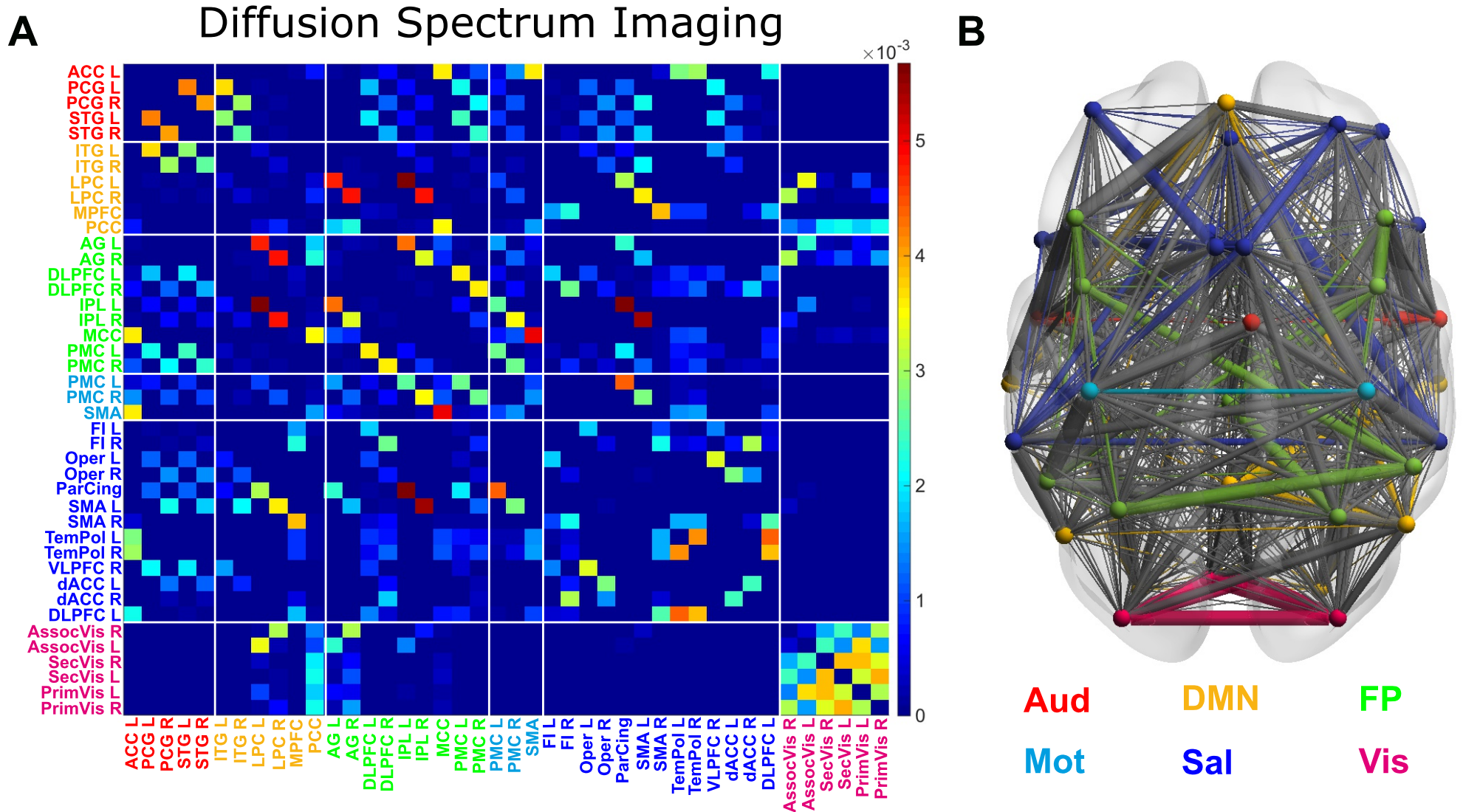


Patterns (per site)





Structure-function correlation



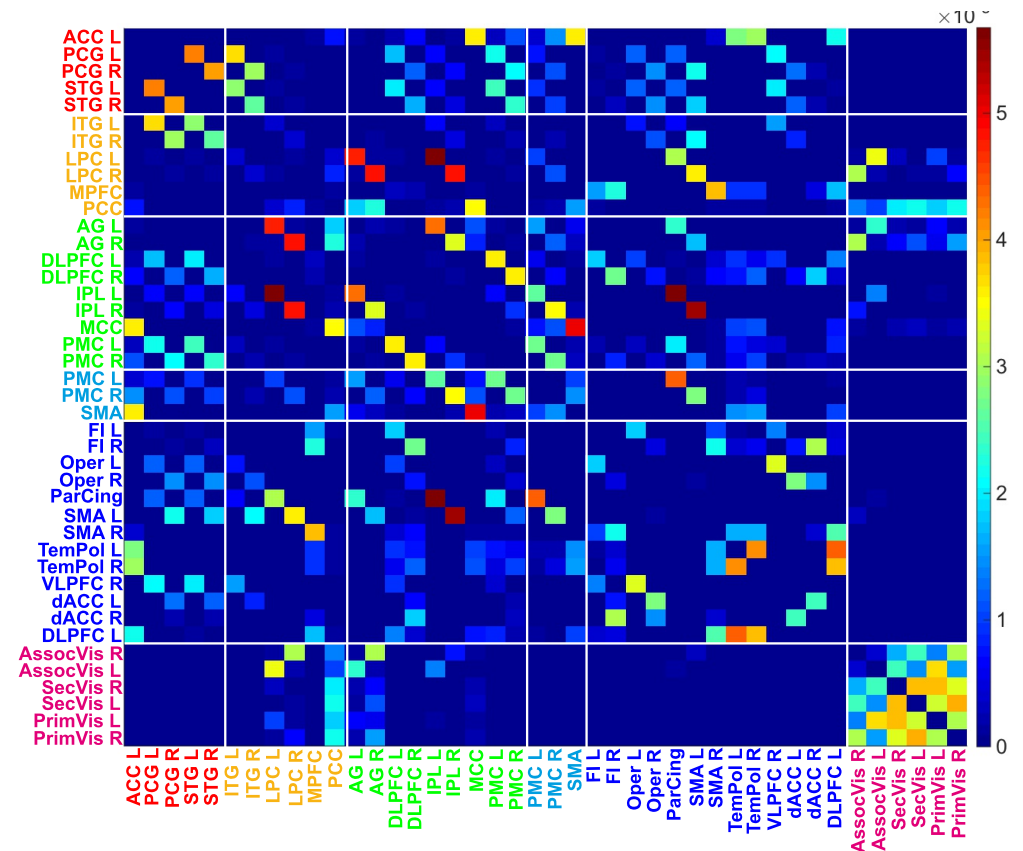
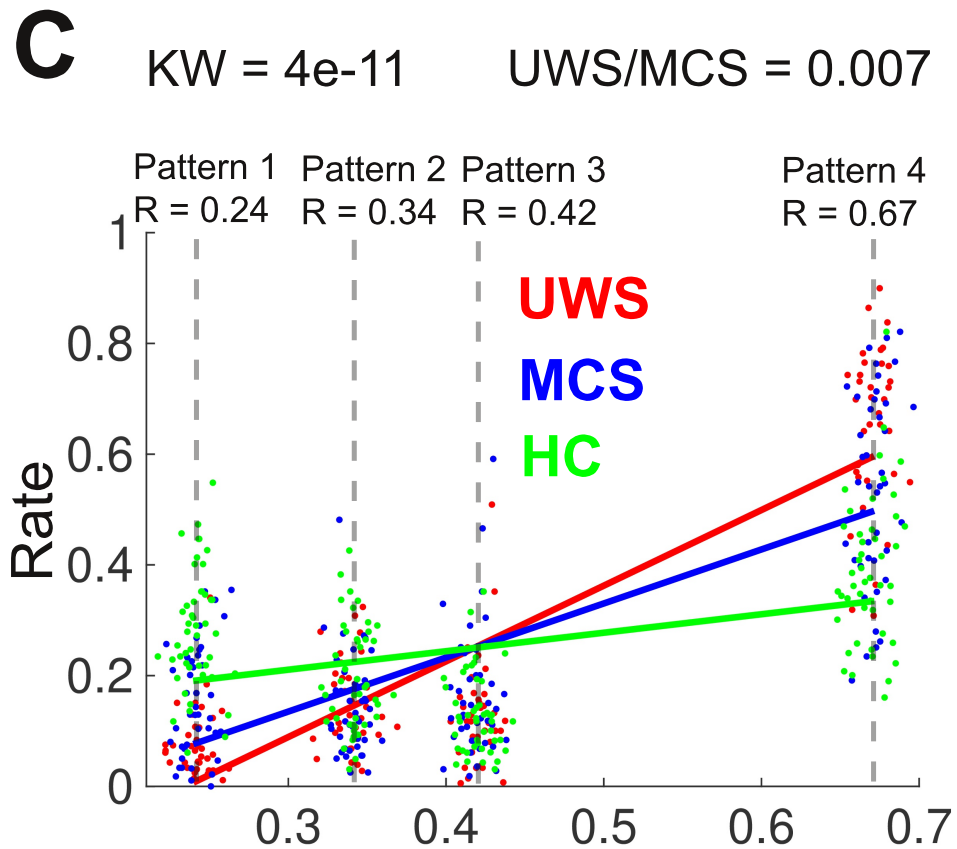
Hagmann, et al, 2008 PLOS Biol. 6, e159.

Demertzi & Tagliazucchi, Dehaene, Deco, Barttfeld, Raimondo, Martial, Fernández-Espejo, Rohaut, Voss, Schiff, Owen, Laureys, Naccache, Sitt.

Science Advances 2019



Structure-function correlation





Dynamics: Markov Process

- *stochastic process that has no memory*
- *selection of next state depends only on current state, and not on prior states*
- *process is fully defined by a set of transition probabilities π_{ij}*
 π_{ij} = probability of selecting state j next, given that presently in state i .
Transition-probability matrix Π collects all π_{ij}

Transition-Probability Matrix

○ Example

- *system with three states*

$$\Pi \equiv \begin{pmatrix} \pi_{11} & \pi_{12} & \pi_{13} \\ \pi_{21} & \pi_{22} & \pi_{23} \\ \pi_{31} & \pi_{32} & \pi_{33} \end{pmatrix} = \begin{pmatrix} 0.1 & 0.5 & 0.4 \\ 0.9 & 0.1 & 0.0 \\ 0.3 & 0.3 & 0.4 \end{pmatrix}$$

If in state 1, will stay in state 1 with probability 0.1

If in state 1, will move to state 3 with probability 0.4

Never go to state 3 from state 2

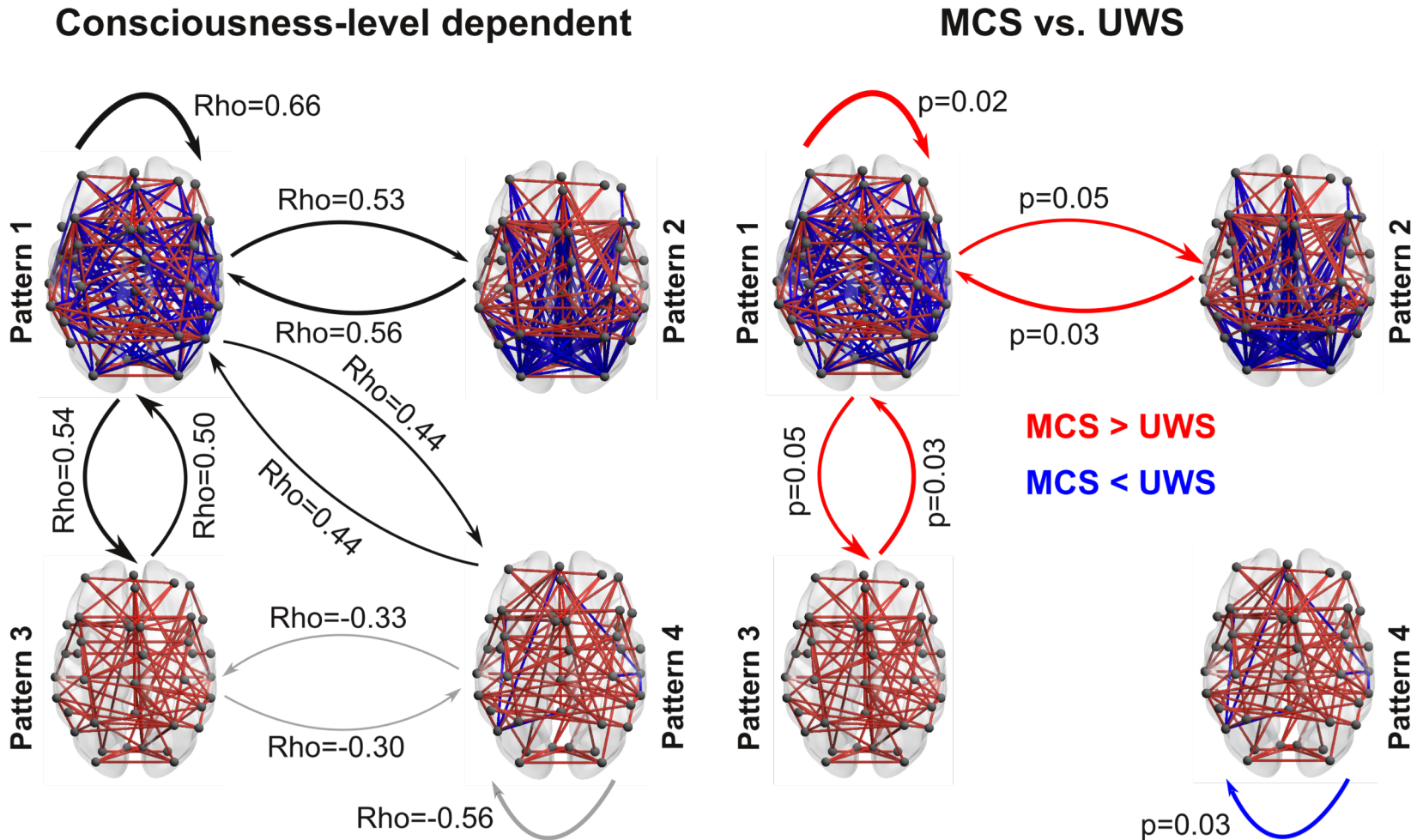
○ Requirements of transition-probability matrix

- *all probabilities non-negative, and no greater than unity*
- *sum of each row is unity*
- *probability of staying in present state may be non-zero*

Transitions differ with respect to state of consciousness



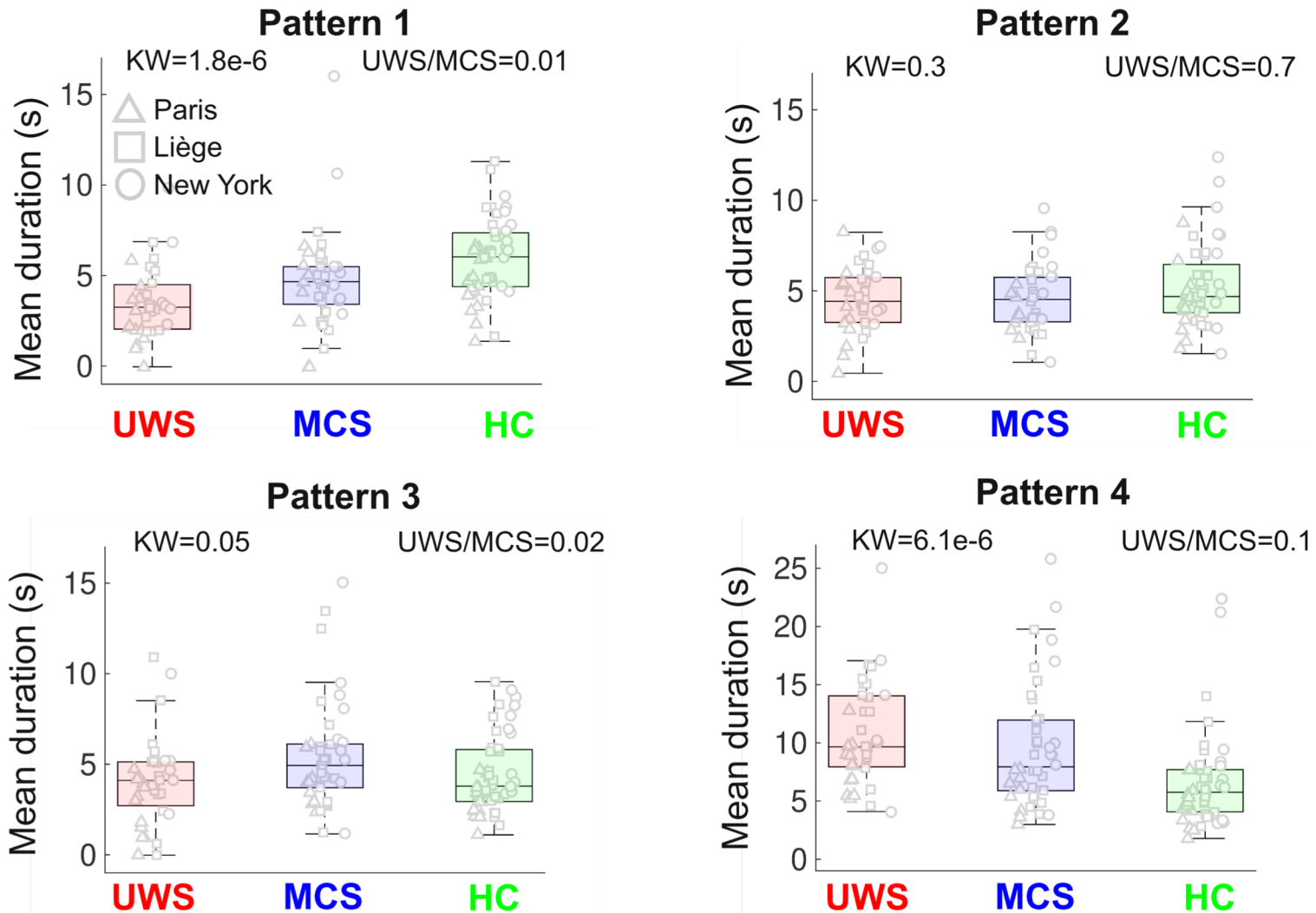
A. Between-pattern transition probabilities



Pattern exploration differs with respect to state of consciousness



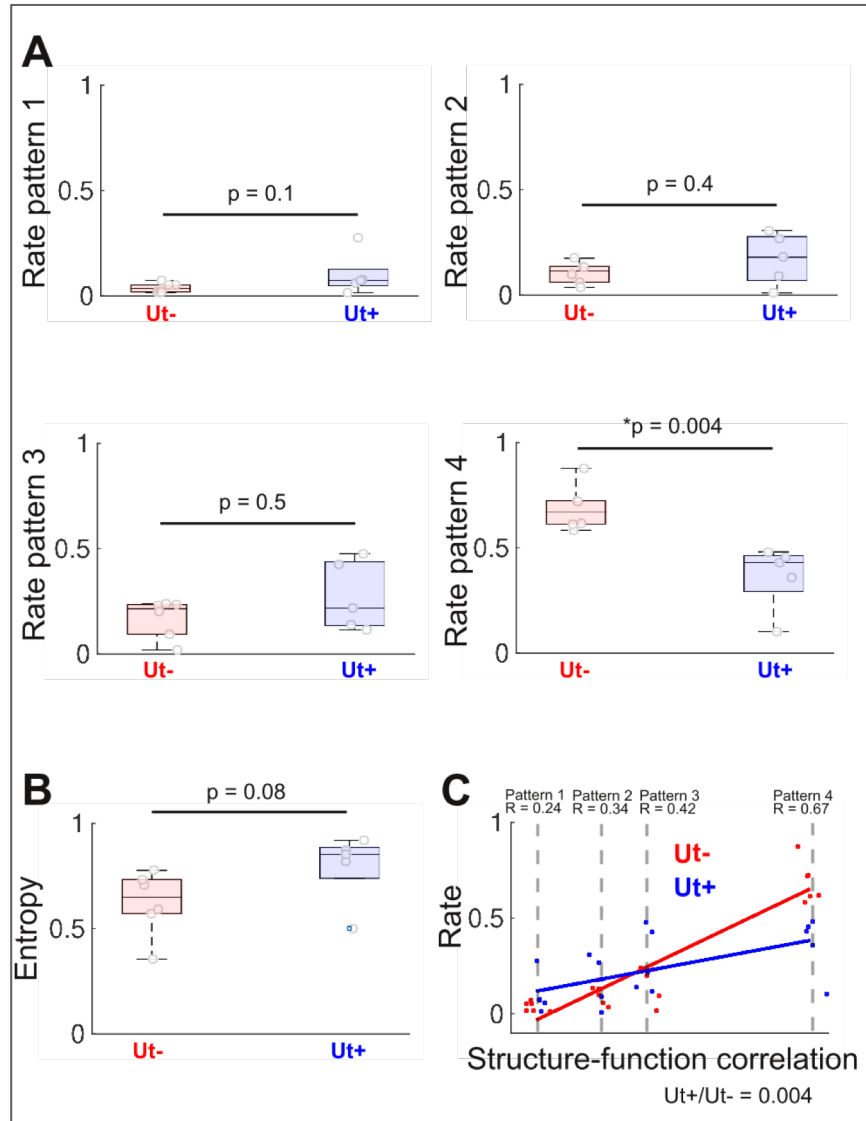
B. Duration of pattern occupation



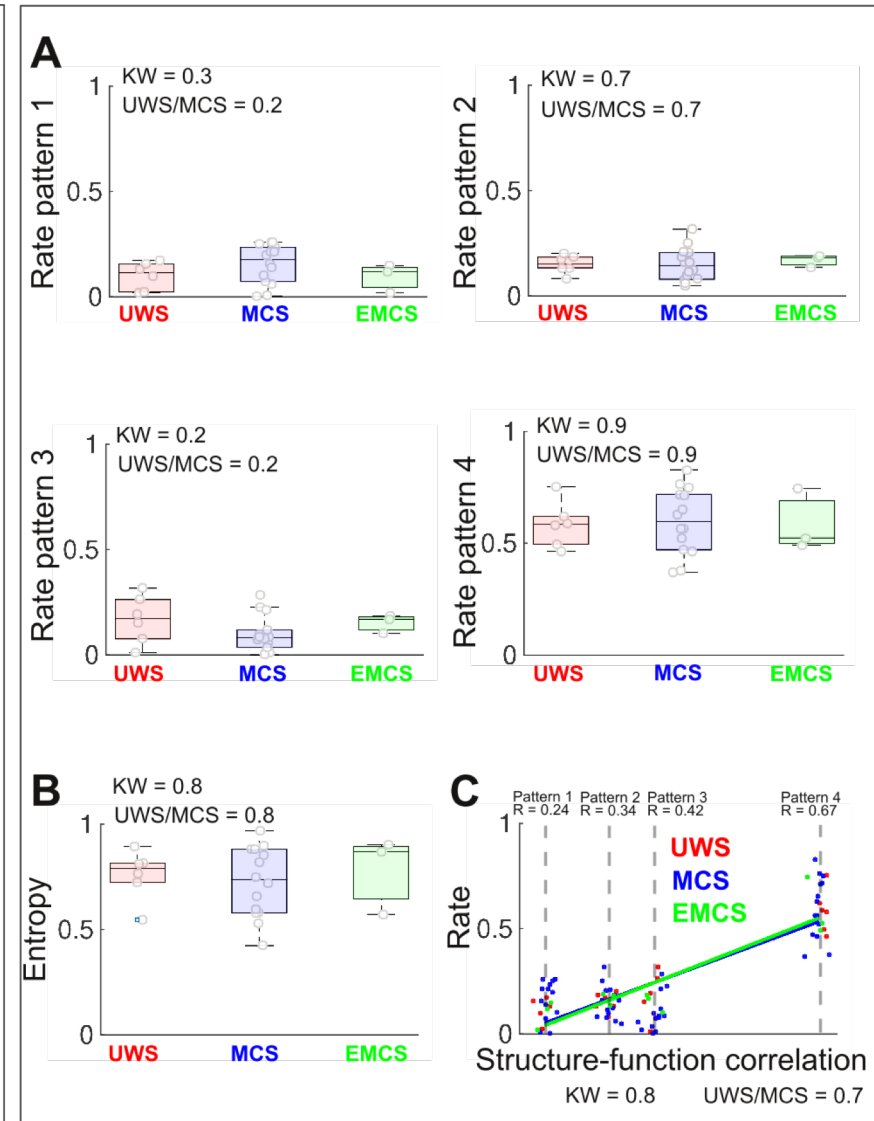


Do we measure consciousness?

Pattern prediction in cognitive-motor dissociation

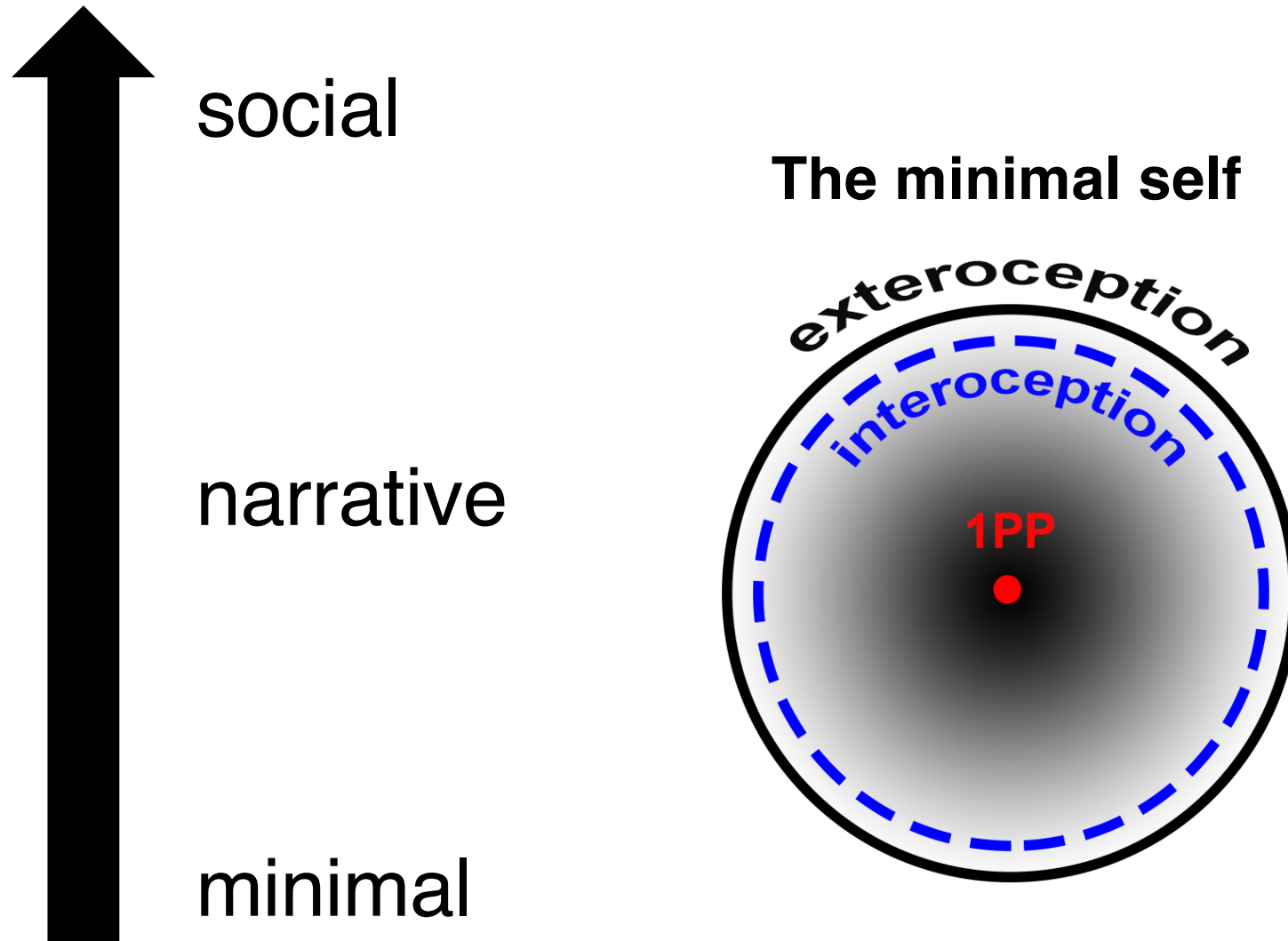


Pattern prediction in anesthesia





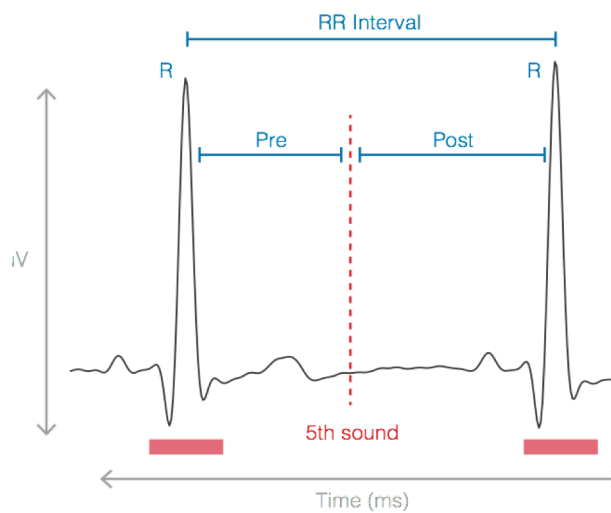
Self = Consciousness?



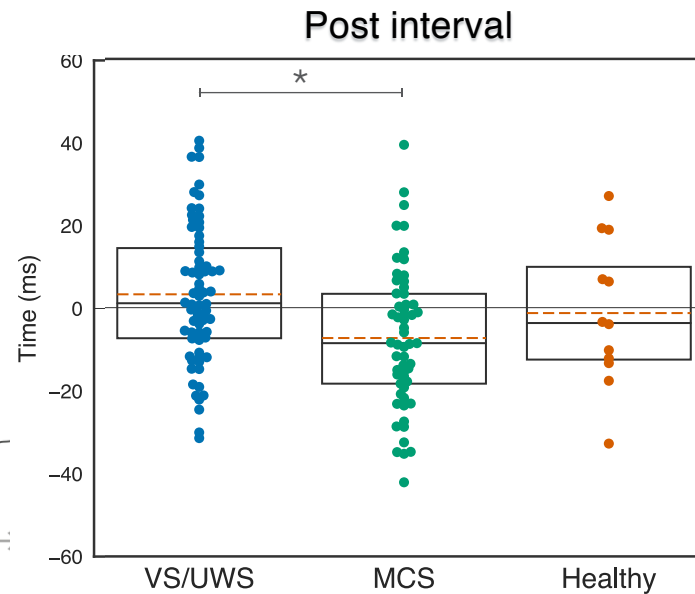
Brain-body interactions



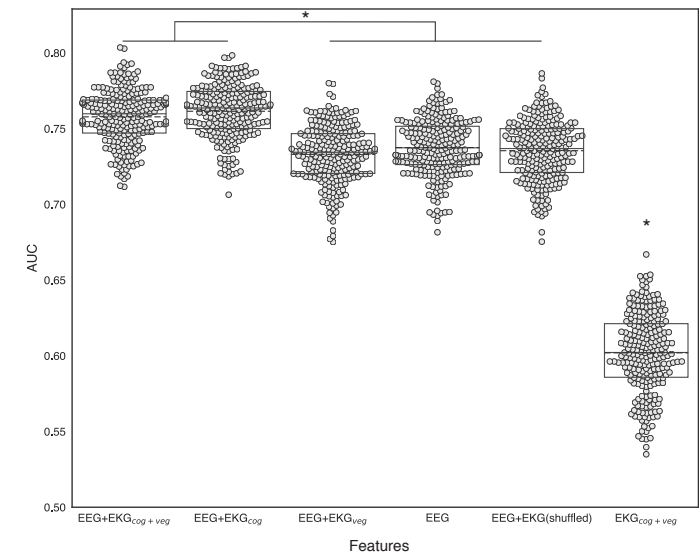
Auditory oddball paradigm



Cardiac cycle phase acceleration only in MCS

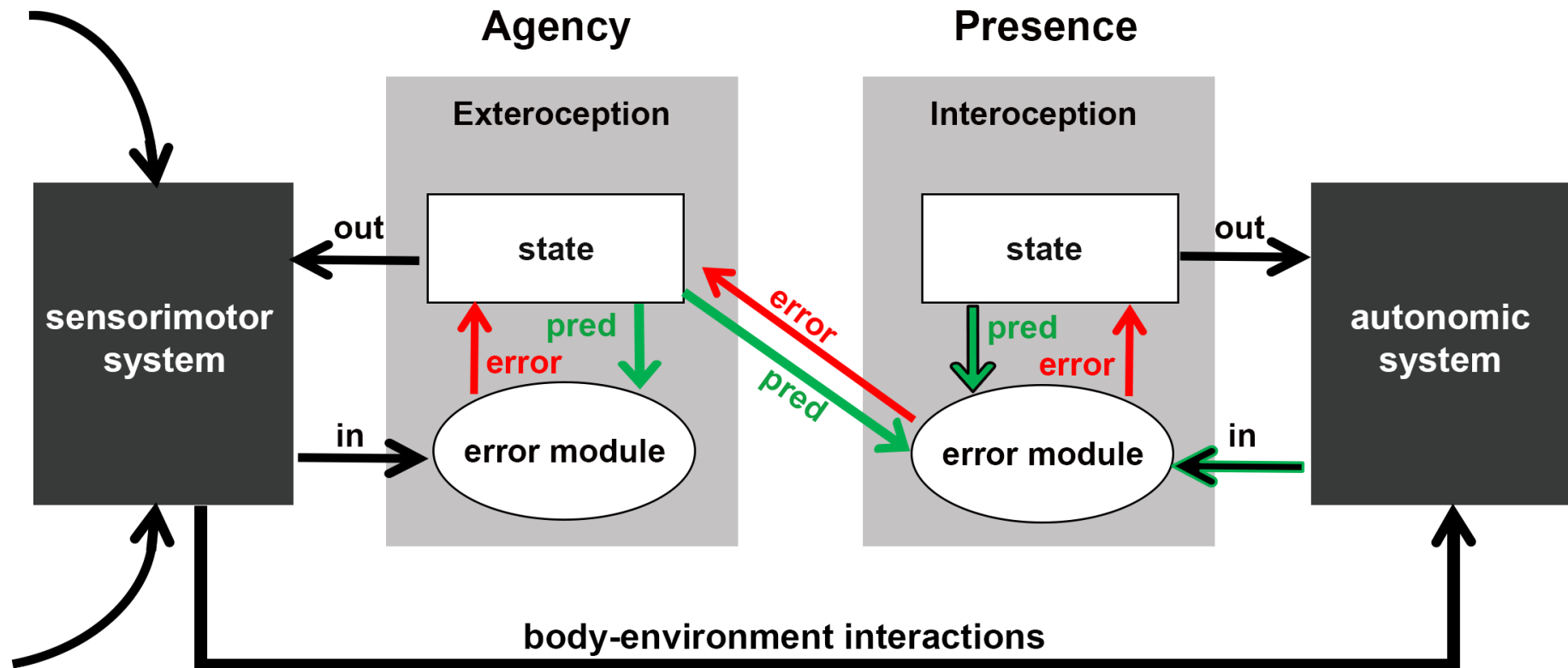


Electrocardiographic markers carry independent information from EEG





Which model for Unconsciousness?



!Apply to our lab!



Taken together...

Consciousness needs a brain which:

- is intrinsically organized
- shows complexity
- shows dynamic flexibility

Consciousness as brain-body interactions

Consciousness as active inference



Thank you

Coma Science Group & PICNIC Lab

The departments of Neurology and Radiology in Liège & Paris

...and mostly
patients and their families!

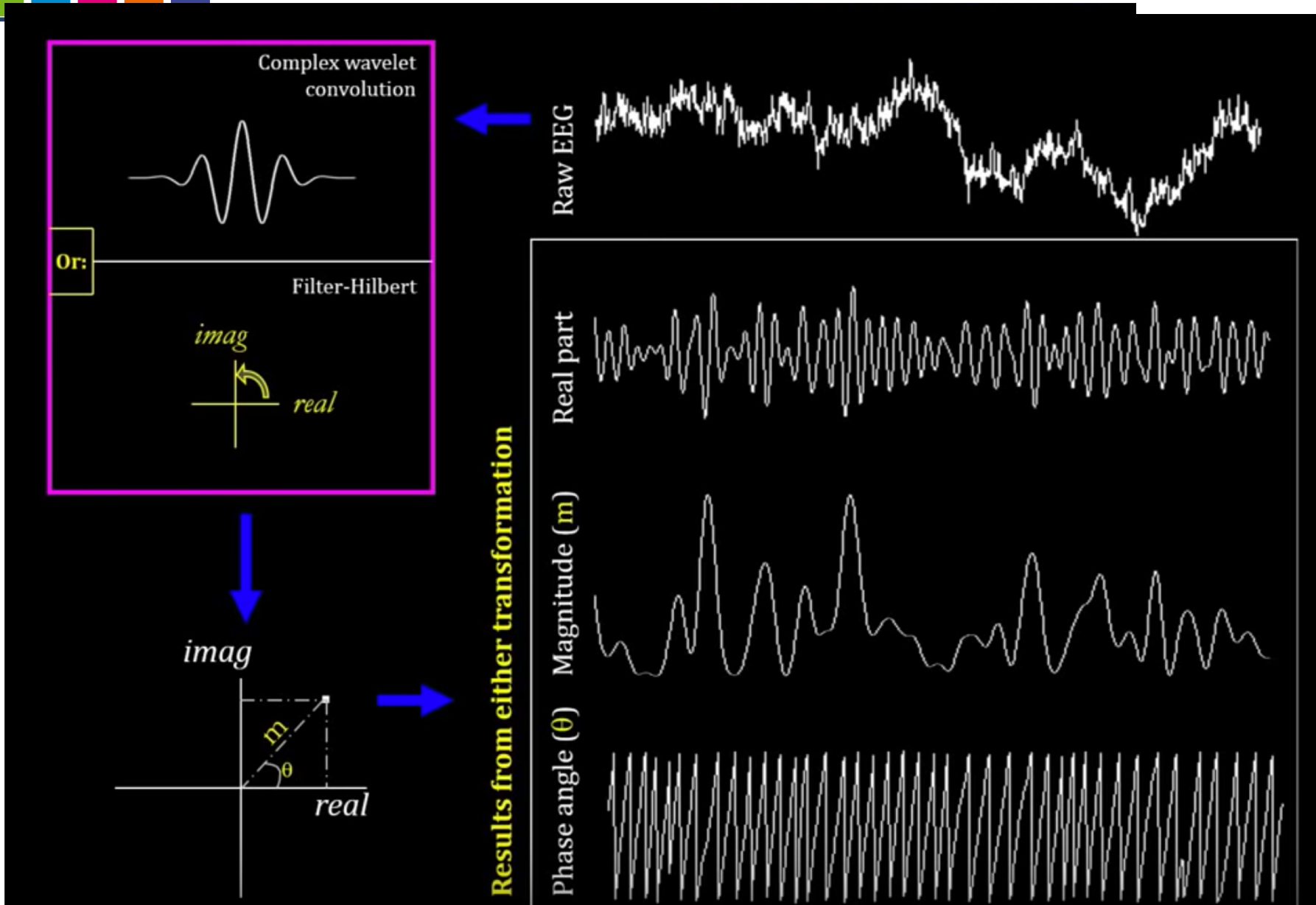


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The Hilbert transform



Phase coherence

