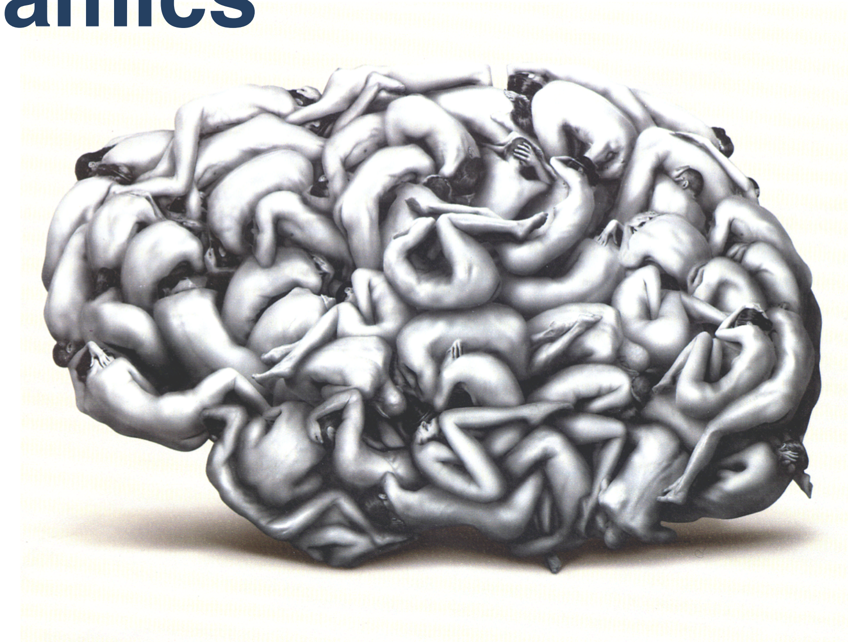
Detecting signatures of consciousness in cortical dynamics



Instituto de Neurobiología
Universidad Nacional Autonoma de Mexico
15 November2018

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University & University Hospital of Liège
Belgium

Some numbers…

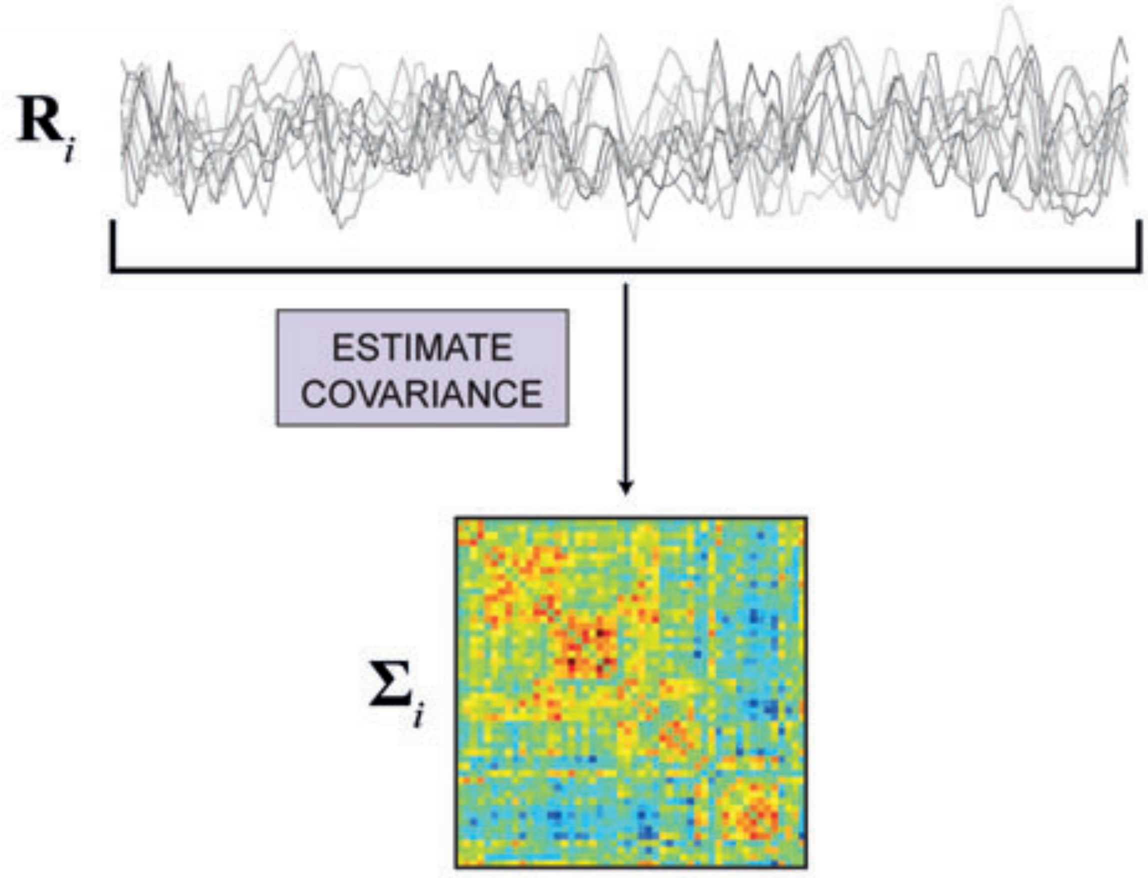
- The human brain is approximately 2% of the weight of the body
- 80% of this energy consumption is used to support neuronal signaling
- Stimulus and performance-evoked changes in brain energy consumption <5%

→ *While conscious awareness is energetically inexpensive, it is dependent upon a very complex, dynamically organized, non-conscious state of the brain that is achieved at great expense*

Raichle & Snyder. Intrinsic Brain Activity and Consciousness.
In: Laureys S, Tononi G, editors. The Neurology of Consciousness. Oxford: Elsevier Academic Press; 2009. p. 81-48

Functional connectivity in rest

Stationary



Allen et al, Cereb Cortex 2014

Stationary rsfc and cognition

G I G A

Stationary 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)

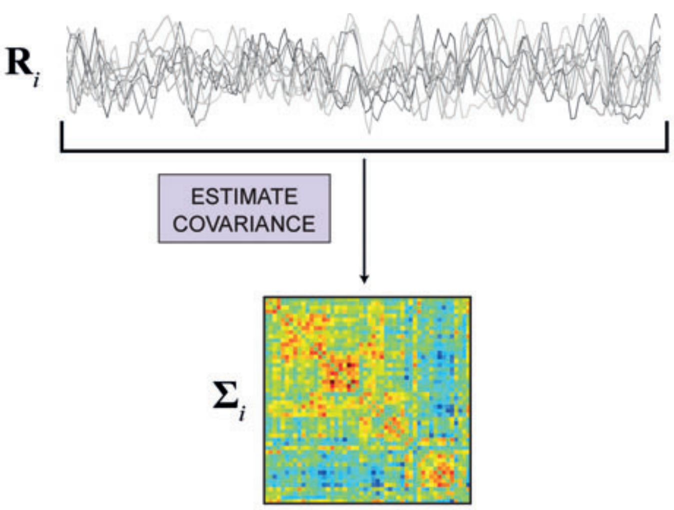
↓

Ongoing interactions among distinct brain regions

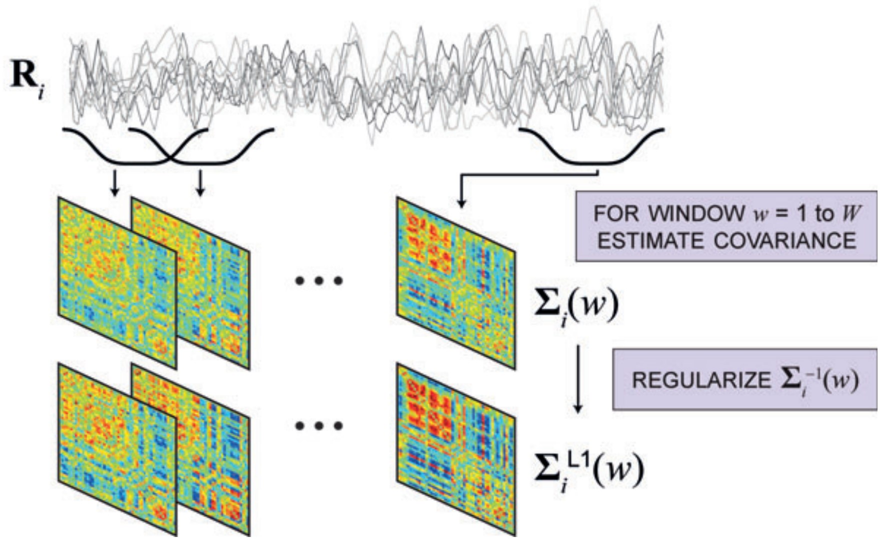
(Hutchison et al, NeuroImage 2013)

Dynamic functional connectivity in rest

Stationary fc



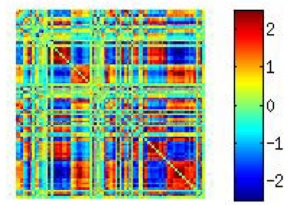
Dynamic fc

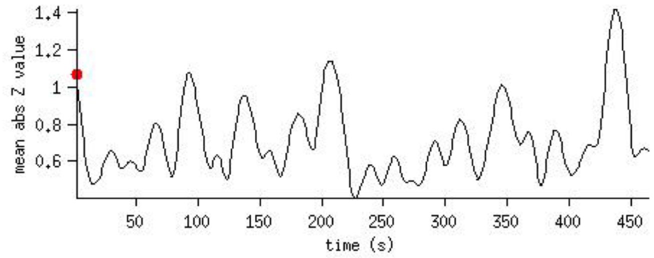


Allen et al, Cereb Cortex 2014

Dynamic rsfc and cognition

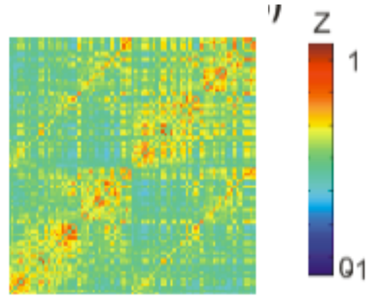
Typical wakefulness: significance for performance, emotion and cognition
(Alavash, et al, *Neuroimage*, 2016; Shine *et al.*, *Neuron*, 2016; Friston, *Neuroimage*, 1997; Thompson *et al.*, *Hum. Brain Mapp,* 2013)





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).



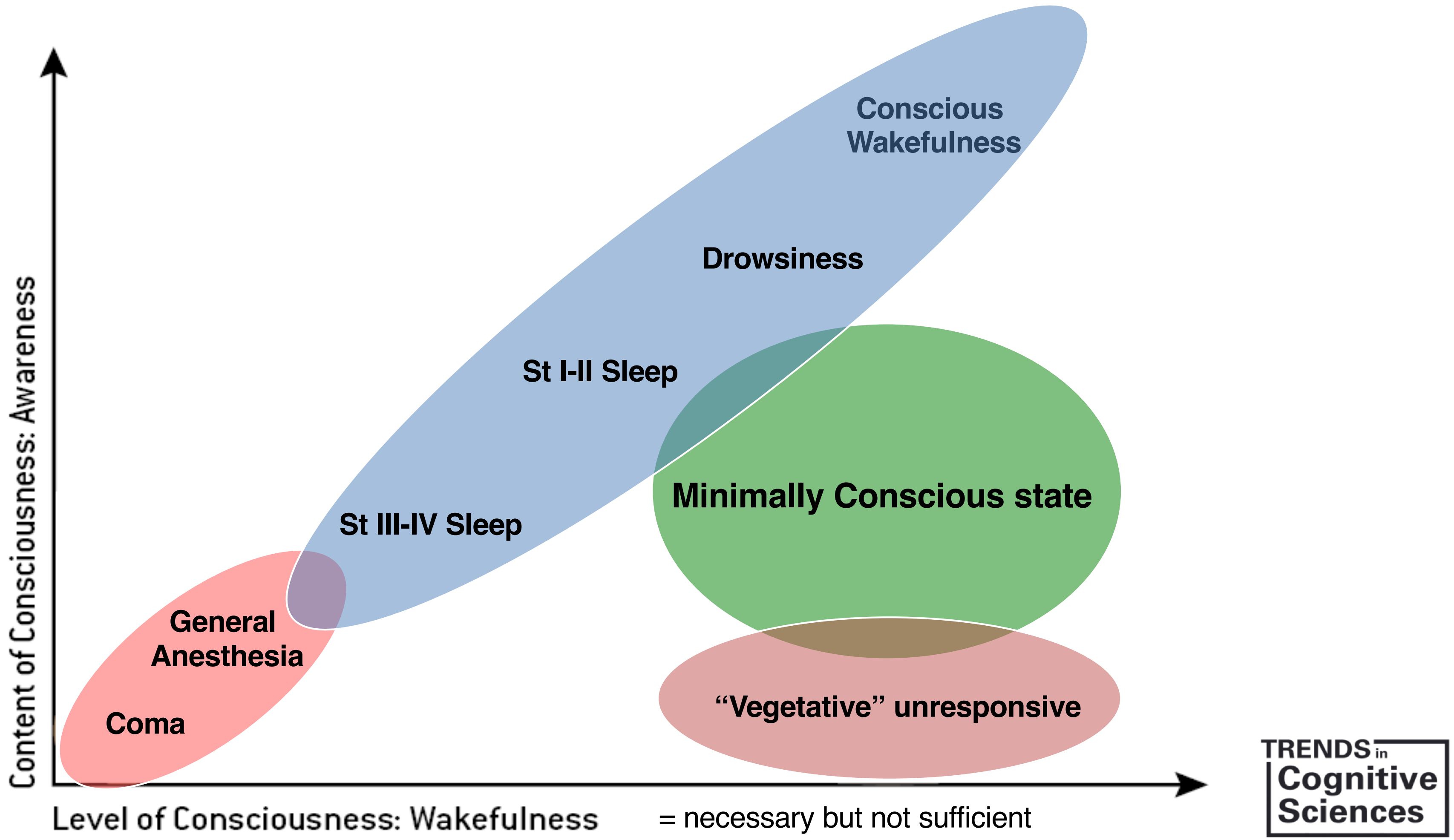
Barttfeld*, Ulhrig*, Sitt*, et al, PNAS 2015

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)

The aim:

to use spontaneous brain dynamics to detect signatures of consciousness in wakeful noncommunicating conditions

Disorders of Consciousness



Laureys. *Trends Cogn Sci* 2005; Laureys et al, *Nat Clin Med* 2008
Demertzi, Boly, Laureys. *Encyclopedia of Consciousness* 2009

Behaviour

Terry Schiavo °1963,
vegetative 1990, † 2005 USA

Study cohort (N=159)

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

LIEGE	
EMCS	3
MCS	14
UWS	6

n = 23

CMD

ONTARIO	
VS/UWS-	6
VS/UWS+	5

n = 11

James S. McDonnell Foundation

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

Analysis pipeline

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]

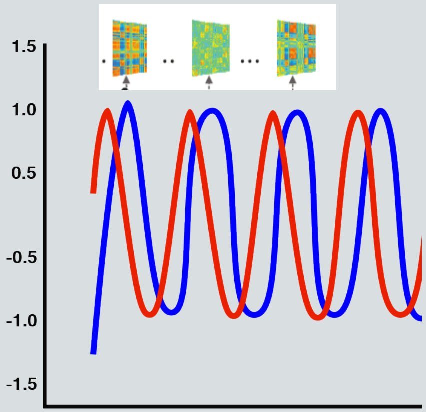
Brain parcellation

(Sphere ROIs)

ROI timeseries extraction

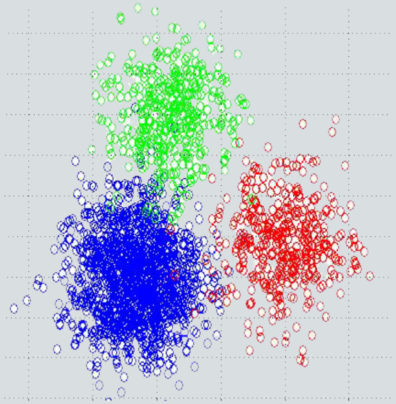
Phase analysis

(Hilbert transform)



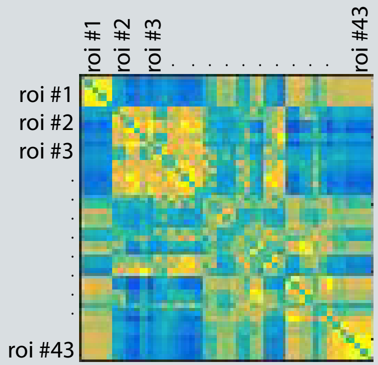
Unsupervised clustering

(k-means)

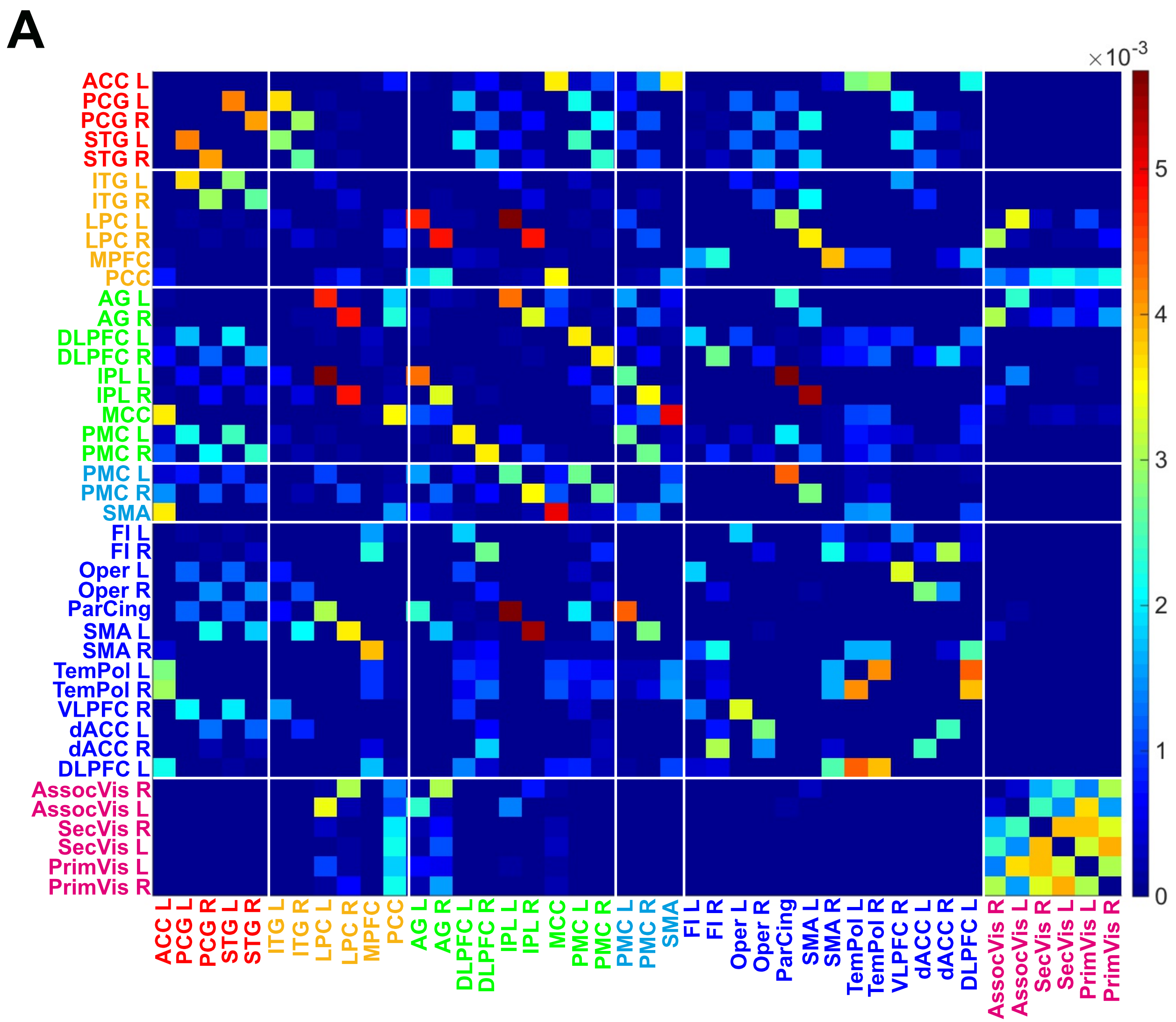


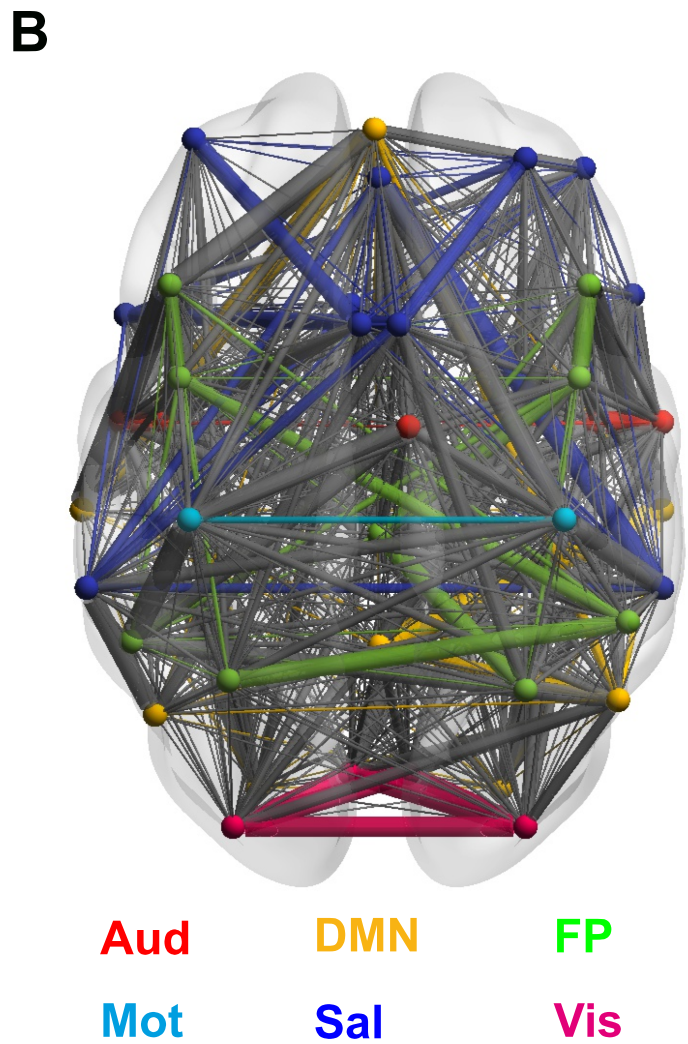
State identification

(cluster centroids)



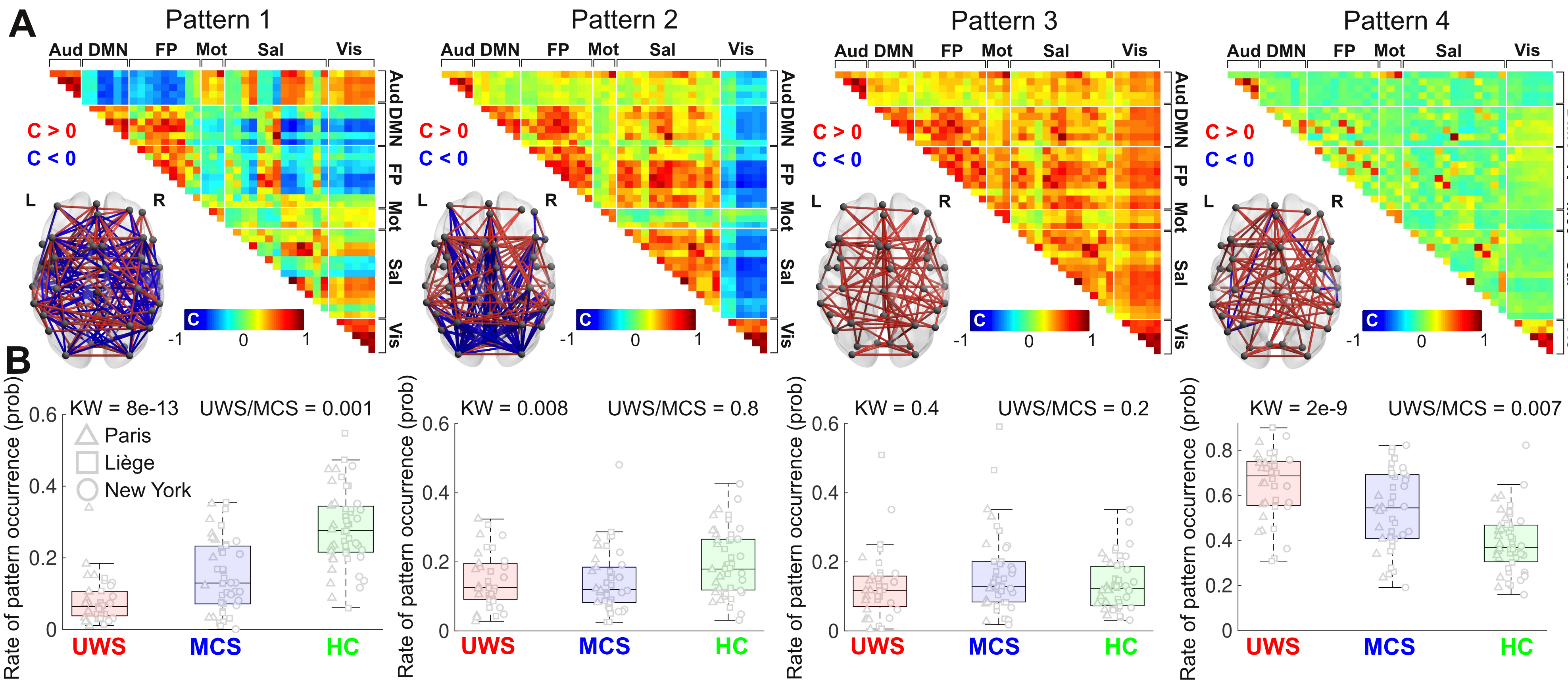
Structure-function correlation



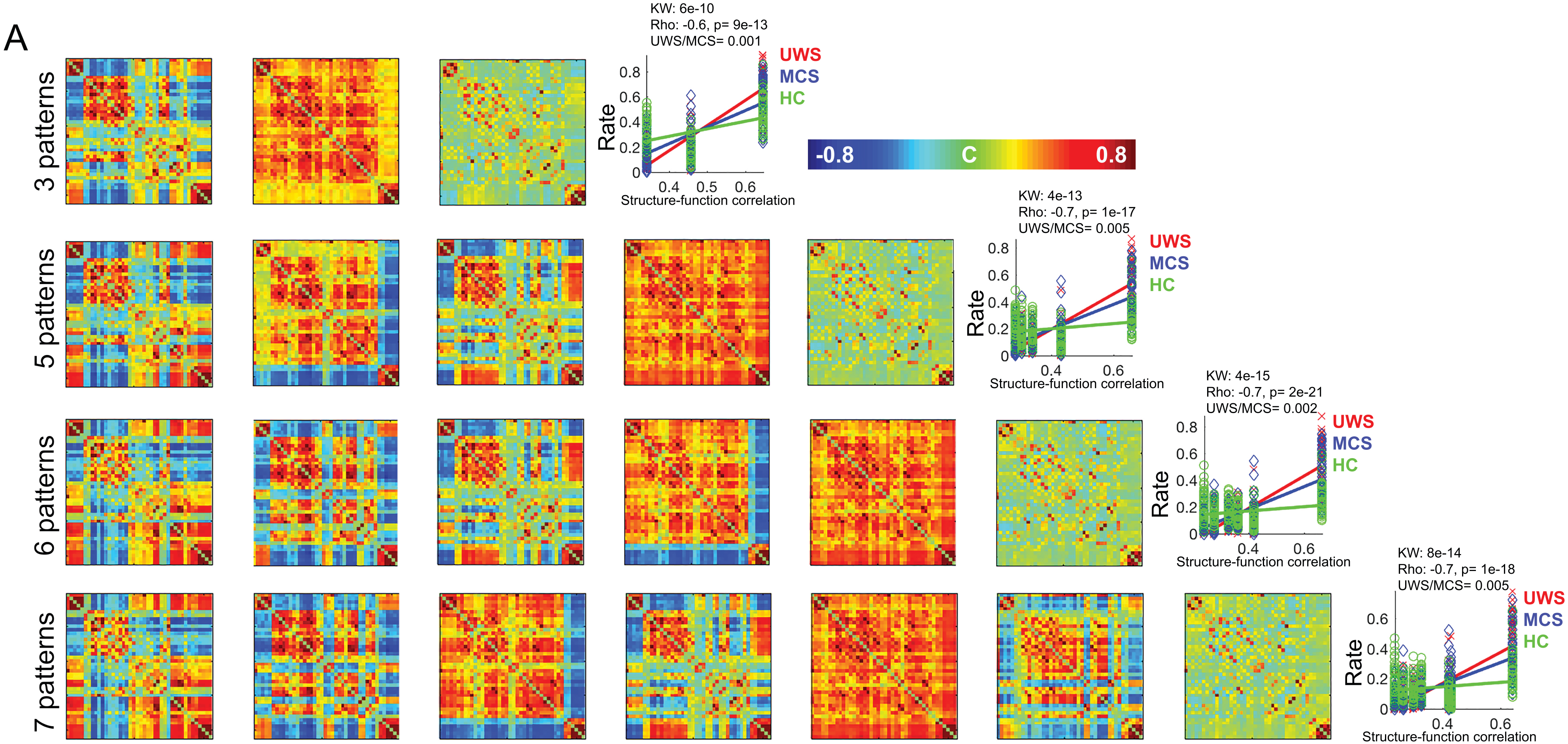


Diffusion Spectrum Imaging

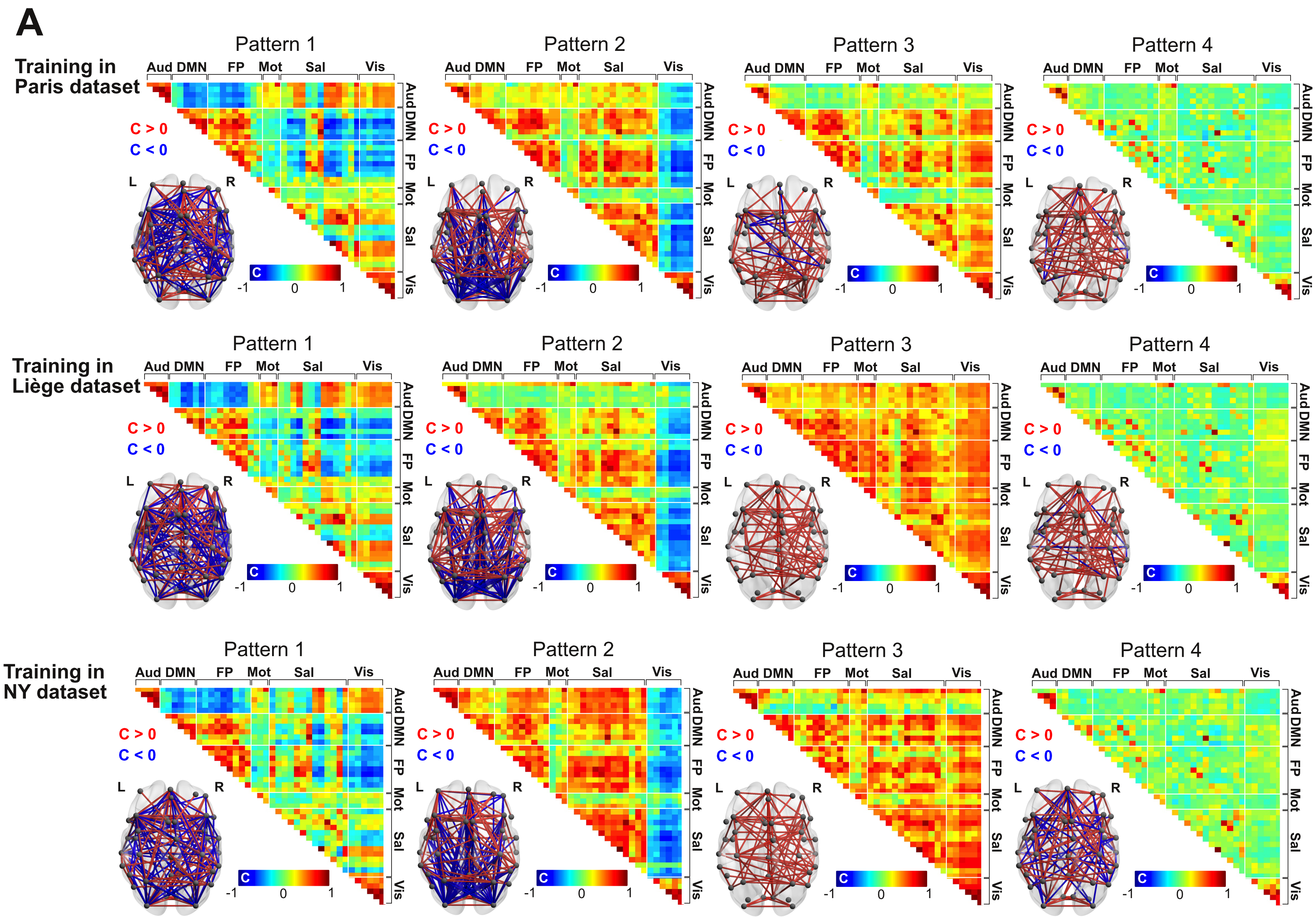
Patterns (all sites)



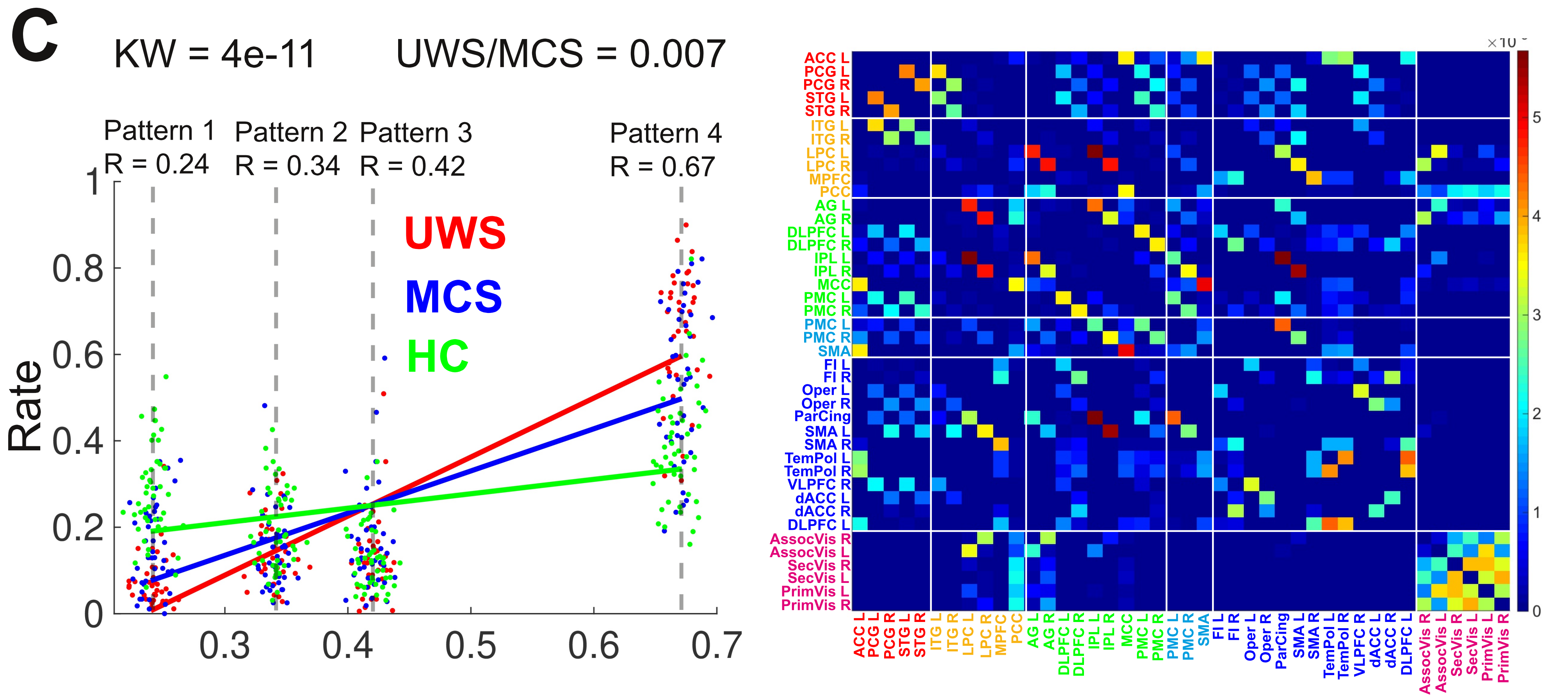
Patterns (different k)



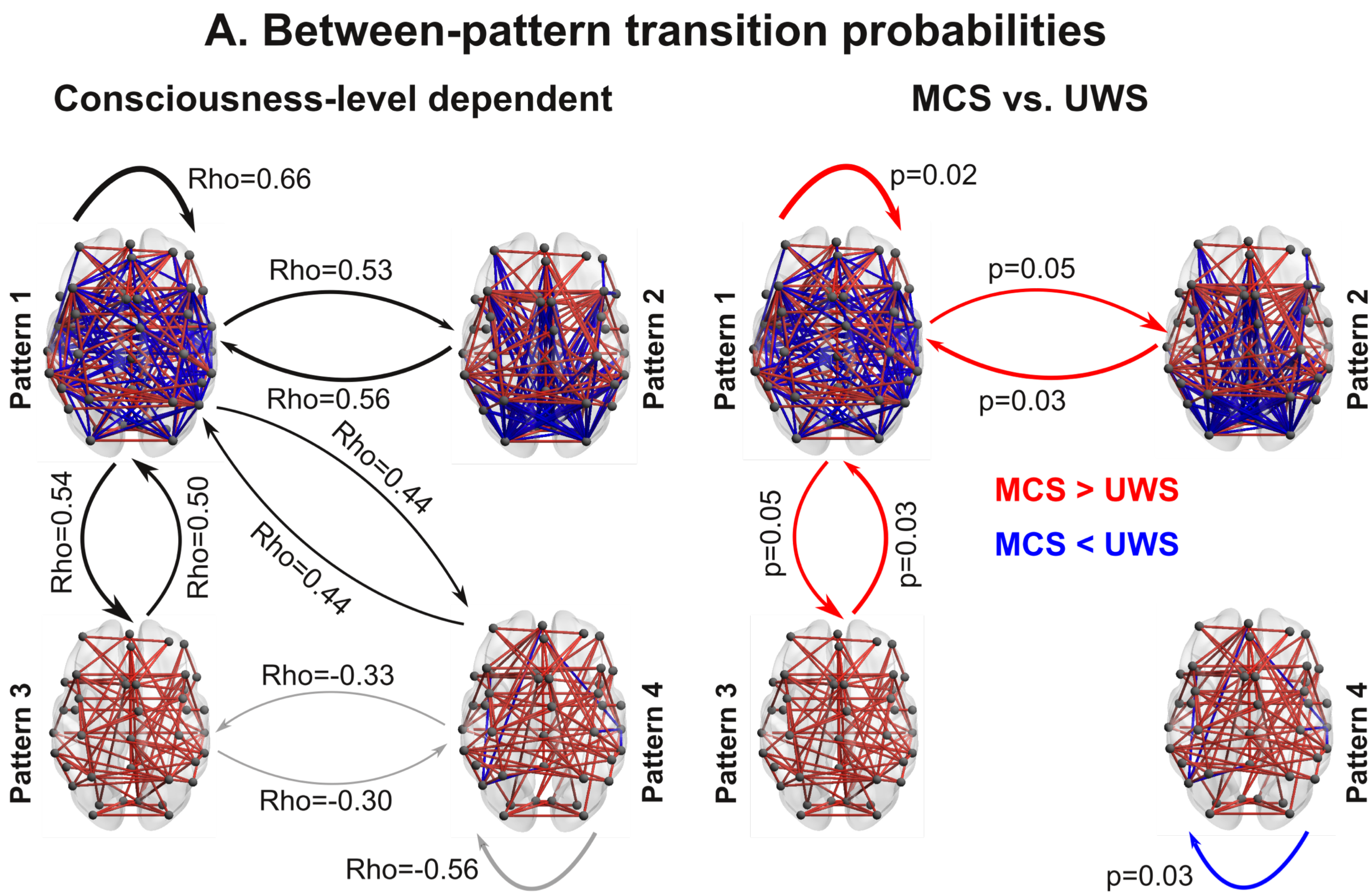
Patterns (per site)



Structure-function correlation

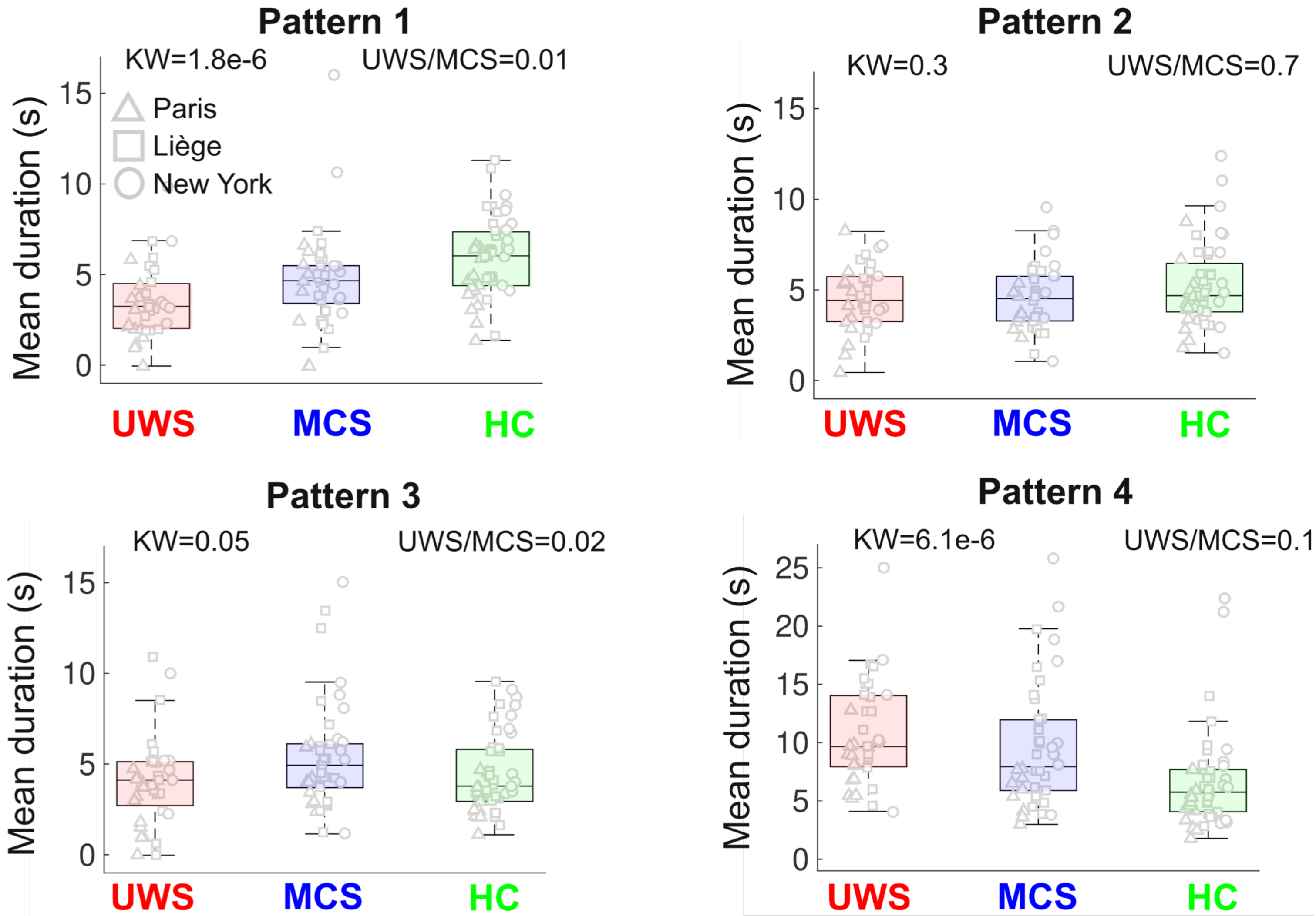


The pattern exploration differs with respect to state of consciousness (1)



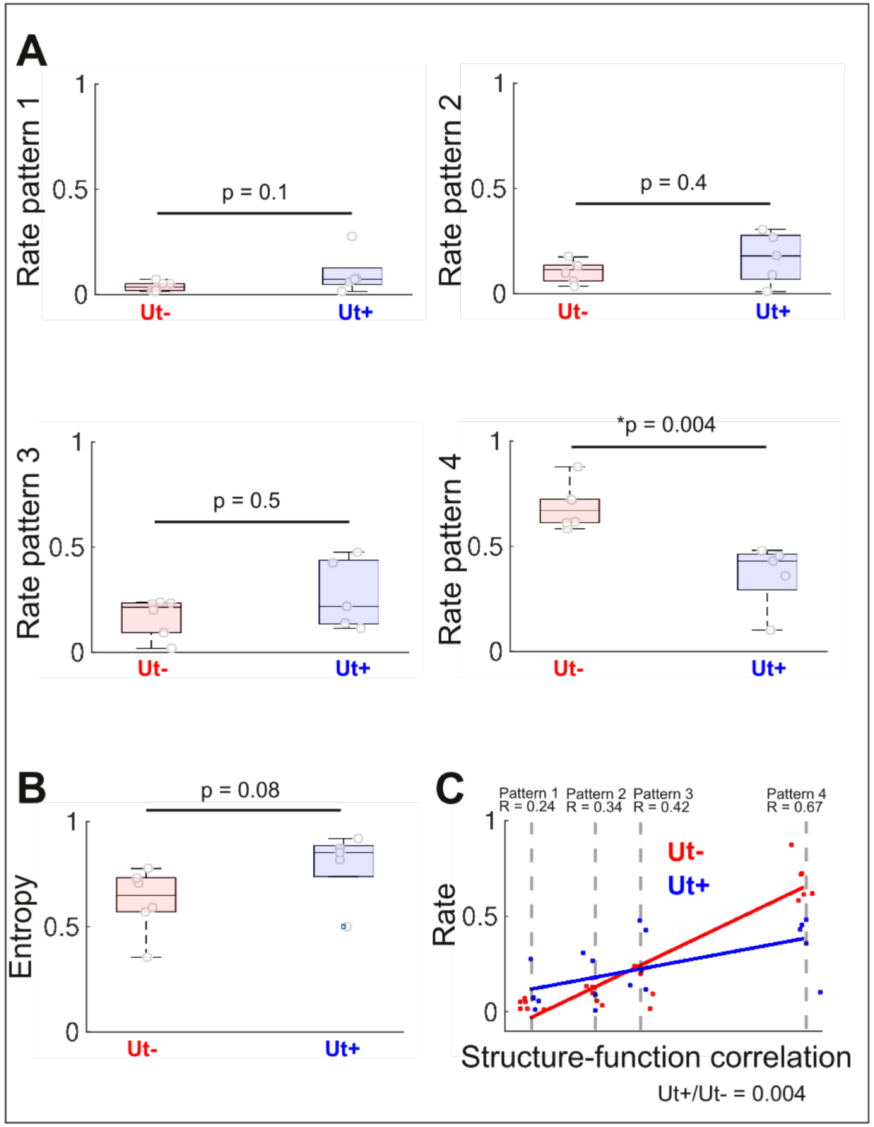
The pattern exploration differs with respect to state of consciousness (2)

B. Duration of pattern occupation

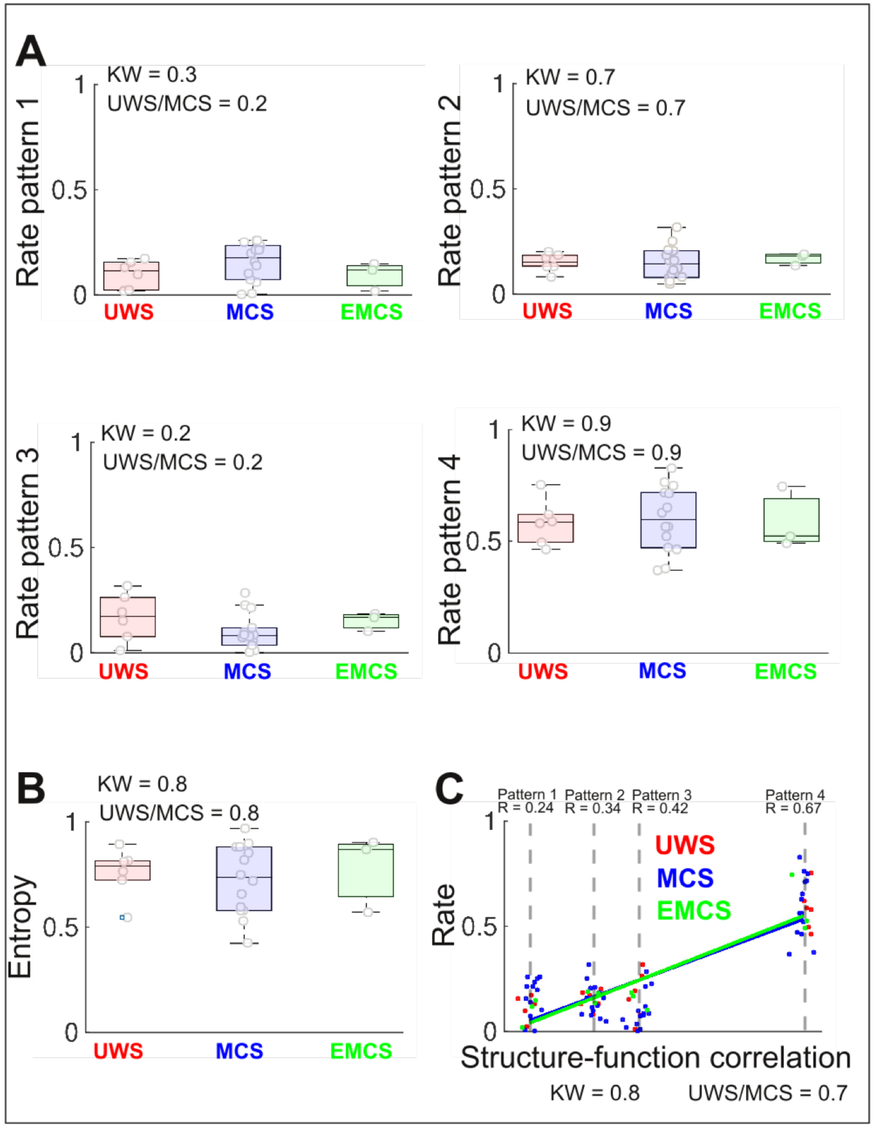


We measure consciousness?

Pattern prediction in cognitive-motor dissociation



Pattern prediction in anesthesia



Rs-fMRI dynamics:

- ➢ reveal complex inter-regional communication as compared to stationary fc
- ➢ differentiate states of consciousness uniformly across centers
- ➢ may reflect cognitive processing (str-funct corr)
- ➢ align with theoretical frameworks on the mechanisms of consciousness

GIGA

Science Advances

Science JOURNALS AAAS

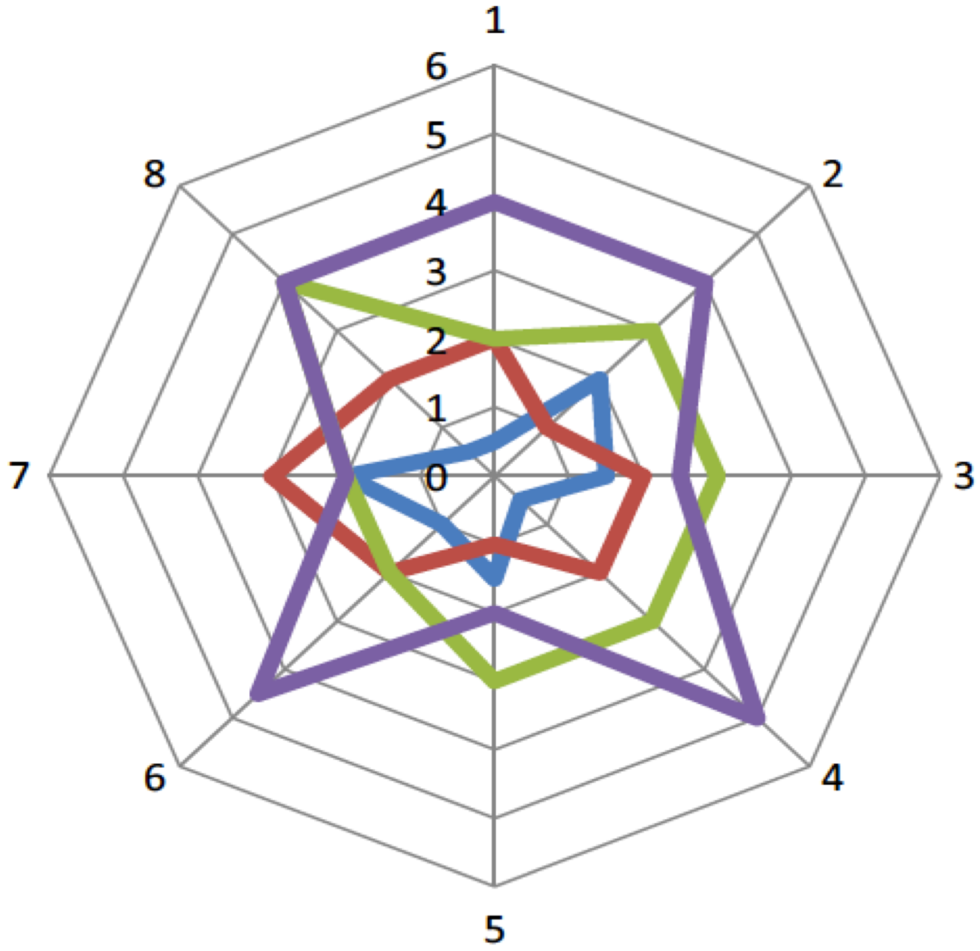
---------- Forwarded message ---------
From: **Kevin LaBar** <scienceadvanceseditorial@aaas.org>
Date: Thu, Nov 15, 2018 at 5:43 AM
Subject: Science Advances aat7603: Accept-Technical Hold
To: <tagliazucchi.enzo@googlemail.com>, <jacobo.sitt@inserm.fr>, <a.demertzi@uliege.be>

Ref.: Ms. No. aat7603
Title: Human consciousness is supported by dynamic complex patterns of brain signal coordination

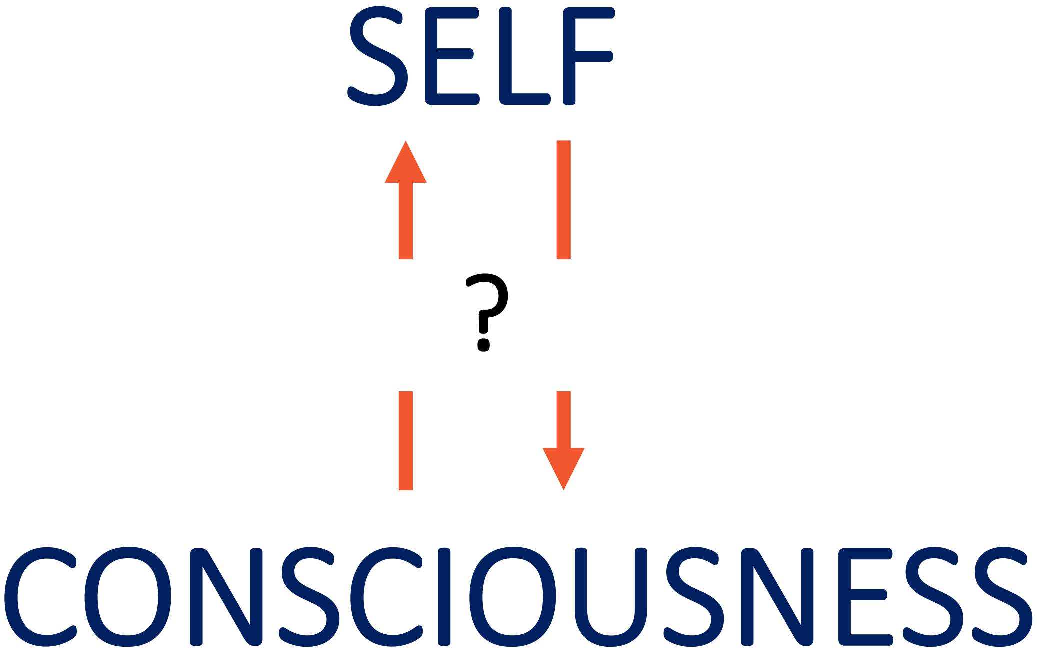
Dear Dr. Tagliazucchi, Sitt, Demertzi,

We are pleased to inform you that our editors are preparing to accept your manuscript, referenced above. However, your paper cannot be formally accepted until some issues related to author paperwork and/or file types have been addressed.

Defining Consciousness



Bayne, Hohwy, Owen. *Trends Cogn Sci* 2016


SELF
?
CONSCIOUSNESS

WHICH SELF IN UNCONSCIOUSNESS?

social

narrative

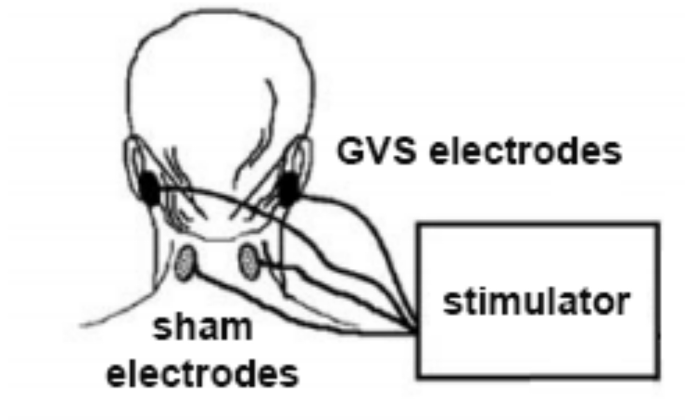
minimal

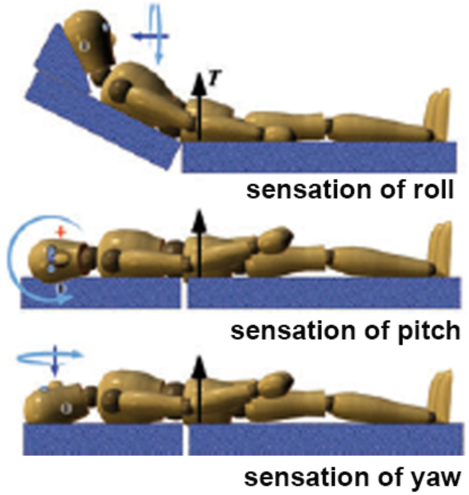
COMMON VIEW: no self

HYPOTHESIS: yes self

MODEL: Embodiment

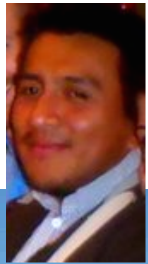
HOW: Probe balance





Thank you for your attention!

a.demertzi@uliege.be
ADemertzi





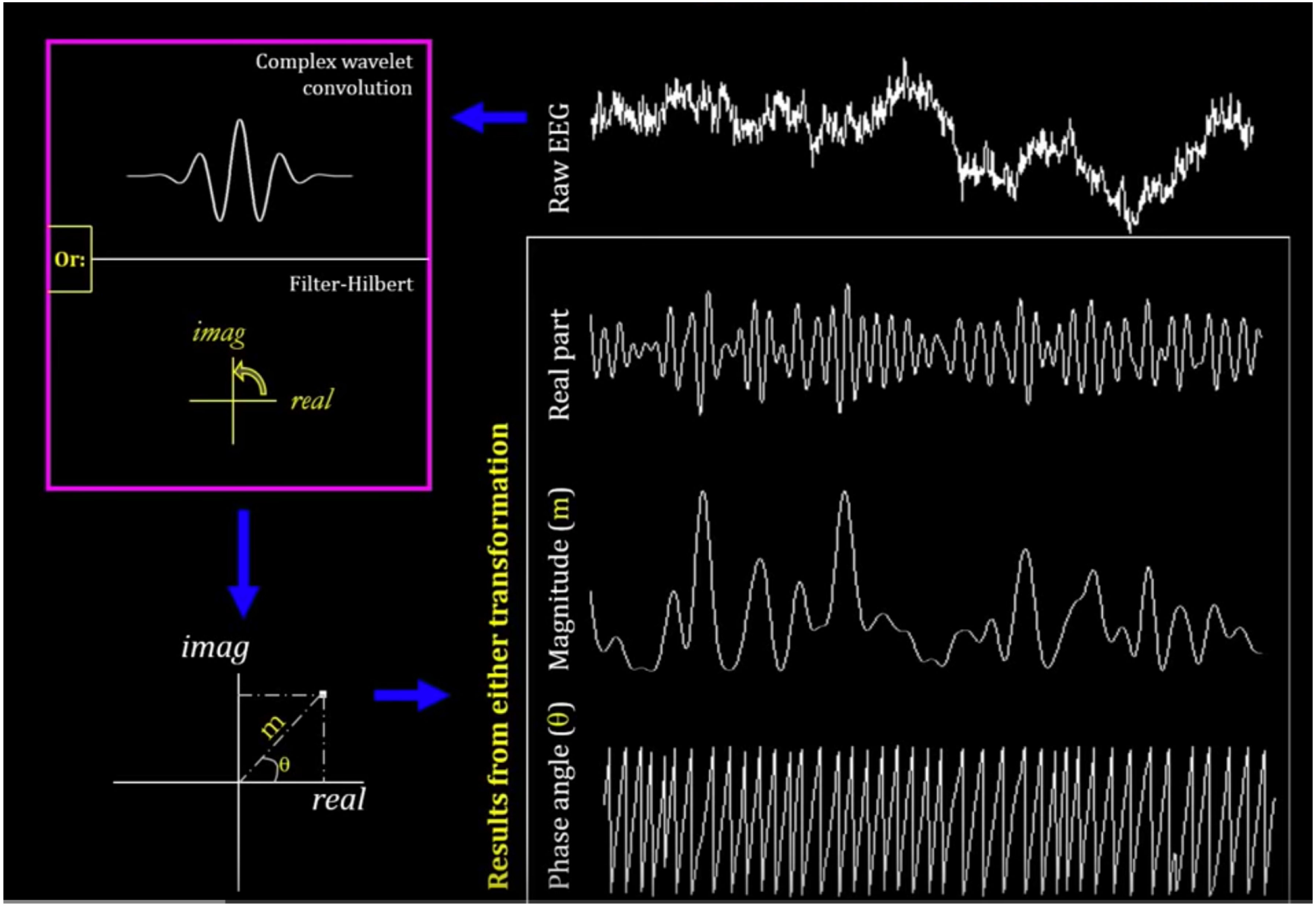






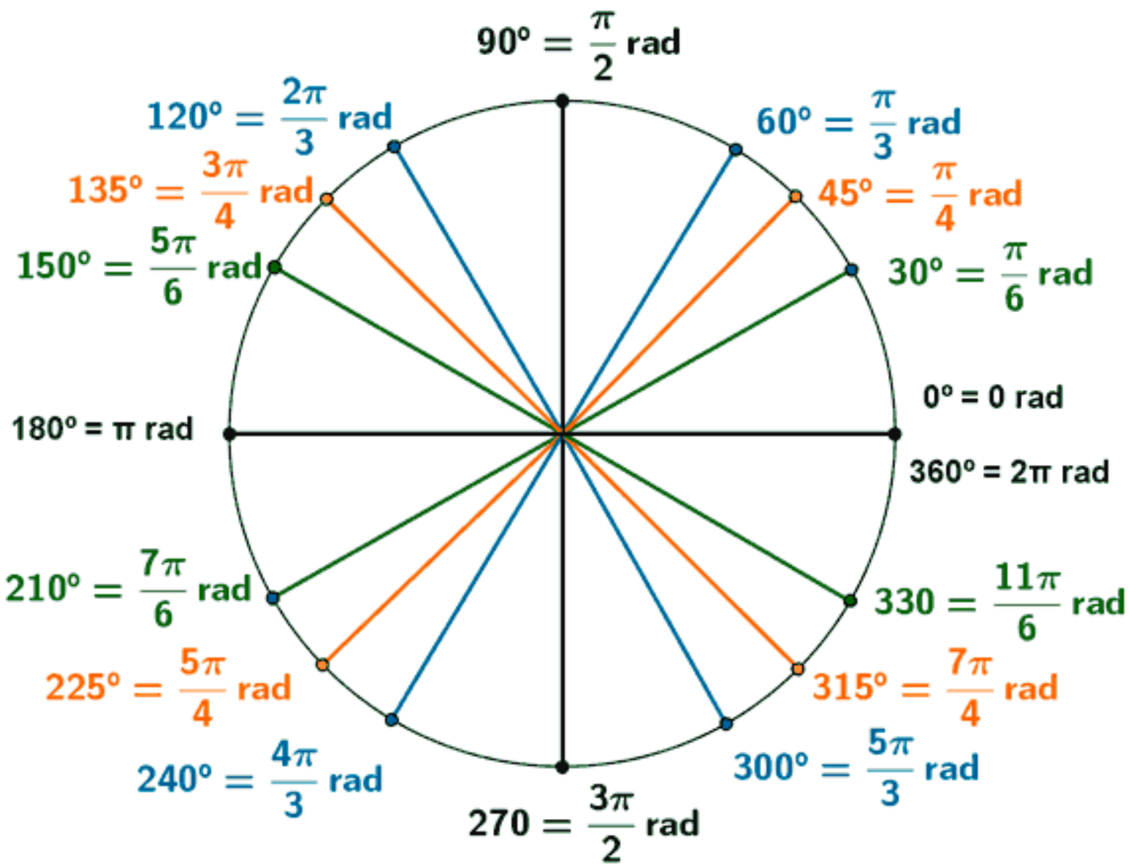


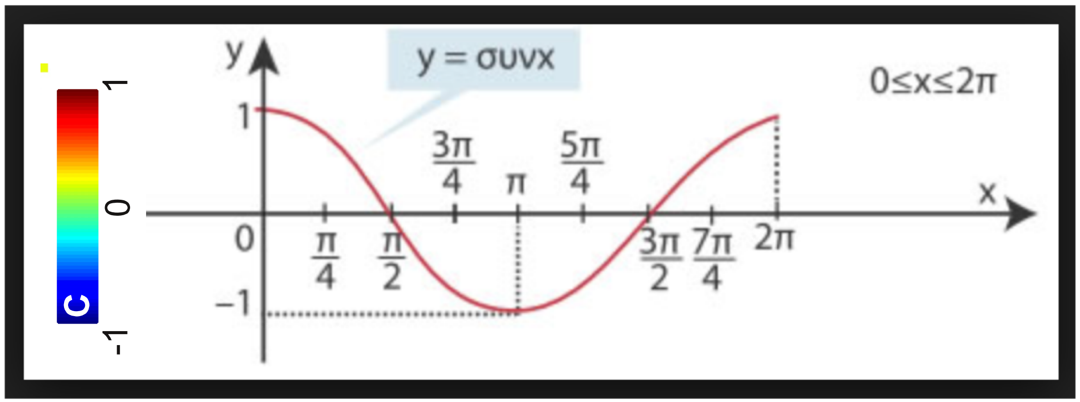

The Hilbert transform



Cohen, Mike X. 2014. *Analyzing Neural Time Series Data, 2014*. Cambridge, MA: The MIT Press. Chapter 14

Phase coherence





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 <u>transition probabilities</u>* 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*