At the boundaries of mental state reportability

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Consciousness

and why I study it

awareness

perception

cognition

thought

imagination

mind

self-awareness

experience

NeuroEthics

Animals

Psychotherapy

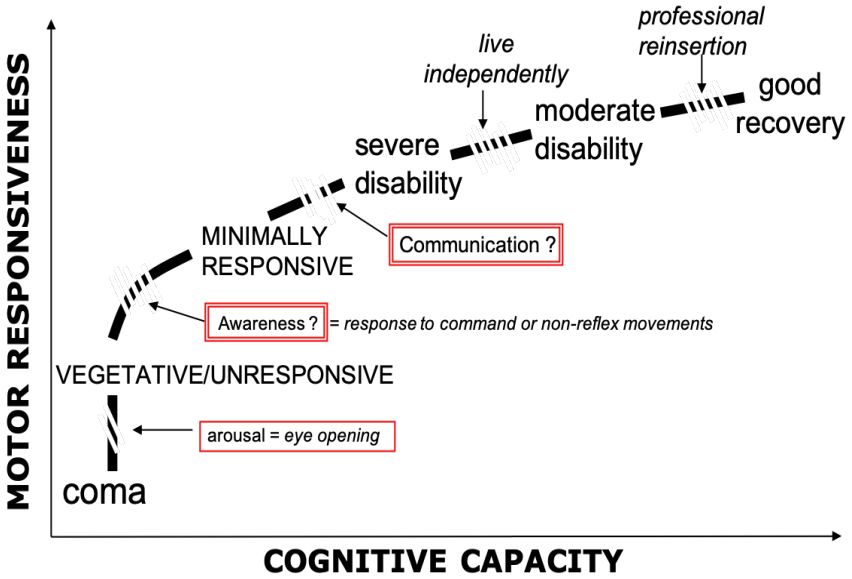
Source: Google pictures (Credit: CC-BY-SA; M Appelman)

Limits of reportability

Clinical Unconsciousness

Disorders of Consciousness

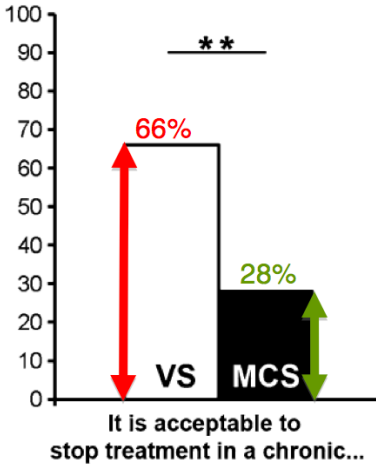
Consciounsess inferred from behavior



Laureys, Perrin, Brédart. *Consc Cogn* 2007
Naccache. *Brain* 2018

End-of-life support for "unconscious" patients

2,475 medical professionals



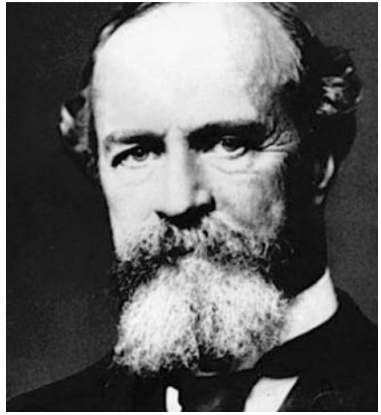
Demertzi et al, *Prog Brain Res* 2009
Demertzi et al, *J Neurol* 2011
Demertzi & Racine et al, *Neuroethics* 2012

The resting paradigm

Brain ~2% body's weight
Evoked changes <5%
80% for neuronal signaling

"While conscious awareness is […] energetically inexpensive, it is dependent upon a very complex, dynamically organized state of the brain that is achieved at great expense"

The stream of thought (Chapter IX)
The Principles of Psychology 1890



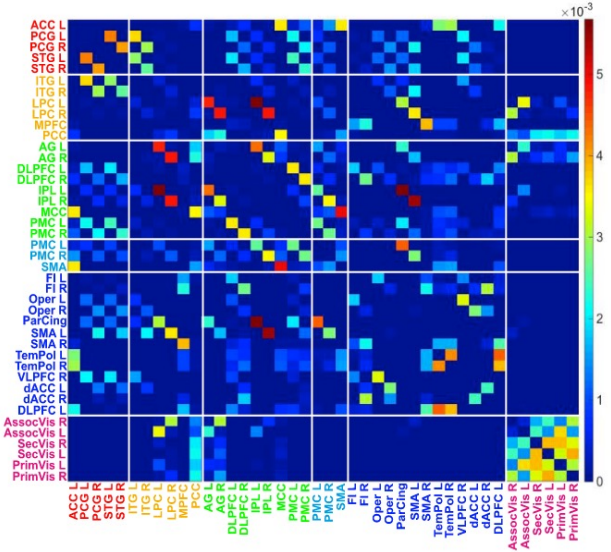
William James (1842-1910)

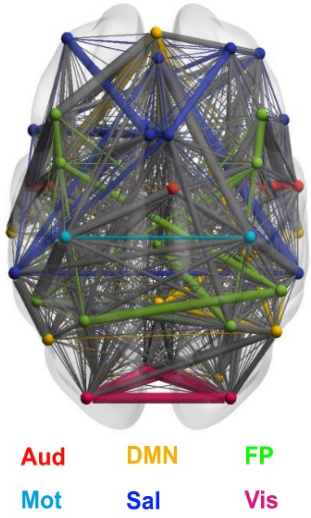
Raichle & Snyder, 2009 In: Laureys S, Tononi G, *The Neurology of Consciousness*. Oxford: Elsevier Academic Press

The brain as a network

100 billion neurons, ~100 trillion synaptic connections

The Connectome





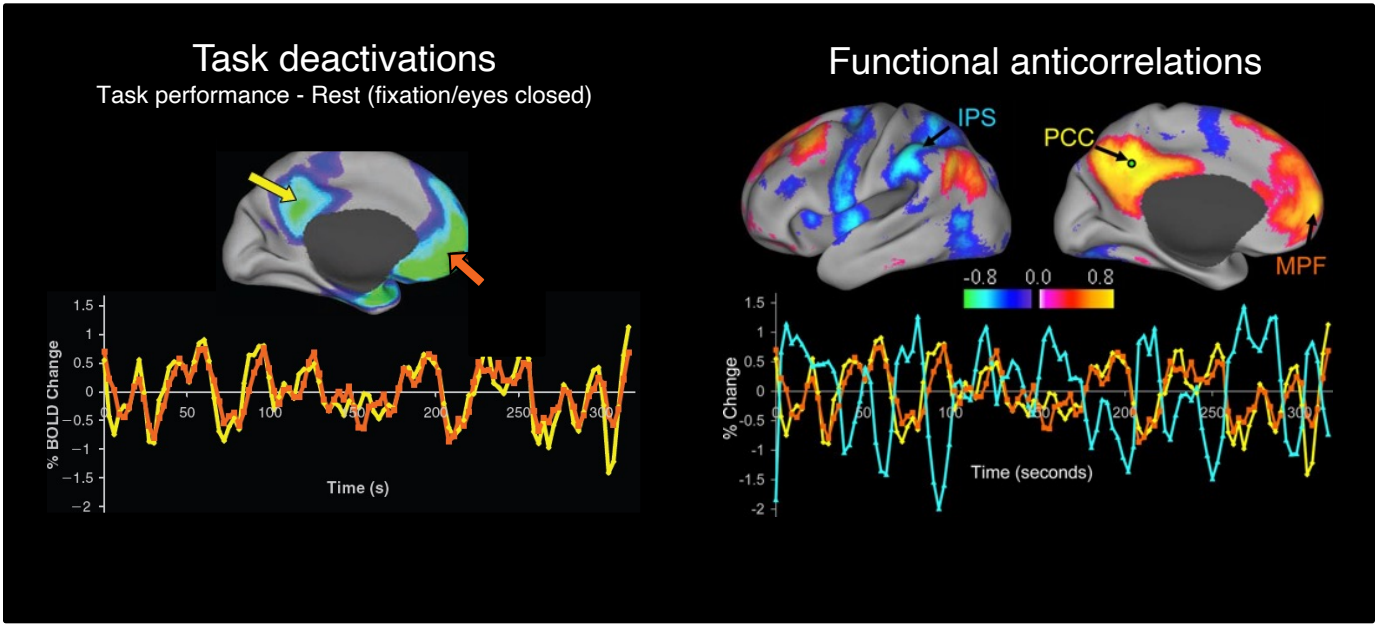
A matrix representing all possible pairwise anatomical connections between neural elements of the brain

Sporns, Tononi, & Koetter. *PLoS Comput. Biol.* 2005

Fornito, Zalesky, Bullmore. Ch 1: An Introduction to Brain Networks. *Fundamentals of Brain Network Analysis, Academic Press* 2016

Image from: Demertzi & Tagliazucchi, Dehaene, Deco, Barttfeld, Raimondo […], Schiff, Owen, Laureys, Naccache, Sitt. *Science Advances* 2019

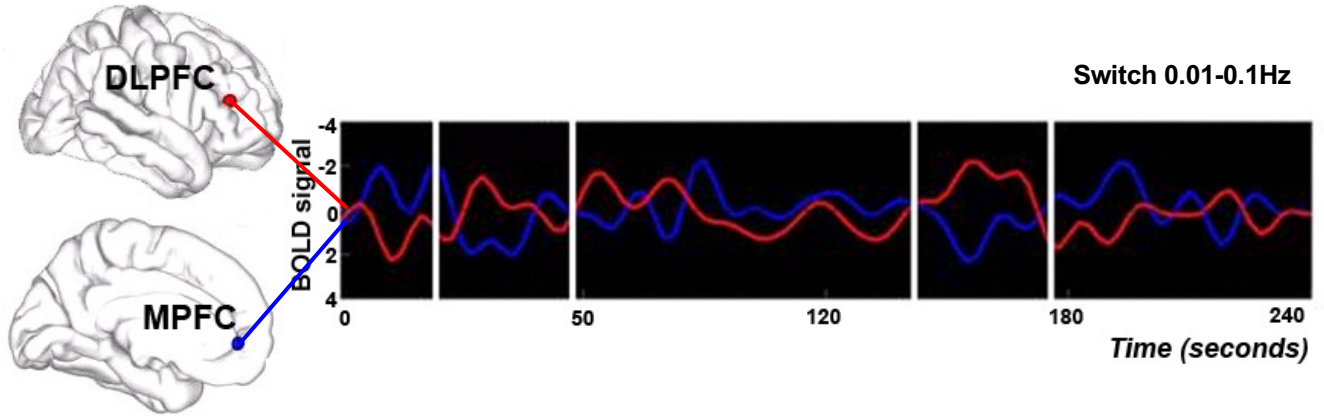
Default mode of brain function



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
Fox et al, *PNAS* 2005

Anticorrelations inform cognitive function?

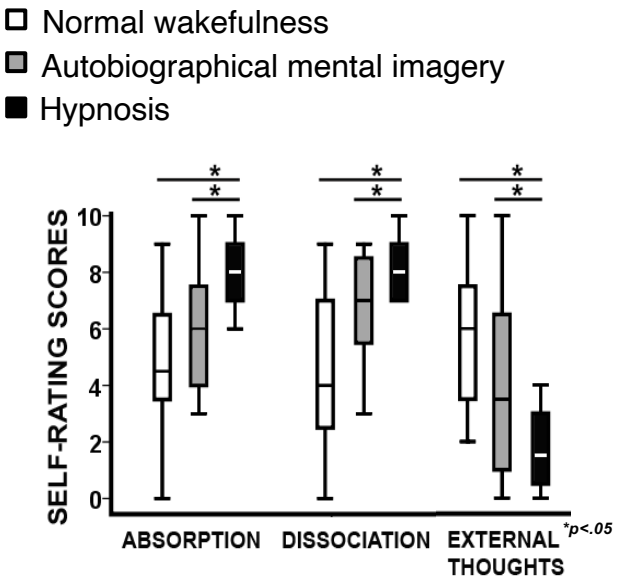
External awareness
***or* anticorrelated network**

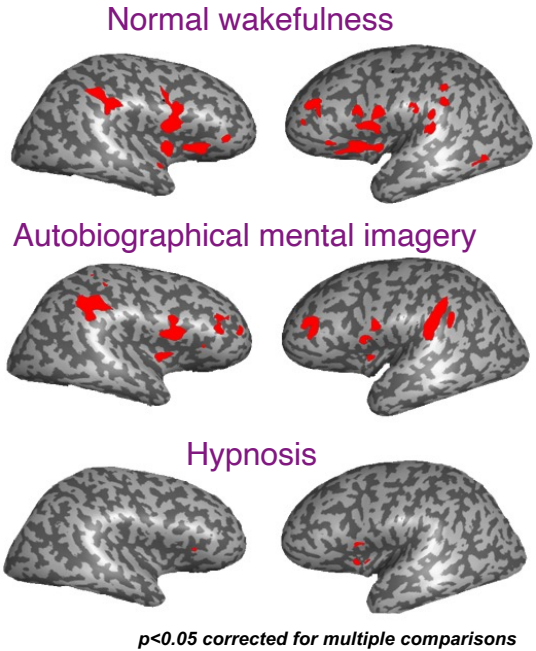


Internal awareness
***or* Default mode network**

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* 2022

Modified awareness reduces anticorrelations

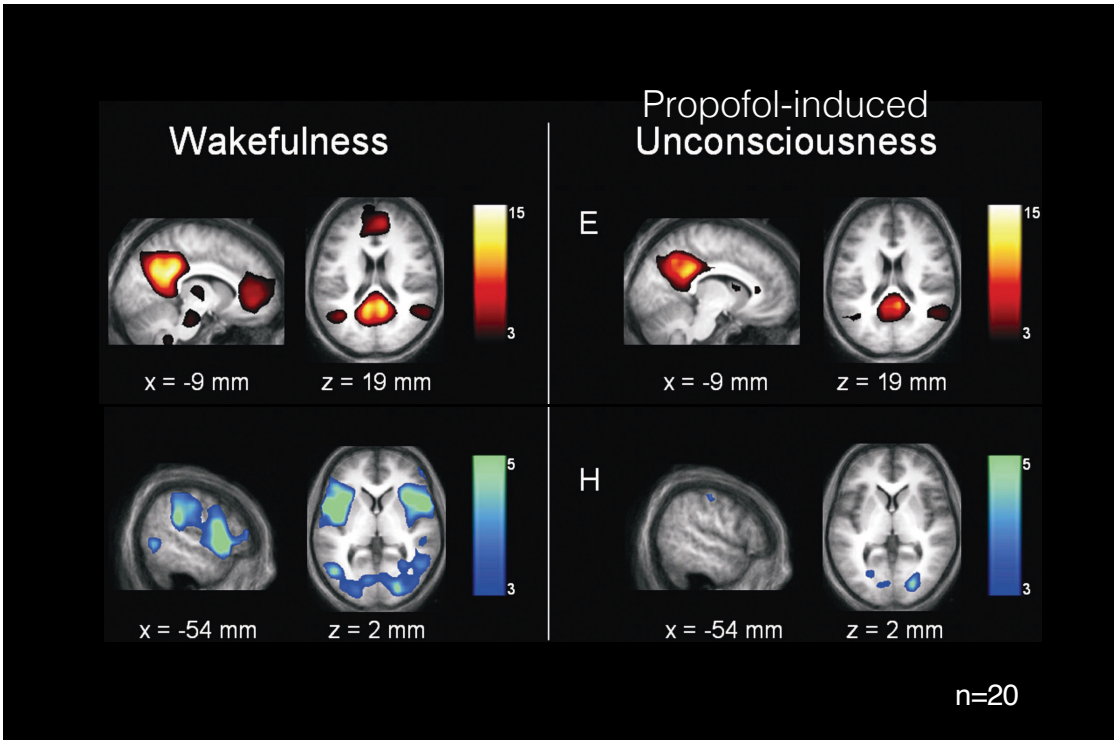




p<0.05 corrected for multiple comparisons

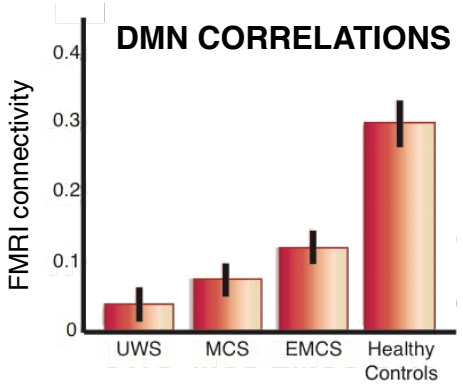
Demertzi, Soddu, Faymonville et al, *Prog Brain Res* 2011
Demertzi, Vanhaudenhuyse, Noirhomme, Faymonville, Laureys, *J Physiol Paris* 2015

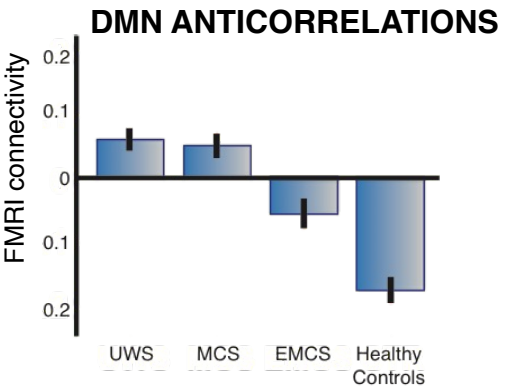
Modified arousal reduces anticorrelations

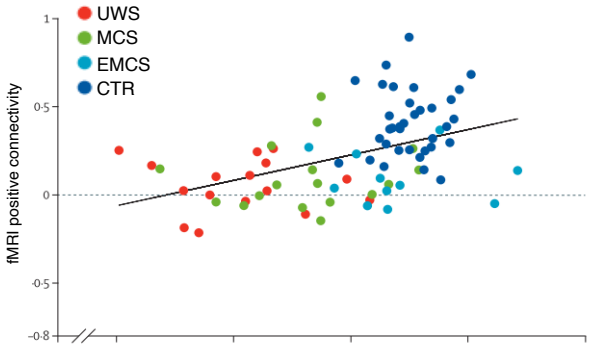


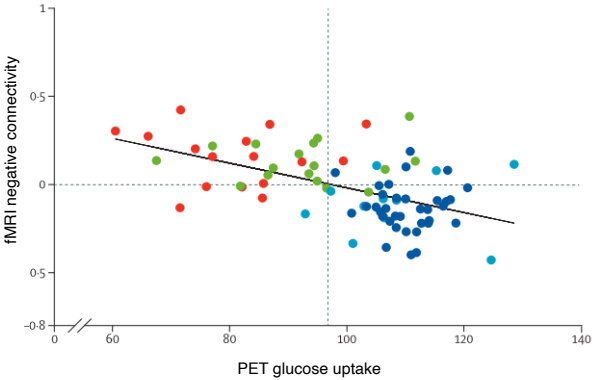
Boveroux et al, *Anesthesiology* 2010

No anticorrelations in DOC



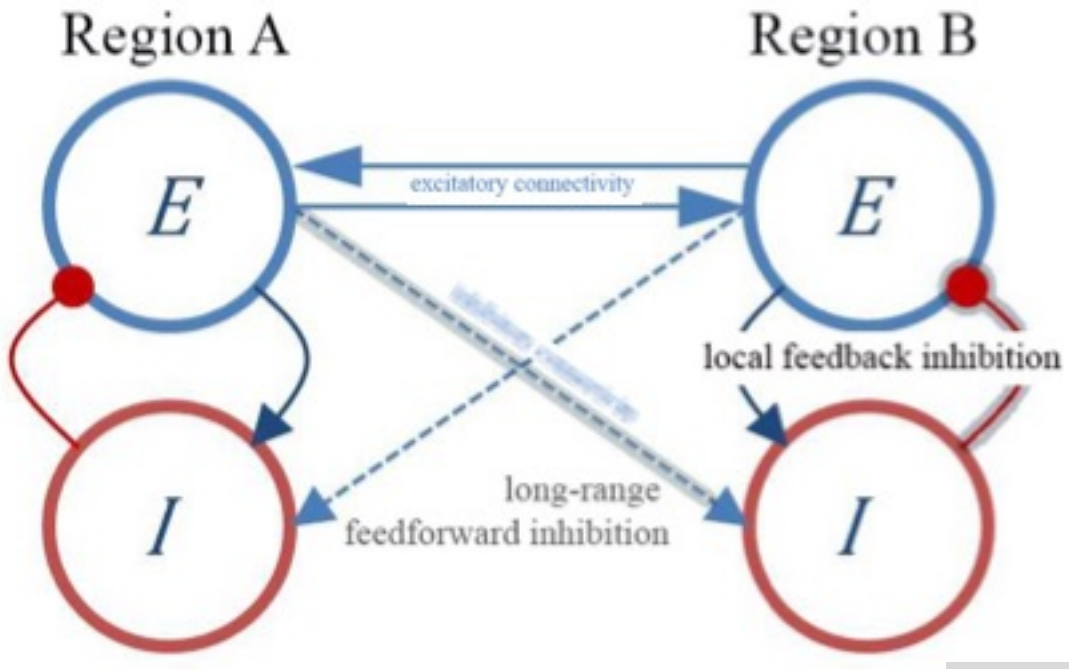






Di Perri, …, Demertzi*, Laureys*, Soddu*, *Lancet Neurol* 2016

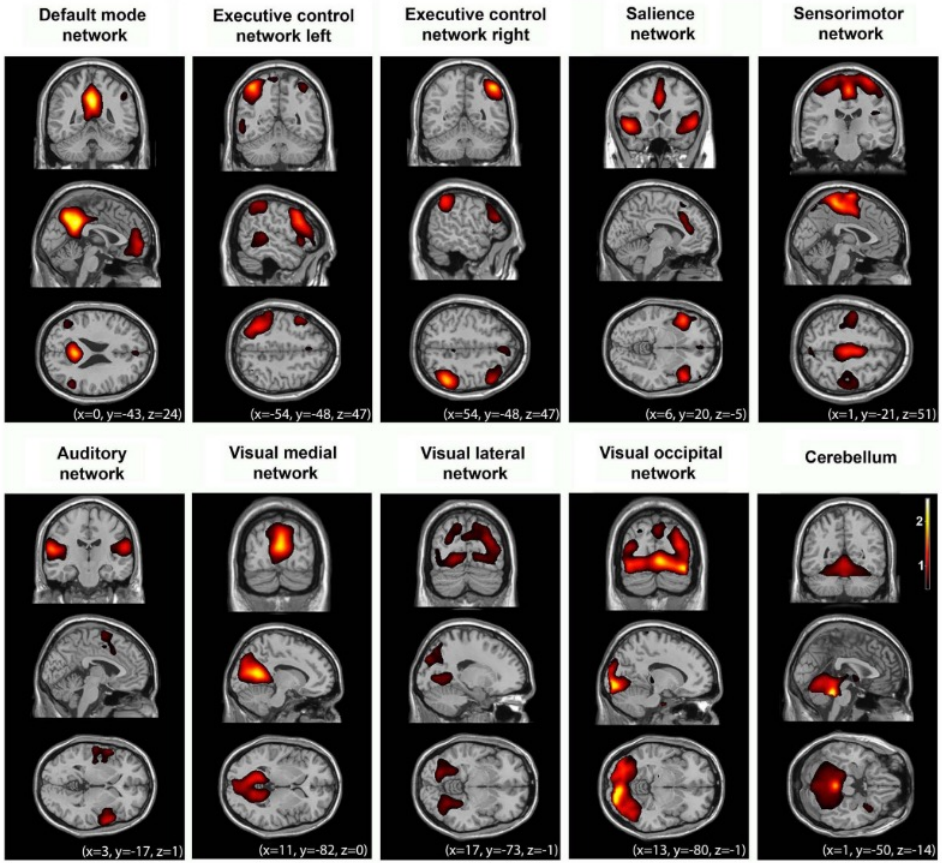
Anticorrelations as a result of neural inhibition



Ignition
Deco et al., *Sci Adv* 2021
Joglekar et al, *Neuron* 2018

Demertzi, Kucyi, Ponce-Alvarez, Keliris, Whitfield-Gabrieli, Deco. *Network Neurosci* 2022

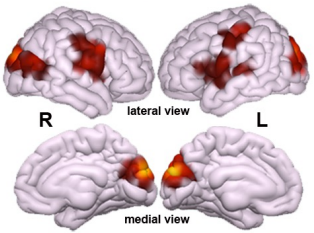
More networks during rest

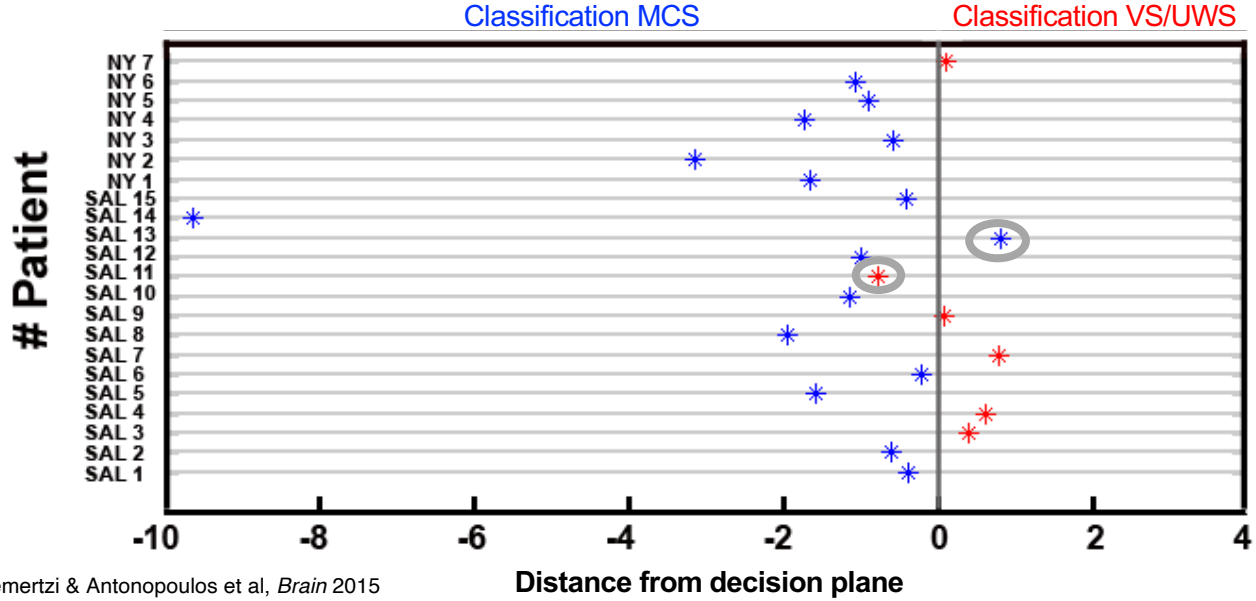


Biswal et al., *Magn Reson. Med* 1995
Smith et al, *PNAS* 2009
Heine et al, *Front Psych 2012*

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

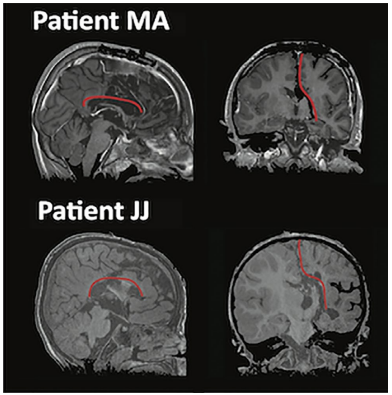




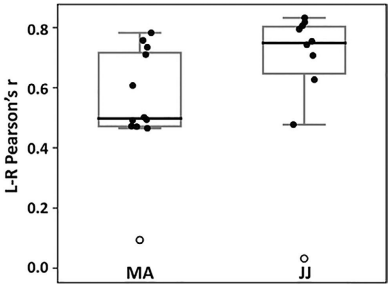
Demertzi & Antonopoulos et al, *Brain* 2015

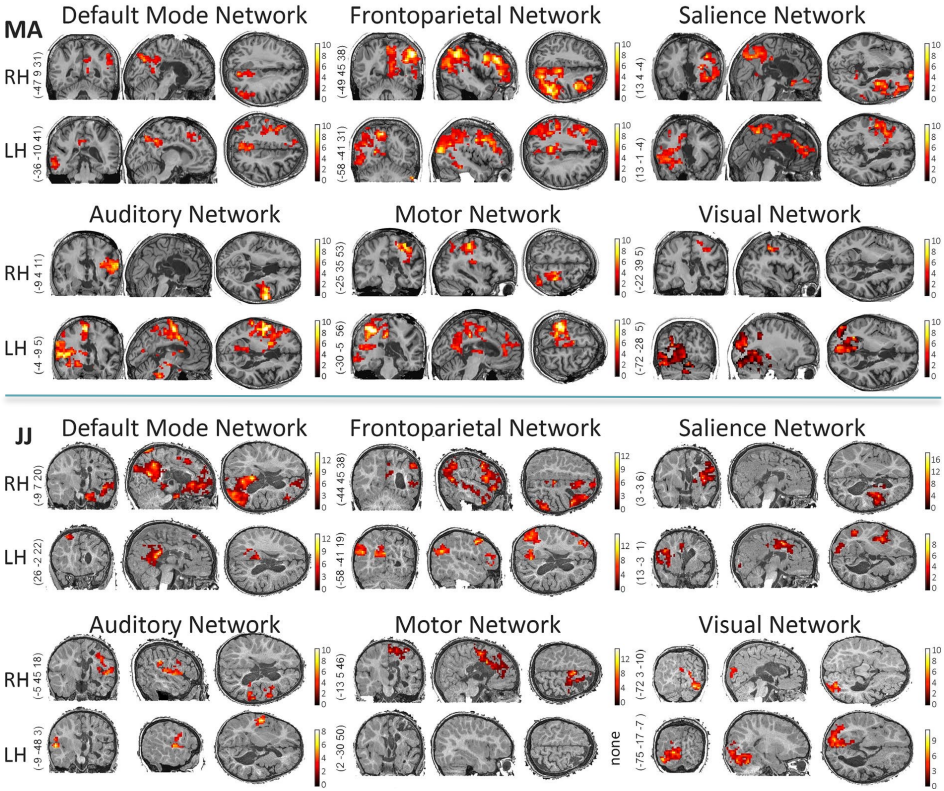
Lower cross-modal interaction in the isolated brain

Complete hemispherotomy



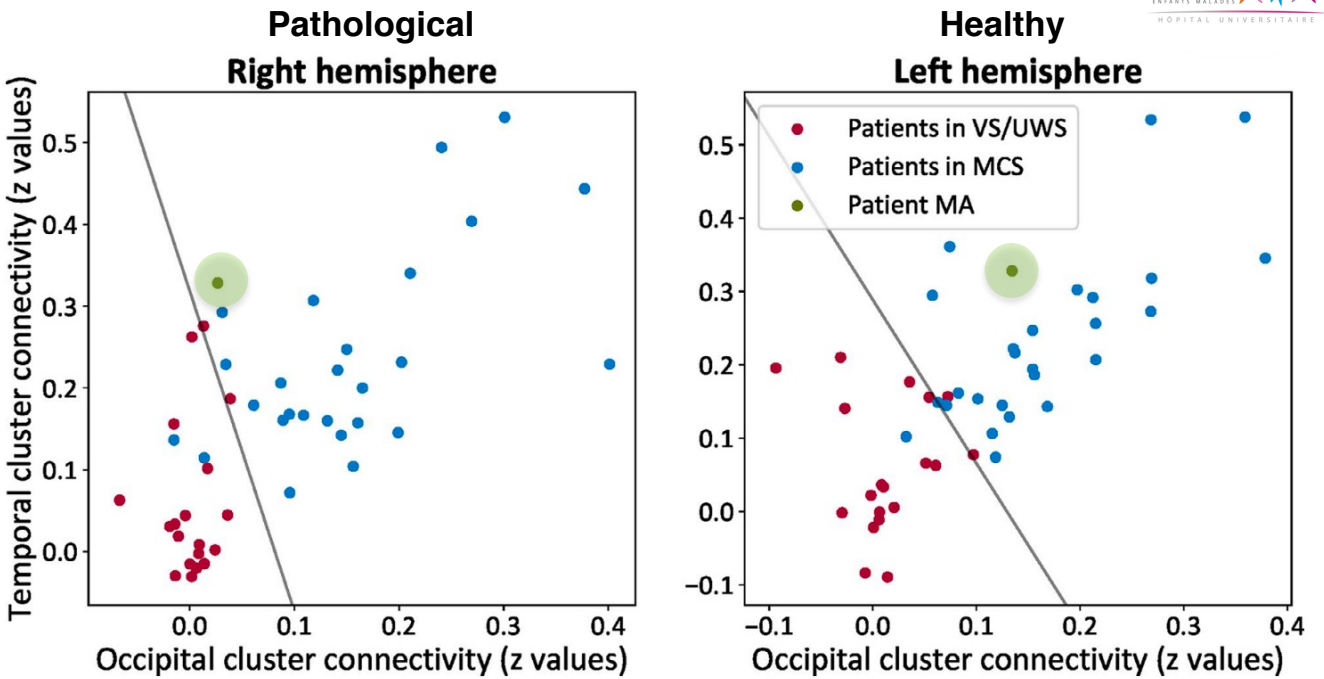
Inter-hemispheric connectivity





Blauwblomme & Demertzi, Tacchela, Fillon, Bourgeois, Losito, Eisermann, Marinazzo, Raimondo, Alcauter, Van De Steen, Colenbier, Laureys, Dangouloff-Ros, Naccache, Boddaert, Nabbout et al, *Epilepsia Open* 2020

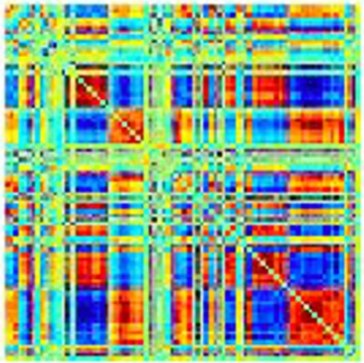
Lower cross-modal interaction in the isolated brain



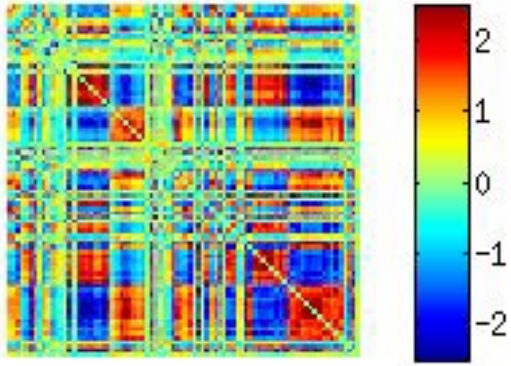
Blauwblomme & Demertzi, Tacchela, Fillon, Bourgeois, Losito, Eisermann, Marinazzo, Raimondo, Alcauter, Van De Steen, Colenbier, Laureys, Dangouloff-Ros, Naccache, Boddaert, Nabbout et al, *Epilepsia Open* 2020

Brain dynamics and cognition

Averaged connectome



Time-varying connectome



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

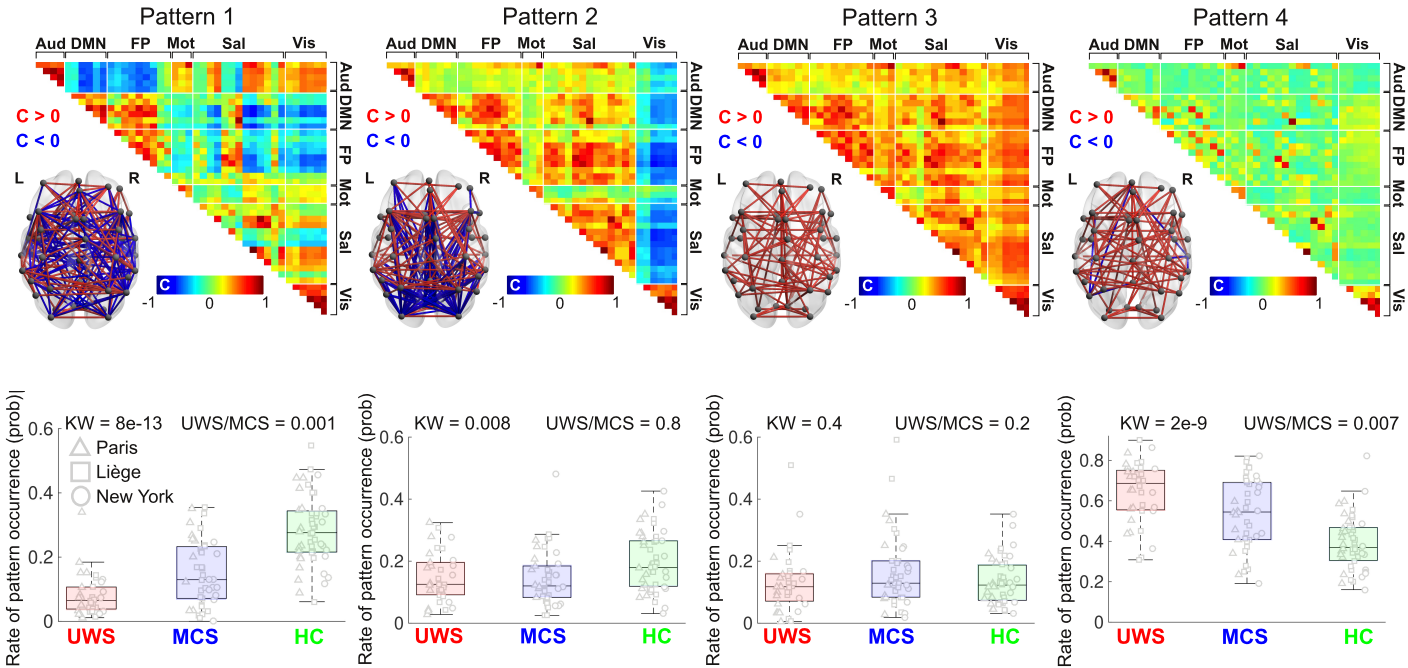
Rigid spatiotemporal organization, less metastable dynamics

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

The brain cannot map the complexity of internal and external world

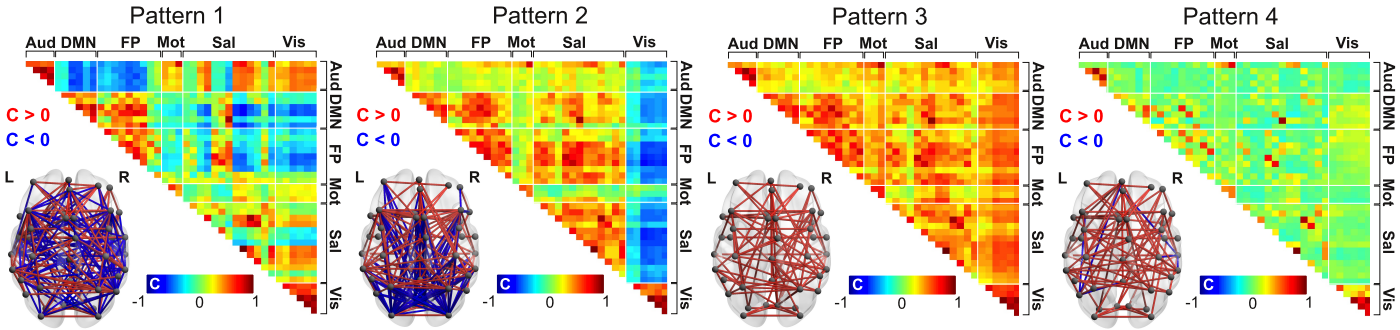
(Dehaene et al, *Trends Cog Sci, 2006;* Tononi et al, *Nat Rev Neurosci.* 2016)

Complex patterns in higher conscious states

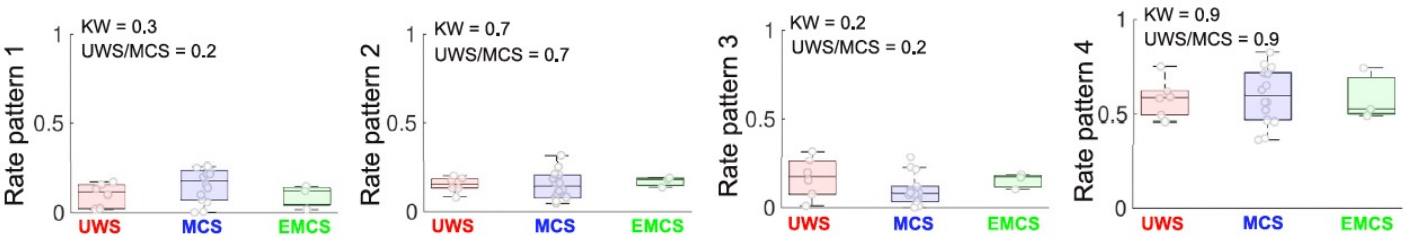


Demertzi & Tagliazucchi, Dehaene, Deco, Barttfeld, Raimondo, Martial, Fernández-Espejo, Rohaut, Voss, Schiff, Owen, Laureys, Naccache, Sitt. *Science Advances* 2019

Complex patterns in higher conscious states

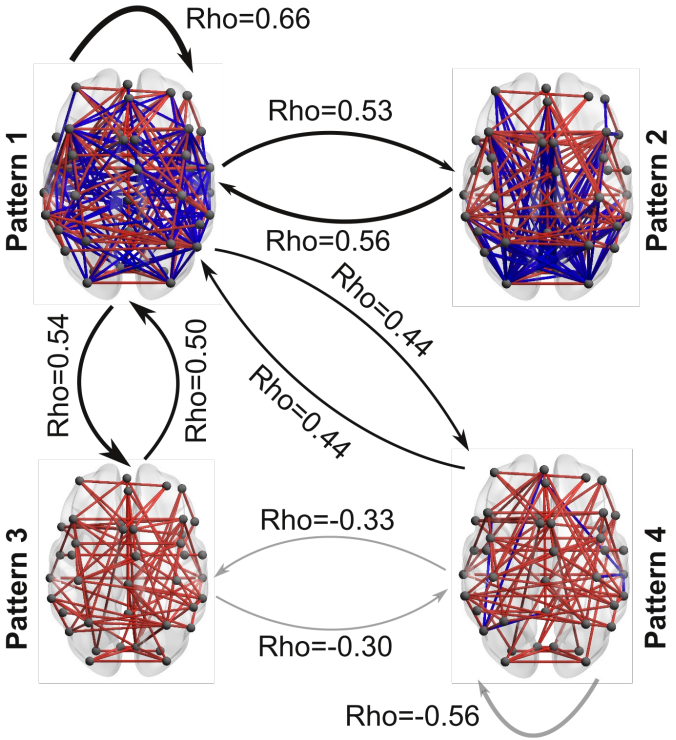


Propofol anesthesia

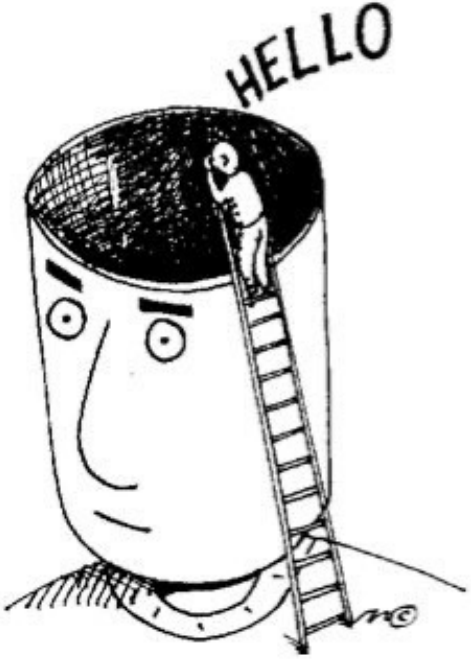


Demertzi & Tagliazucchi, Dehaene, Deco, Barttfeld, Raimondo, Martial, Fernández-Espejo, Rohaut, Voss, Schiff, Owen, Laureys, Naccache, Sitt. *Science Advances* 2019

More chances to transition when conscious



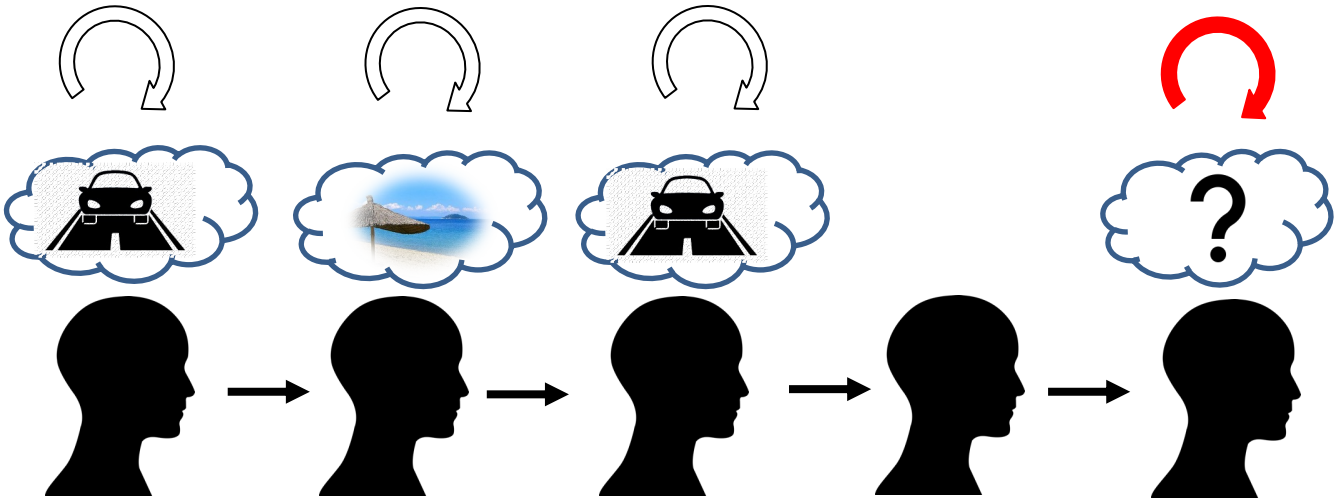
Demertzi & Tagliazucchi, Dehaene, Deco, Barttfeld, Raimondo, Martial, Fernández-Espejo, Rohaut, Voss, Schiff, Owen, Laureys, Naccache, Sitt. *Science Advances* 2019



Limits of reportability

Typical Conscious state

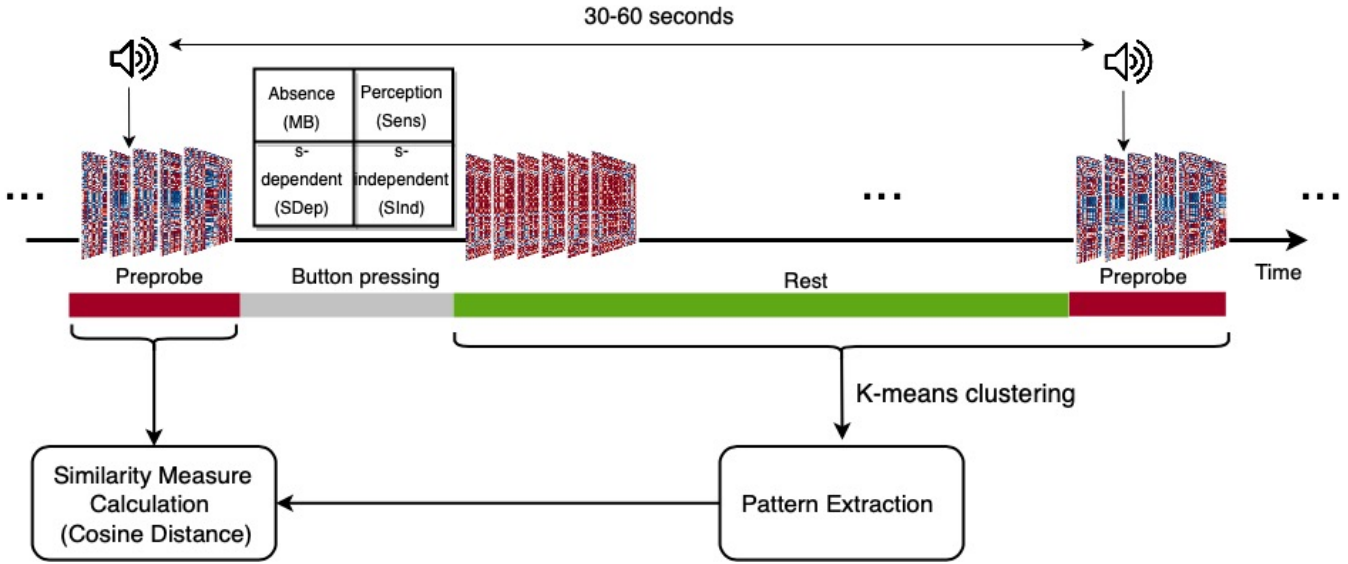
Mental states



Slide courtesy: Boulakis Paris

Christoff et al, *Nat Rev Neurosci* 2016

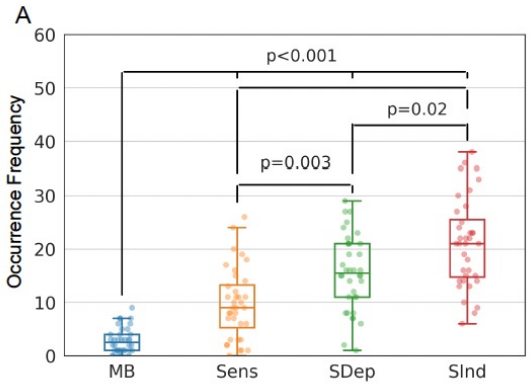
Experience-sampling



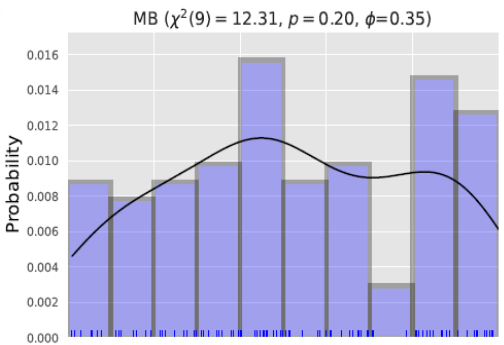
Mortaheb, Van Calster, Raimondo, Klados, Boulakis, Georgoulaa, Majerus, Van De Ville*, Demertzi*. *PNAS* 2022
Van Calster, D'Argembeau, Salmon, Peters, Majerus, *J Cogn Neurosci* 2017

Mind Blanking has a distinct behavioral profile

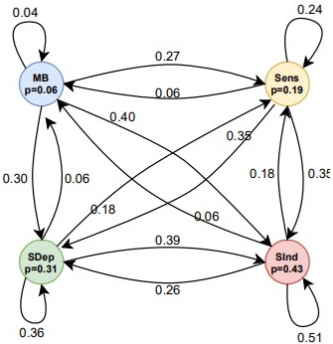
Less frequent



Equally probable across time

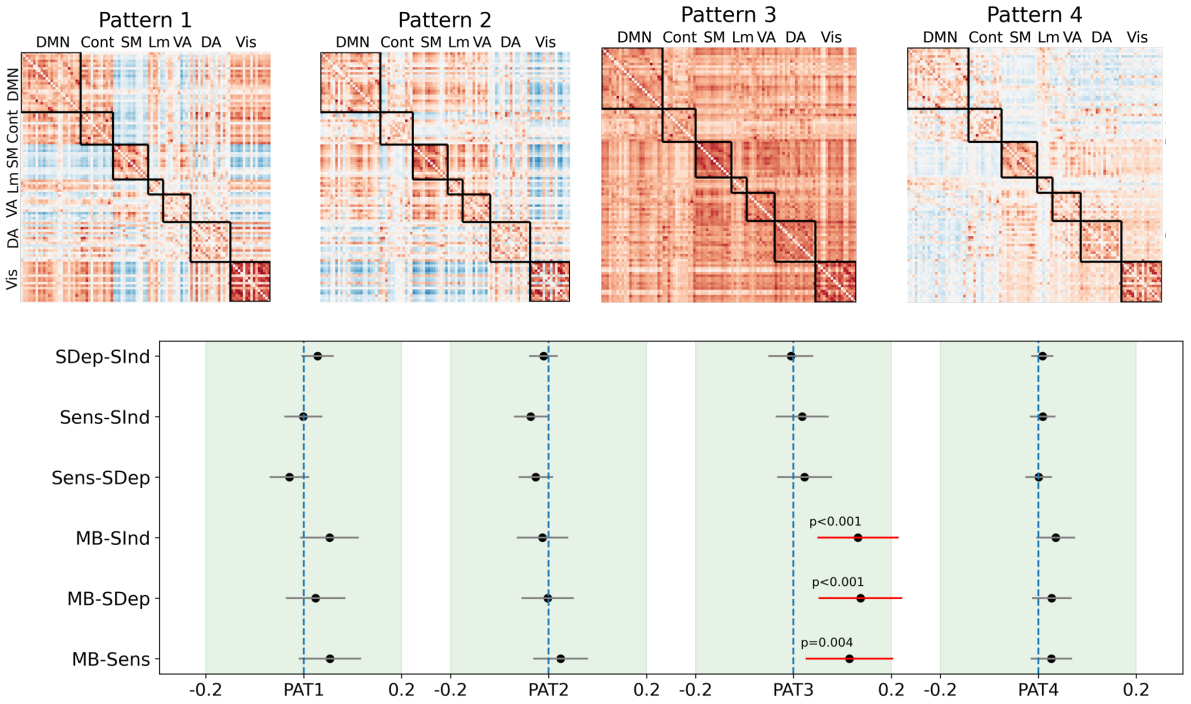


Transient relay



Mortaheb, Van Calster, Raimondo, Klados, Boulakis, Georgoulaa, Majerus, Van De Ville*, Demertzi*. *PNAS* 2022
Van Calster, D'Argembeau, Salmon, Peters, Majerus, *J Cogn Neurosci* 2017

MB is linked to a hyper-connected state

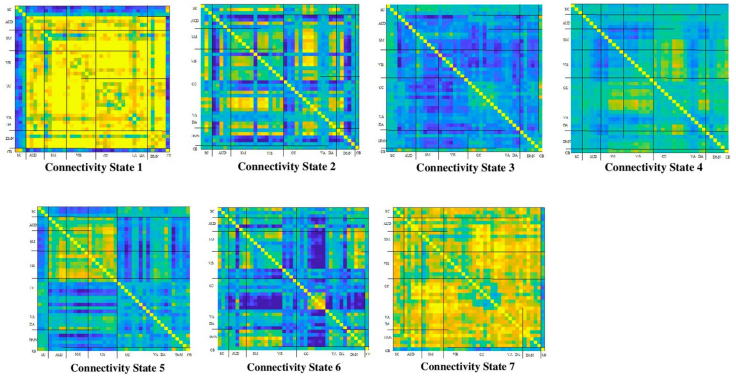


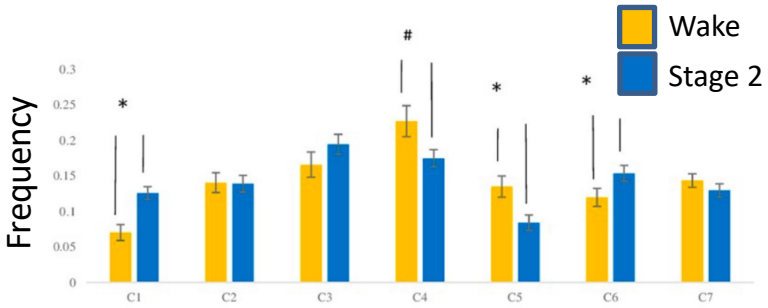
Mortaheb, Van Calster, Raimondo, Klados, Boulakis, Georgoulaa, Majerus, Van De Ville*, Demertzi*. *PNAS* 2022
Van Calster, D'Argembeau, Salmon, Peters, Majerus, *J Cogn Neurosci* 2017

Higher functional connectivity due to slow waves

NREM sleep

Humans

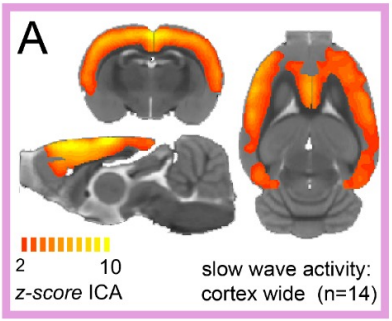


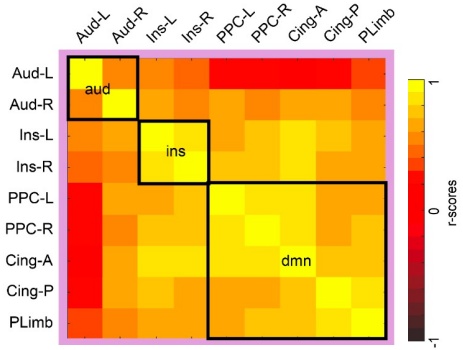


El-Baba et al, *PLOS One* 2019

Isoflurane anesthesia

Rats

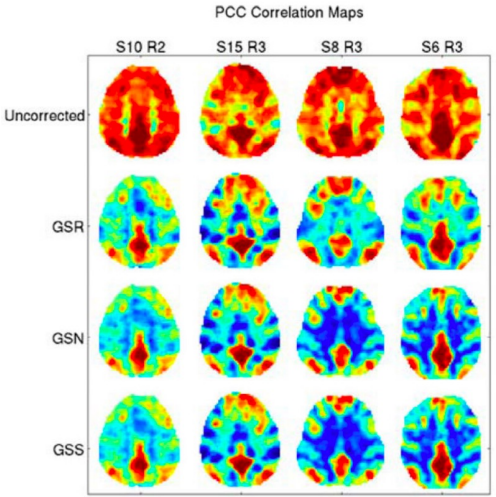




Aedo-Jury et al, *eLife* 2019

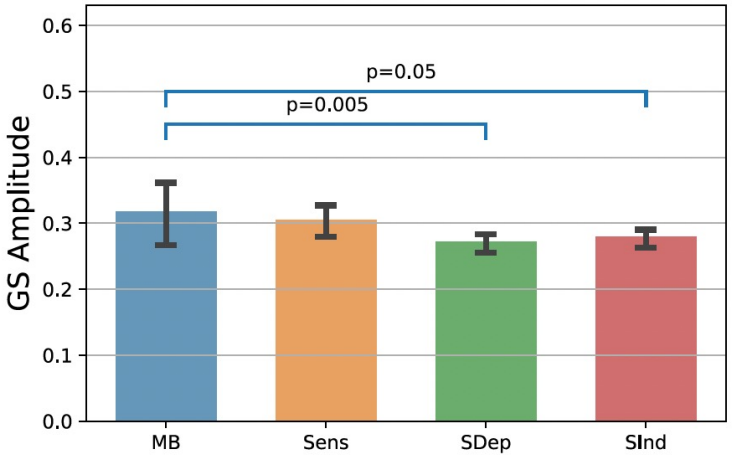
Lower cortical arousal in MB?

Global signal
Average voxel timeseries
Zarahn, Aguirre, D'Esposito, NeuroImage 1997
("Global flow'' in PET, Friston et al., 1990)



Liu et al, *NeuroImage* 2017

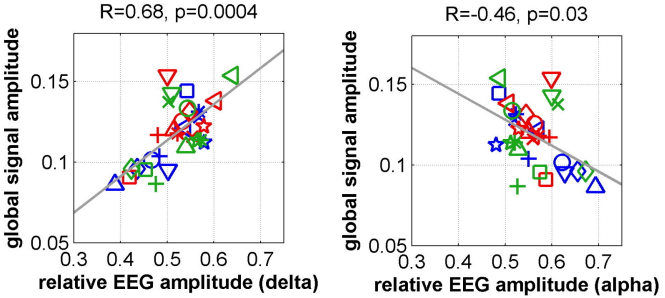
Higher Global Signal Amplitude
around MB reports



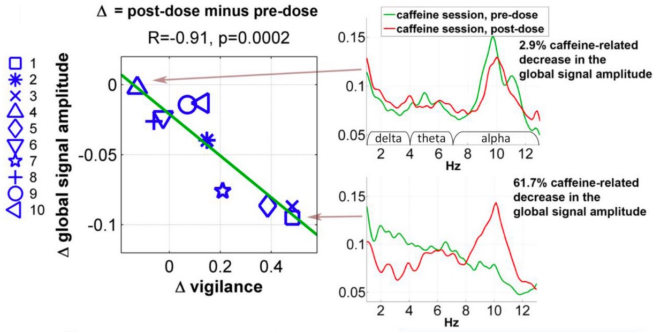
Mortaheb et al, *PNAS* 2022

GS amplitude and Arousal

GS amplitude is linked to low arousal

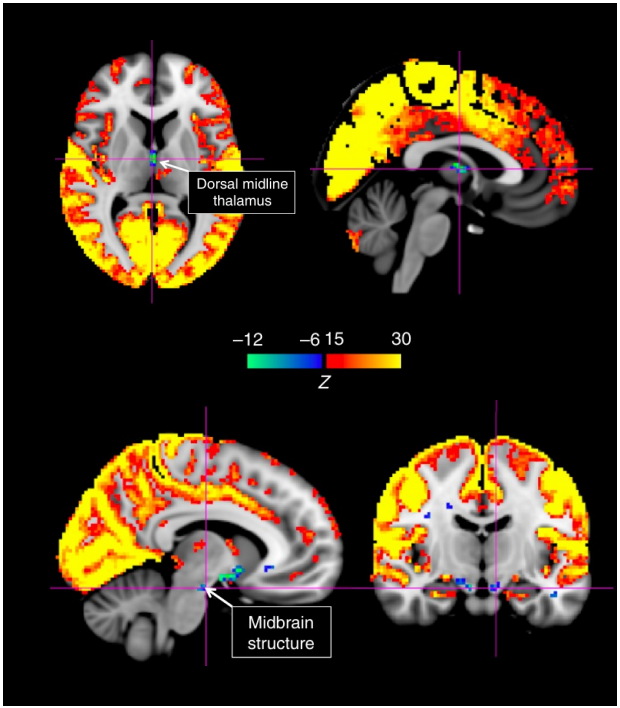


GS amplitude decreases with caffeine intake



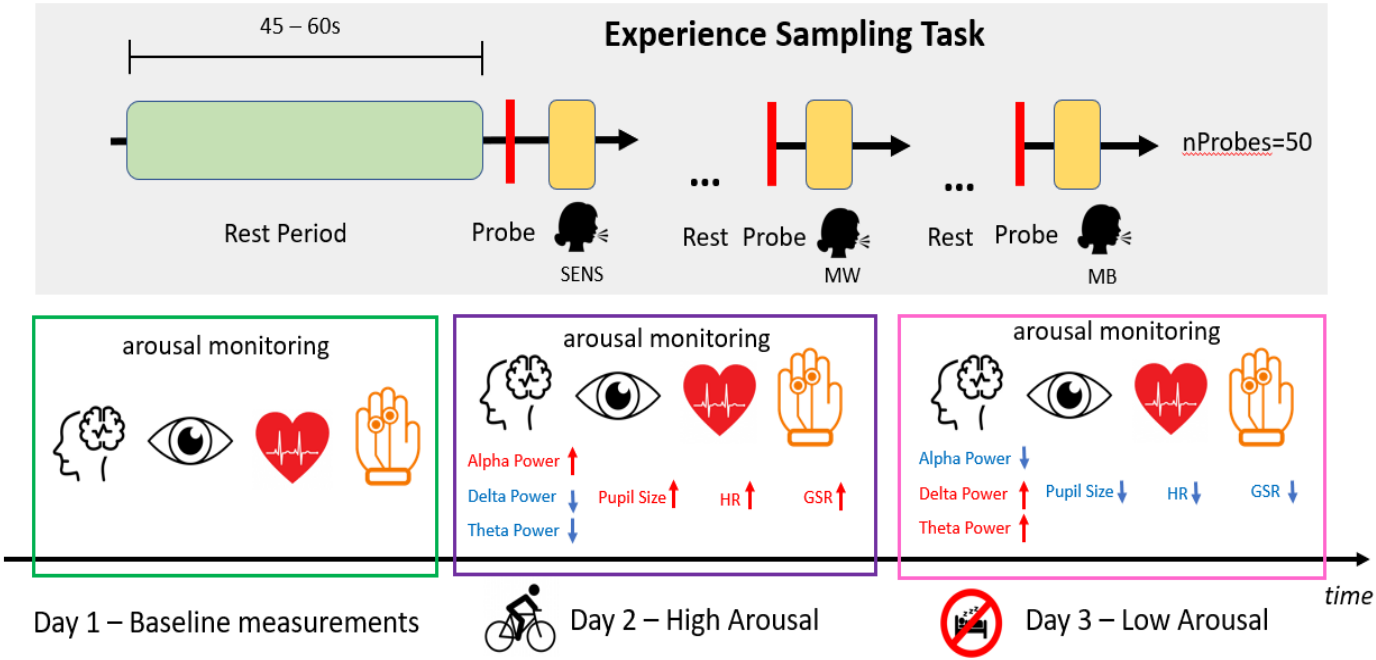
Wong et al, *Neuroimage* 2013

GS amplitude linked to signal decreases in subcortical structures of arousal



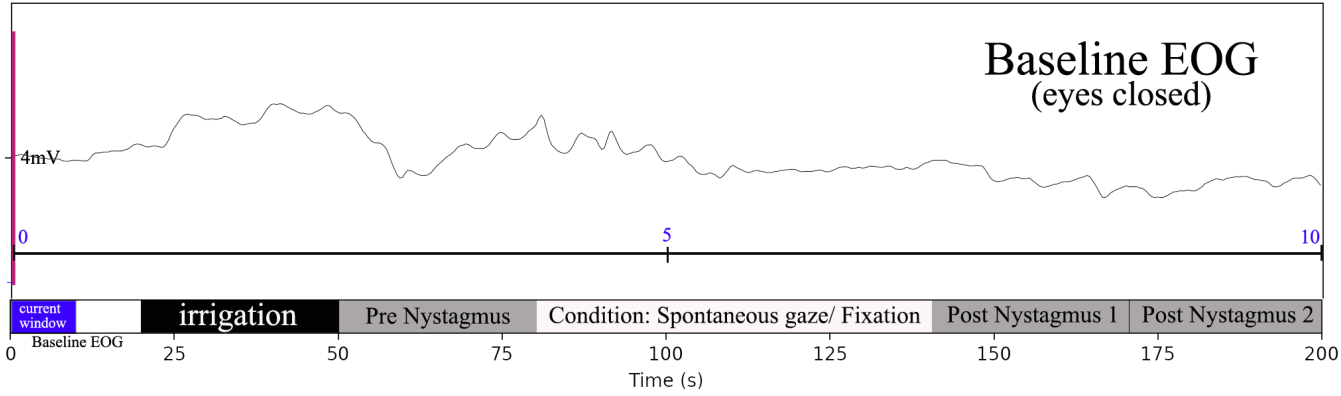
Liu et al, *Nat Commun* 2018

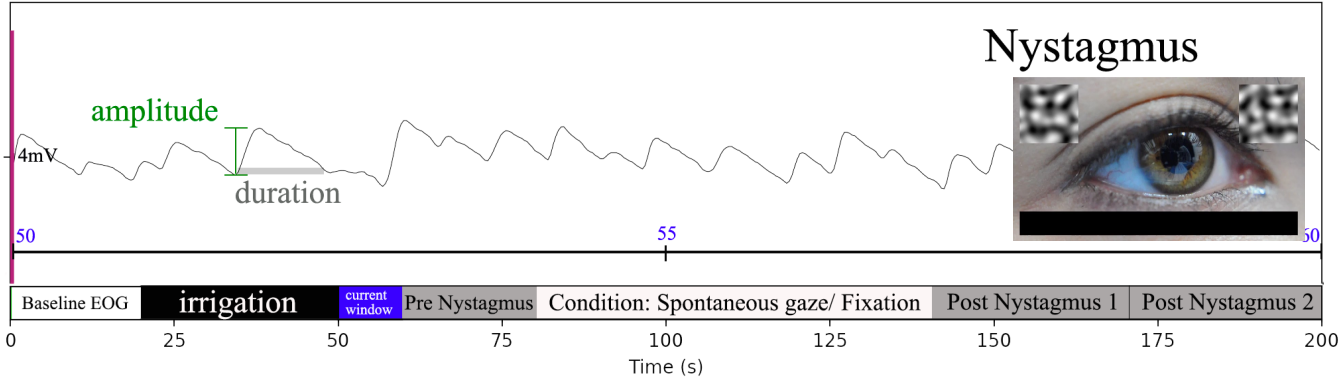
Hypothesis:
Mental state reportability has an embodied component



Boulakis, Raimondo, Mortaheb, Schmidt, Demertzi. *Scientific Reports* (accepted as Registered Report Stage 1)

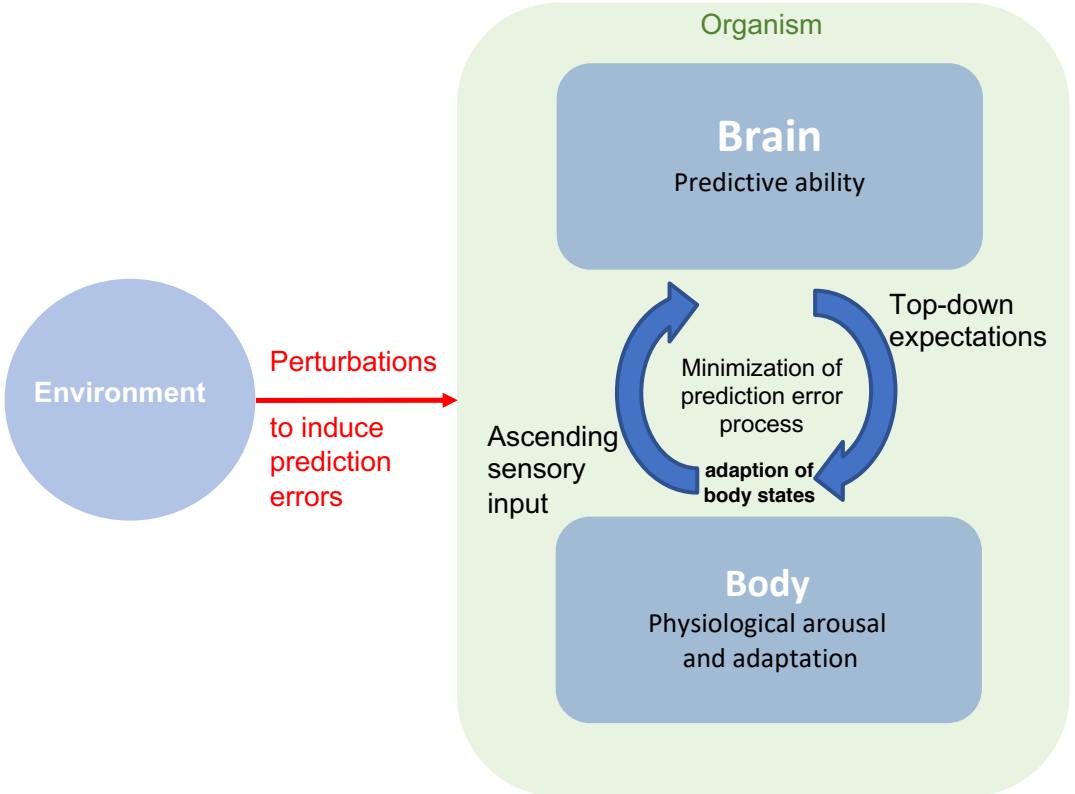
Evidencing sentience in low arousal by probing brain-body interactions





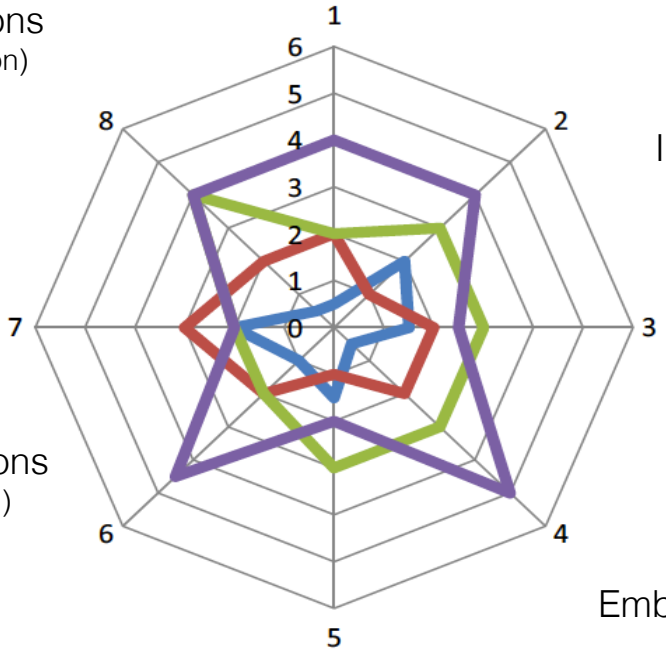
Koroma & Delcamp et al. Volitional activity is partially carried in autonomic reflexive responses https://osf.io/8cqxj/

The Active Inference principle



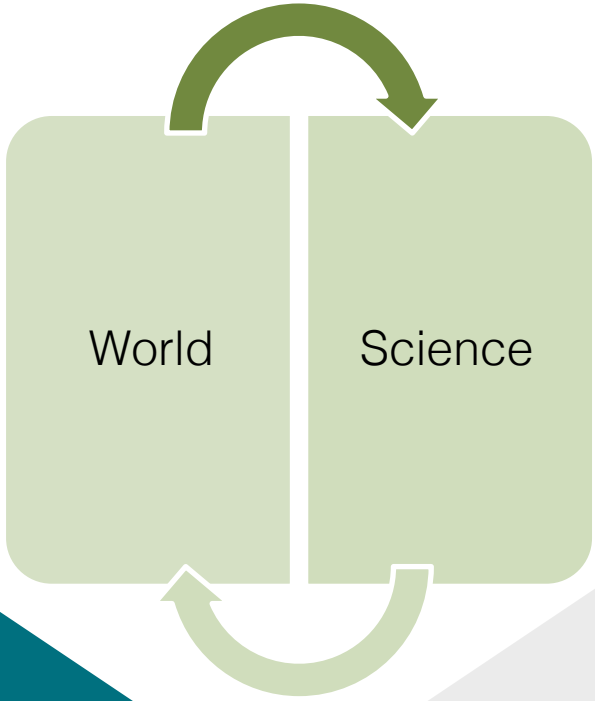
Seth, A. K. & Friston, K. J. (2016) Active interoceptive inference and the emotional brain. Phil Trans R Soc London B: 371

Consciousness is multidimensional



Bayne, Hohwy, Owen *Trends Cogn Sci* 2016

Consciousness



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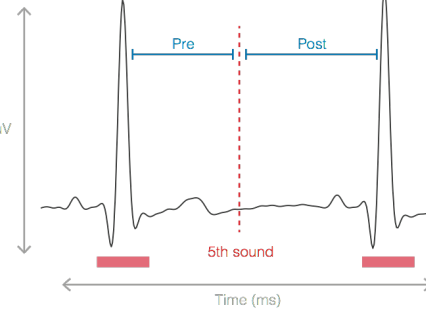
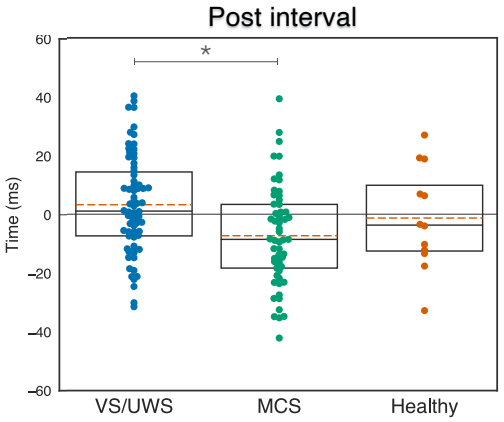
Cardiac reactions to oddballs in MCS

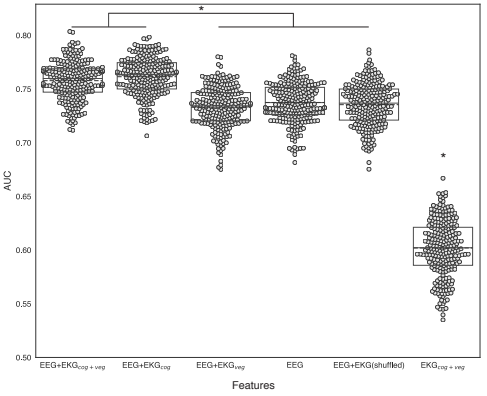
Auditory oddball paradigm



Cardiac cycle-phase acceleration only in MCS



Electrocardiographic markers carry independent information from EEG



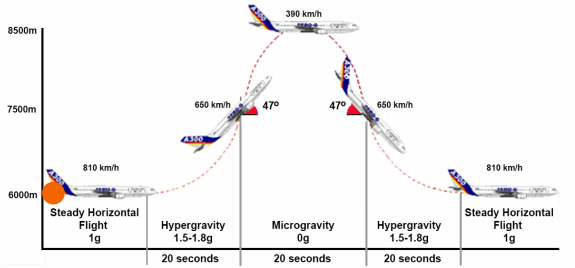
Annals of NEUROLOGY
An Official Journal of the American Neurological Association and the Child Neurology Society

Federico Raimondo [1,2,3,4] Benjamin Rohaut, MD, PhD [5,6]
Athena Demertzi, PhD [3,5] Melanie Valente,[3,5] Denis A. Engemann [3,5,7,8]
Moti Salti, PhD,[9] Diego Fernandez Slezak, PhD,[1,2]
Lionel Naccache, MD, PhD,[3,4,5,6,10] and Jacobo D. Sitt, MD, PhD [3,5]

Extreme environment reduces anticorrelations

Parabolic flight

European Space Agency

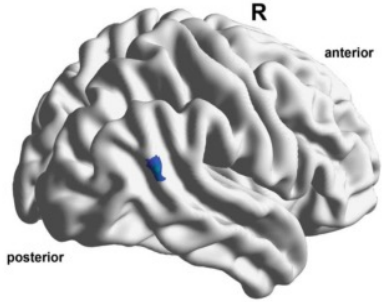


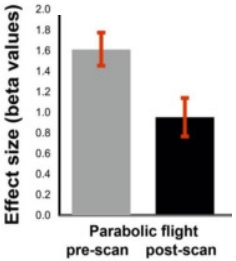
Flight trajectory

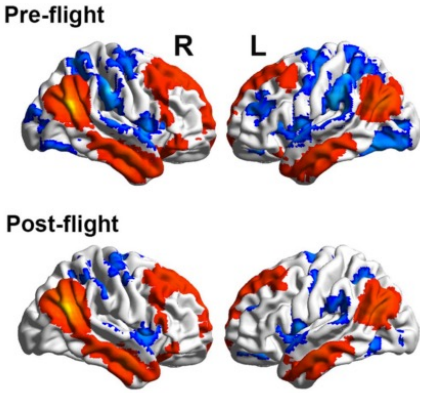
Angelique Van Ombergen[1], Floris L. Wuyts[1], Ben Jeurissen[2], Jan Sijbers[2], Floris Vanhevel[3], Steven Jillings[1], Paul M. Parizel[3], Stefan Sunaert[4], Paul H. Van de Heyning[1], Vincent Dousset[5], Steven Laureys[6] & Athena Demertzi[6,7]

SCIENTIFIC REPORTS

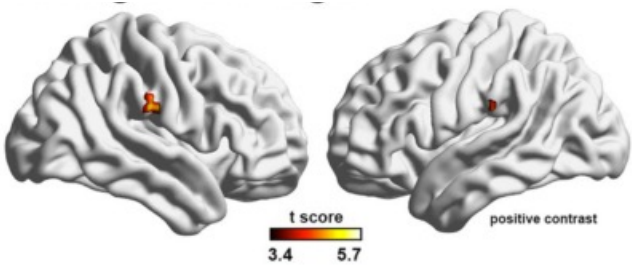
Extreme environment reduces anticorrelations

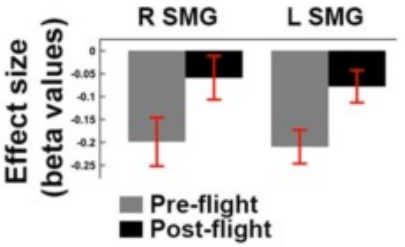






Post – Pre flight





Van Ombergen … and Demertzi, *Sci Reports* 2017
Demertzi et al, *Brain Str Funct* 2015