

The neural basis of Consciousness

Proxies to conscious activity in the absence of reportability

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Topics in Behavioural Neuroscience

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May 5 2022

Consciousness

awareness

perception

mind

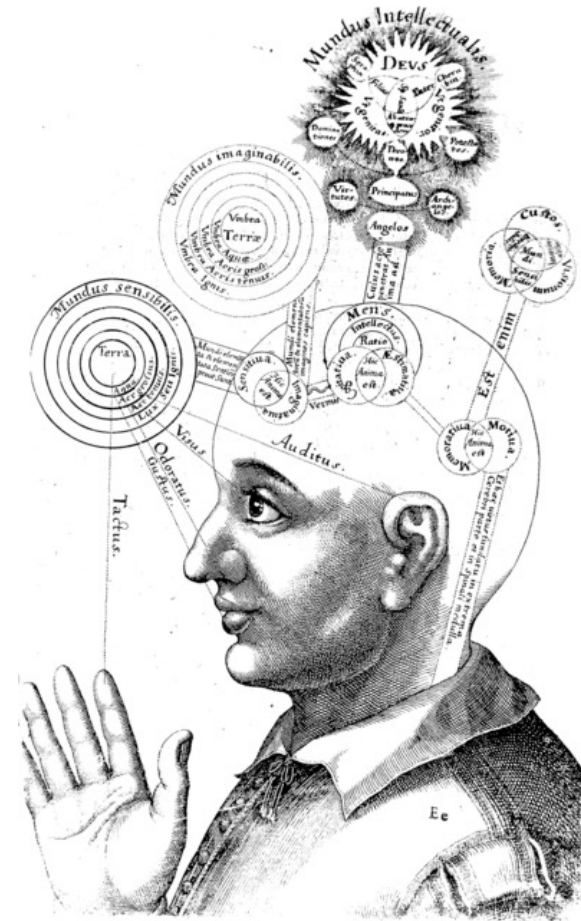
cognition

thought

self-awareness

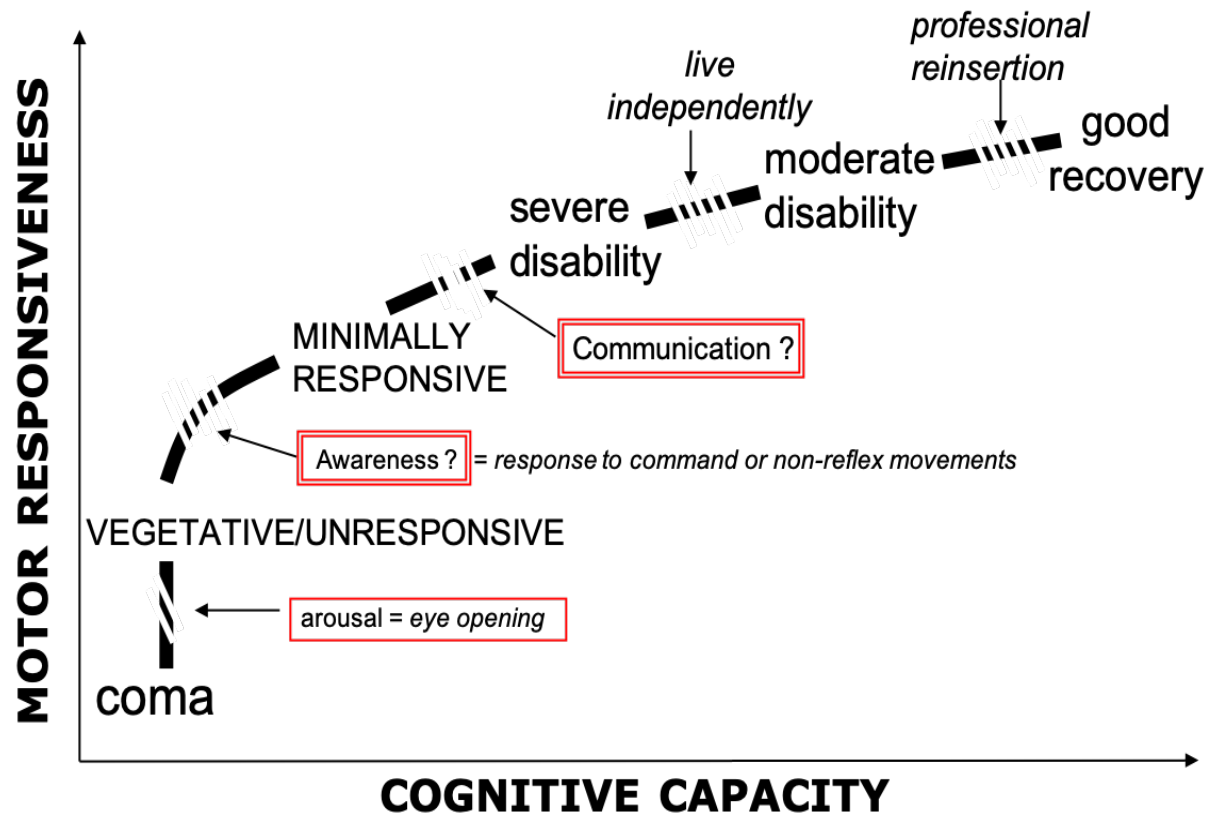
imagination

experience



17th century Robert Fludd (Paracelsian physician)

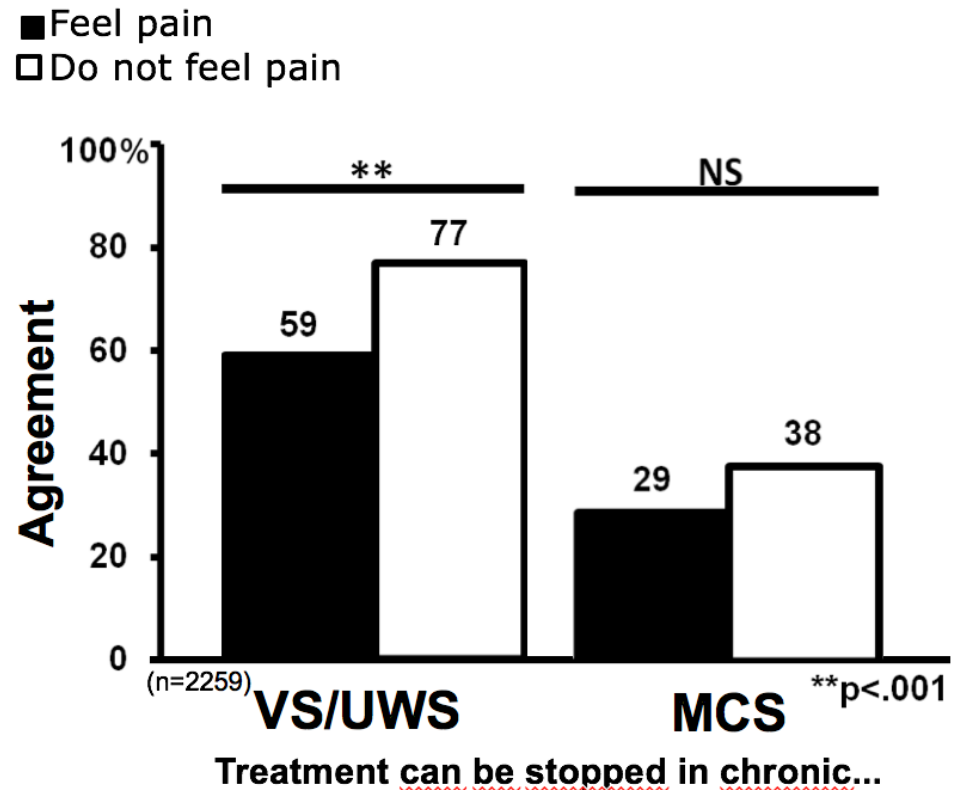
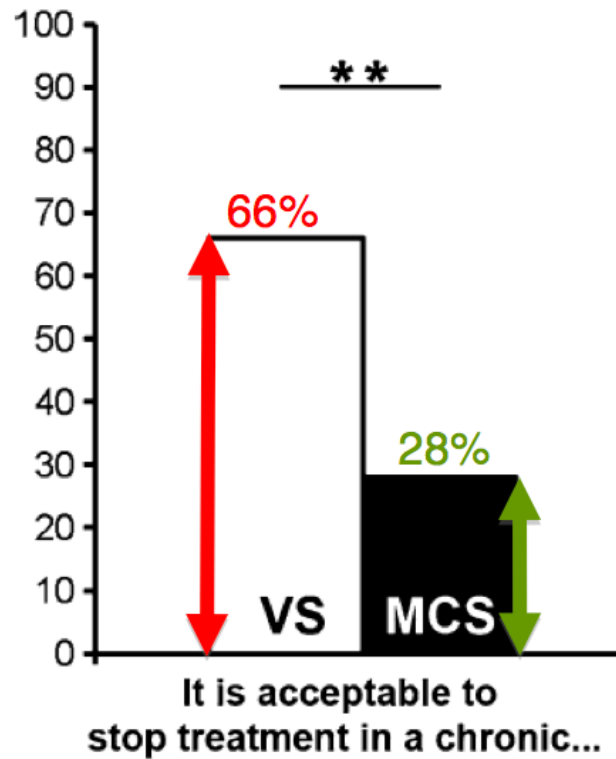
Mental life is referred from behavior



Source: Google pictures (Credit: CC-BY-SA; M Appelman)

Consciousness as an ethical imperative

2,475 medical professionals



We cannot always trust behavior

JFK COMA RECOVERY SCALE - REVISED ©2004																	
Record Form																	
This form should only be used in association with the "CRS-R ADMINISTRATION AND SCORING GUIDELINES" which provide instructions for standardized administration of the scale.																	
Patient:				Diagnosis:				Etiology:									
Date of Onset:				Date of Admission:													
	Date																
	Week	ADM	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
AUDITORY FUNCTION SCALE																	
4 - Consistent Movement to Command *																	
3 - Reproducible Movement to Command *																	
2 - Localization to Sound																	
1 - Auditory Startle																	
0 - None																	
VISUAL FUNCTION SCALE																	
5 - Object Recognition *																	
4 - Object Localization: Reaching *																	
3 - Visual Pursuit *																	
2 - Fixation *																	
1 - Visual Startle																	
0 - None																	
MOTOR FUNCTION SCALE																	
6 - Functional Object Use †																	
5 - Automatic Motor Response *																	
4 - Object Manipulation *																	
3 - Localization to Noxious Stimulation *																	
2 - Flexion Withdrawal																	
1 - Abnormal Posturing																	
0 - None/Flaccid																	
OROMOTOR/VERBAL FUNCTION SCALE																	
3 - Intelligible Verbalization *																	
2 - Vocalization/Oral Movement																	
1 - Oral Reflexive Movement																	
0 - None																	
COMMUNICATION SCALE																	
2 - Functional: Accurate †																	
1 - Non-Functional: Intentional *																	
0 - None																	
AROUSAL SCALE																	
3 - Attention																	
2 - Eye Opening w/o Stimulation																	
1 - Eye Opening with Stimulation																	
0 - Unarousable																	
TOTAL SCORE																	

Denotes emergence from MCS[†]
Denotes MCS*

Standardized assessment

n=103 post-comatose patients

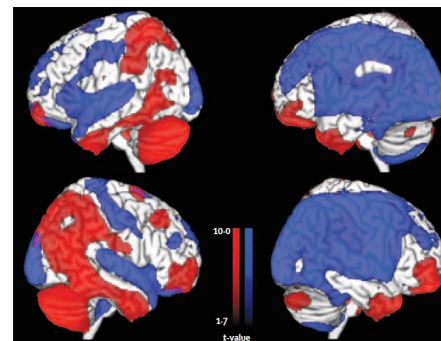
45 Clinical diagnosis of VS
18 Coma Recovery Scale MCS



40% misdiagnosis

Schnakers et al, *Ann Neurol* 2006; *BMC Neurol* 2009

Standardized assessment & Neuroimaging

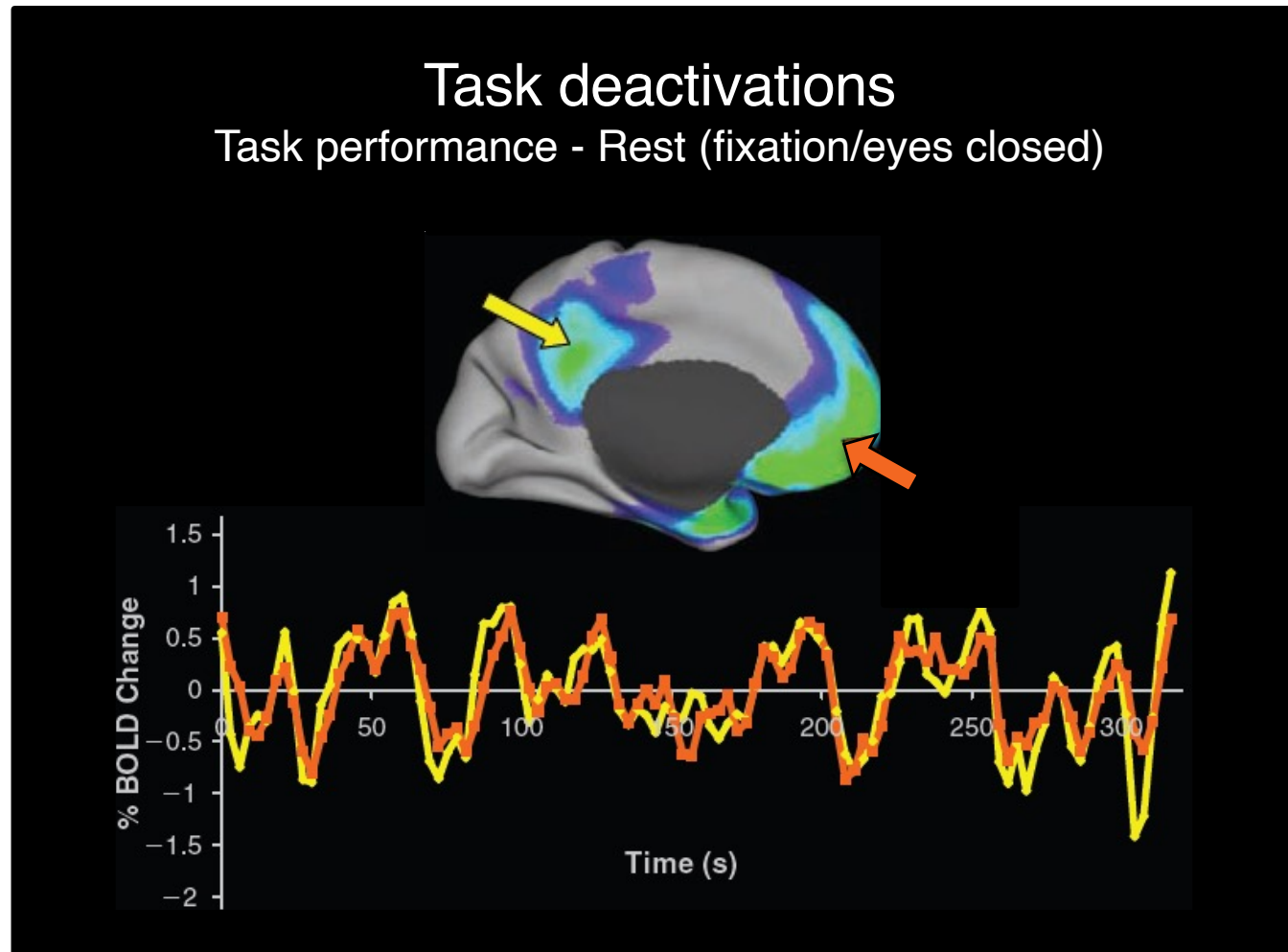


	Coma Recovery Scale-Revised results		
	UWS	MCS	Total
Clinical consensus diagnosis			
¹⁸F-FDG PET			
VS/UWS	24 (21%)	5 (4%)	29 (26%)
MCS	12 (11%)	71 (63%)	83 (74%)
Total	36 (32%)	76 (68%)	112 (100%)

UWS=unresponsive wakefulness syndrome. MCS=minimally conscious state.

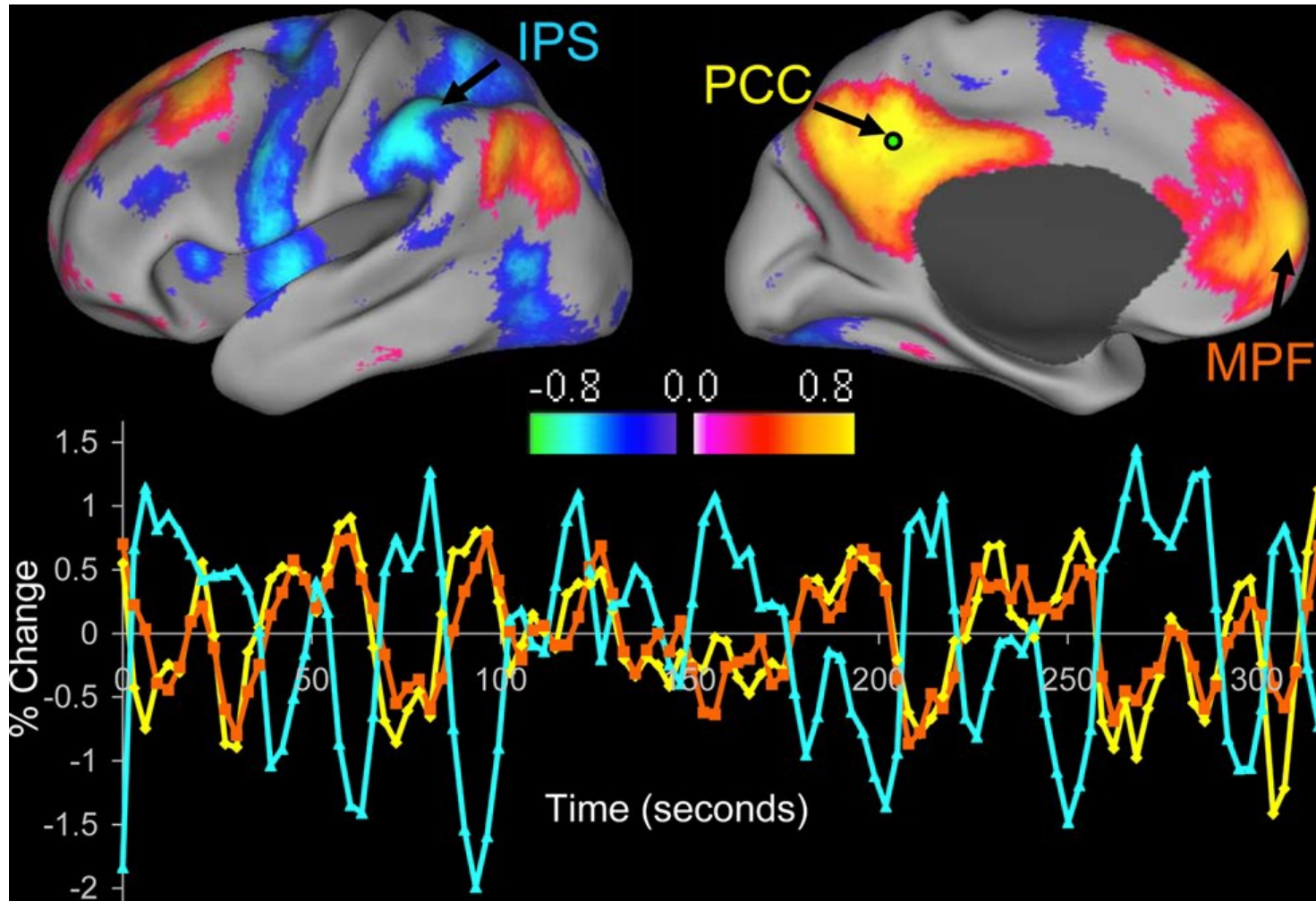
Table 2: Diagnostic results by modality

Default mode of brain function



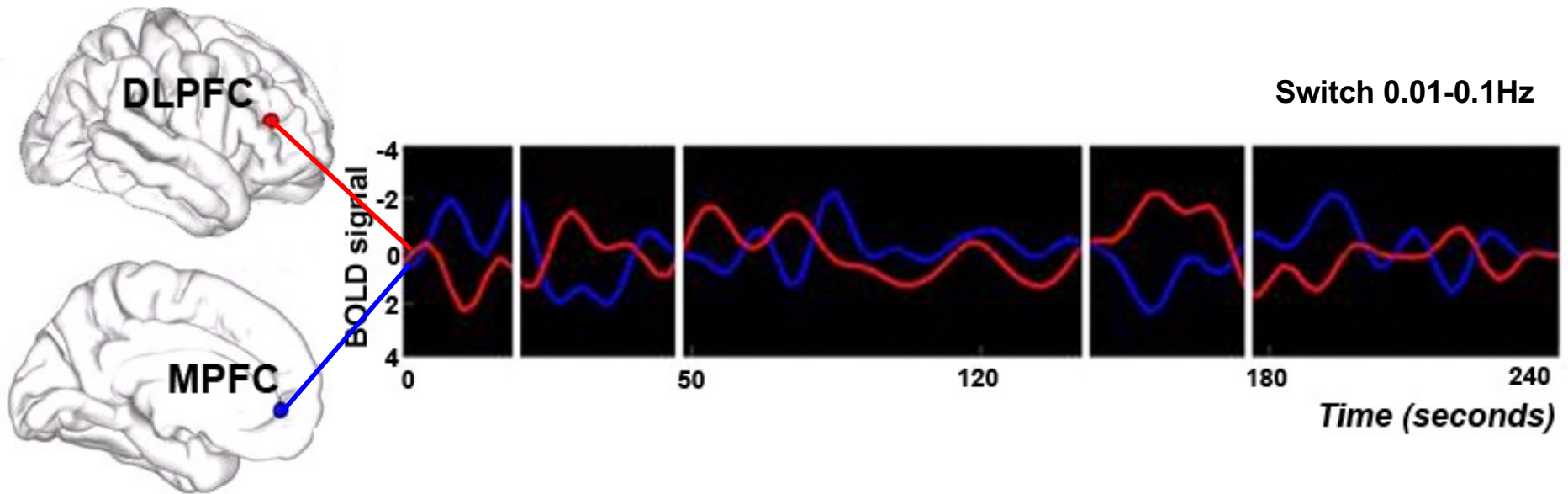
Demertzi & Whitfield-Gabrieli, in: *Neurology of Consciousness* 2nd ed. 2015
Demertzi, Soddu, Laureys, *Curr Opin Neurobiology* 2013
Demertzi et al, *Front Hum Neurosci* 2013
Raichle et al, *PNAS* 2001

Functional correlations & anticorrelations



Anticorrelations inform cognitive function?

**External awareness
or anticorrelated network**

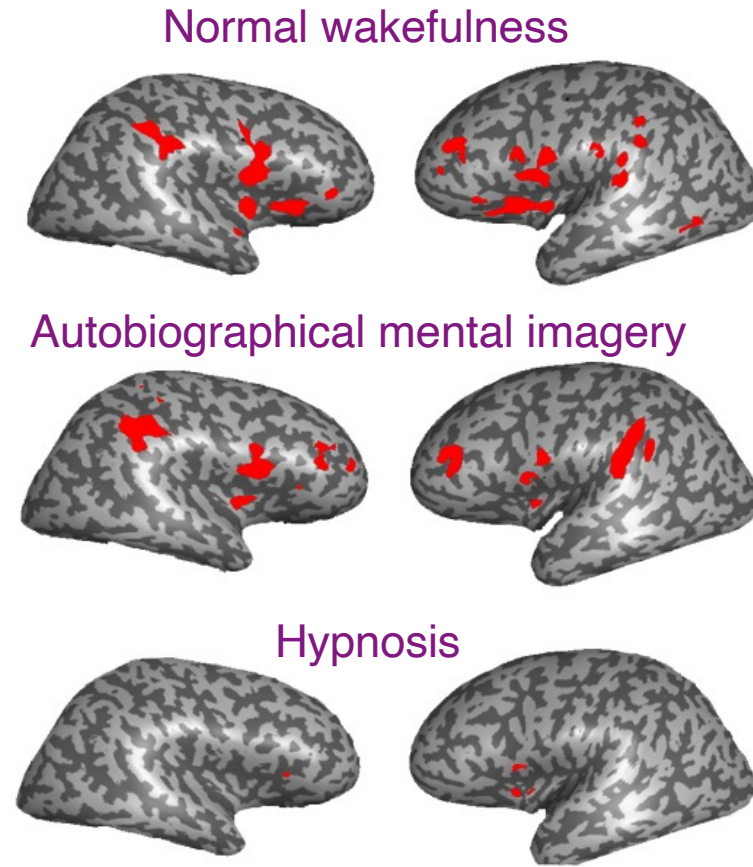
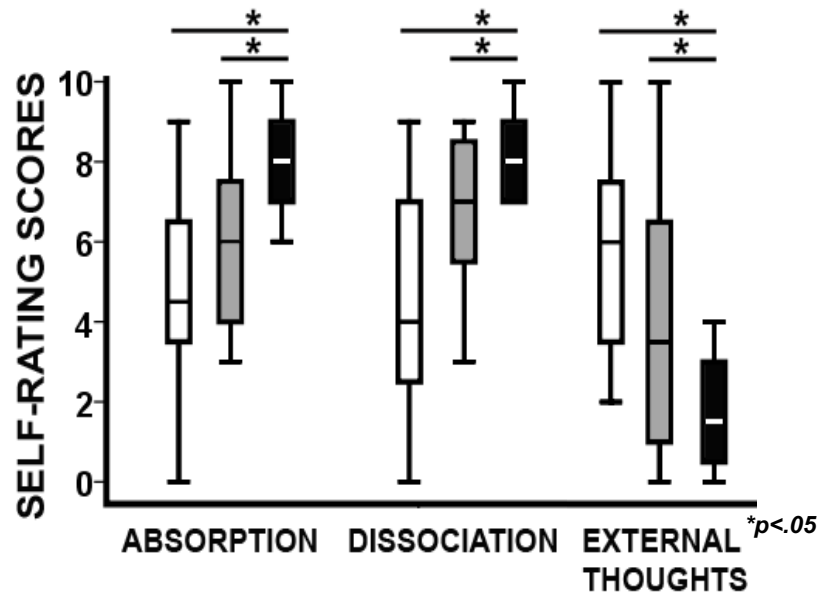


**Internal awareness
or Default mode network**

Vanhaudenhuyse*, Demertzi* et al, *J Cogn Neurosci* 2011
Demertzi, Soddu, Laureys, *Curr Opin Neurobiology* 2013
Demertzi & Whitfield-Gabrieli, in: *Neurology of Consciousness* 2nd ed. 2015
Demertzi et al, *Front Hum Neurosci* 2013
Demertzi, Kucyi, Ponces-Alvarez, Keliris, Whitfield-Gabrieli, Deco. *Netw Neurosci* in press

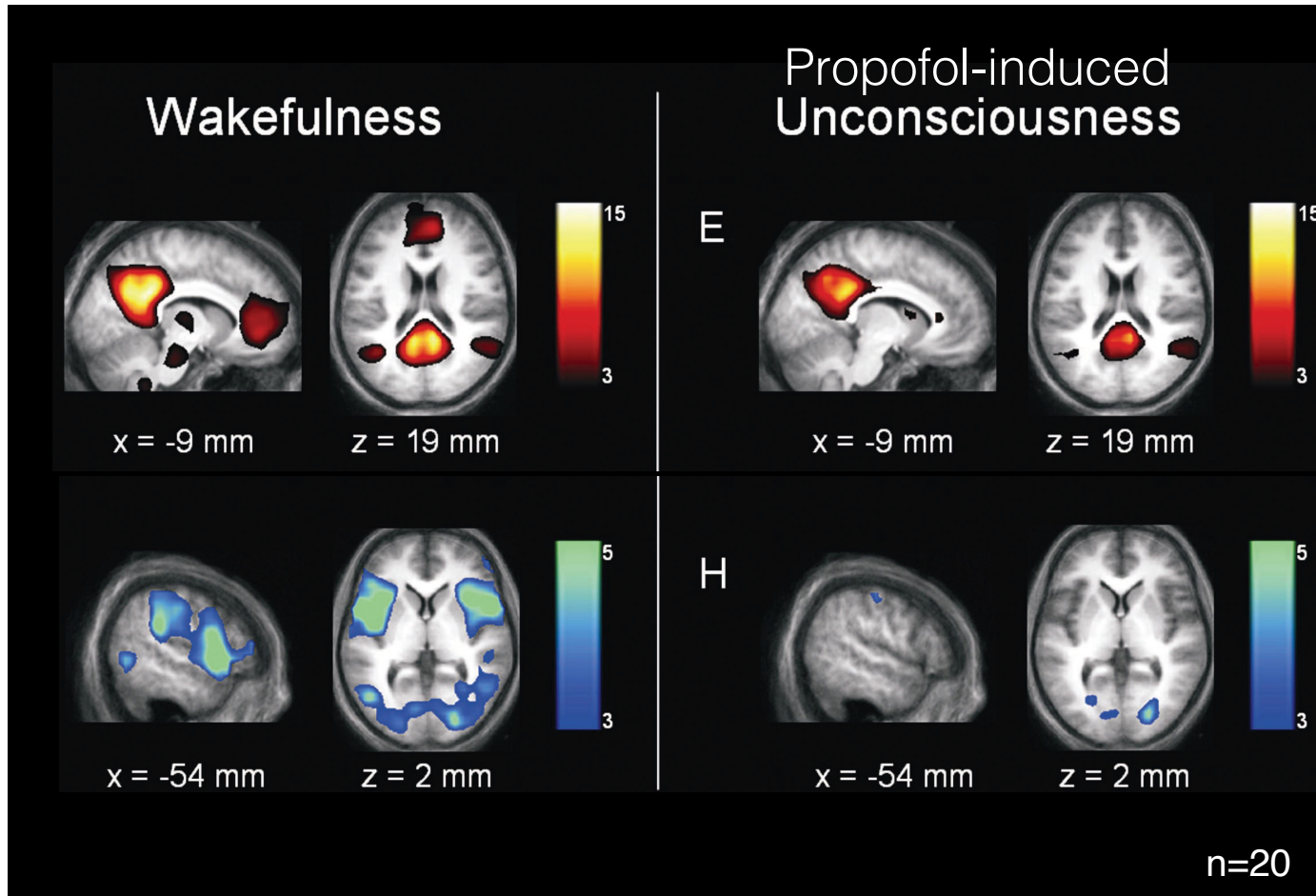
Modified awareness reduces anticorrelations

- Normal wakefulness
- ▒ Autobiographical mental imagery
- Hypnosis



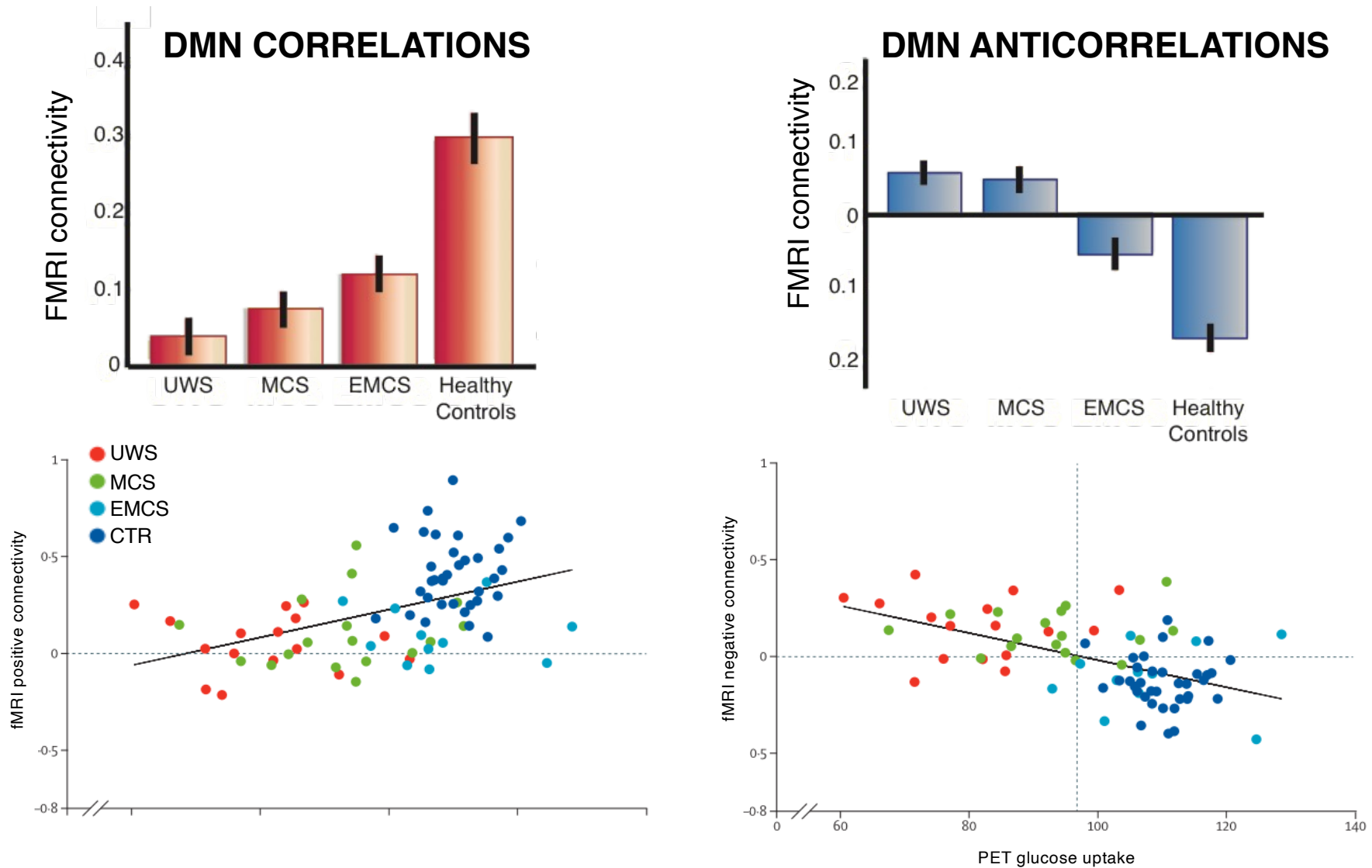
p < 0.05 corrected for multiple comparisons

Modified arousal reduces anticorrelations



Anticorrelations

No anticorrelations in DOC



Anticorrelations \approx Consciousness

Anticorrelations **reduce** in intensity or are undetectable in :

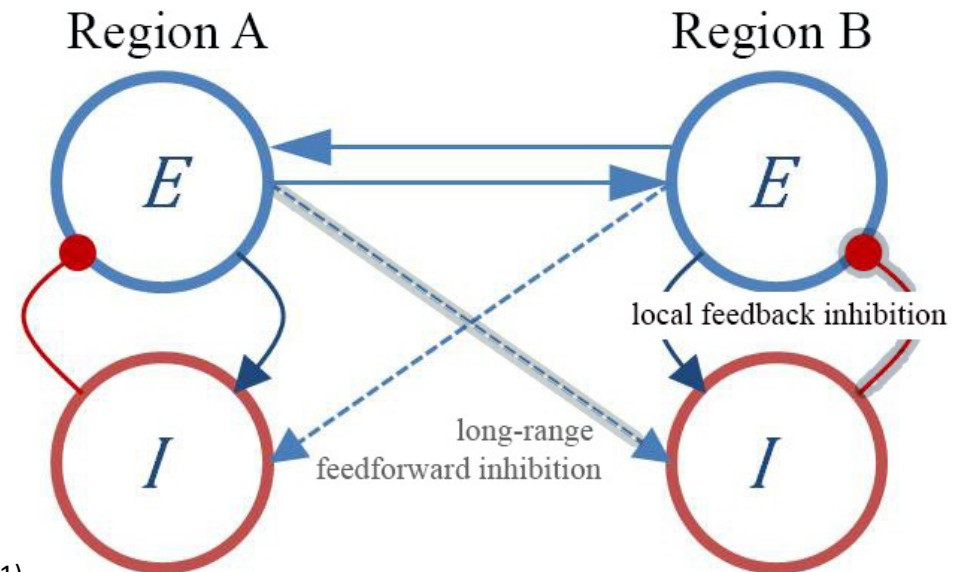
- unresponsive patients (Di Perri et al., 2016; Threlkeld et al., 2018)
- hypnosis (Demertzi et al., 2011)
- in deep anesthesia (Boveroux et al., 2010)
- after sleep deprivation (De Havas et al., 2012; Yeo et al., 2015)
- slow wave sleep and REM (Chow et al., 2013)
- deep sedation (Luppi et al., 2019)

Anticorrelations **recover**:

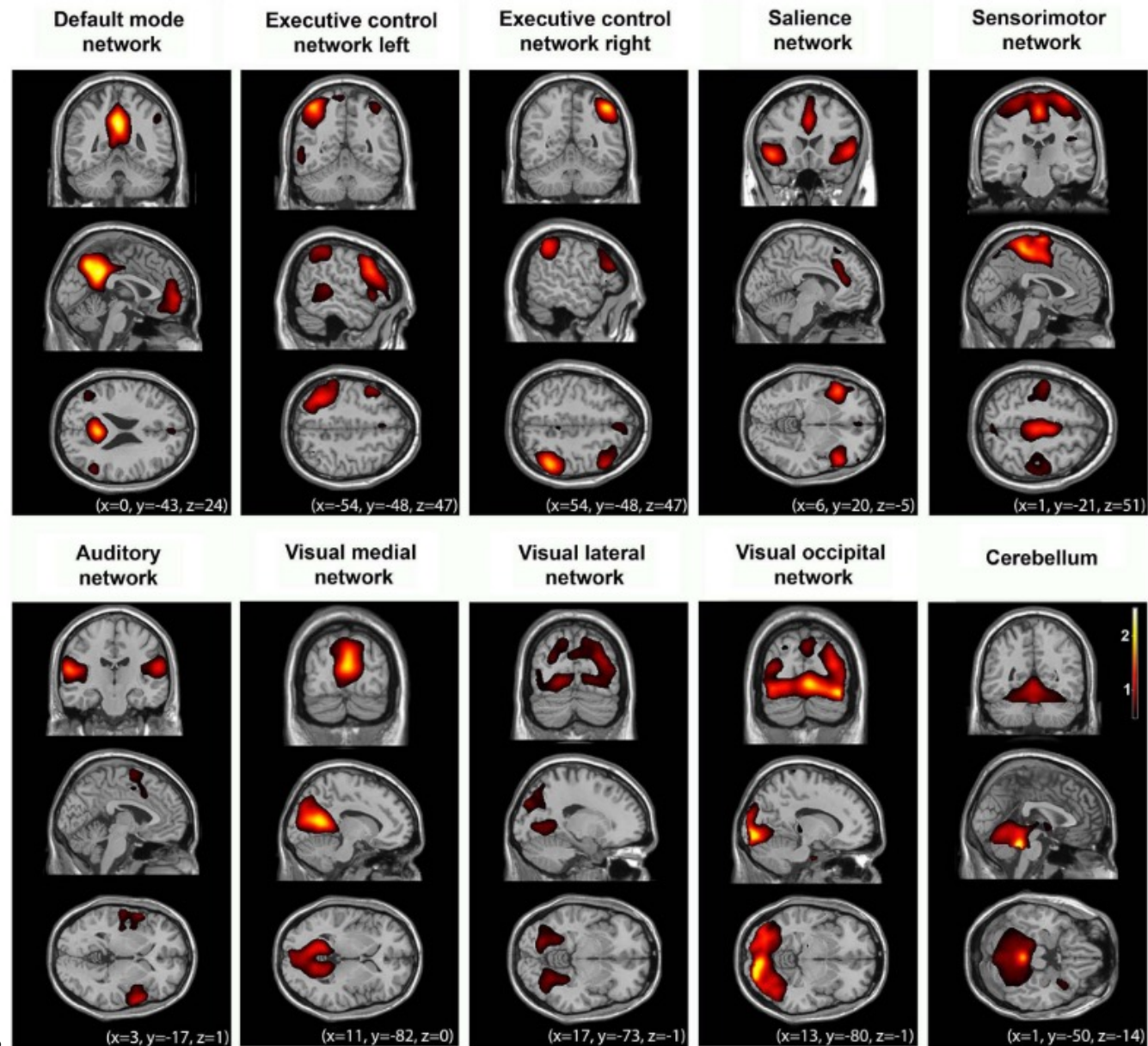
- at post-anesthetic period (Nir et al., 2020)
- after DOC (Di Perri et al., 2016; Threlkeld et al., 2018)

Anticorrelations **contribute** to:

- cognitive function (Keller et al., 2015; Vanhaudenhuyse et al., 2011)
- greater intensity \rightarrow better performance (Kucyi et al., 2017)
- between-subject performance (Spreng et al., 2010).
- life span
 - start weak in children, strengthen during adolescence, end up anticorrelated in young adulthood (Chai et al., 2014)
 - get selectively decreased during healthy aging (Keller et al., 2015)



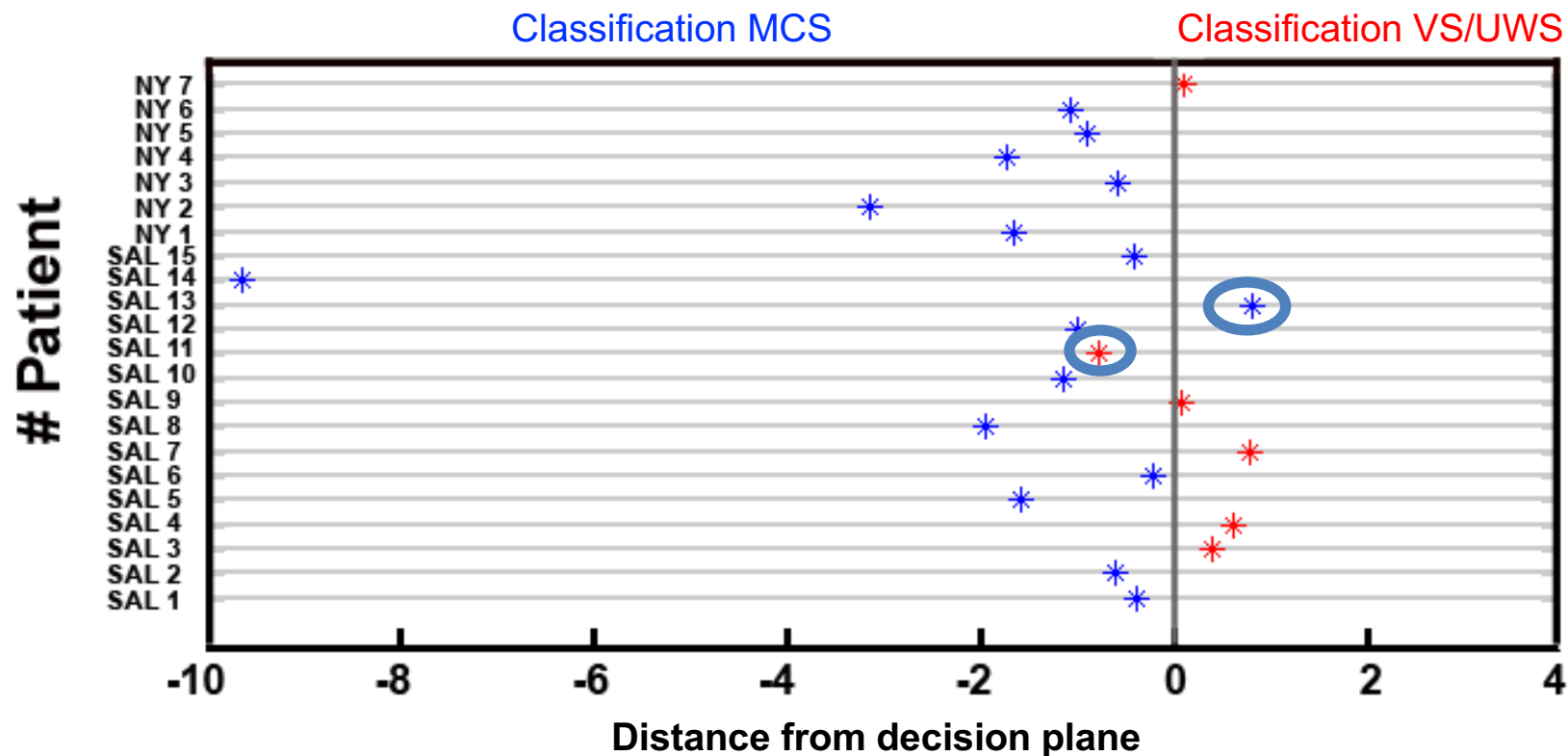
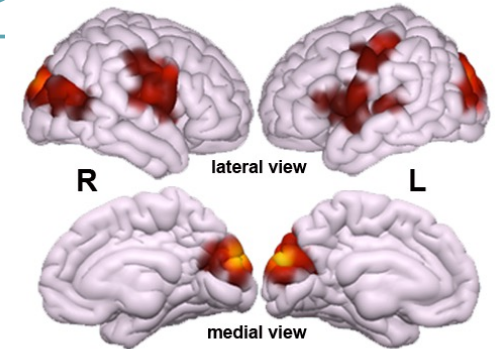
More networks during rest



Biswal et al., *Magn Reson. Med* 1995
 Smith et al, *PNAS* 2009
 Heine et al, *Front Psych* 2012

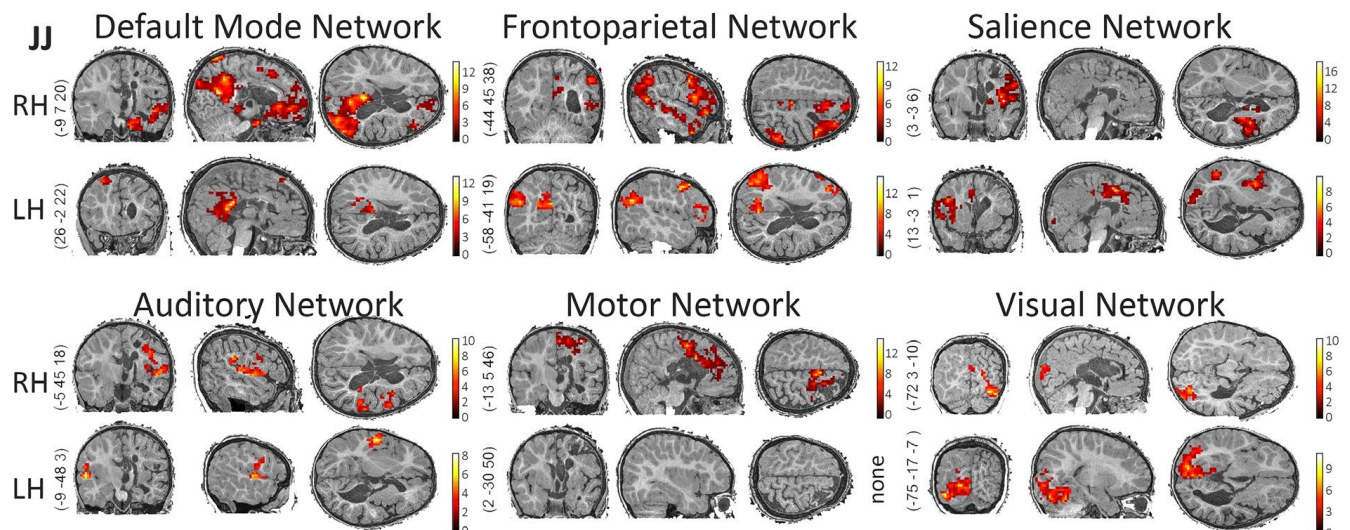
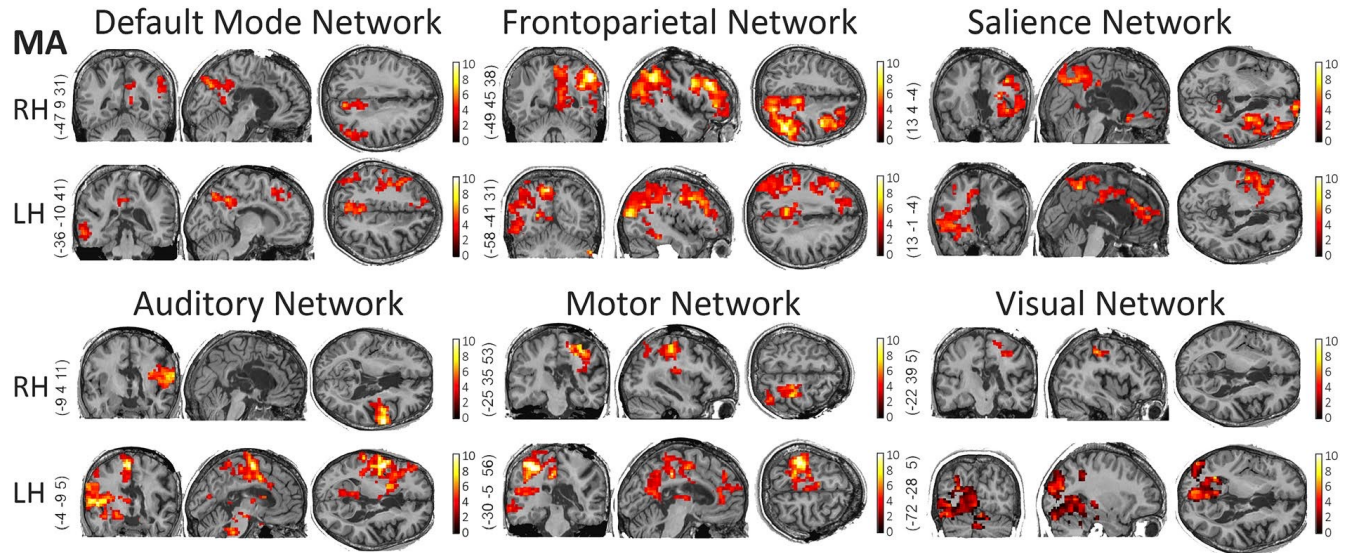
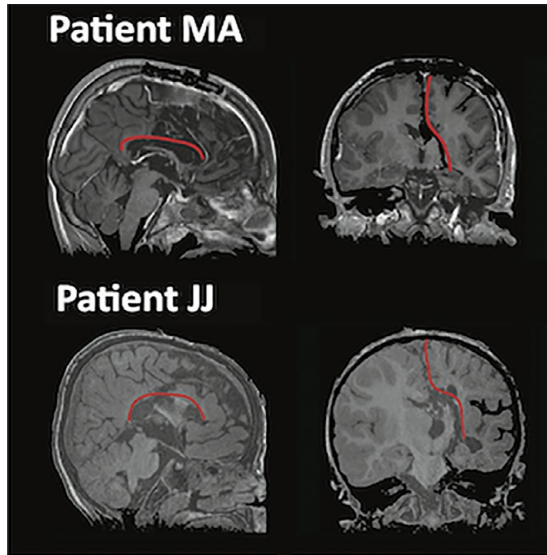
Lower cross-modal interaction in UWS

- Training set: 45 DOC (26 MCS, 19 VS/UWS)
 - 14 trauma, 28 non-trauma, 3 mixed
 - 34 patients assessed >1m post-insult
- Test set:
 - **16 MCS**, **6 VS/UWS** (15 non-trauma; all chronic)
 - 2 different centers

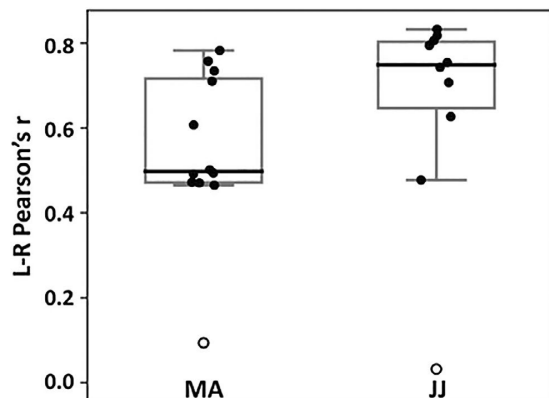


Lower cross-modal interaction in the isolated brain

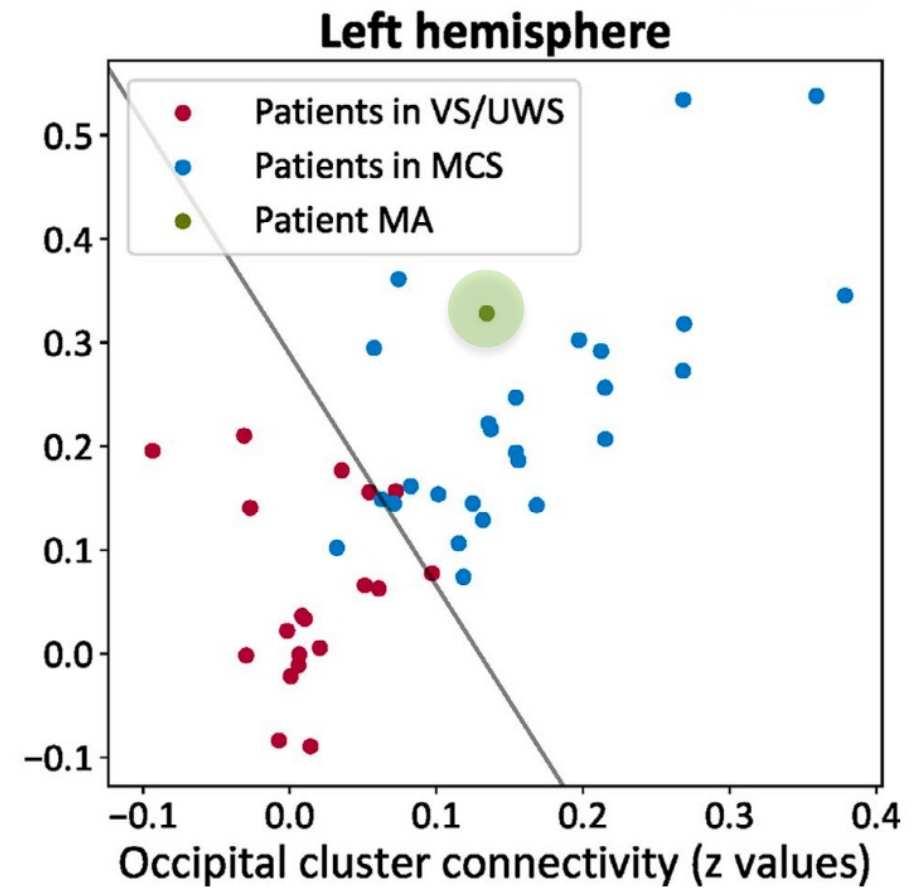
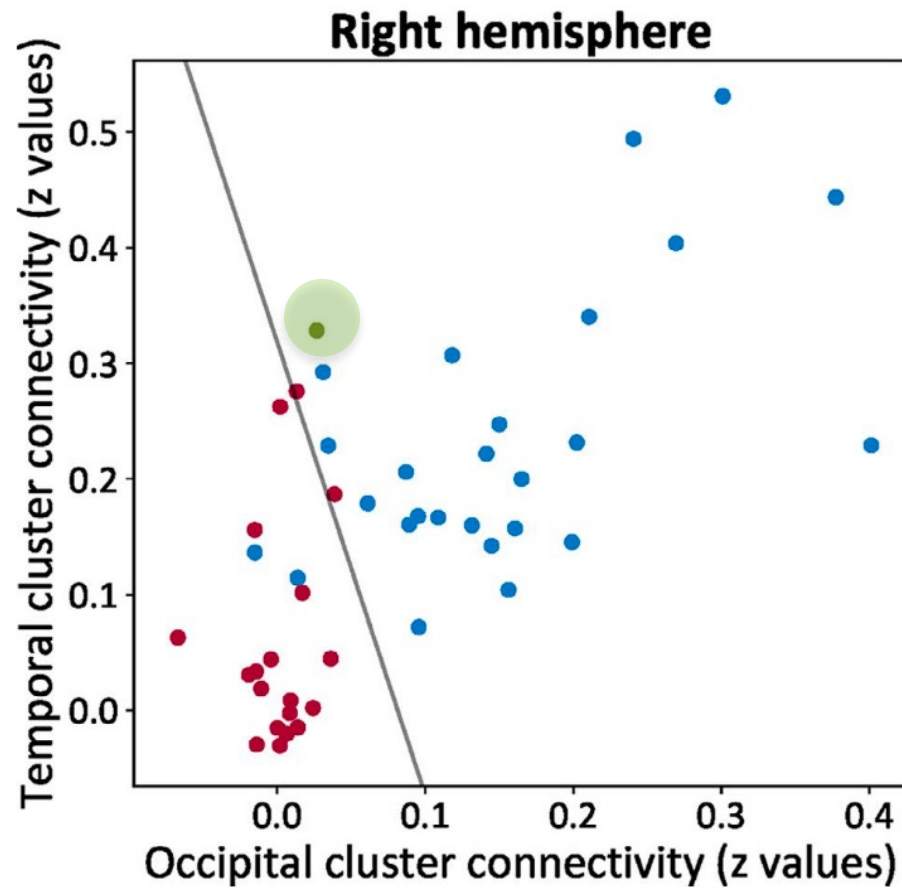
Complete hemispherotomy



Inter-hemispheric connectivity



Lower cross-modal interaction in the isolated brain



Brain dynamics and cognition

Typical wakefulness

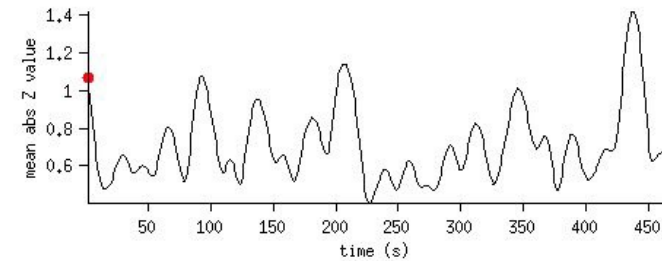
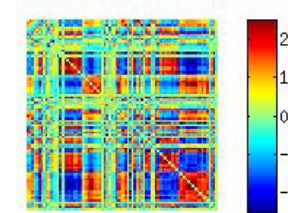
Performance, emotion and cognition

Alavash et al, *Neuroimage*, 2016

Shine et al *Neuron*, 2016

Friston *Neuroimage*, 1997

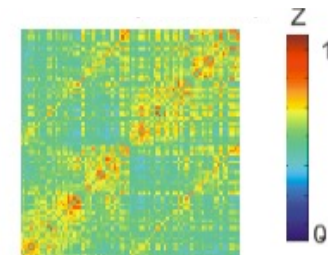
Thompson et al, *Hum Brain Mapp*, 2013



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 et al, *PNAS* 2014; Grandjean et al, *Neuroimage* 2017; Liang et al, *Neuroimage* 2015)



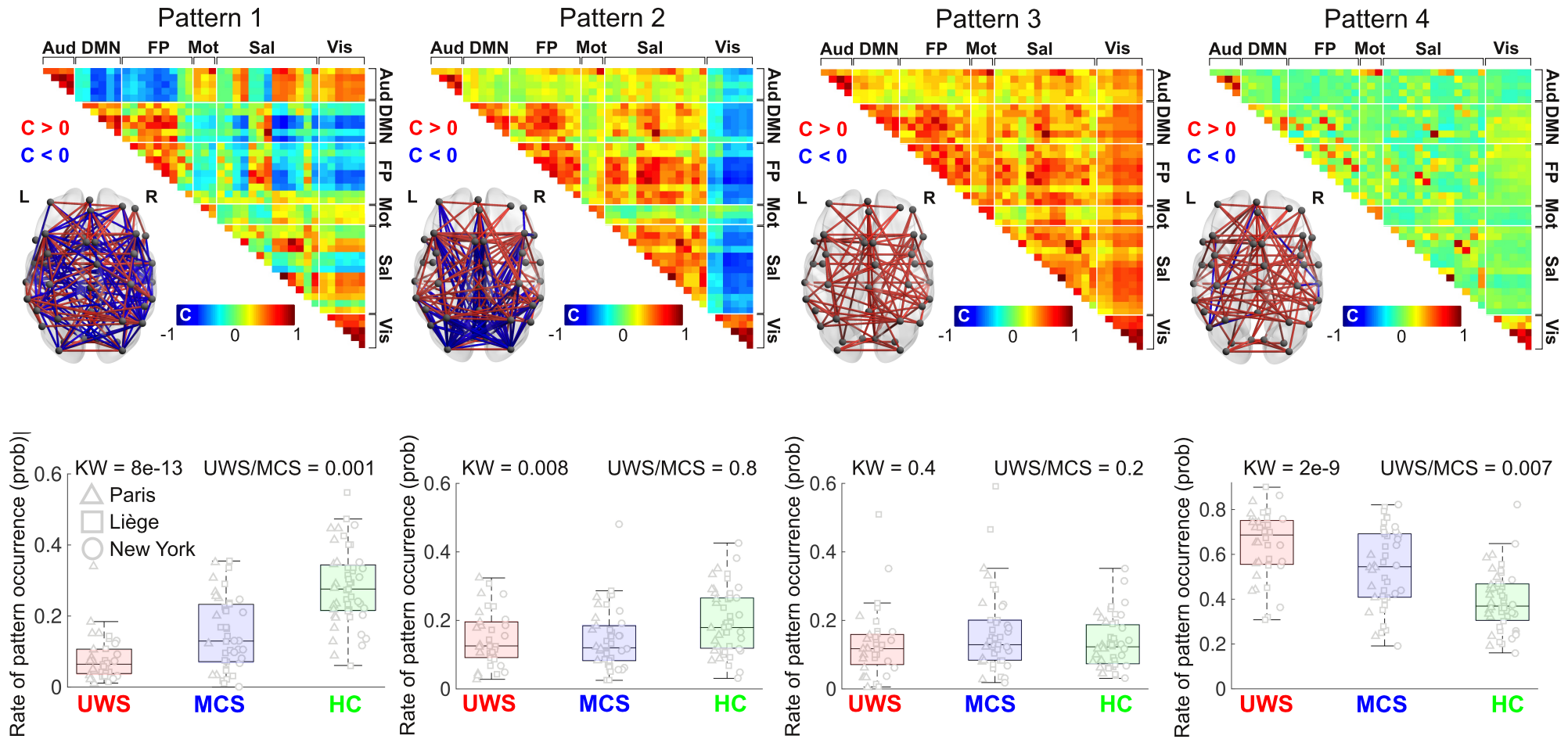
Barttfeld*, Ulhrig*, Sitt*, et al, *PNAS* 2015



The brain cannot map the complexity of the internal and external world

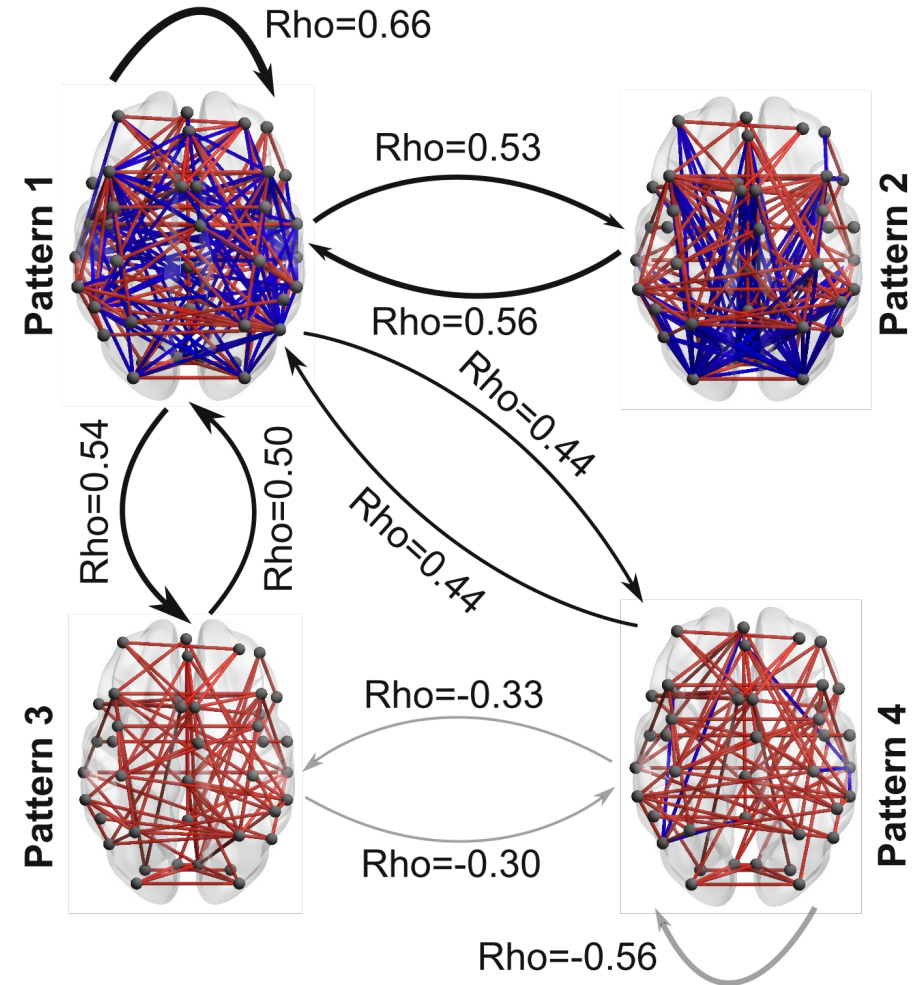
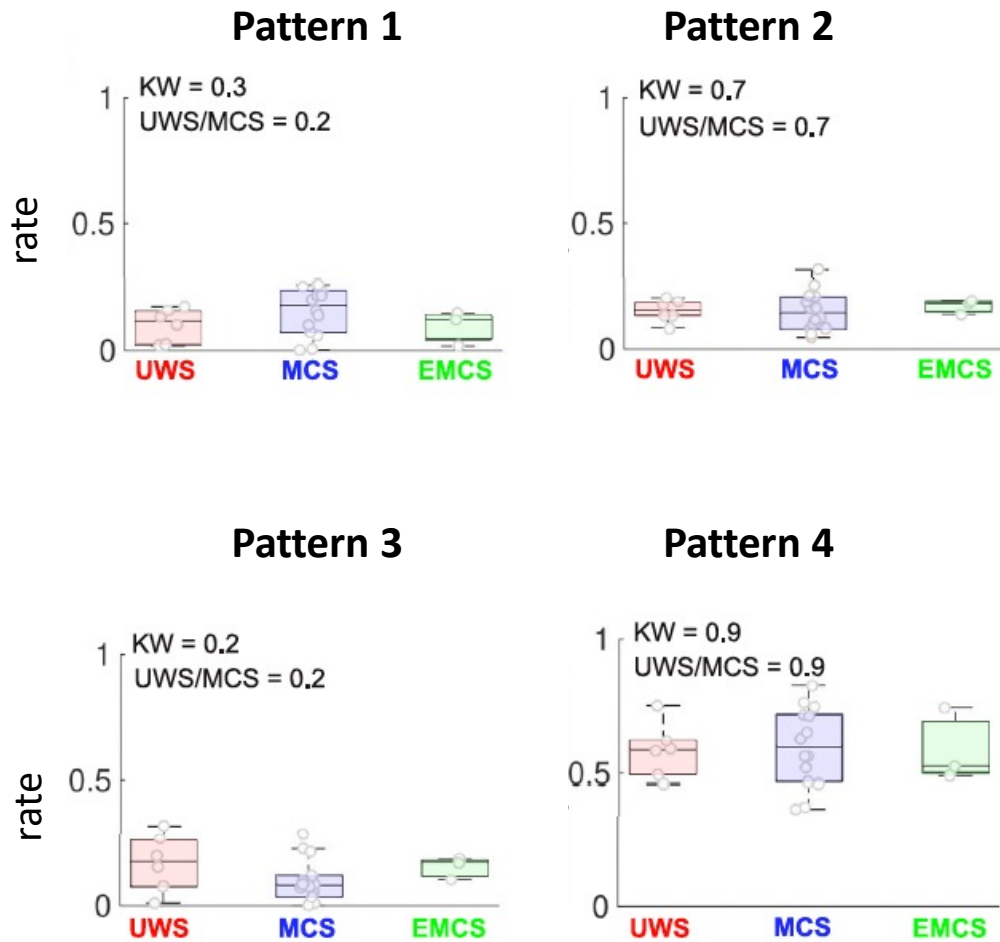
(Dehaene et al, *Trends Cog Sci*, 2006; Tononi et al, *Nat Rev Neurosci*. 2016)

Complex patterns in higher conscious states

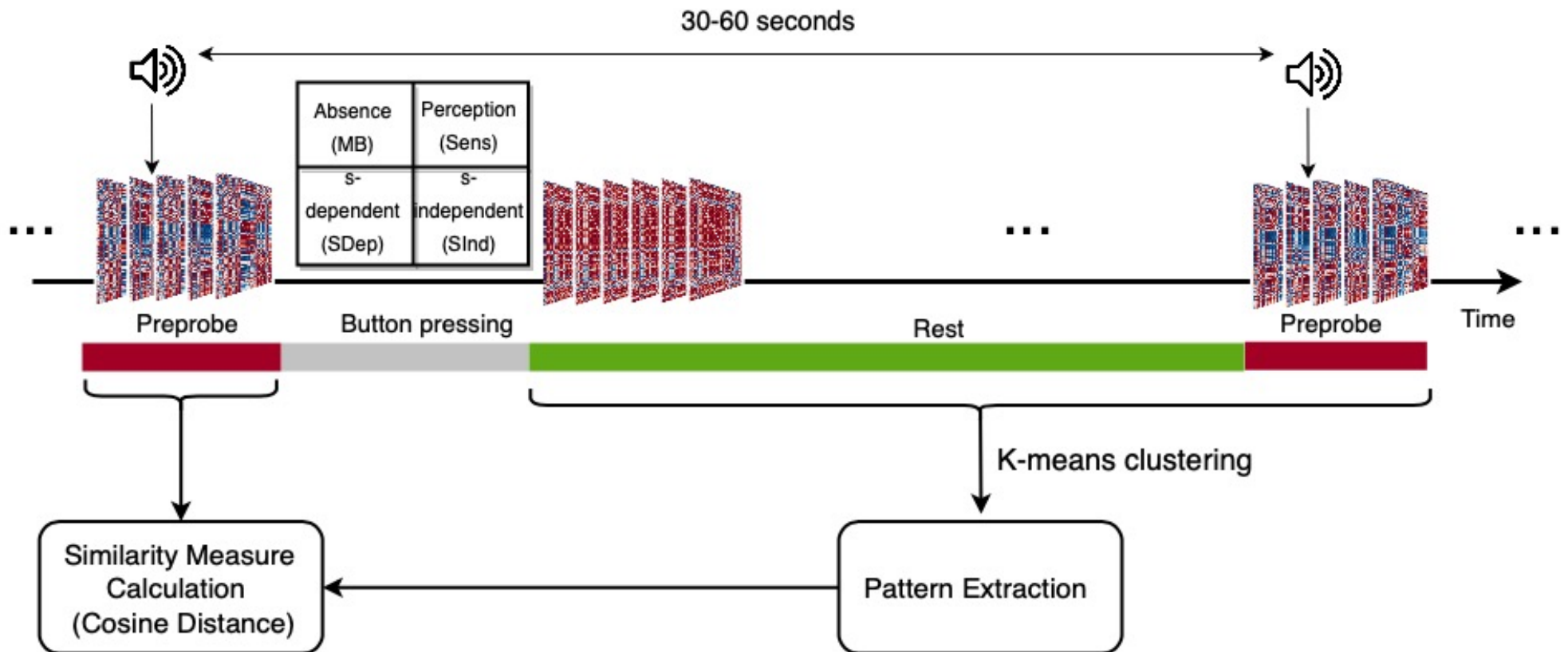


More chances to transition when conscious

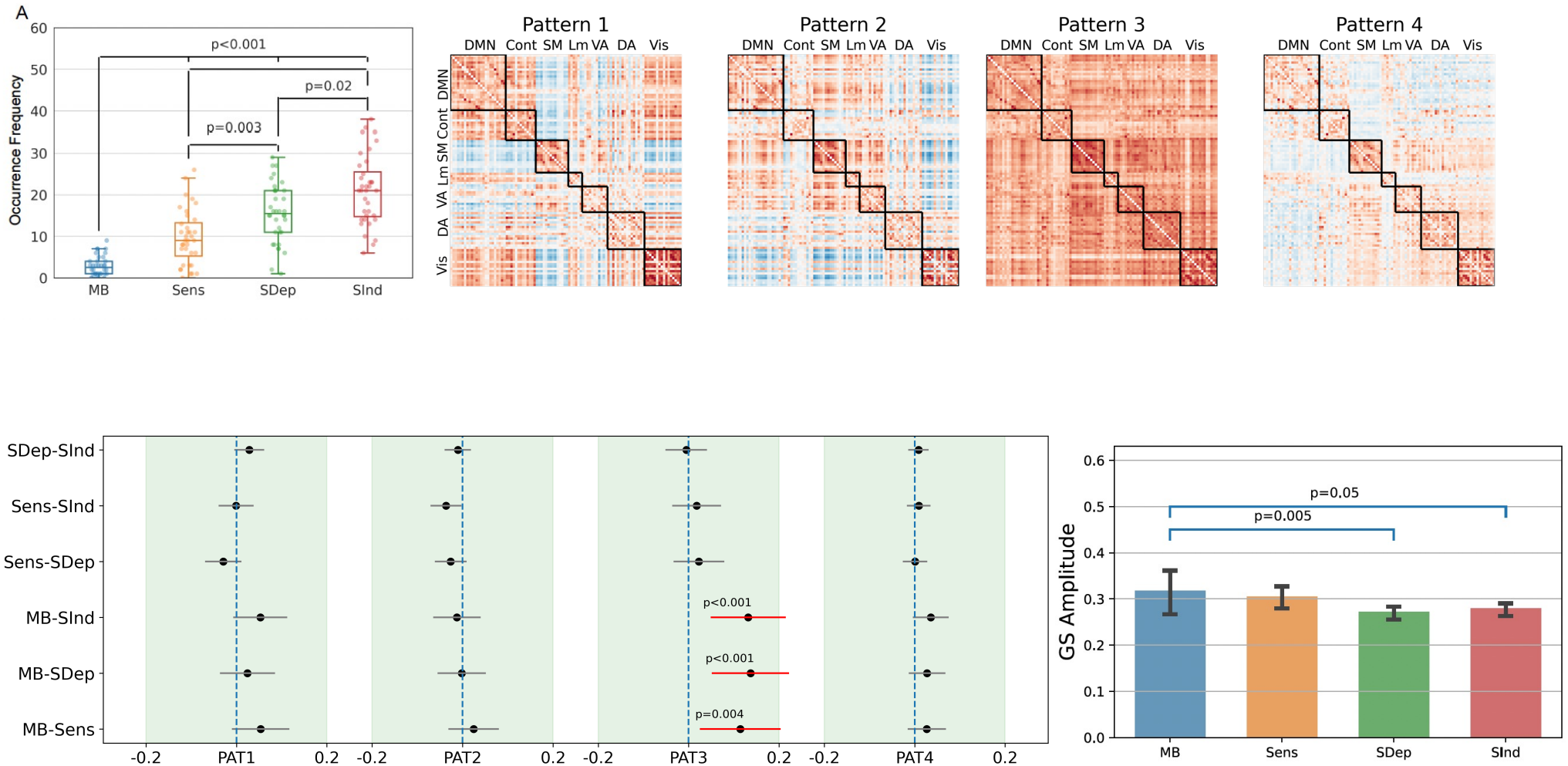
Propofol anesthesia



Wakeful and unconscious? The case of Mind Blanking

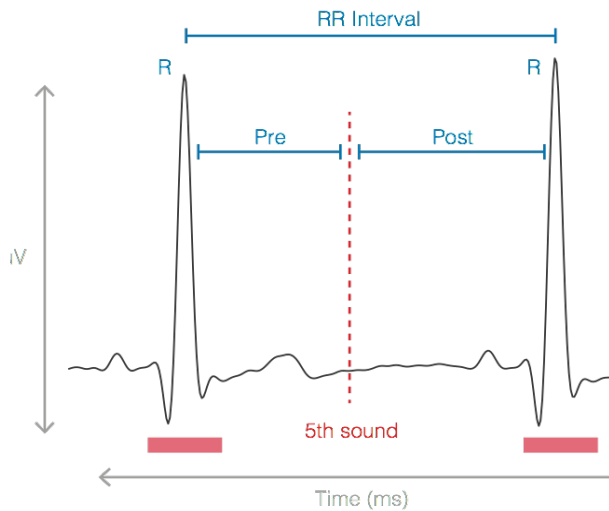


Wakeful and unconscious? The case of Mind Blanking

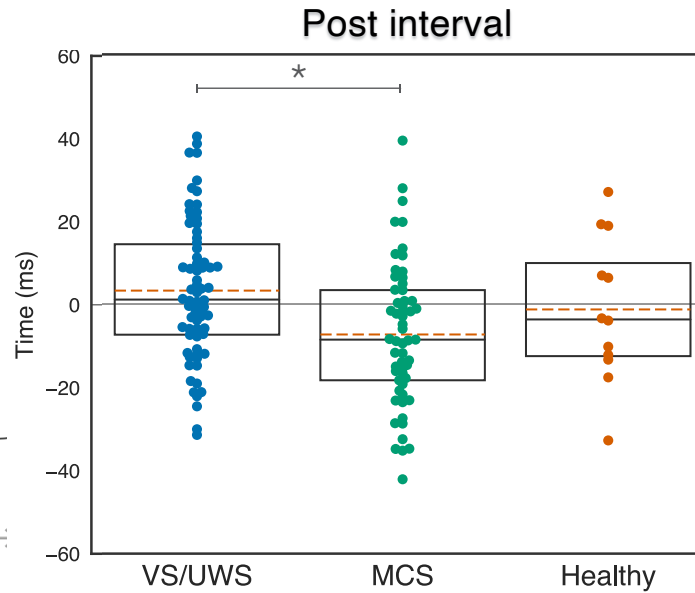


Cardiac reactions to oddballs in MCS

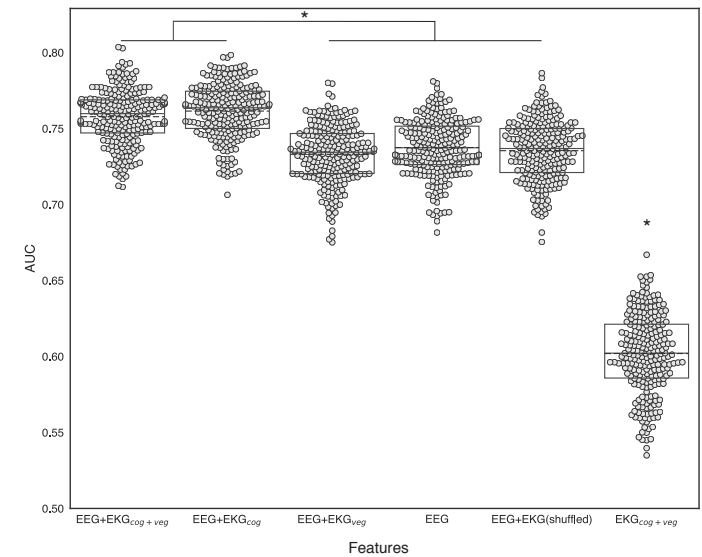
Auditory oddball paradigm



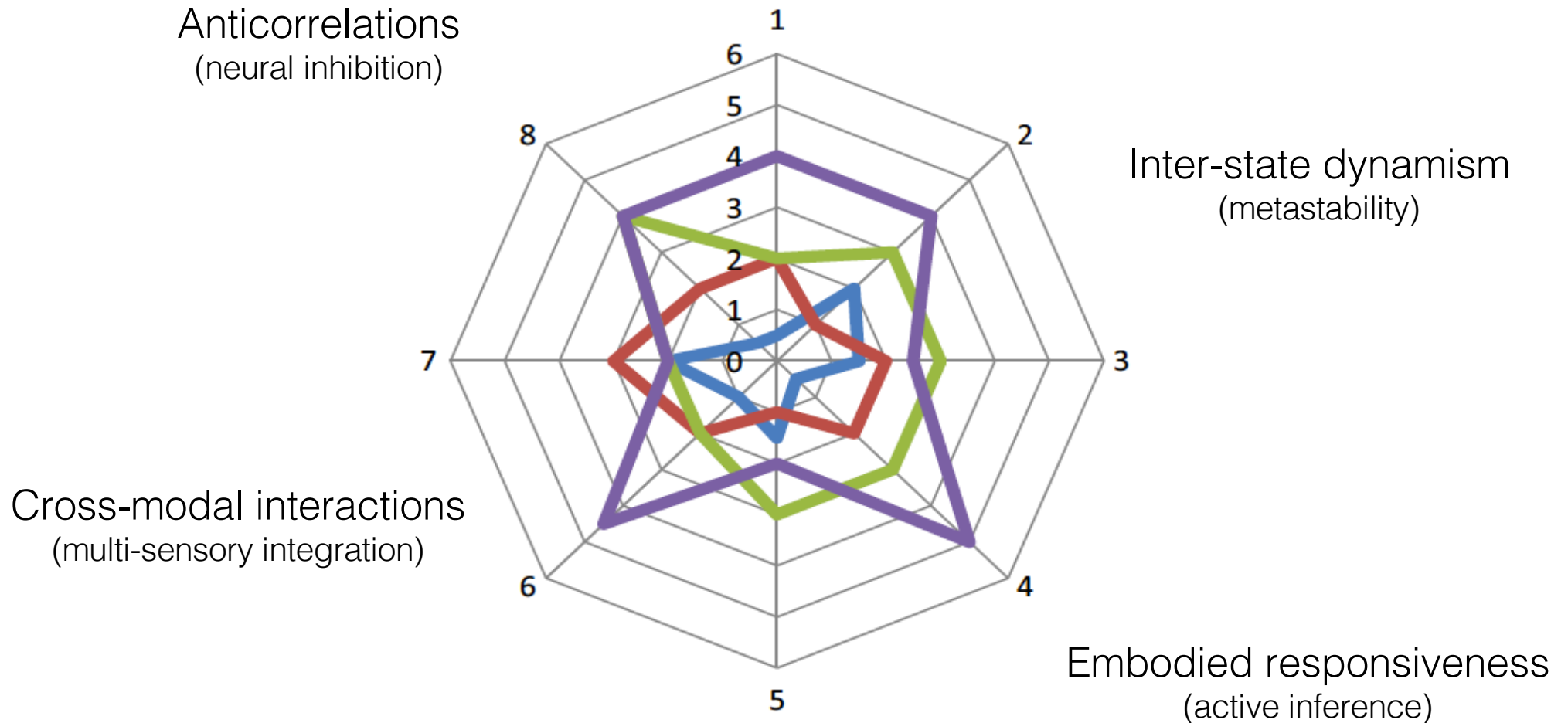
Cardiac cycle-phase acceleration only in MCS

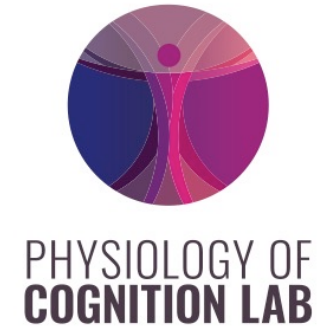


Electrocardiographic markers carry independent information from EEG



Consciousness is multidimensional





Consciousness is
a construct of collective consensus
and concerns us all



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