One hour in the Global Neuronal Workspace of an ASSC President

28th ANNUAL MEETING OF THE ASSC
6-9 JULY 2025 HERAKLION, CRETE

Lionel Naccache
Pitié-Salpêtrière Hospital, Sorbonne Université, ICM, INSERM, Paris, France
lionel.naccache@gmail.com

Disclosure of Conflict of Interest

Co-scientific founder and shareholder of Neurometers (2024)

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lionel naccache <lionel.naccache@gmail.com> lun. 22 janv. 2024 22:29

À assc1997.director

Dear Lucie,

Dear Members of ASSC Board of Directors: dear Ghislaine, Joseph, Elisabeth, Simon, Biyu, Jacobo, Claire, Megan, and Olivia,

I am sorry for my kind of emphatic response, but I'm (really) extremely glad of this election, and I will do my best to serve this role with (my conscious and my top-down driven unconscious) enthusiasm :).

Obviously, I more than agree to give the 1-hour talk in Crete (therefore in Greece, one of the original lands of consciousness studies, how lucky I am) in July 2025 (my calendar is now booked for these dates :)).

Even if I'm not a systematic participant of all ASSC annual meetings, my first ever participation to a scientific conference... was actually ASSC #2 in Bremen (extract of the program below*), during my PhD, and since then ASSC always kept a special flavor to me.

Thank you, and I send to each of you my best wishes for 2024 (and 2025 :))

Amitiés,

Lionel

* "CS 4: Unconscious Perception Holiday Inn Stockholm 2

14.00 ARMIN HEINECKE: Unconscious perception: priming of multiple features?

14.30 ULLIN T. PLACE: The neuroanatomy of consciousness and the zombie-within

15.00 LIONEL NACCACHE: Imaging unconscious semantic priming: A chronometric, ERP and fMRI study"

https://theassc.org/wp-content/uploads/2021/03/ASSC-2_Program3.pdf

Lionel

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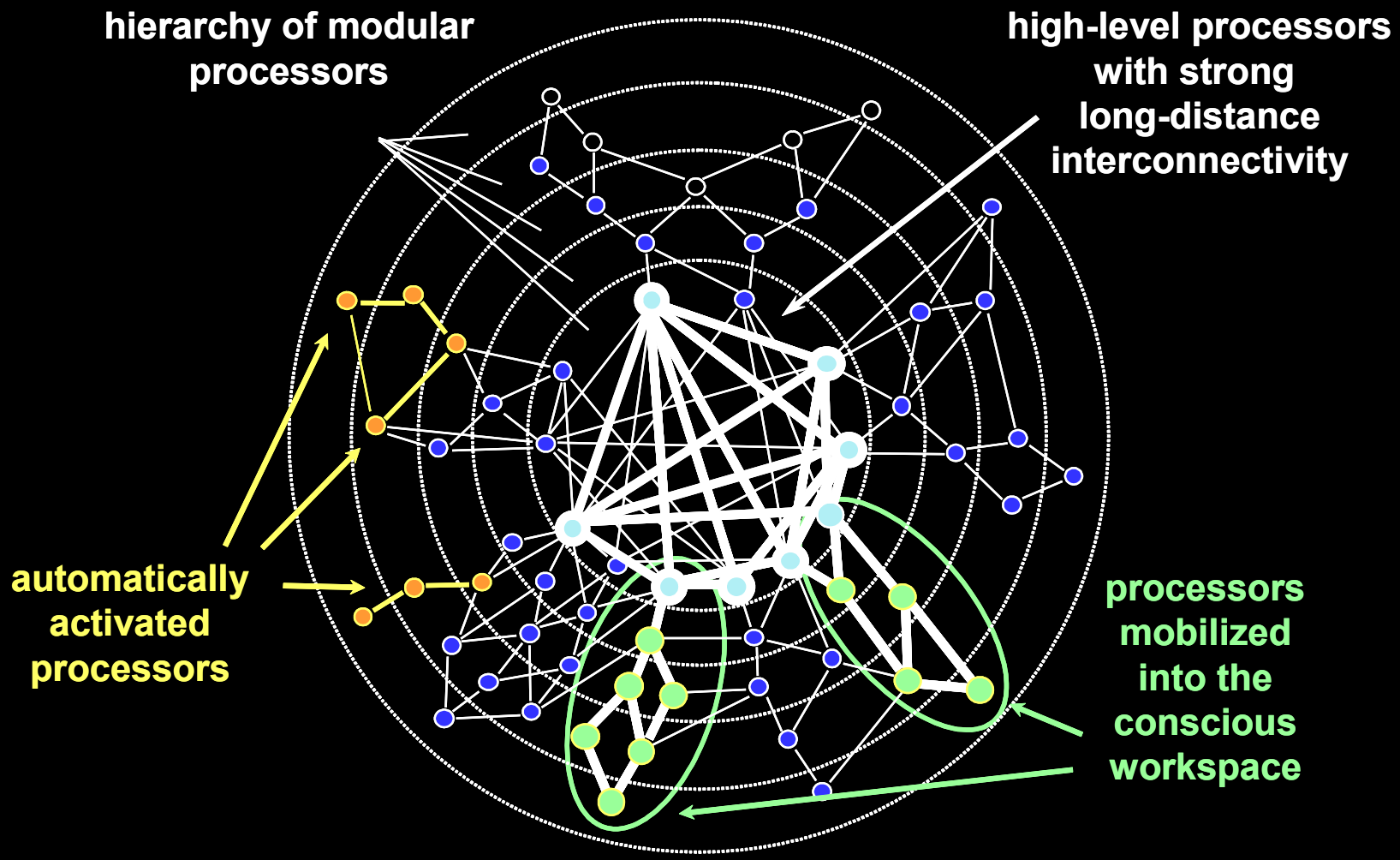
Global Neuronal Workspace

- ***Synthetic résumé of GNW framework***
- ***Questions/Ideas about conscious access***
- ***Questions/Ideas about conscious state***
  - ➔ *with a strong focus on disorders of consciousness*
- ***Questions/Ideas about conscious stream***

Global Neuronal Workspace

- ***Synthetic résumé of GNW framework***

A brief primer of *GNW* framework



Baars, 1989
Dehaene, Changeux, Naccache, Sackur, Sergent, TICS 2006
Dehaene, Changeux, Naccache, Springer 2011

Dehaene & Naccache, Cognition 2001
Dehaene & Changeux, Neuron 2011
Naccache, Philos. Trans. Roy. Soc. B 2018

A theory driven by cognitive psychology

- ***From psychology to the brain***

  ➔ **A definition:**

  Being conscious = being able to <u>self-report</u>

Baars, 1989
Dehaene, Changeux, Naccache, Sackur, Sergent, TICS 2006
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Dehaene & Naccache, Cognition 2001
Dehaene & Changeux, Neuron 2011
Naccache, Philos. Trans. Roy. Soc. B 2018

SELF-REPORT IS NOT A BEHAVIOR
BUT AN INTERNAL PROCESS

“I see X, I feel Y, I remember Z, I’m doing X …”
(not necessarily verbal)

A theory driven by cognitive psychology

- ***From psychology to the brain***

➔ **A definition:**

Being conscious = being able to self-report

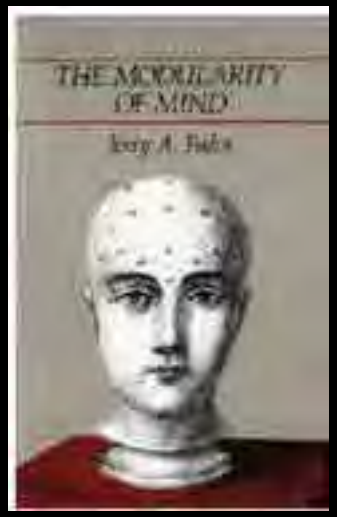
➔ **Conscious state & Conscious content**

➔ **Cognitive properties** of consciously accessed representations such as:

. **Cognitive availability**
. Explicit durable maintenance of information
. Cognitive flexibility and novel operations
. Transfer to long term episodic memory
. Strategic cognitive control

Baars, 1989
Dehaene, Changeux, Naccache, Sackur, Sergent, TICS 2006
Dehaene, Changeux, Naccache, Springer 2011

Dehaene & Naccache, Cognition 2001
Dehaene & Changeux, Neuron 2011
Naccache, Philos. Trans. Roy. Soc. B 2018



From psychology to the brain

Psychology

- **Modularity** of many unconscious cognitive processes

- **Non modularity** of conscious cognition

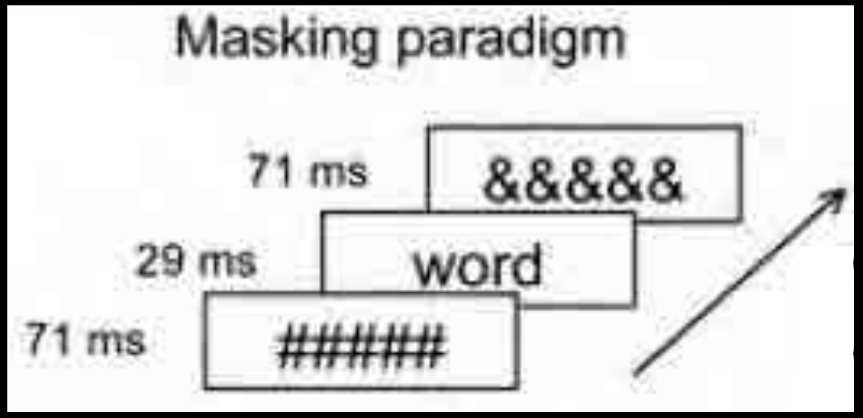
Brain function

- **Neural modularity** of many unconscious cognitive processes

- **Neural non modularity** of conscious cognition

Fodor, 1983
Baars, 1989
Dehaene & Naccache, Cognition 2001

An illustration



Psychology

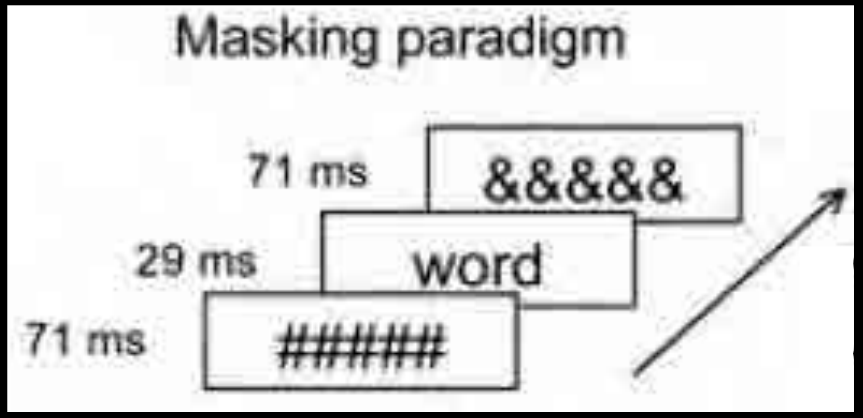
- **Unconscious:**
transient activation of word attributes inaccessible to report, to strategic processing, to episodic memory, to novel operations and to other cognitive domains

Brain function

- **Unconscious:**
transient activation of VWFA region inaccessible to high-level fronto-parietal networks

Dehaene, Naccache et al., Nature Neurosc. 2001

An illustration



Psychology

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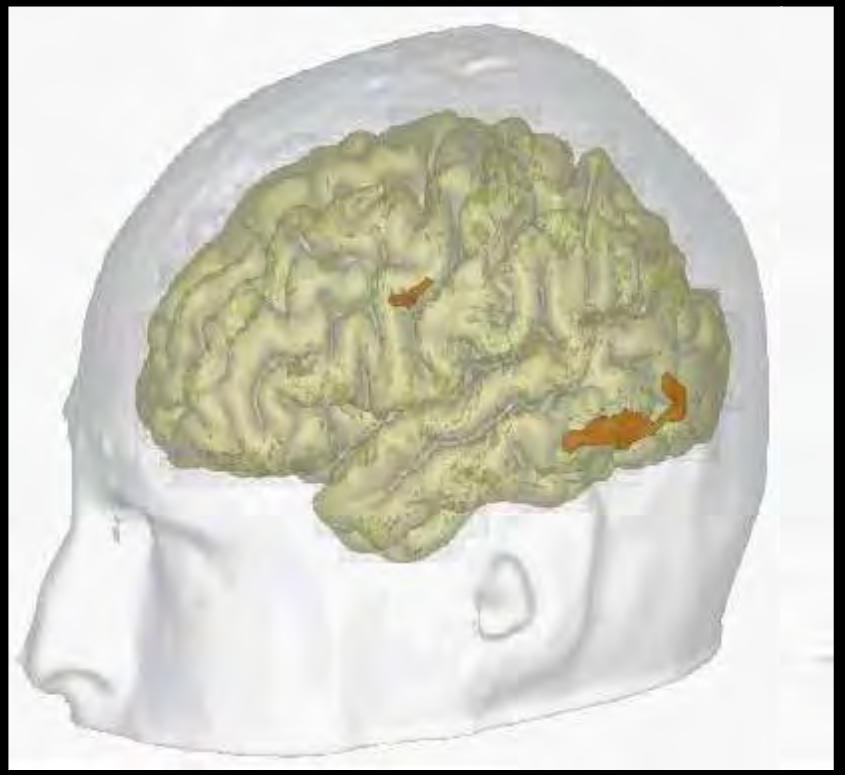
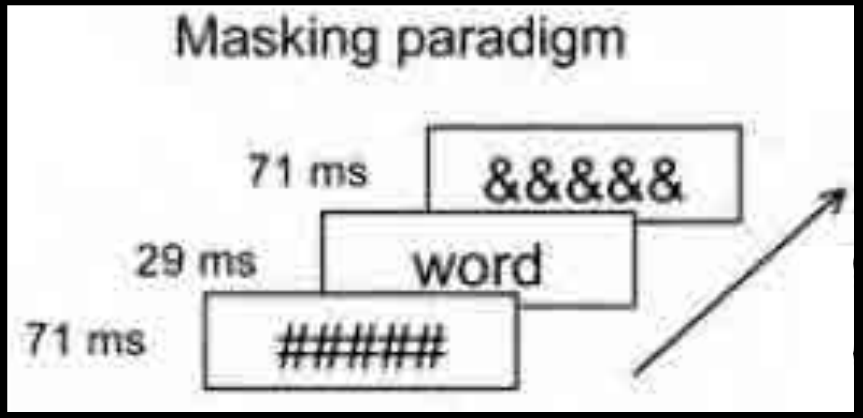
Brain function



Dehaene, Naccache et al., Nature Neurosc. 2001

An illustration



Psychology

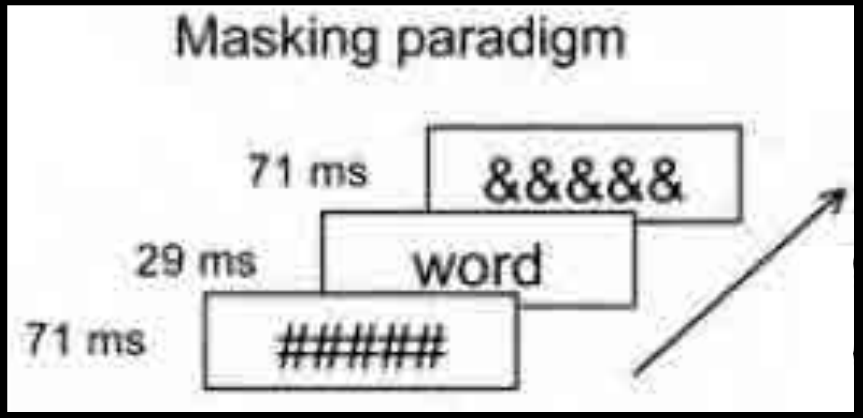
- **Conscious:** durable activation of word attributes accessible to report, to strategic processing, to episodic memory, to novel operations and to other cognitive domains

Brain function

- **Conscious:** durable activation of VWFA region accessible to high-level fronto-parietal networks that subtends all these functions

Dehaene, Naccache et al., Nature Neurosc. 2001

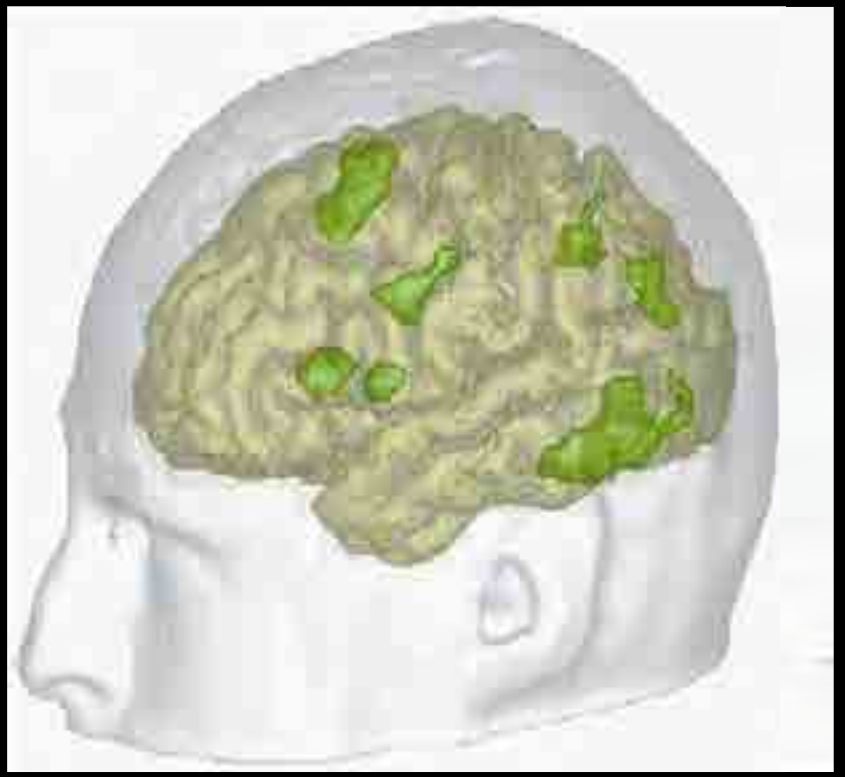
An illustration



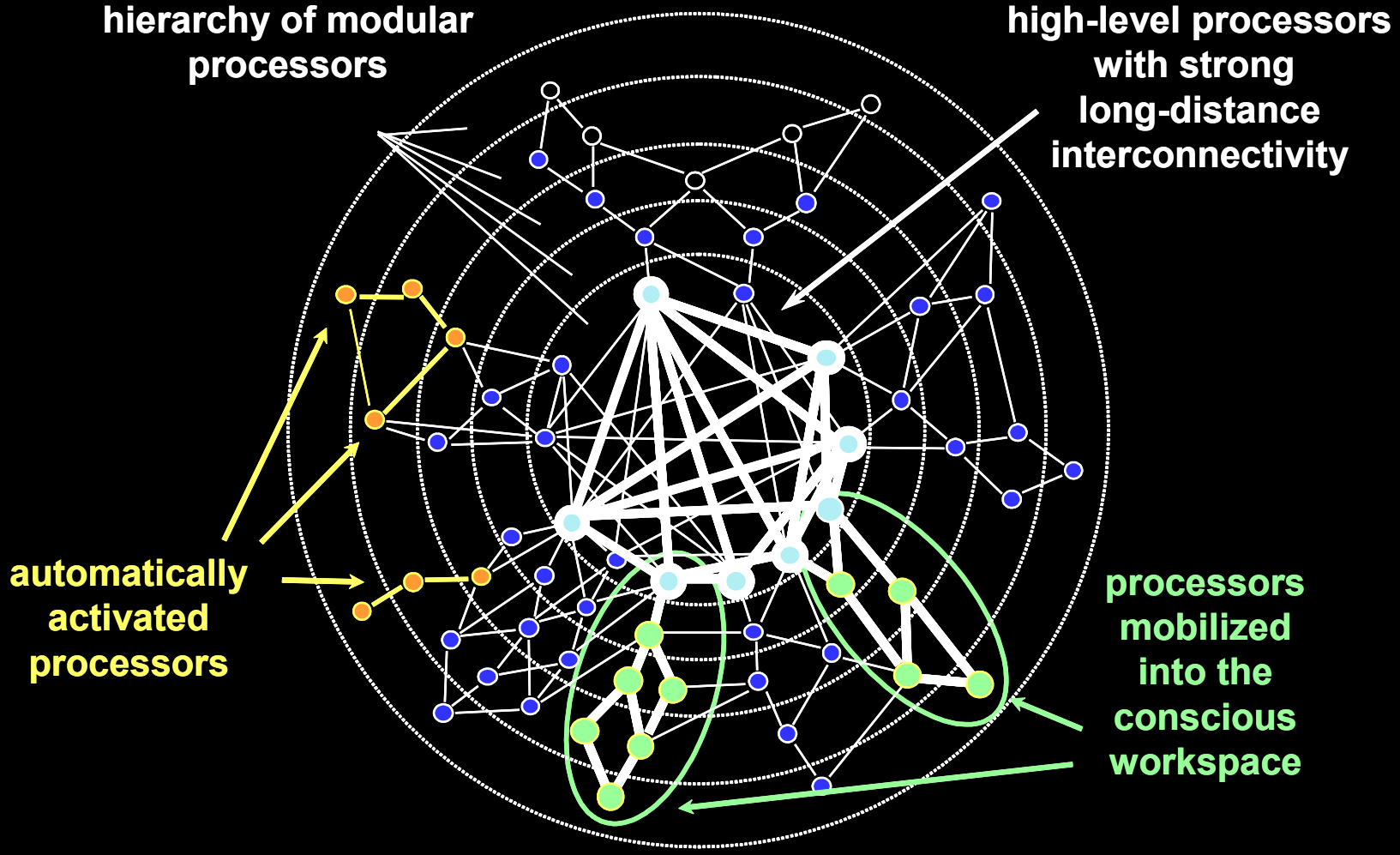
Psychology

- **Conscious:** durable activation of word attributes accessible to report, to strategic processing, to episodic memory, to novel operations and to other cognitive domains

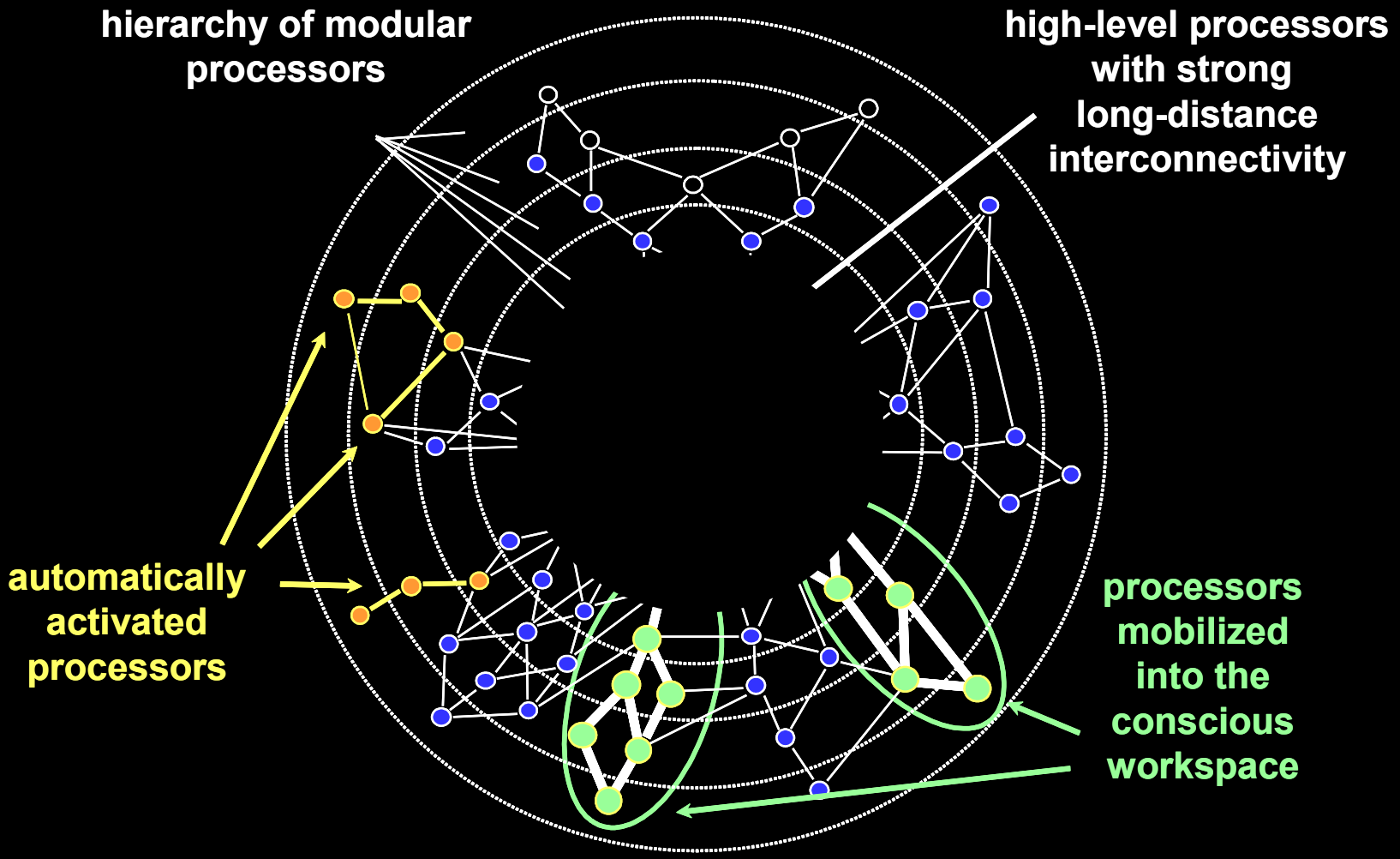
Brain function



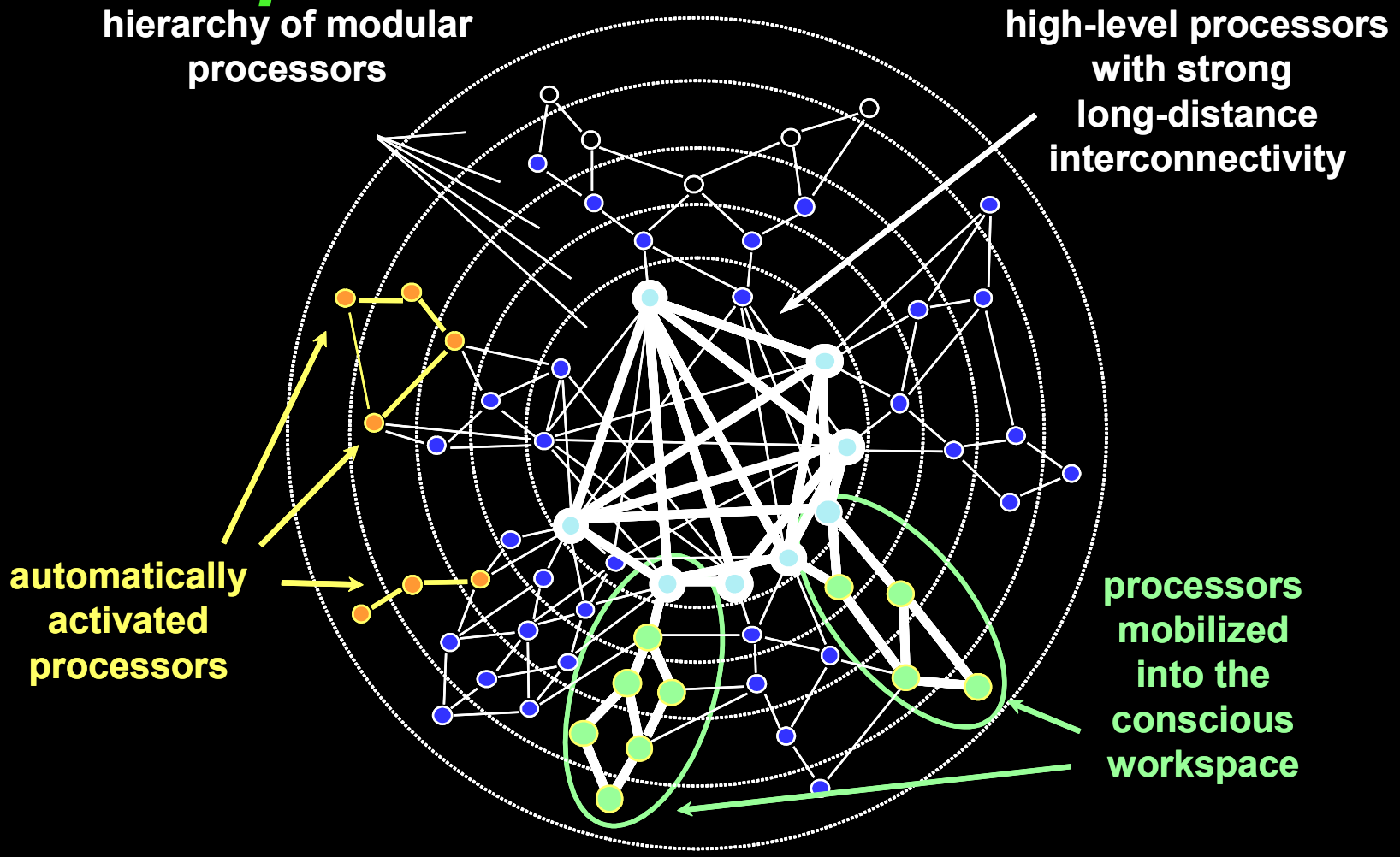
Dehaene, Naccache et al., Nature Neurosc. 2001


hierarchy of modular processors
high-level processors with strong long-distance interconnectivity
automatically activated processors
processors mobilized into the conscious workspace

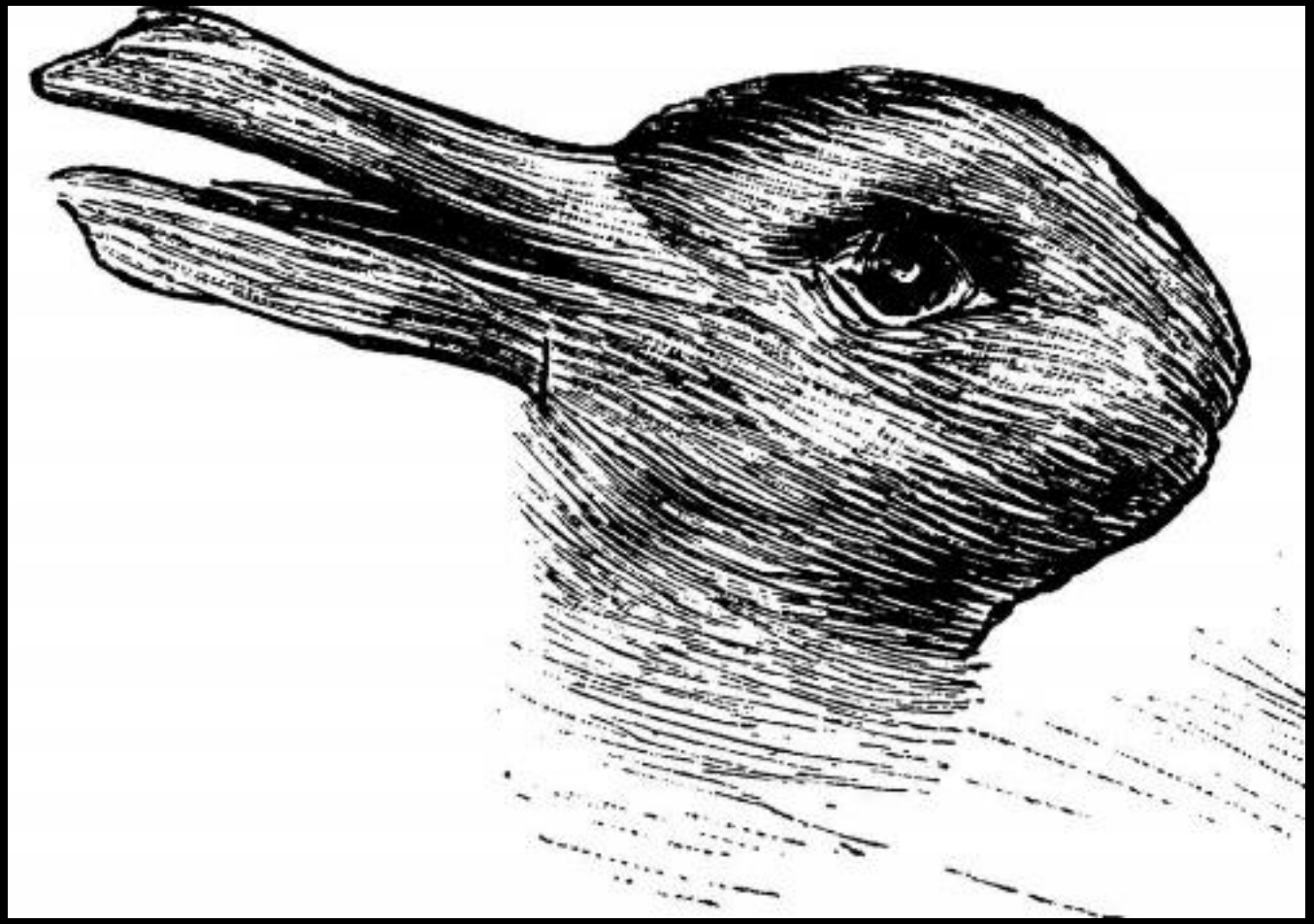
Unconscious modular cognition would operate in a modular neural space



Conscious non modular cognition would operate in a non-modular neural space that is… the GNW

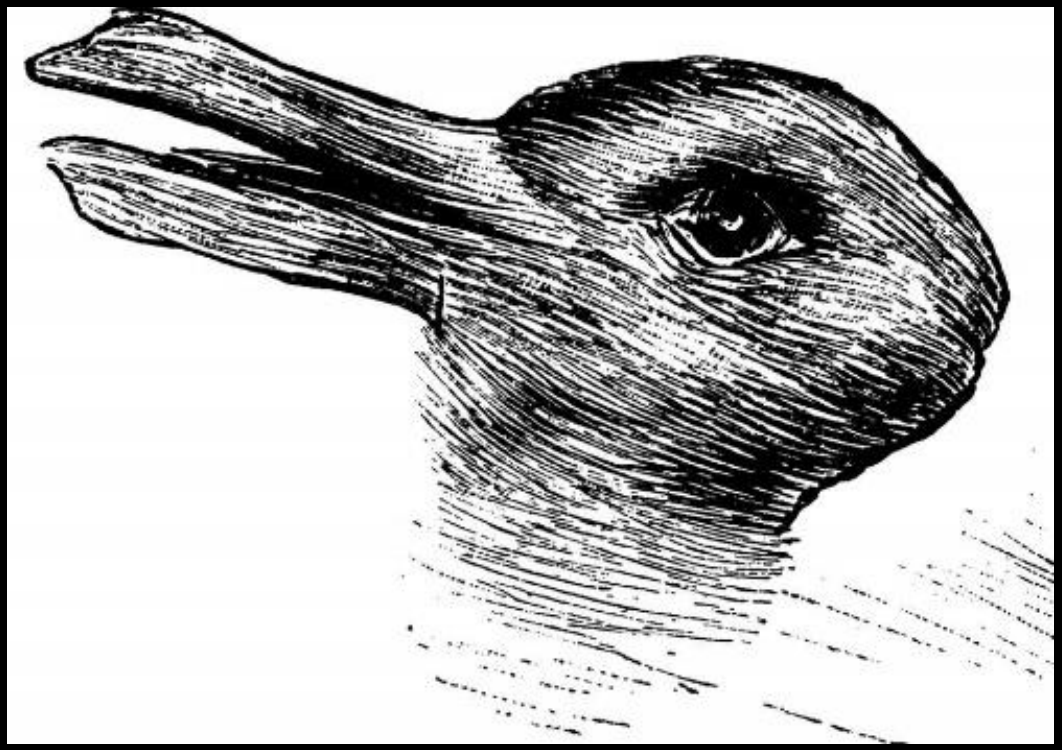


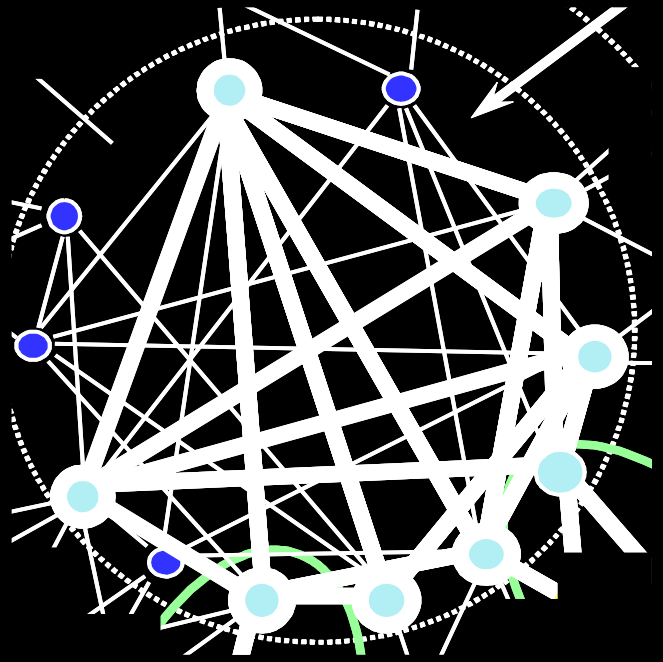
At any moment, a single complex representation occupies our conscious mind



”We have only one thought of the same thing at the same time” *Descartes (Passions of the soul, 1649)*

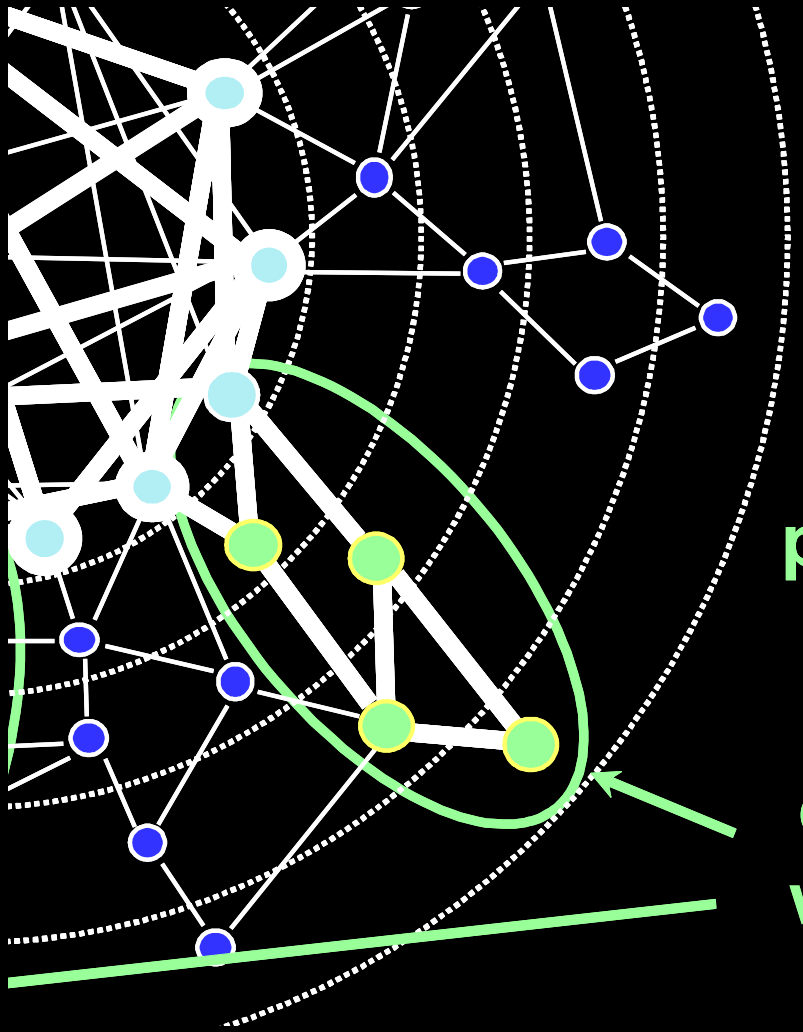
At any moment, a single complex representation occupies our **GNW !**





"We have only one thought of the same thing at the same time" *Descartes (Passions of the soul, 1649)*

The mechanism of conscious access: Top-down amplification and *all-or-none* ignition

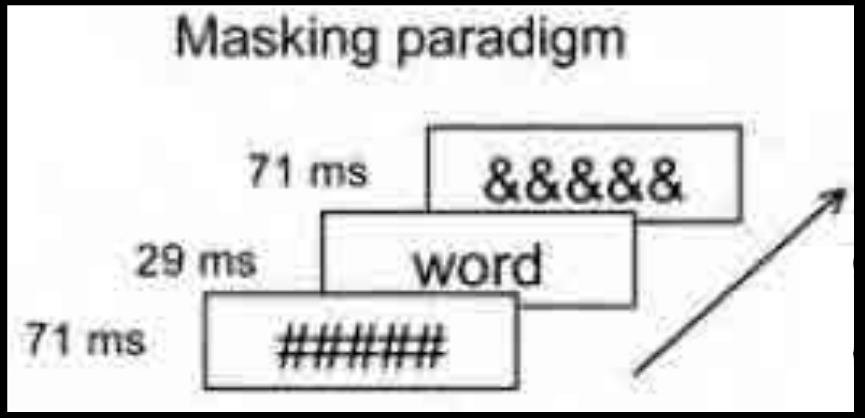


➔ Dynamic 'fuzzy' frontiers of GNW according to 'mobilized processors'

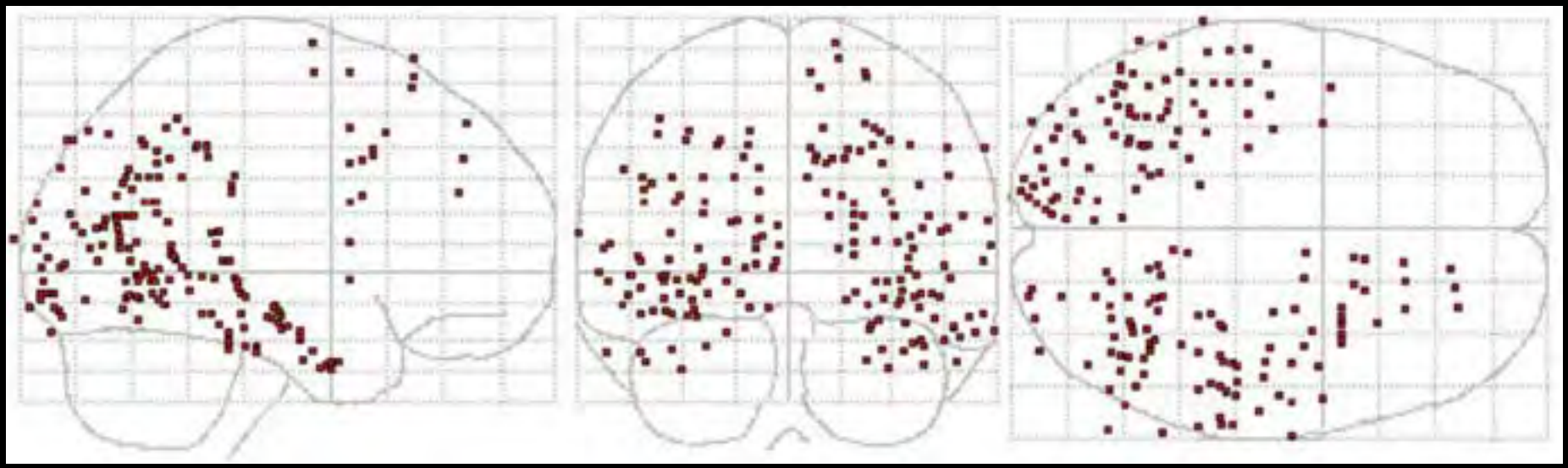
processors mobilized into the conscious workspace

Dehaene & Naccache, Cognition 2001

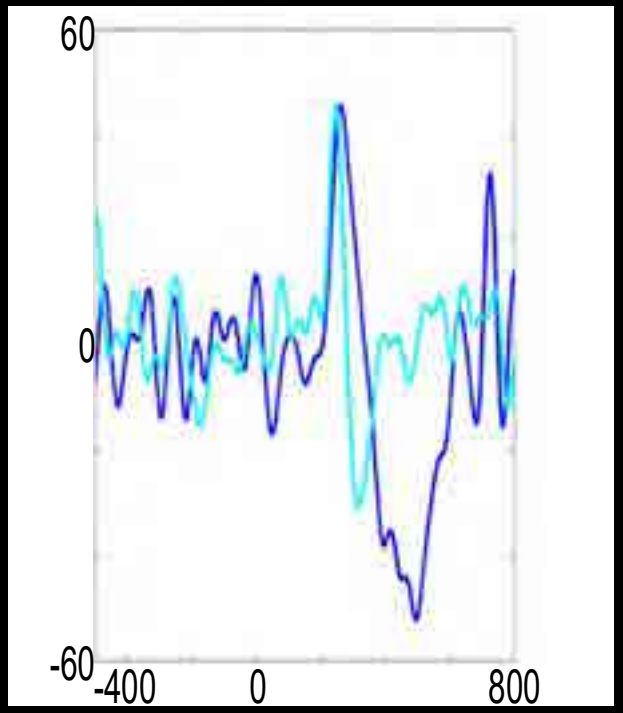
An illustration

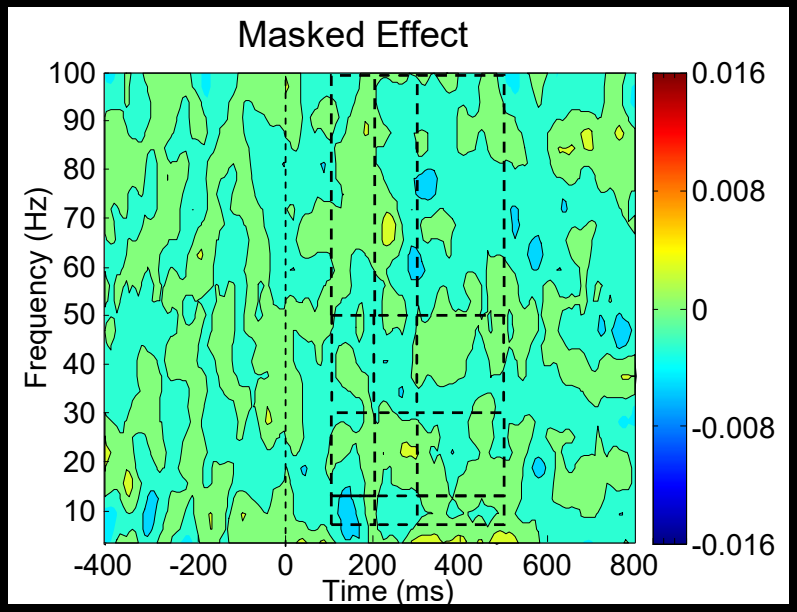


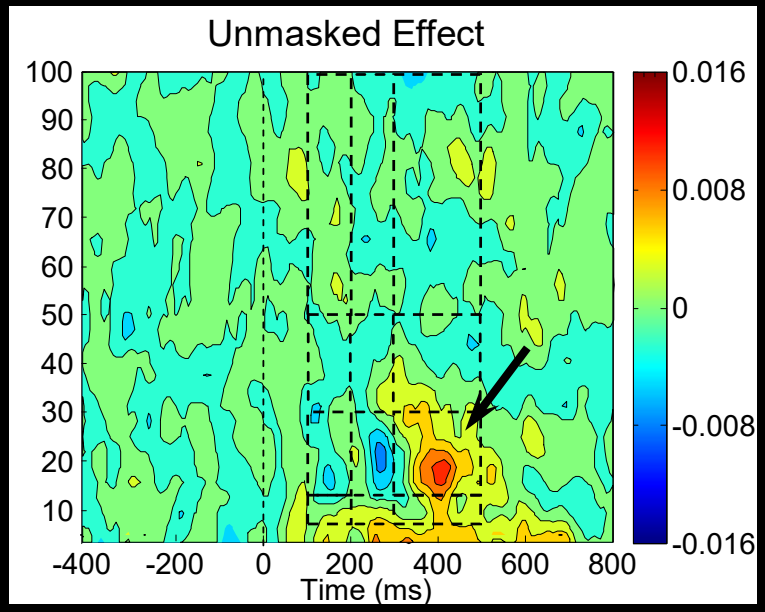
Cognitive availability of representations occurs when neural availability does



Gaillard, … & Naccache PLoS Biology, 2009
El Karoui,… & Naccache Cerebral Cortex, 2014

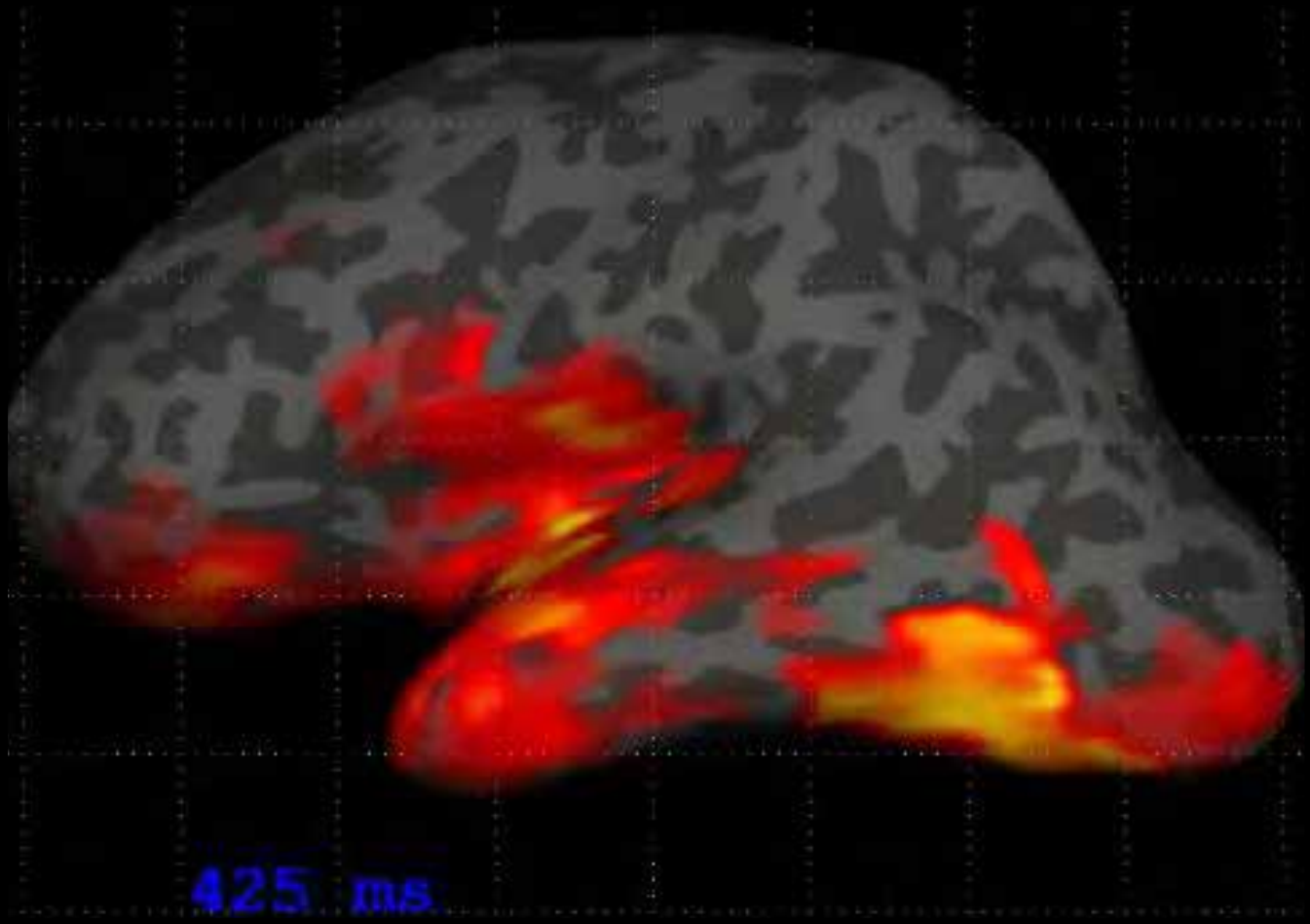






Gaillard, … & Naccache PLoS Biology, 2009

Late, sustained & brain-scale activation as a signature of GNW conscious access



Marinkovic et al., Neuron 2003

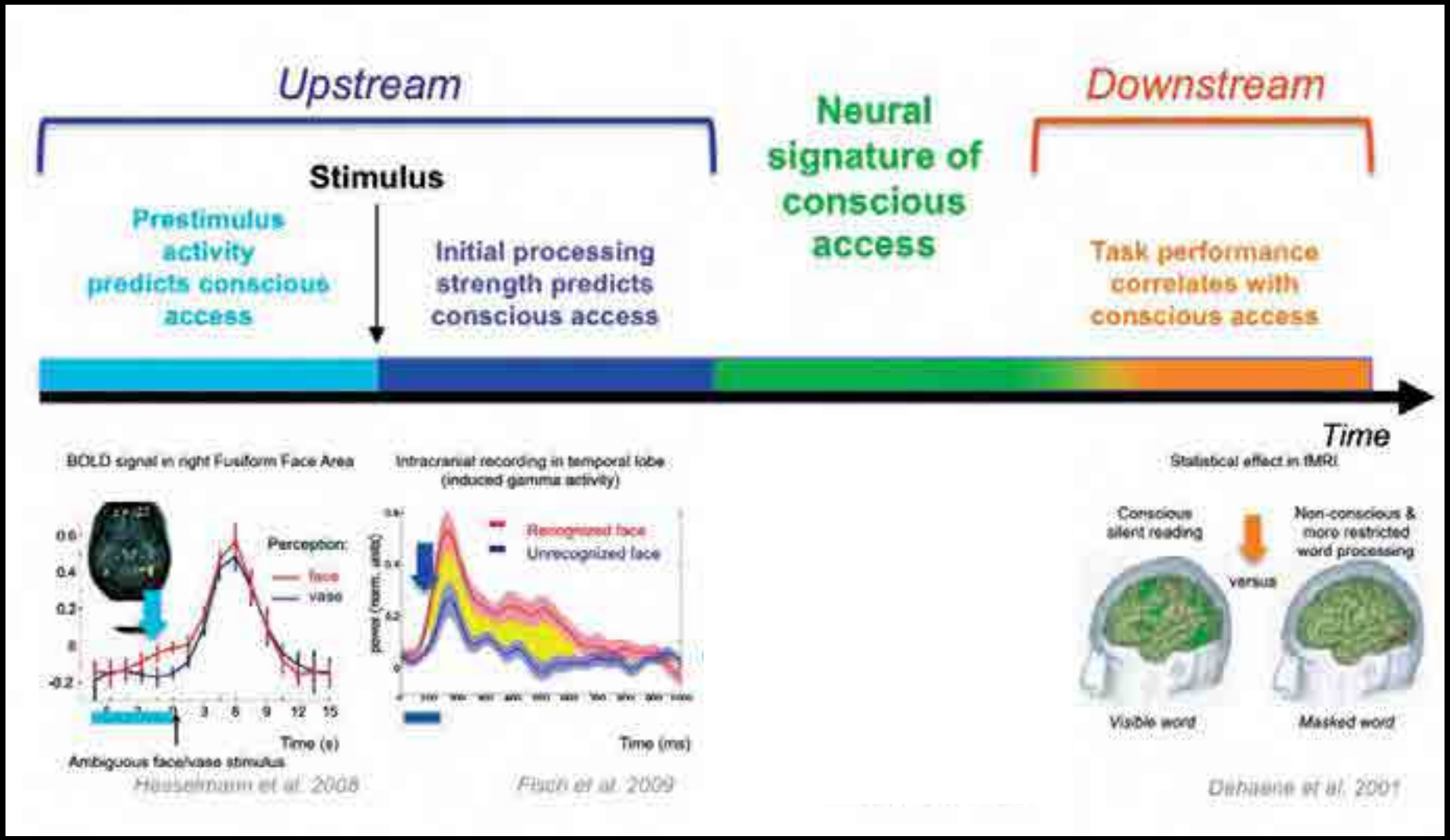
Global Neuronal Workspace

- *Synthetic résumé of GNW framework*
- *Questions/Ideas about conscious access*

<u>Question :</u> ***What is (are) the neural signature(s) of conscious access ?***

➔ **GNWT : Conscious access as a late event associated with neural access to GNW**

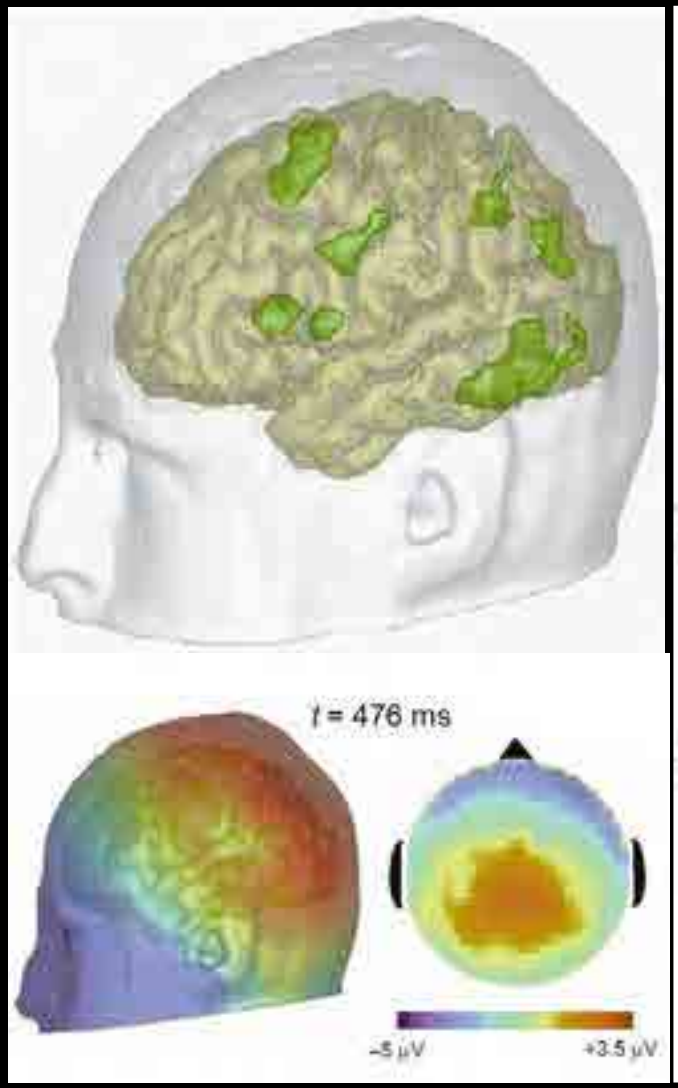
➔ About the difficult 'non-hard' problem of Conscious Access …

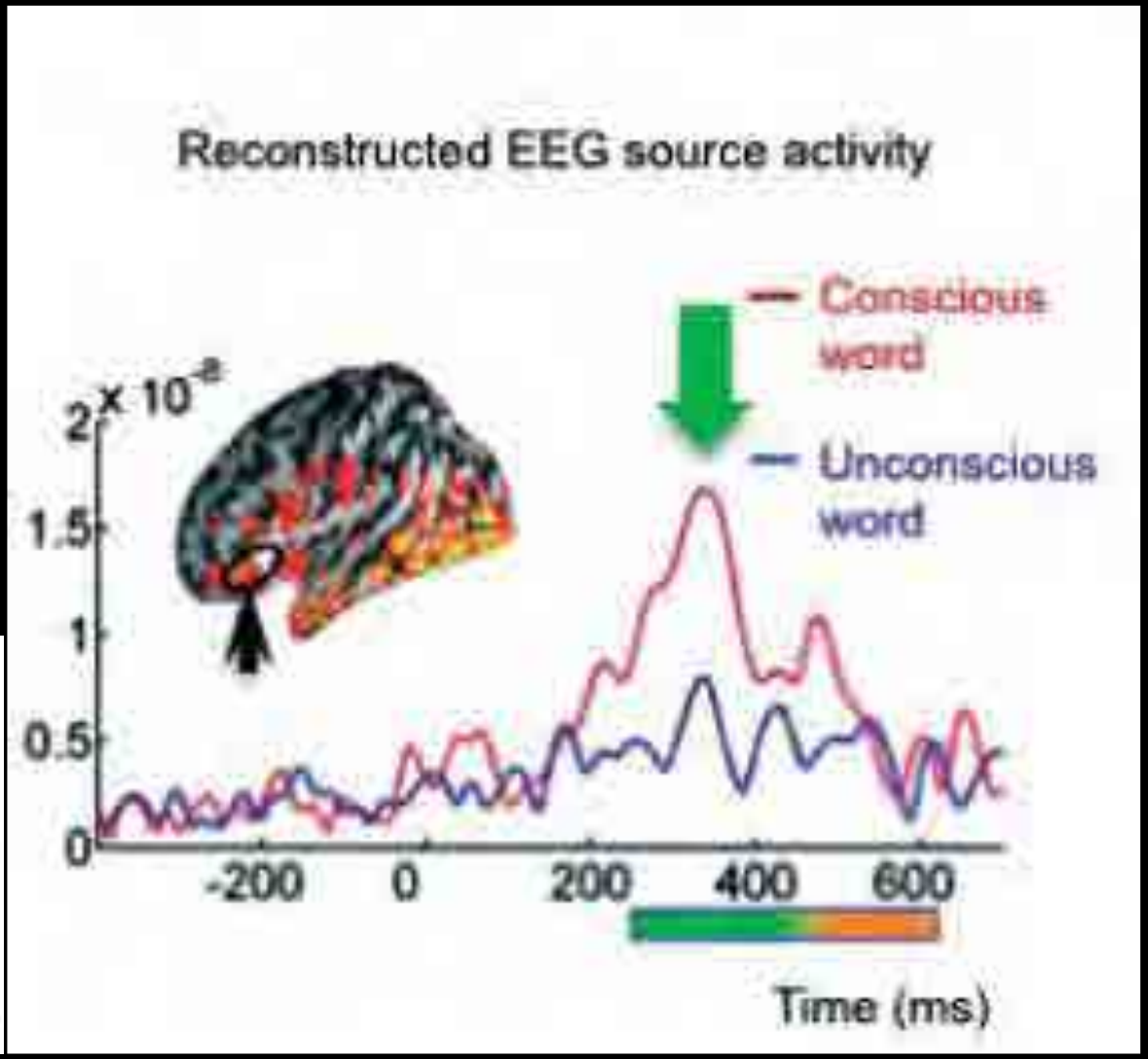


Sergent & Naccache, Arch. Ital. Biol. 2012

Aru, Bachmann, Singer & Melloni, Neurosc. & Bhv Rev. 2012

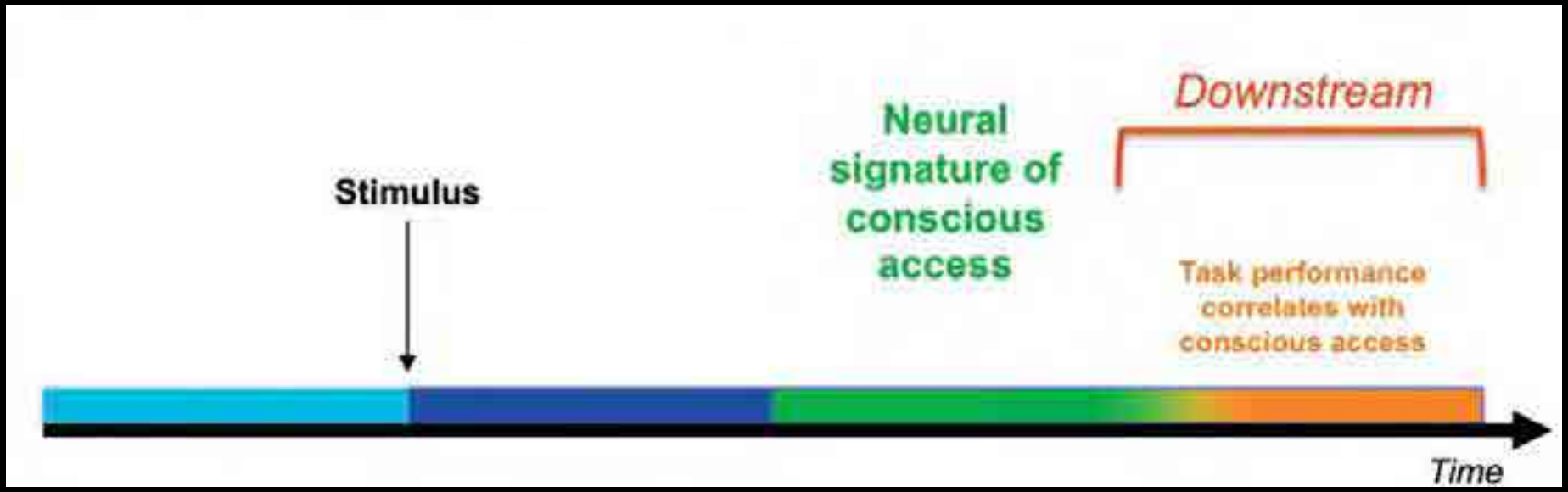
Act I : Conscious access = late global event





Dehaene, Naccache, Cohen et al., Nature Neuroscience 2001
Sergent, Baillet, Dehaene Nature Neuroscience 2005

Act II : Conscious access … or post-perceptual processing ?



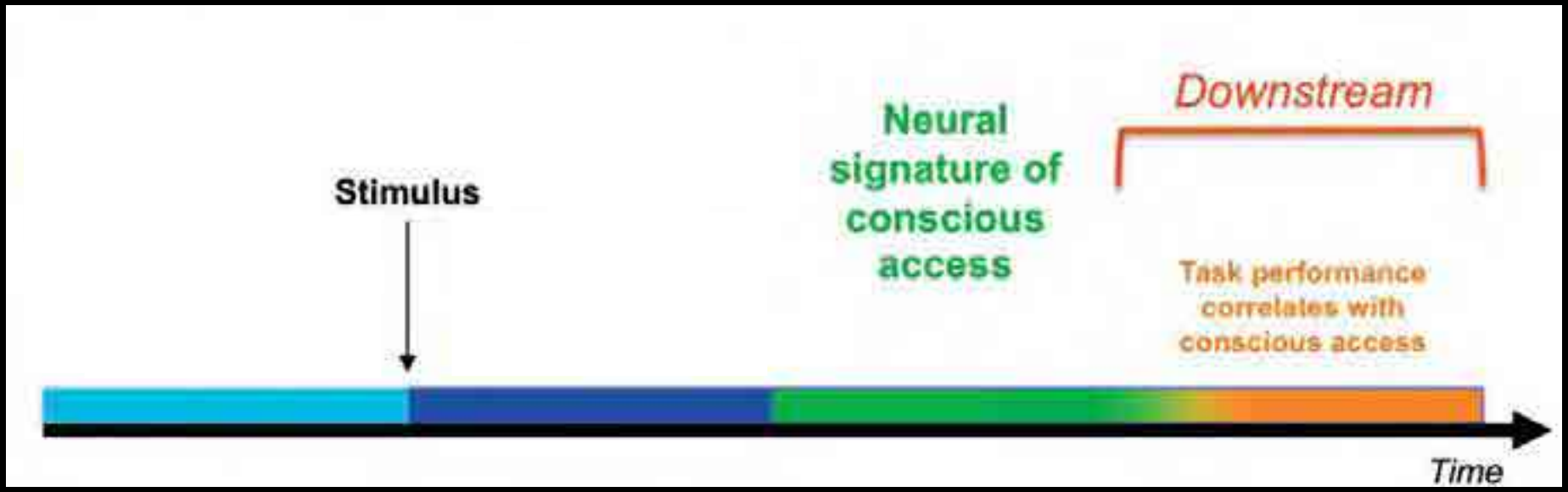
➔ Relevance of '*No-Report*' paradigms

‘NO-REPORT’ = NO BEHAVIORAL REPORT

BUT

‘NO-REPORT’ ≠ ABSENCE OF SELF-REPORT

Act II : Conscious access … or post-perceptual processing ?

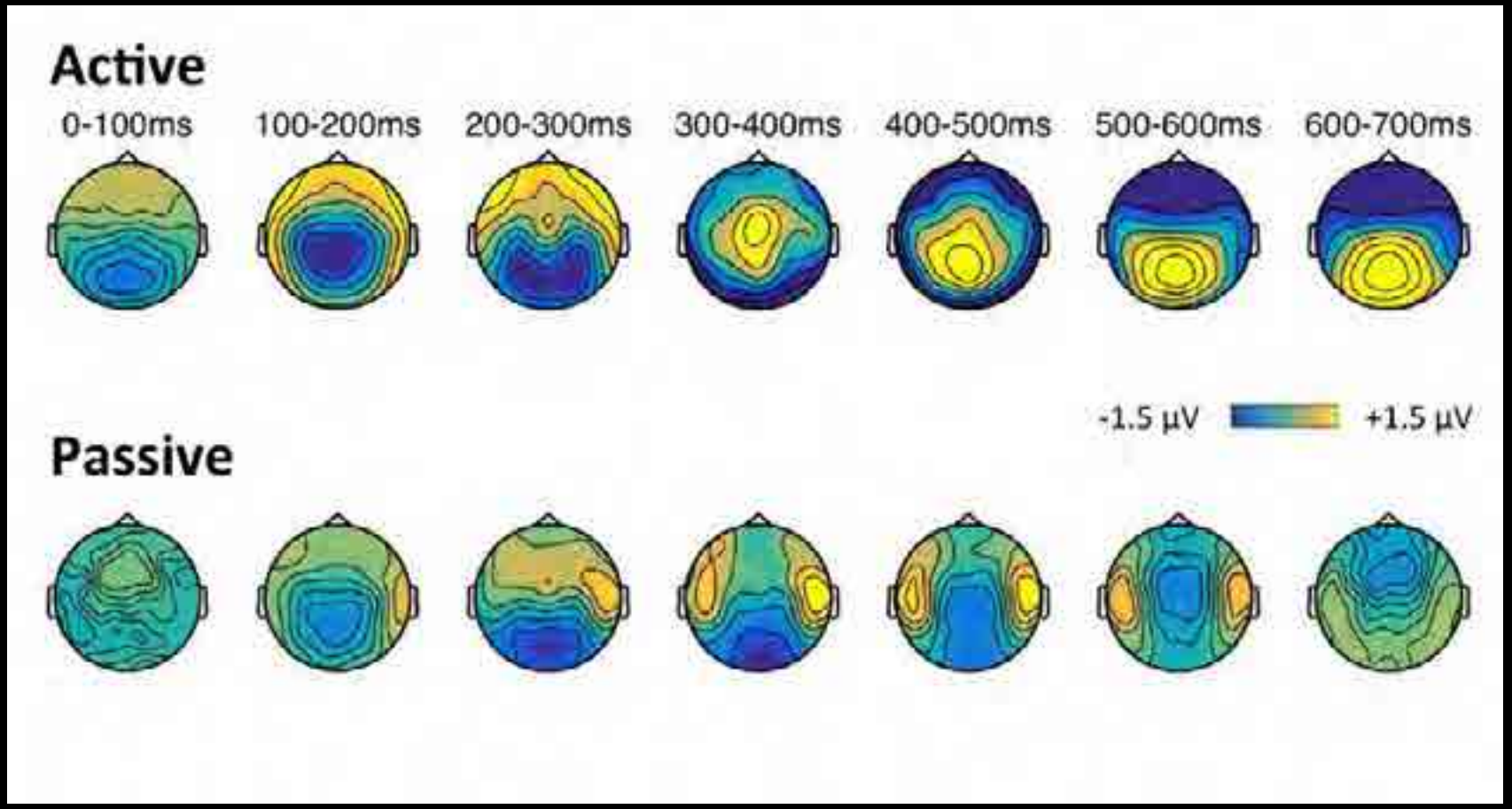


➔ Relevance of '*No-Report*' paradigms

➔ <u>But</u> assuming that stimuli are consciously accessed

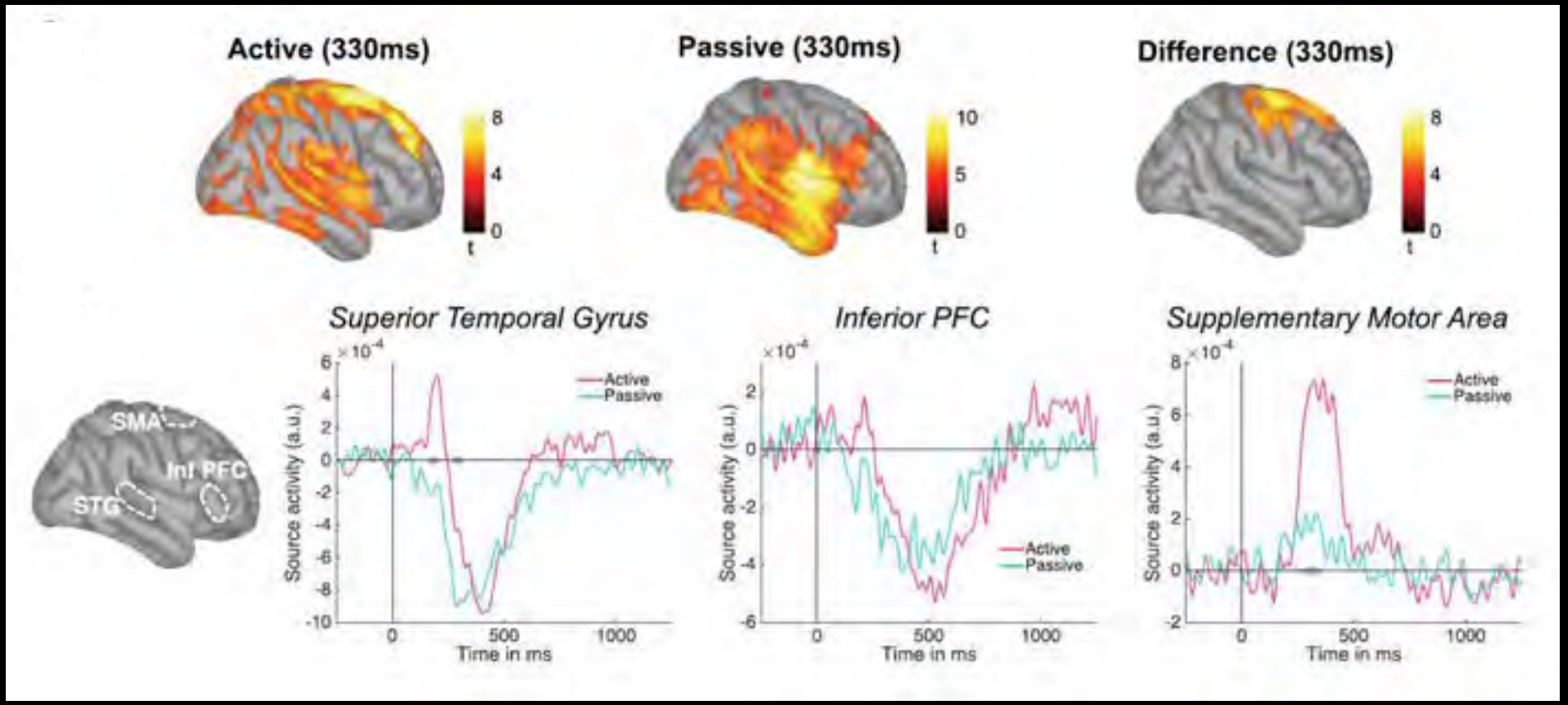
➔ <u>But</u> residual uncontrolled post-processing ?

Act III : GNW activated during 'No Report No explicit task' condition



Sergent et al. Nat. Comm. 2021
see also: Cohen, … Pitts Cer. Cortex 2024

Act III : GNW activated during 'No Report No explicit task' condition except for response preparation & execution network (bhv report)



Sergent et al. Nat. Comm. 2021
see also: Cohen, … Pitts Cer. Cortex 2024

Question : ***Should we discard P3b as ERP signature of conscious access ?***

⇒ Not a systematic signature of consc. access

BUT …

Conscious access is not a passive broadcasting within GNW, but rather an active dynamic process the result of which may vary according to the current conscious posture ***(≡GNW configuration)***

Naccache Cortex 2016
Naccache Proc. Roy. Soc. B 2018
Naccache *in press* 2025

Question : ***Should we discard P3b as ERP signature of conscious access ?***

⇒ Not a systematic signature of consc. access

BUT …

Beware the '*hunt for post-perceptual processing*' **:**
idealized vision of conscious access as a purely passive access to a still representation uncontaminated by 'post-perceptual processing'.
Example : from '*No report*' to '*No cognition*' paradigms (Block, 2019)

Question : ***Should we discard P3b as ERP signature of conscious access ?***

⇒ Not a systematic signature of consc. access

BUT …

Beware the '*hunt for post-perceptual processing*' **:**
idealized vision of conscious access as a purely passive access to a still representation uncontaminated by 'post-perceptual processing'.
Example : from '*No report*' to '*No cognition*' paradigms (Block, 2019)

➔ risk of throwing out the baby (conscious experience) with the bathwater (post-perceptual processing).

Conscious access IS “post-perceptual”

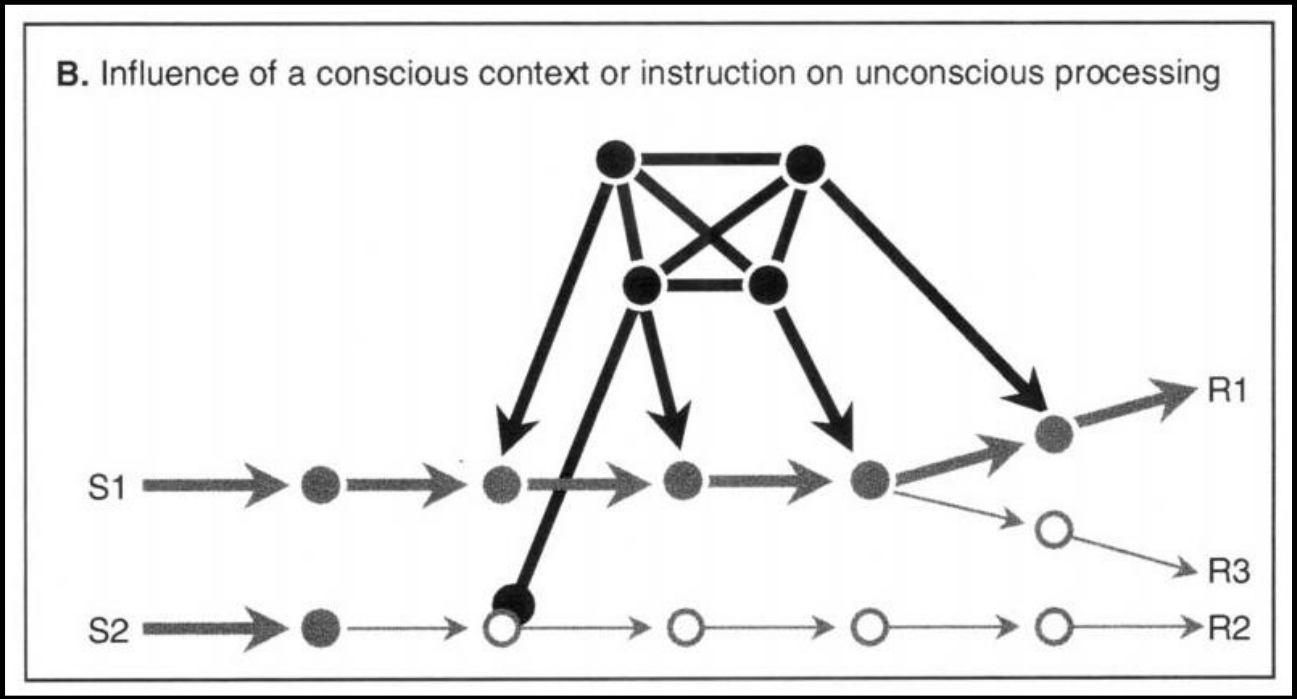
⇒ second stage of processing

⇒ active interpretative process

⇒ dynamic process : ‘perceptual palimpsest’ (not a still state)

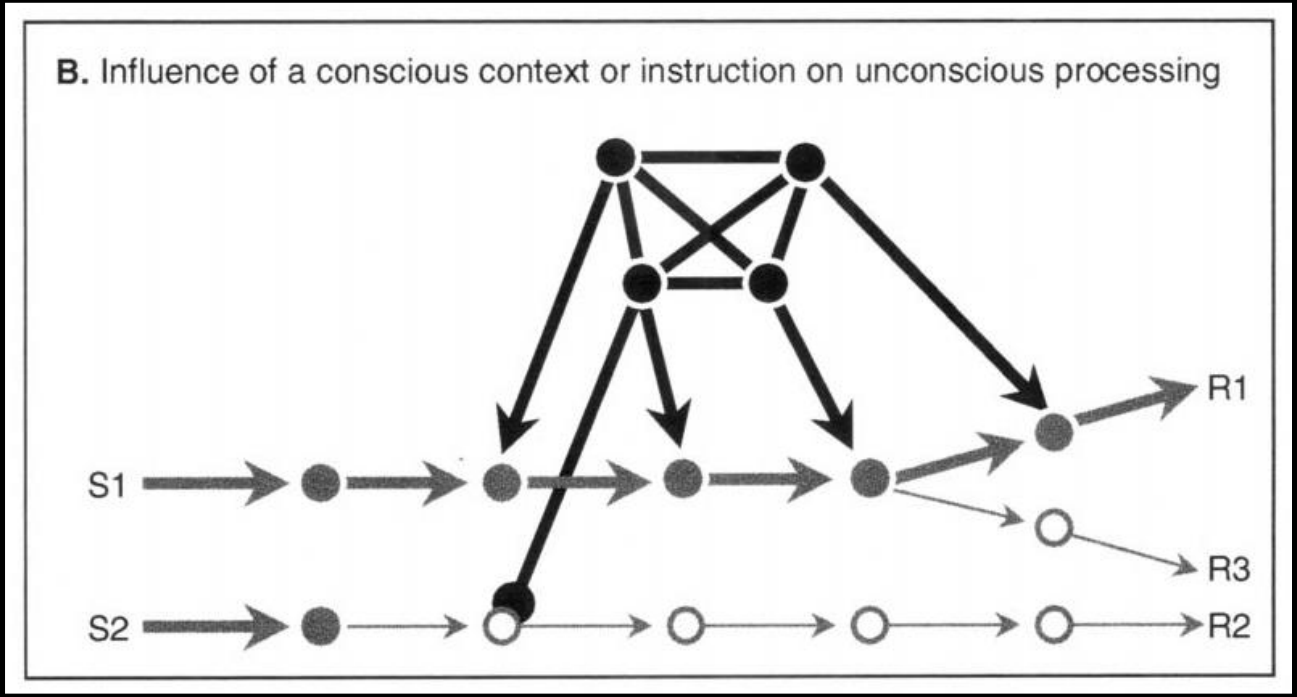
⇒ strong influences of the current conscious posture on unconscious representations to be accessed (or not)

Importance of conscious influences on unconscious cognitive processing:



Dehaene & Naccache, Cognition 2001
Naccache et al., Psychological Science 2002
Rohaut, … & Naccache, Neurosc. Consc. 2016

Importance of conscious influences on unconscious cognitive processing:



➔ *Revision of ucs 'automaticity'*

Dehaene & Naccache, Cognition 2001
Naccache et al., Psychological Science 2002
Rohaut, … & Naccache, Neurosc. Consc. 2016

Question : ***Should we discard P3b as ERP signature of conscious access ?***

⇒ Not a systematic signature of consc. access

⇒ Late GNW negativity as ‘primary report’ ERP signature (≡neural access to GNW without explicit self-report) ?

⇒ P3b as a ‘meta-report’ C.A. (≡neural access to GNW in an explicit self-report posture) ?

Naccache Cortex 2016
Naccache Proc. Roy. Soc. B 2018
Naccache *in press* 2025

Clarifying a GNW ambiguity :

⇒ ***Self-Reported vs Self-Reportable stimulus***

⇒ 'Primary-report' = GNW access without explicit self-reporting posture

⇒ .Clearly different from unconscious processing (no GNW access and no self-reportability)

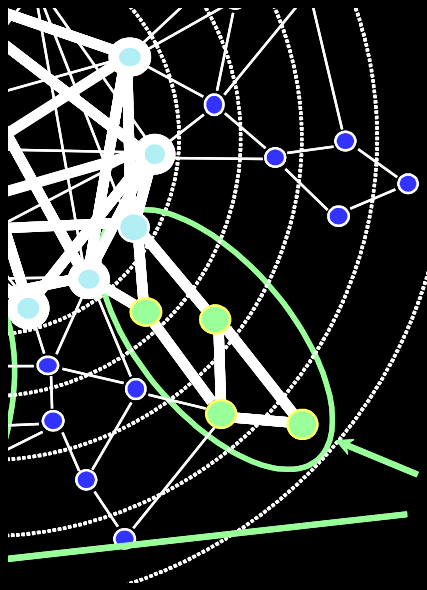
⇒ .Revisiting the overflow argument with no risk of 'panpsychism'/'pan-consciousness'

⇒ 'Meta-report'= GNW access under explicit self-reporting posture (not necessarily preceded by a primary report)

⇒ H.O.T. as Meta-reports subset of GNW contents

Naccache Proc. Roy. Soc. B 2018
Naccache *in press* 2025

Illustrating the active nature of conscious access by its absence : the case of hypnotic deafness

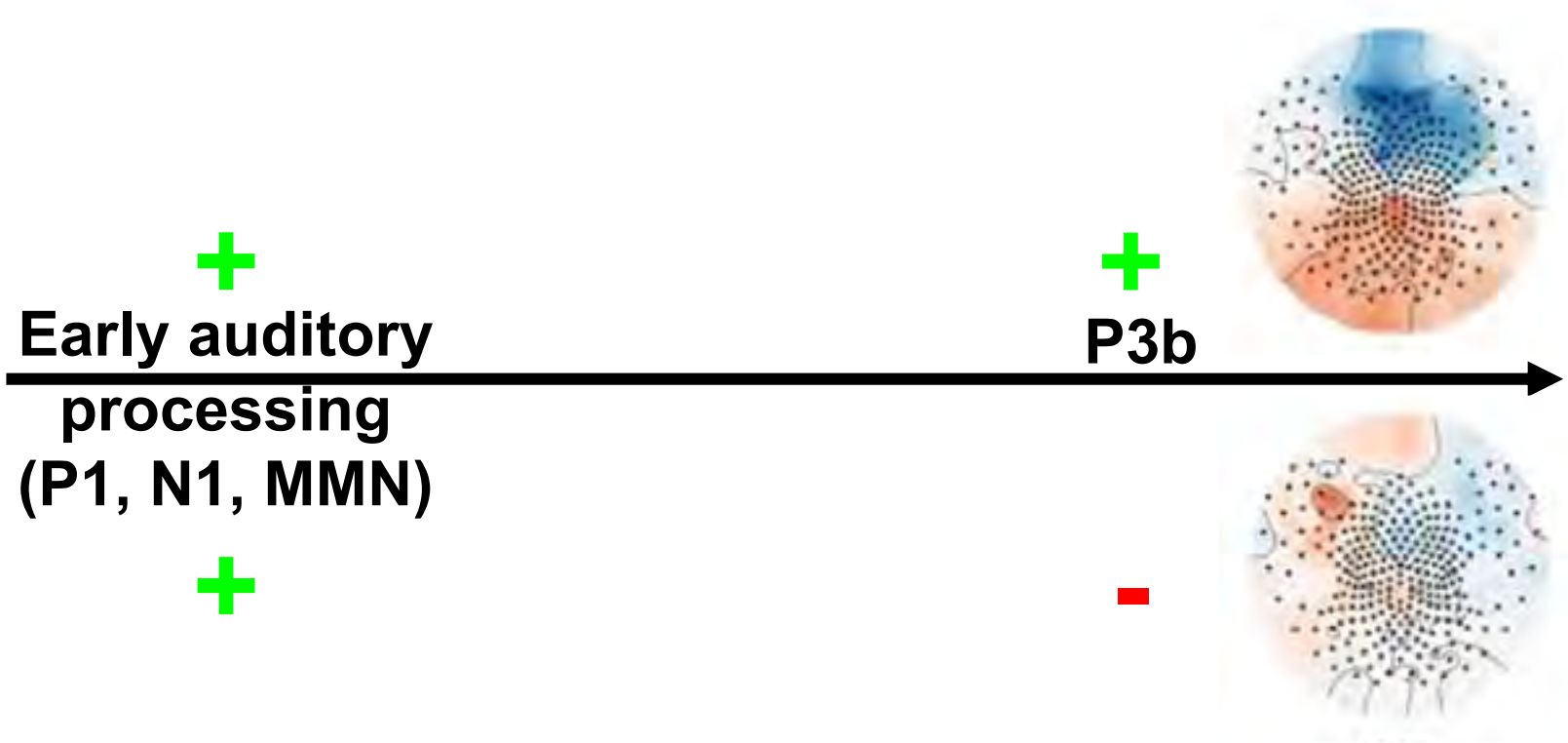


processors mobilized into the conscious workspace

Dehaene & Naccache, Cognition 2001

Munoz-Musat, … & Naccache, Front. Neurosc. 2022

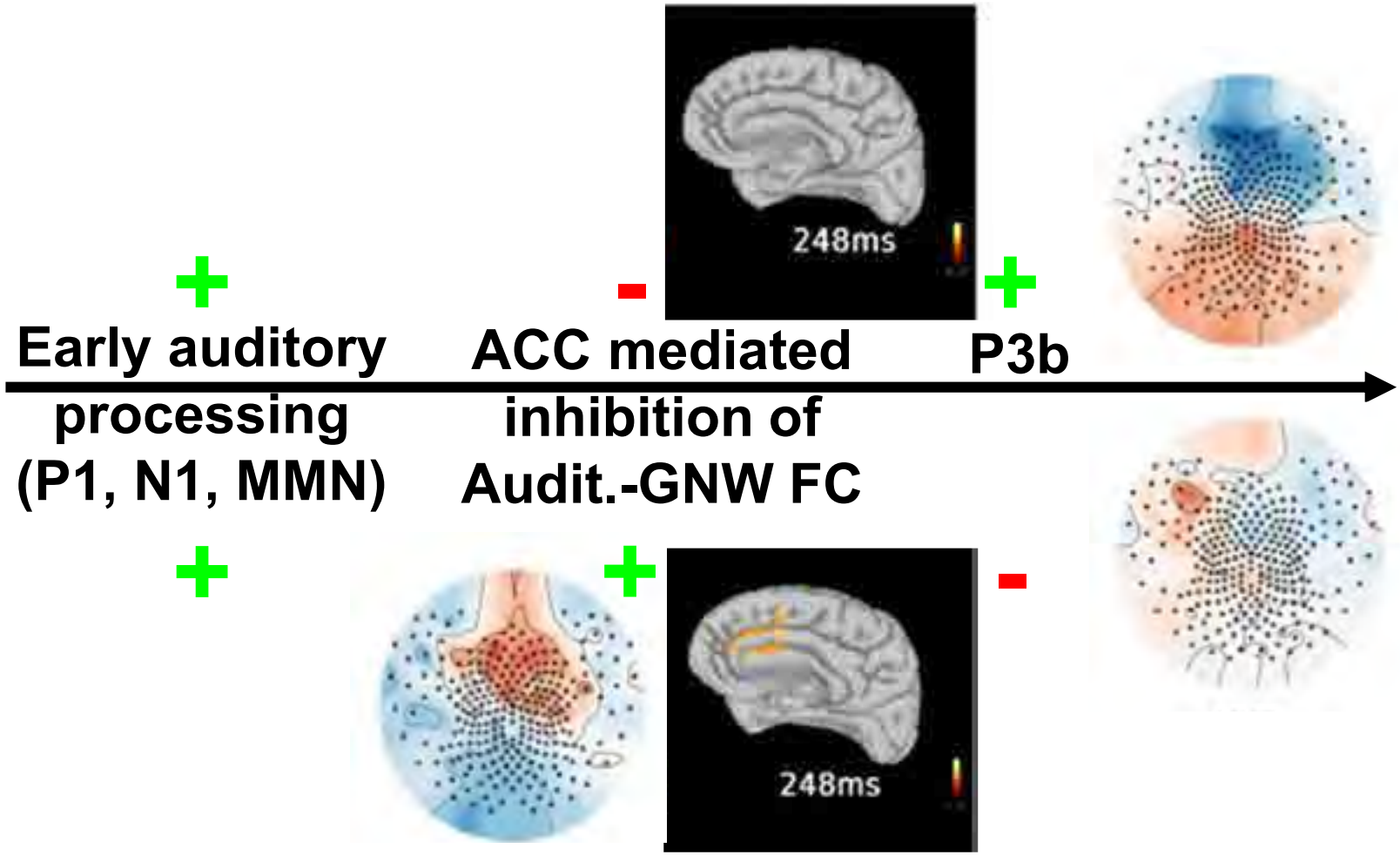
In the absence of hypnotic deafness



During hypnotic deafness

Munoz-Musat, … & Naccache, Front. Neurosc. 2022

In the absence of hypnotic deafness

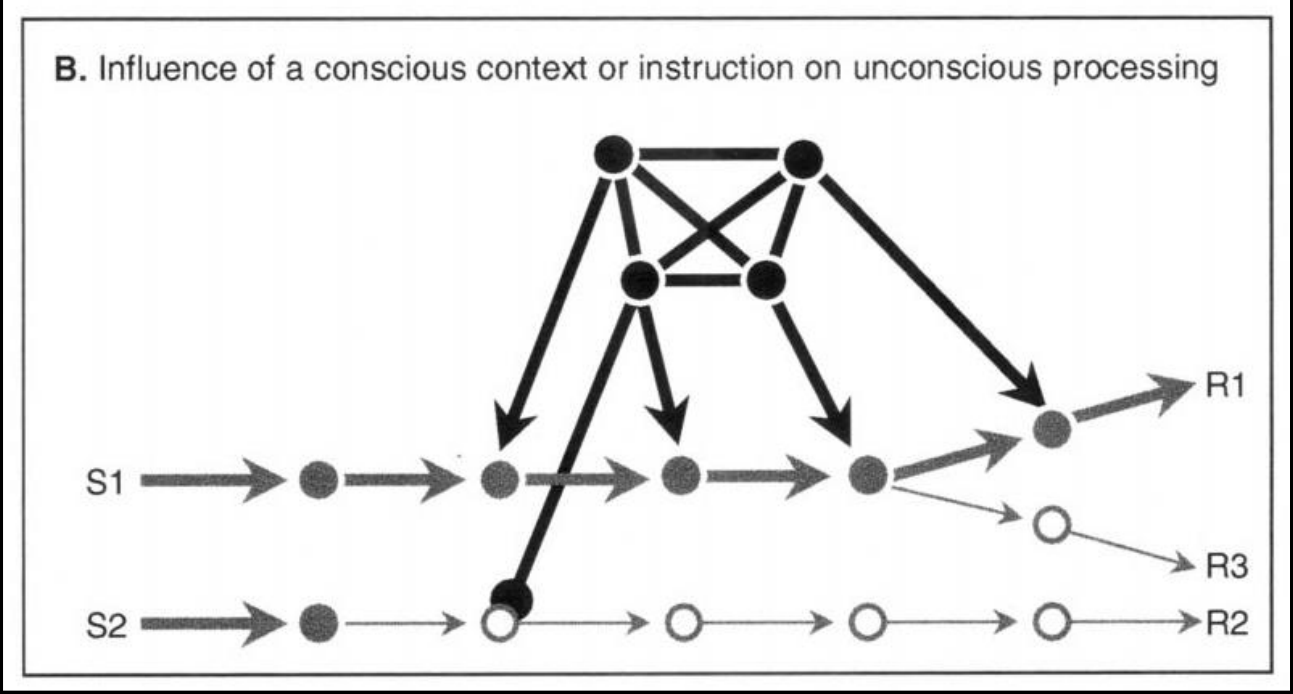


During hypnotic deafness

Munoz-Musat, … & Naccache, Front. Neurosc. 2022

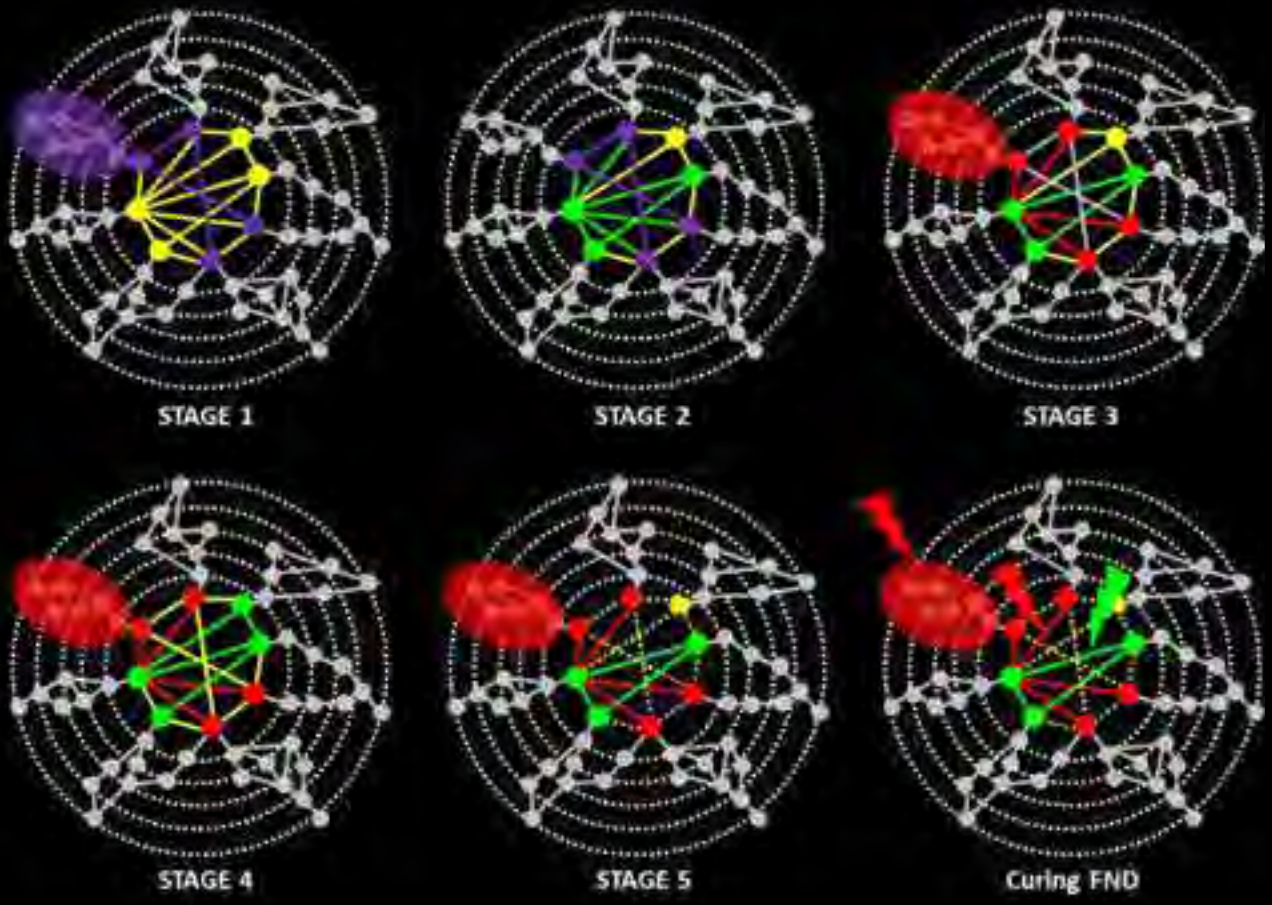
Breton, Munoz-Musat, … & Naccache, in preparation (listen to Manon Breton's talk ☺)

Importance of conscious influences on unconscious cognitive processing



Dehaene & Naccache, Cognition 2001
Naccache et al., Psychological Science 2002
Rohaut, … & Naccache, Neurosc. Consc. 2016

A new look at 'Functional Neurological Disorders' (F.N.D.) : involuntary symptoms triggered by a voluntary conscious posture



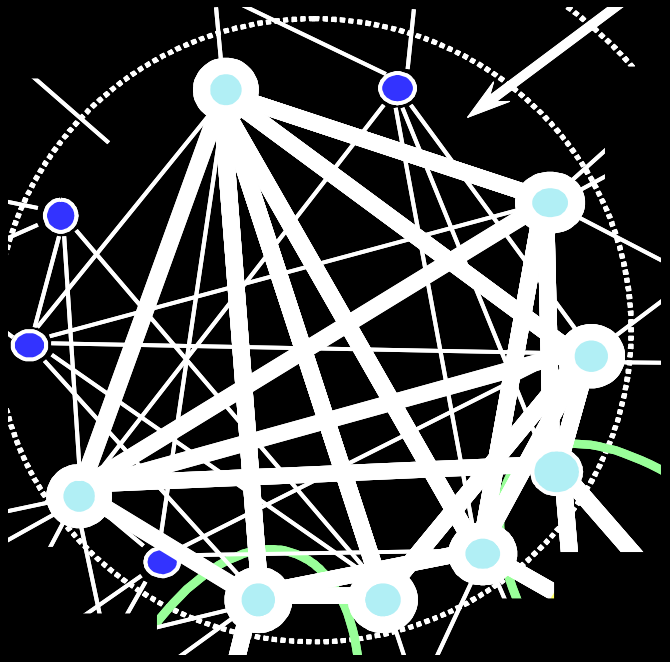
Naccache, *Le Nouvel inconscient* (Odile Jacob) 2006
Naccache & Munoz-Musat, Dialogues in Clin. Neurosc. 2024

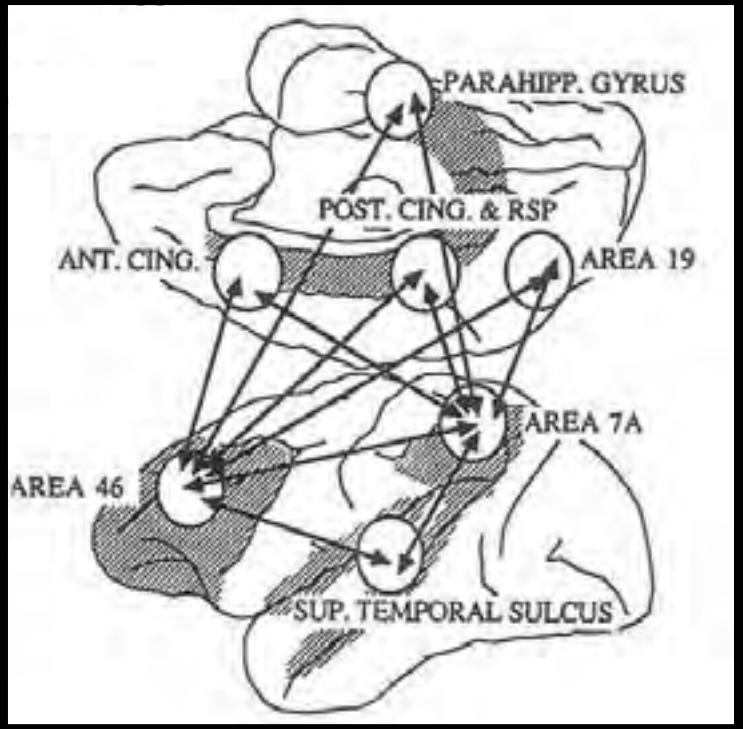
Global Neuronal Workspace

- ***Synthetic résumé of GNW framework***
- ***Questions/Ideas about conscious access***
- ***Questions /Ideas about conscious state***
  with a strong focus on disorders of consciousness

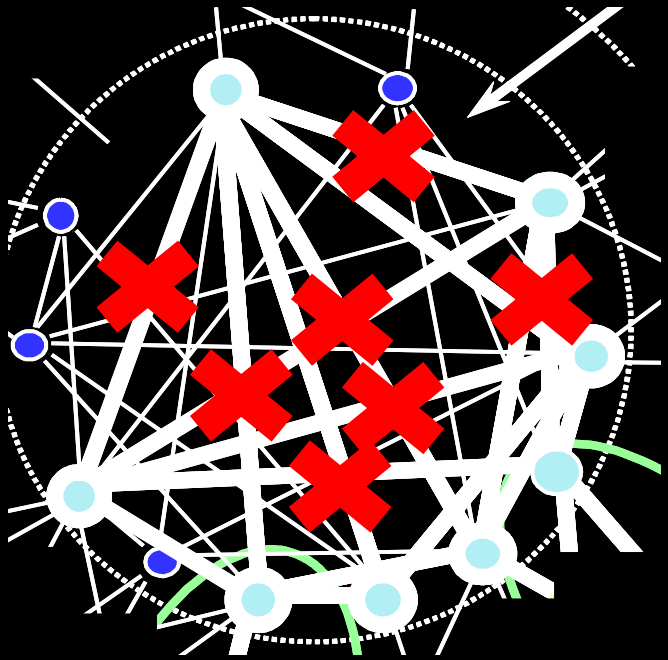
➔ Consciousness would require complex and differentiated processing with long-distance functional connectivity within a GNW

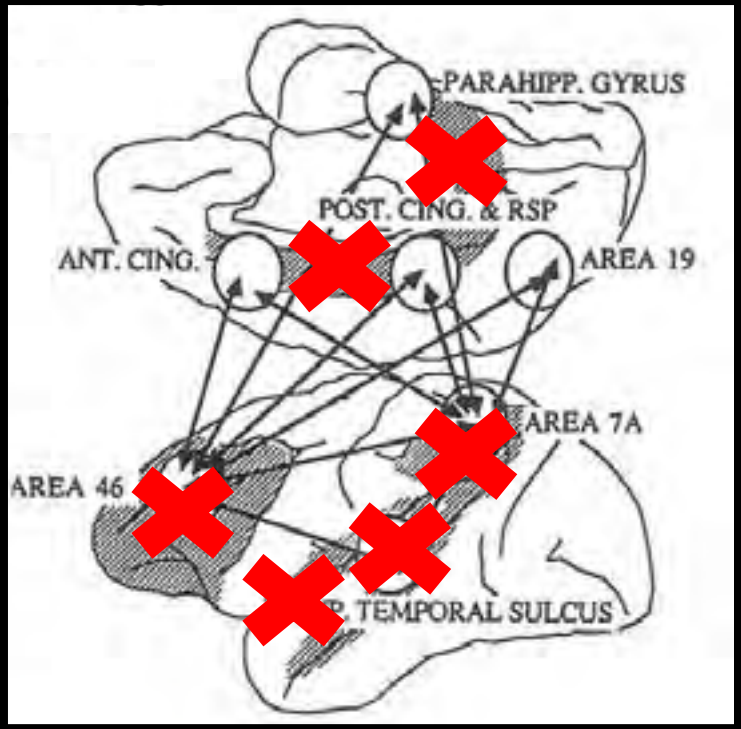
By the way : GNW is not limited to PFC but includes Fronto-Parietal cortices !



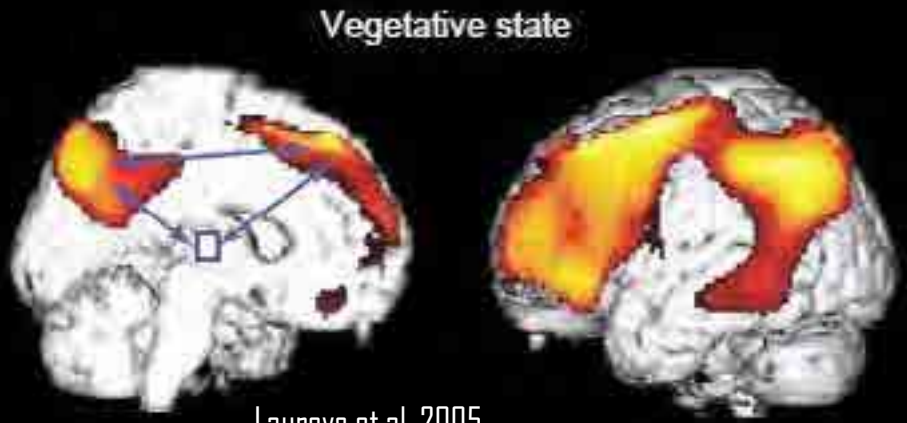


➔ Consciousness would require complex and differentiated processing with long-distance functional connectivity within a GNW

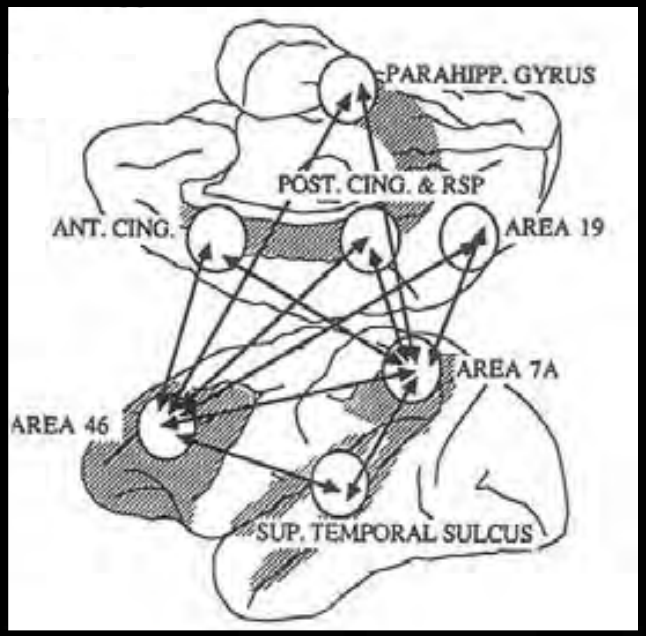




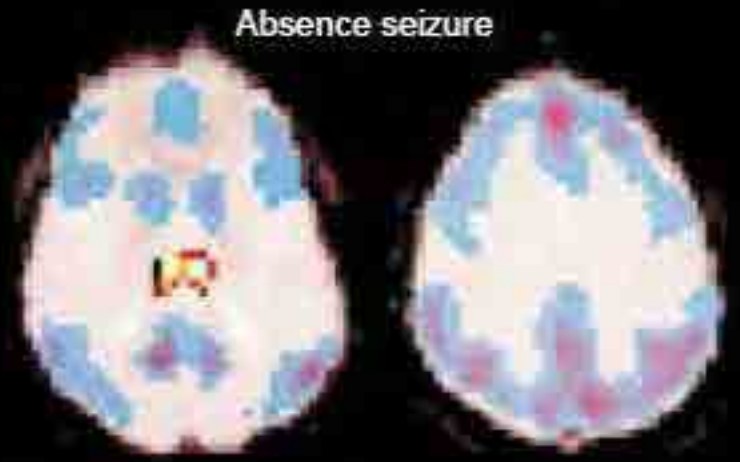
➔ Loss of Consciousness maps with GNW lesions and/or dysfunction



Laureys et al. 2005



Blumenfeld, H. et al. (2004)

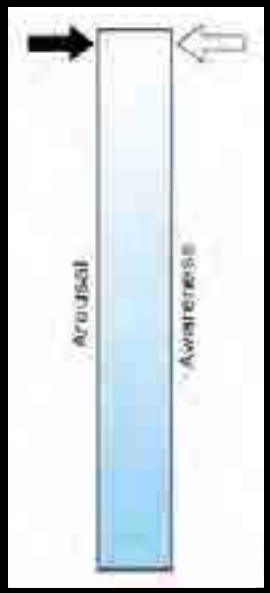


Salek-Haddadi, A. et al. (2003)

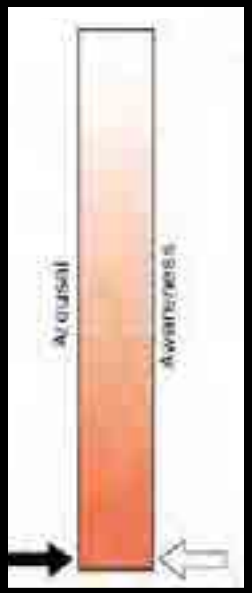
➔ Testing GNW predictions in neurological Disorders of Consciousness (DoC)

Probing conscious state and conscious access in DoC patients and testing GNWT predictions :

With a behavioral approach (no functional brain-imaging):



Consciousness



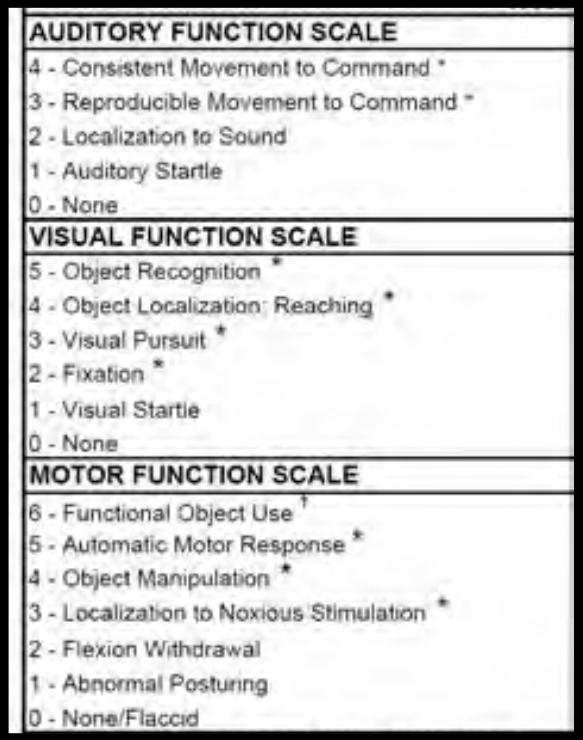
Comatose
Deep sleep
Gen. Anesth.

Vegetative State (VS/UWS)

Minimally conscious State (MCS)

Plum & Posner, 1972
Giacino et al., Neurology,2002
Laureys, Owen, Schiff, Lancet Neurol 2004

‘Gold-standard’ of MCS diagnosis: the CRS-R



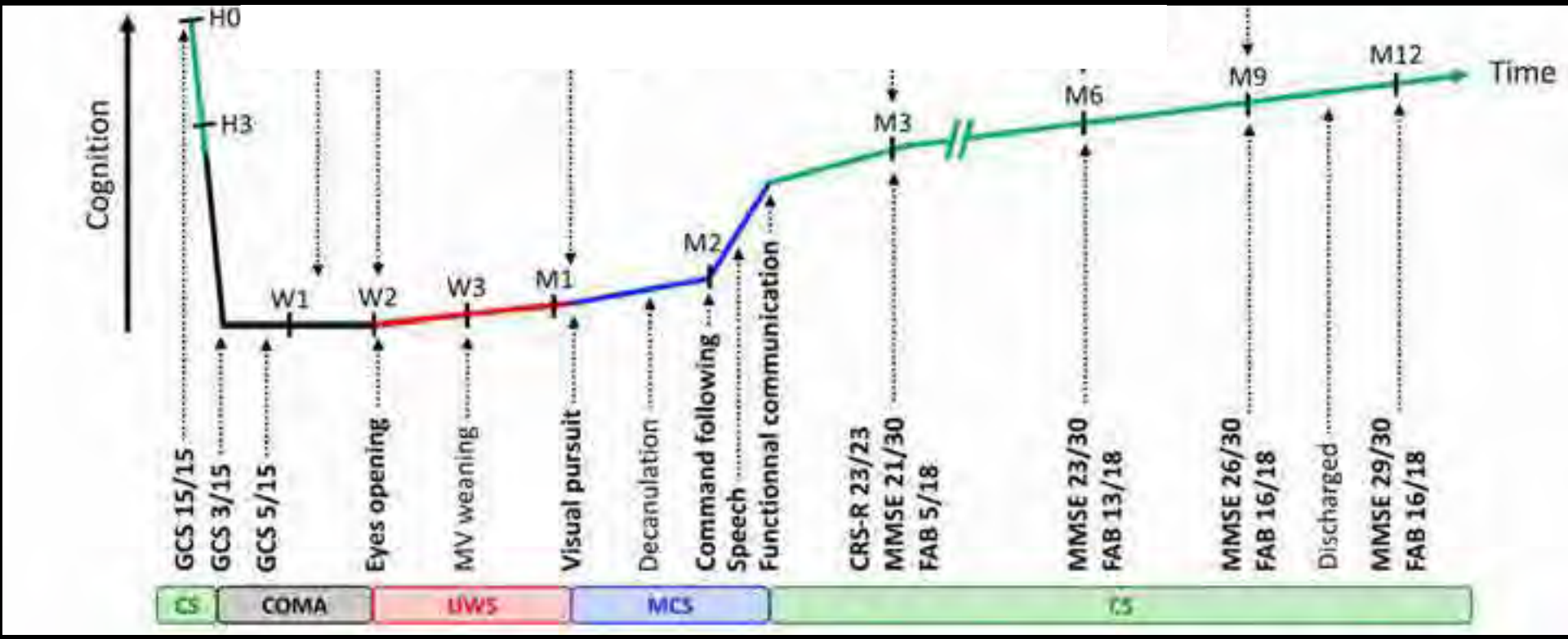
AUDITORY FUNCTION SCALE
4 - Consistent Movement to Command *
3 - Reproducible Movement to Command *
2 - Localization to Sound
1 - Auditory Startle
0 - None
VISUAL FUNCTION SCALE
5 - Object Recognition *
4 - Object Localization: Reaching *
3 - Visual Pursuit *
2 - Fixation *
1 - Visual Startle
0 - None
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

“cognitively mediated behavior occurs inconsistently, but is reproducible or sustained long enough to be differentiated from reflexive behavior”

Kalmar & Giacino., Neuropsychol. Rehab. 2005
Giacino et al. Neurology 2002

Typical clinical trajectories after a severe brain injury:



Hermann,… Naccache & Monsel, ACTN 2018

Question: But what does it mean to be in a MCS ?

⇒ *word 'conscious' in 'minimally conscious'*
⇒ *what is 'minimal' ? (minimal(e) in French)*
⇒ *e.g.: visual pursuit is not self-report*
⇒ *bhv communication of self-reports : no MCS anymore but EMCS (=conscious)*
⇒ ***What does mean MCS ?***

Naccache, Brain 2018

	Item	Cortically Mediated Behavior?
AUDITORY FUNCTION		
4	Consistent movement to command	YES
3	Reproducible movement to command	YES
2	Localization to sound	NO
1	Auditory startle	NO
0	None	X
VISUAL FUNCTION		
5	Object recognition	YES
4	Object localization: reaching	YES
3	Visual pursuit	YES
2	Fixation	DEBATED
1	Visual startle (blink to threat)	NO
0	None	X
MOTOR FUNCTION		
6	Functional object use	YES
5	Automatic motor response	YES
4	Object manipulation	YES
3	Localization to noxious stimulation	YES
2	Flexion withdrawal	NO
1	Abnormal posturing	NO
0	None/Flaccid	X
OROMOTOR FUNCTION		
3	Intelligible verbalization	YES
2	Vocalization/Oral movement	DUBIOUS
1	Oral reflexive movement	NO
0	None	X
COMUNICATION		
2	Functional: accurate	YES
1	Non functional: intentional	YES
0	None	X
AROUSAL		
3	Attention	DUBIOUS
2	Eye opening without stimulation	NO
1	Eye opening with stimulation	NO
0	Unarousable	X

Naccache, Brain 2018

	Item	Cortically Mediated Behavior?
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Cortical networks

Brainstem: Superior olivary complex

Brainstem: cochlear nucleus/LLN/caudal pontine reticular nucleus (PnC)

GREEN = MCS items

RED = VS/UWS items

ORANGE = DUBIOUS/LOOSE items

YELLOW = CONSCIOUS items (EMCS)

Naccache, Brain 2018

	Item	Cortically Mediated Behavior?
AUDITORY FUNCTION		
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Cortical networks

Brainstem: Superior olivary complex

Brainstem: cochlear nucleus/LLN/caudal pontine reticular nucleus (PnC)

Cortical network: occipito-parietal-FEF

Occipital cortex?

Brainstem: tectobulbar fibers / rostral colliculi of the midbrain

Cortex

Spinal cord reflex & sometimes higher

Subcortical responses (Jackson): decortication / decerebration

Cortex : language networks

Loose criterion: from subcortical to cortical involvement (phonological networks)

Brainstem

Cortex

Loose criterion: mostly cortex but?

Brainstem Reticular Formation(ARAS)

Brainstem Reticular Formation (ARAS)

Naccache, Brain 2018

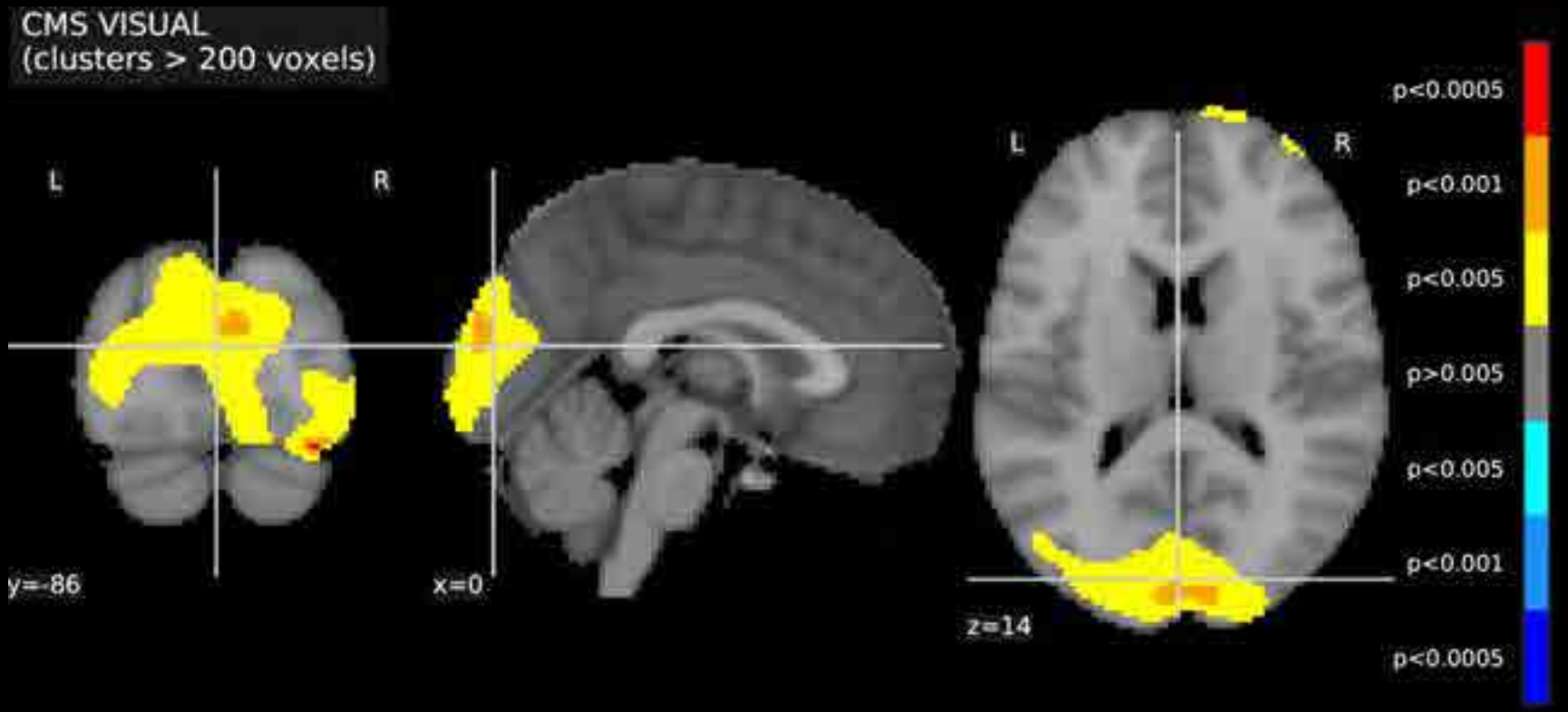
So, stating that a patient is in a MCS means, - with 100% certitude -, that some his/her overt behaviors are cortically-driven.

➔ **CRS-R criteria used to define MCS actually define a Cortically Mediated State (CMS)**

➔ **MCS/CMS conveys very important information for CS recovery but does not necessarily mean conscious**

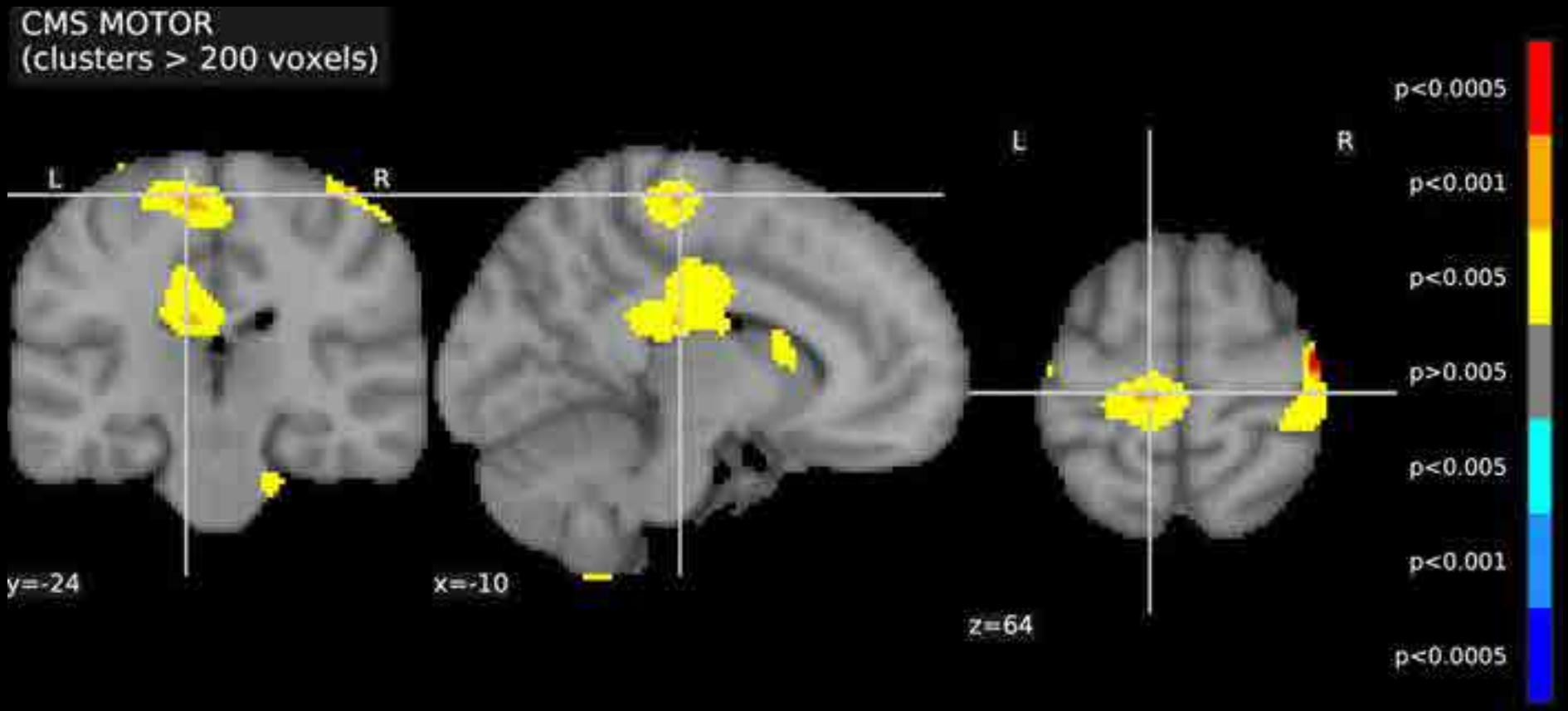
Naccache, Brain 2018

➔Imaging specific CMS networks with resting state PET



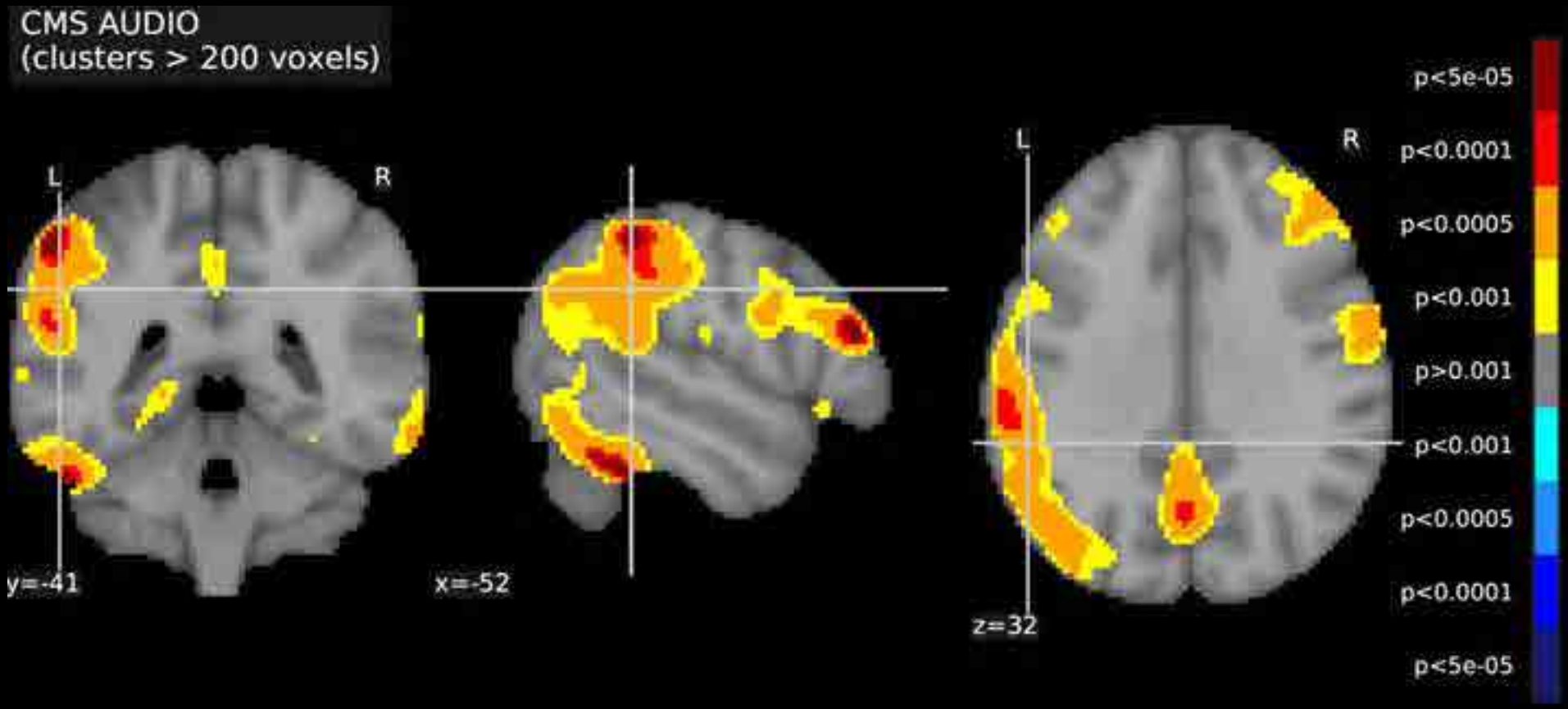
Hermann,… et Naccache, Neurosc. of Consciousness 2022

➔Imaging specific CMS networks with resting state PET



Hermann,… et Naccache, Neurosc. of Consciousness 2022

➔Imaging specific CMS networks with resting state PET



➔ GNW in Auditory MCS/CMS (response to command)

➔ “Closer” to a conscious state ?

Hermann,… et Naccache, Neurosc. of Consciousness 2022

So, stating that a patient is in a MCS means, - with 100% certitude -, that some his/her overt behaviors are cortically-driven.

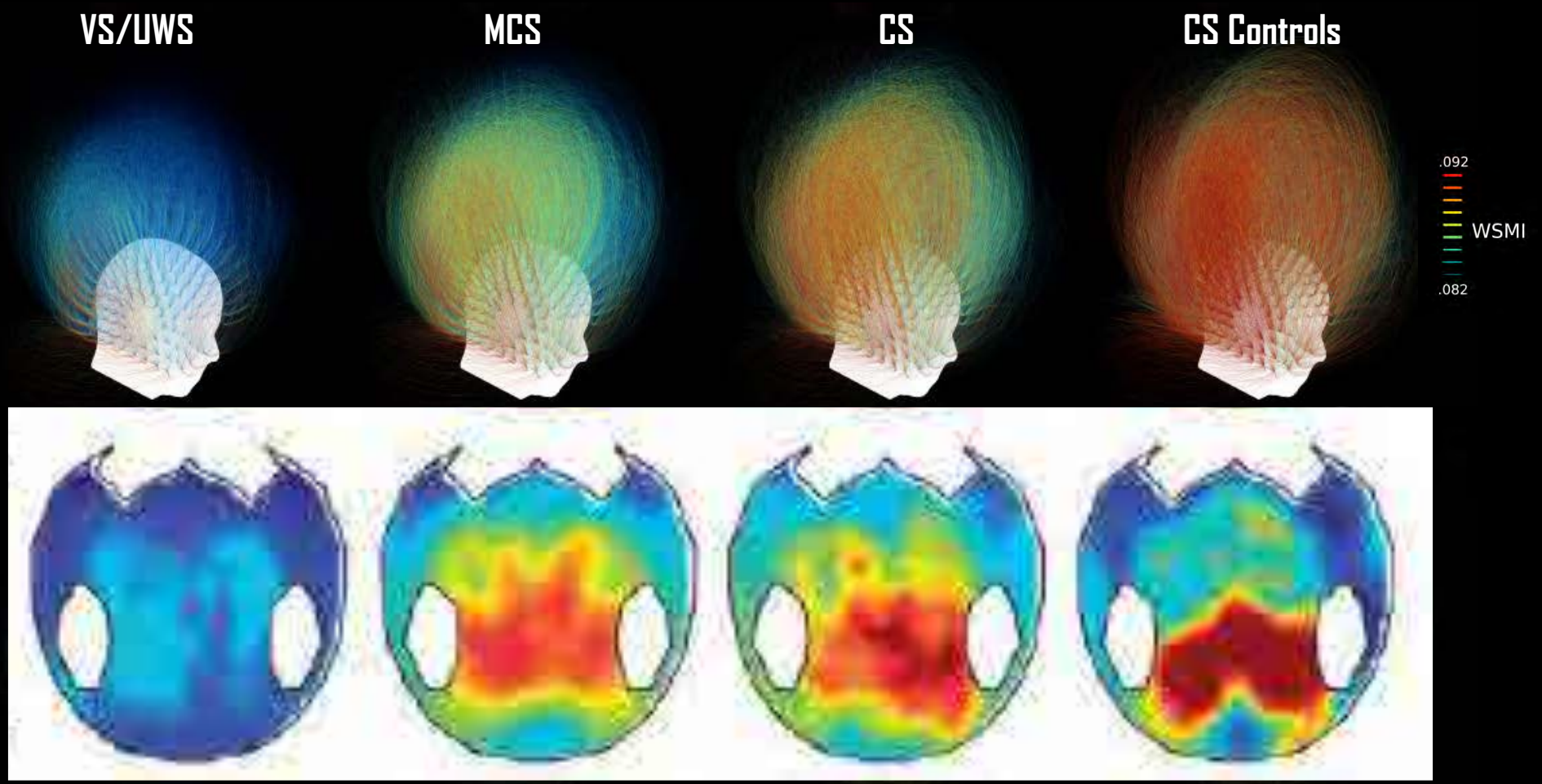
- ➔ **CRS-R criteria used to define MCS actually define a Cortically Mediated State (CMS)**
- ➔ **MCS/CMS conveys very important information for CS recovery but does not necessarily mean conscious**
- ➔ **Necessity to enrich behavioral observation and to go beyond behavior to probe covert conscious states**

Naccache, Brain 2018

Probing conscious state beyond behavior

Naccache, Science 2006
Bekinschtein & Naccache, PNAS 2009

Long-distance functional connectivity correlates with conscious states



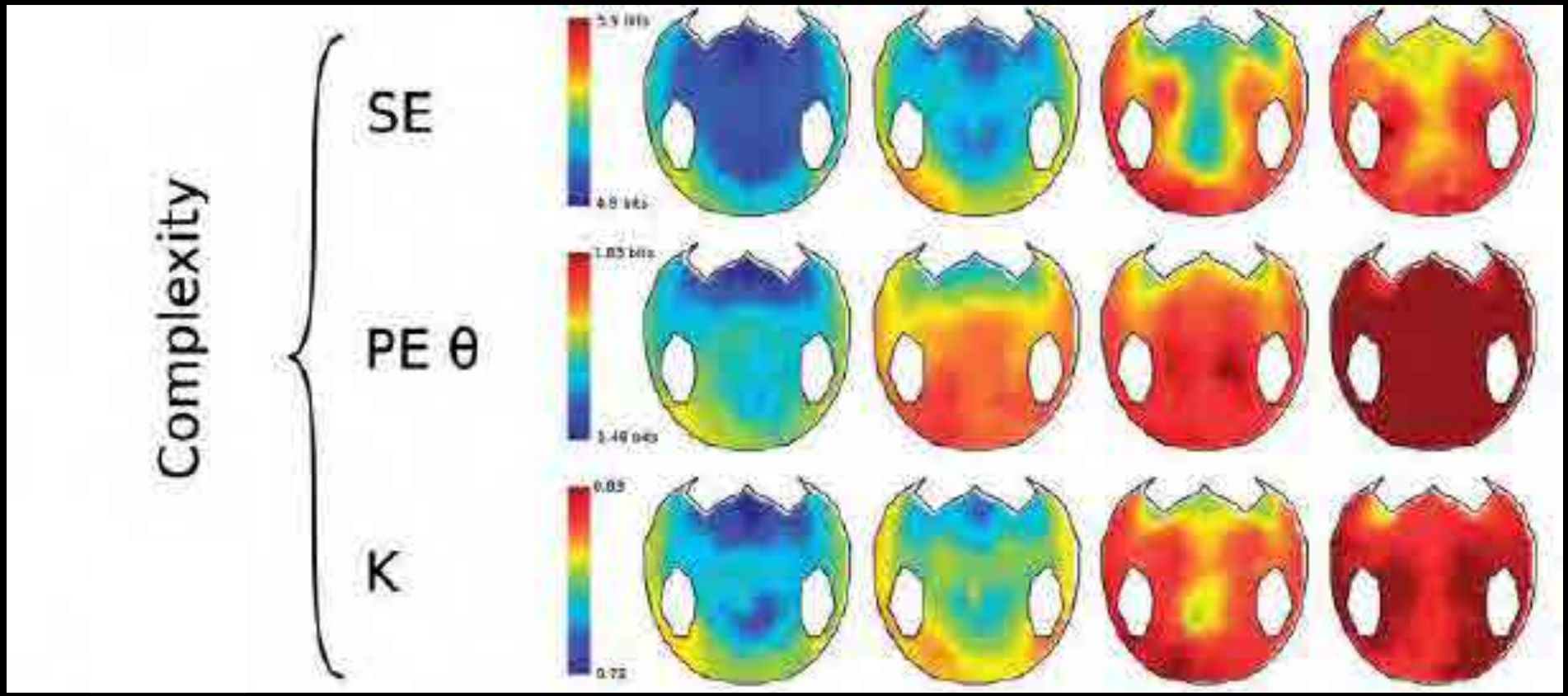
King, Sitt et al., Current Biology 2013

Cortical activity is complex during conscious states

« *The repertoire of possible contents of consciousness is thus characterized by an enormous combinatorial diversity: each workspace state is `highly differentiated' and of `high complexity', in the terminology of Tononi and Edelman (1998).* » (Dehaene & Naccache, 2001)

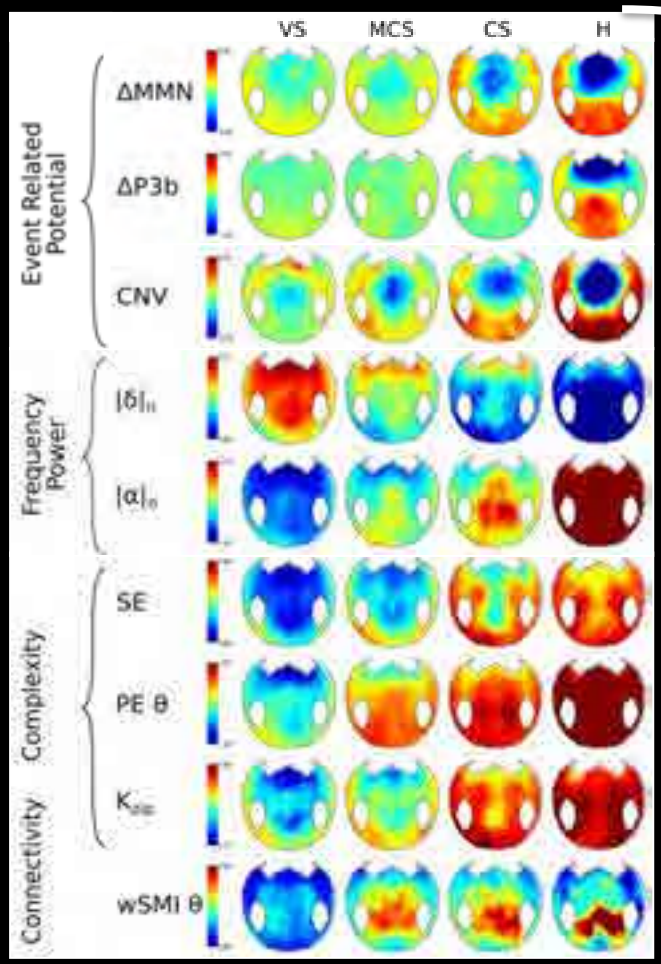
Sitt, King,… & Naccache, Brain 2014

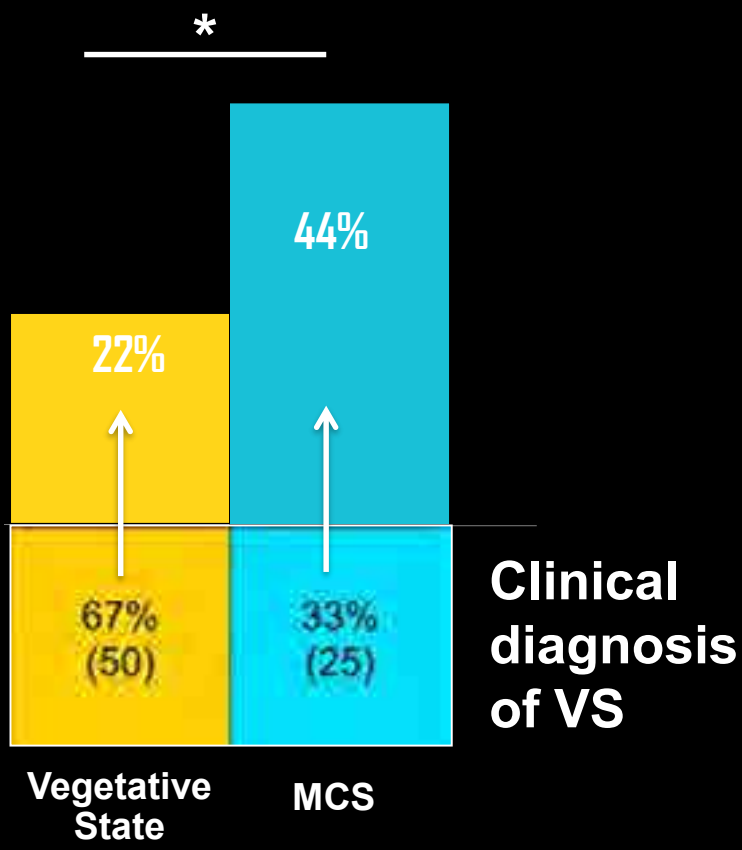
Cortical activity is complex during conscious states



Sitt, King,… & Naccache, Brain 2014

➔ Automatic processing of neural signatures of conscious states : EEG

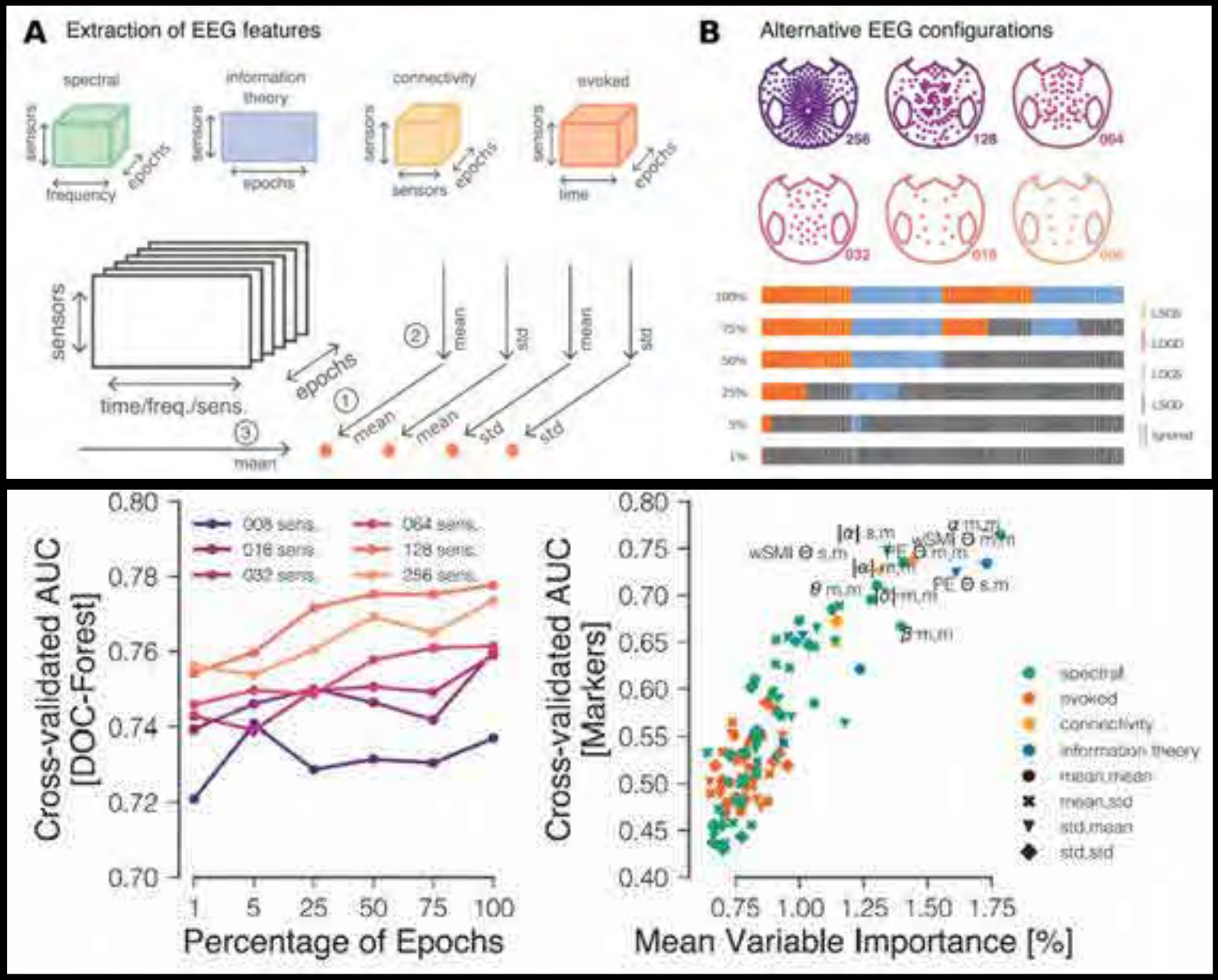




EEG-based algorithmic diagnosis

Sitt, King,…, Dehaene, Naccache, Brain 2014

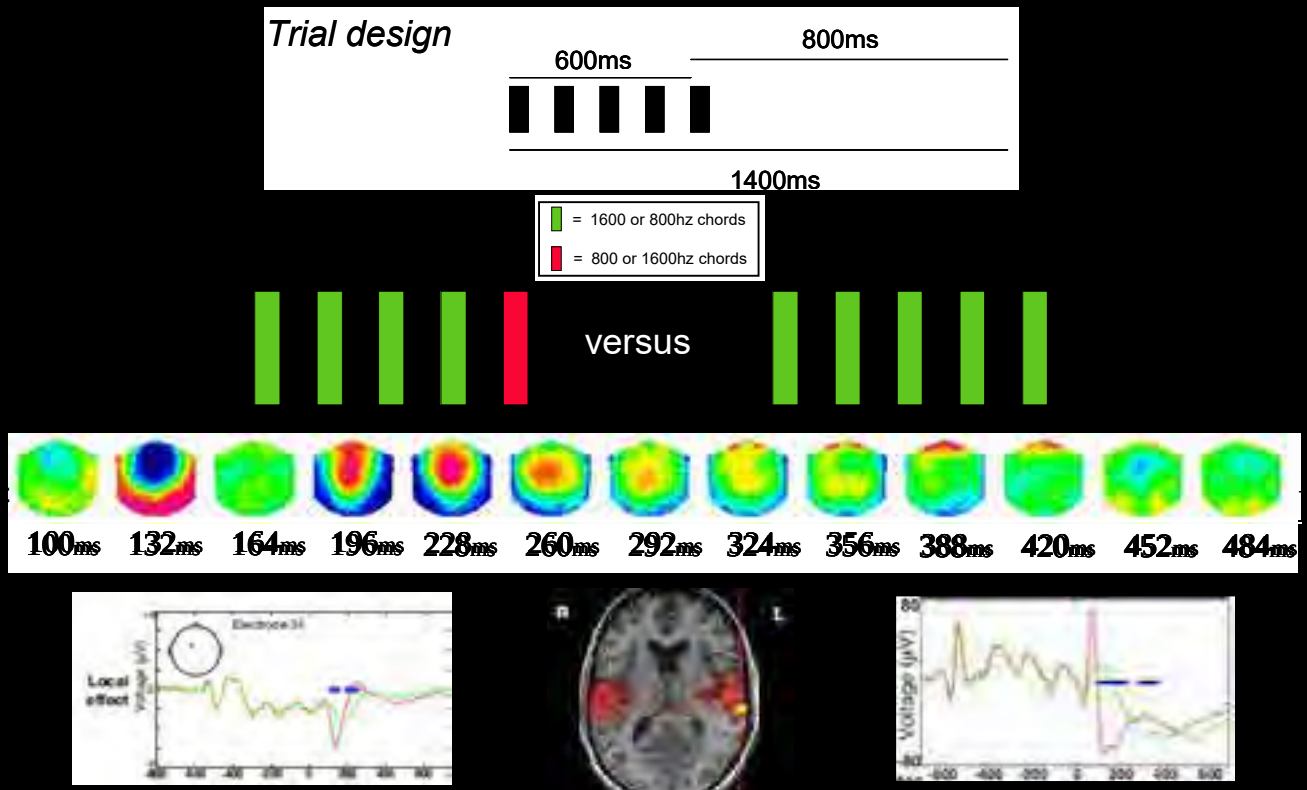
➔Toward a generalized & accessible diagnostic tool (EEG)



Engemann, Raimondo et al., Brain 2018

Probing conscious access beyond behavior

Local Global auditory paradigm

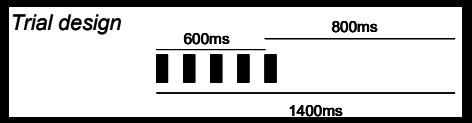


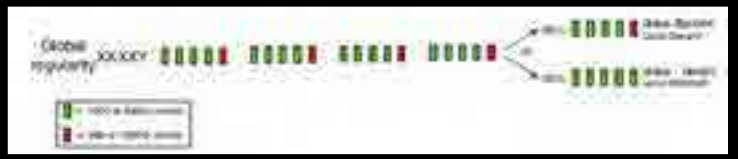
« Local » effect captures the correlates of local regularity violations (MMN) and does not require awareness of the global regularity

Bekinschtein,… & Naccache, PNAS 2009

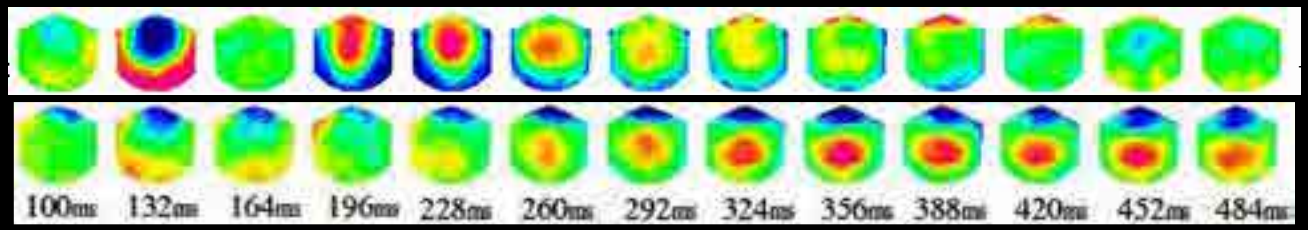
El Karoui,… & Naccache, Cer. Cortex 2014

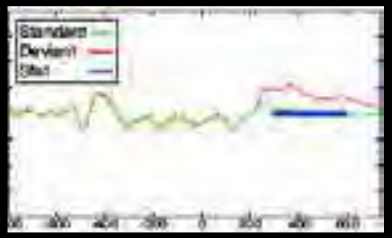
Disentangling UCS from CS processing

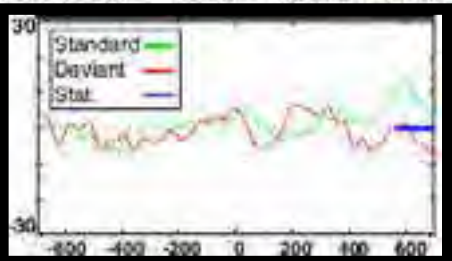




= pure global regularity violation



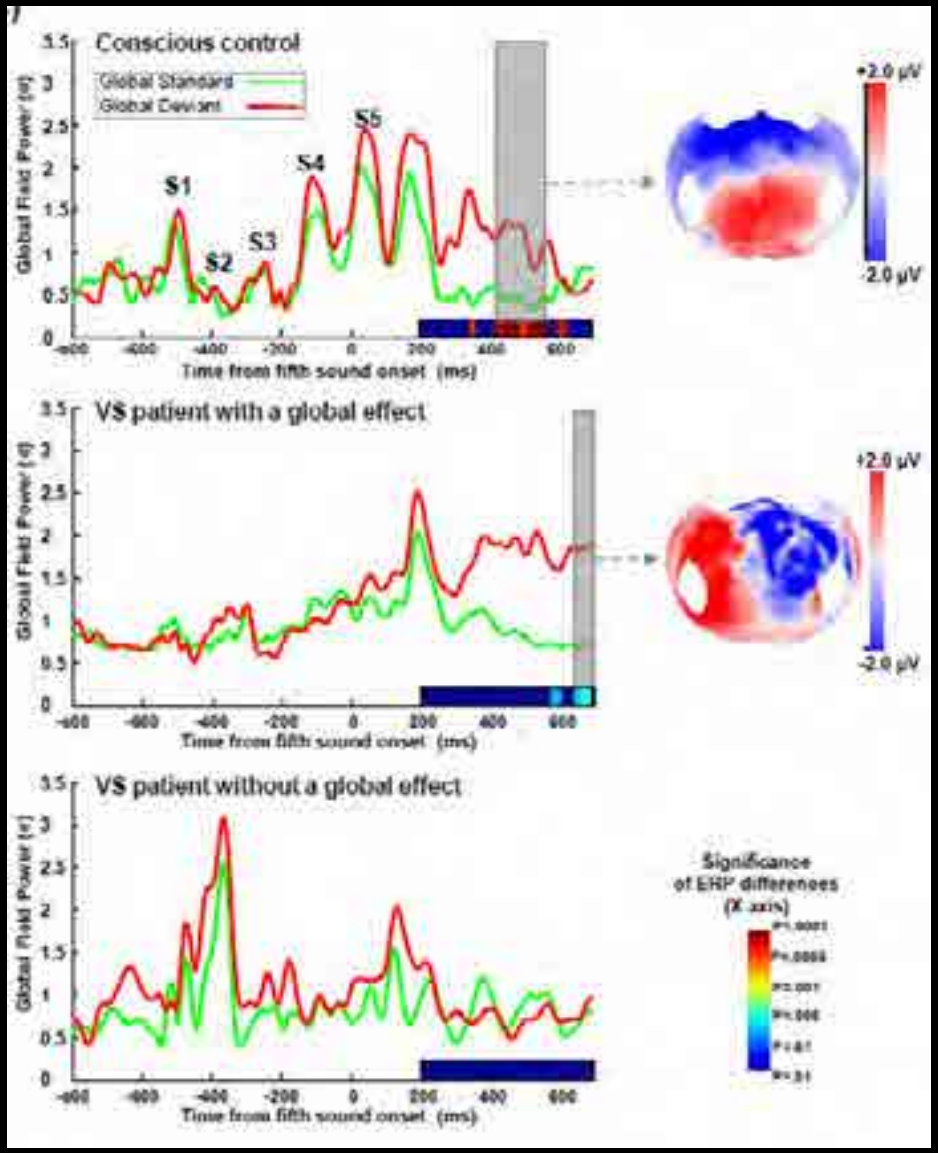




In HV, global effect is observed only in subjects aware of global regularity

Bekinschtein,… & Naccache, PNAS 2009
El Karoui,… & Naccache, Cer. Cortex 2014

In DoC patients is a very specific sign of overt CS recovery (covert CS during testing?)

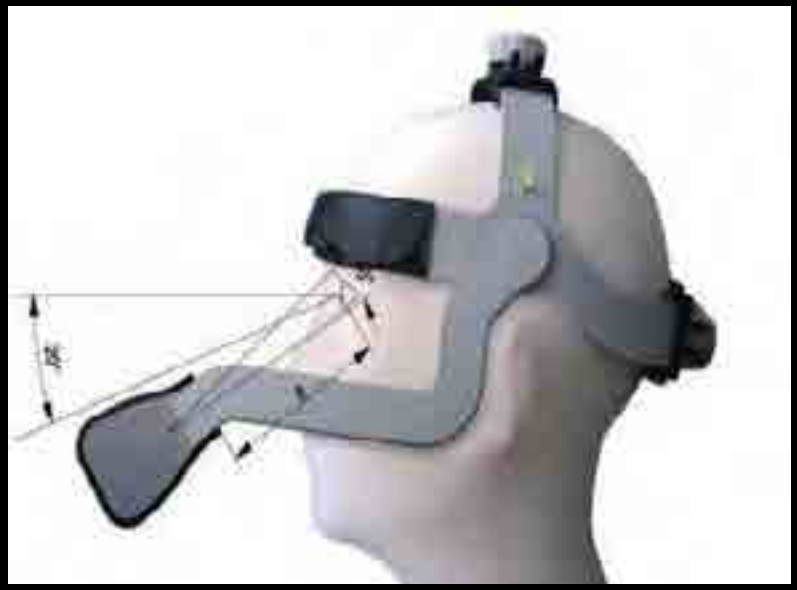


The global effect is specific of conscious states … but is a loosely sensitive marker.

Patients with a GE are behaviorally conscious at 6 months with a PPV=80% in survivors (N=237)

Faugeras,… & Naccache, Neurology 2011
Faugeras,… & Naccache, Neuropsychologia 2012
Sitt,… & Naccache, Brain 2014
Perez,… & Naccache, Front. Neurol. 2021

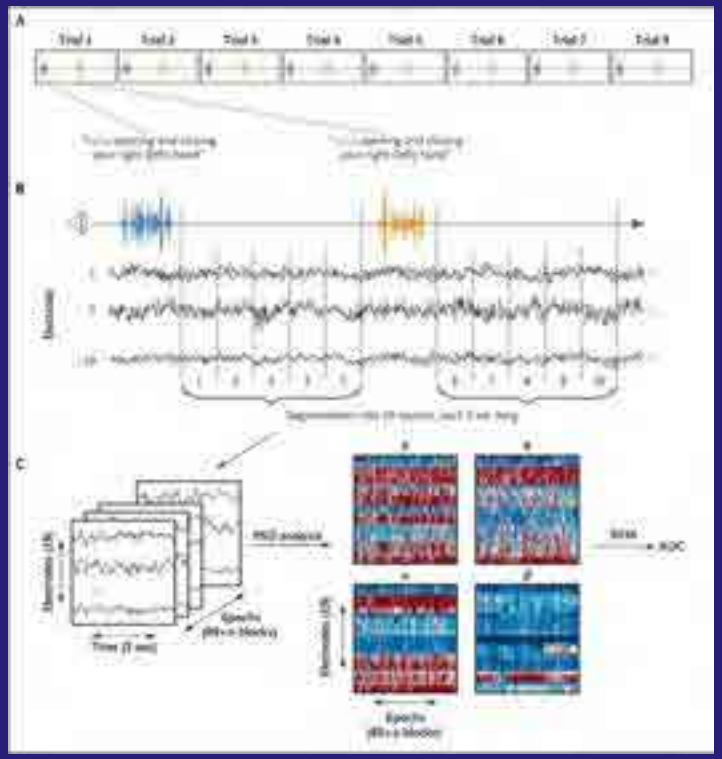
« Local Global » for your eyes only!

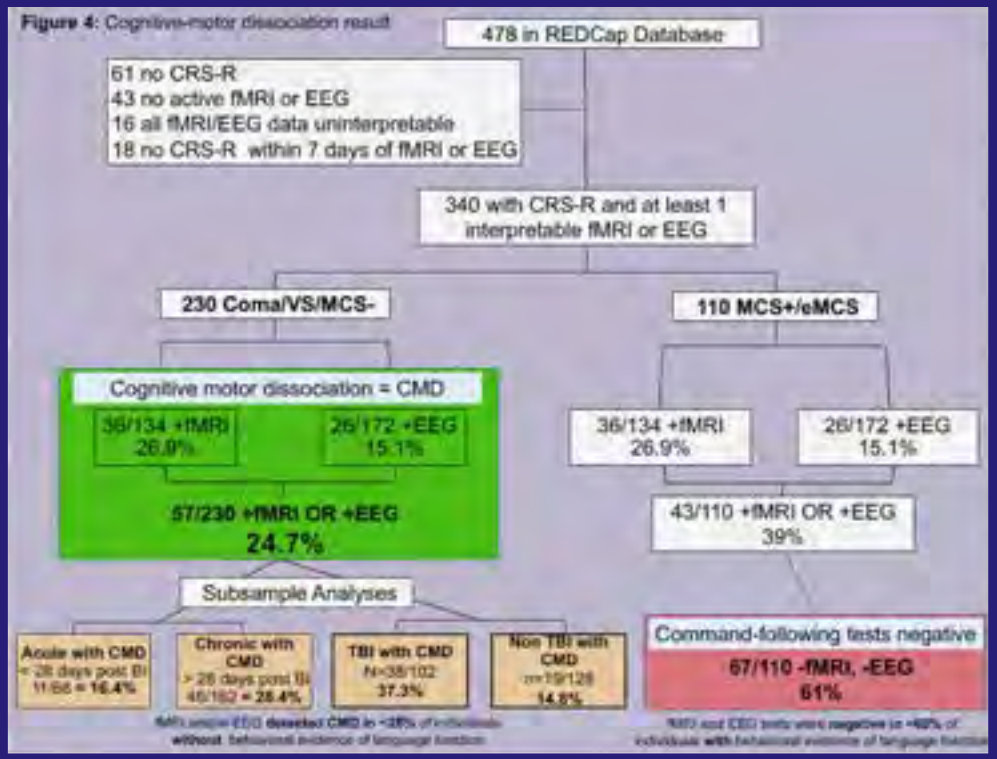


Pupil dilation as a correlate of conscious access

Quirins, Valente,… & Naccache, Scientific Reports 2018

Probing ‘response to command’ in brain activity

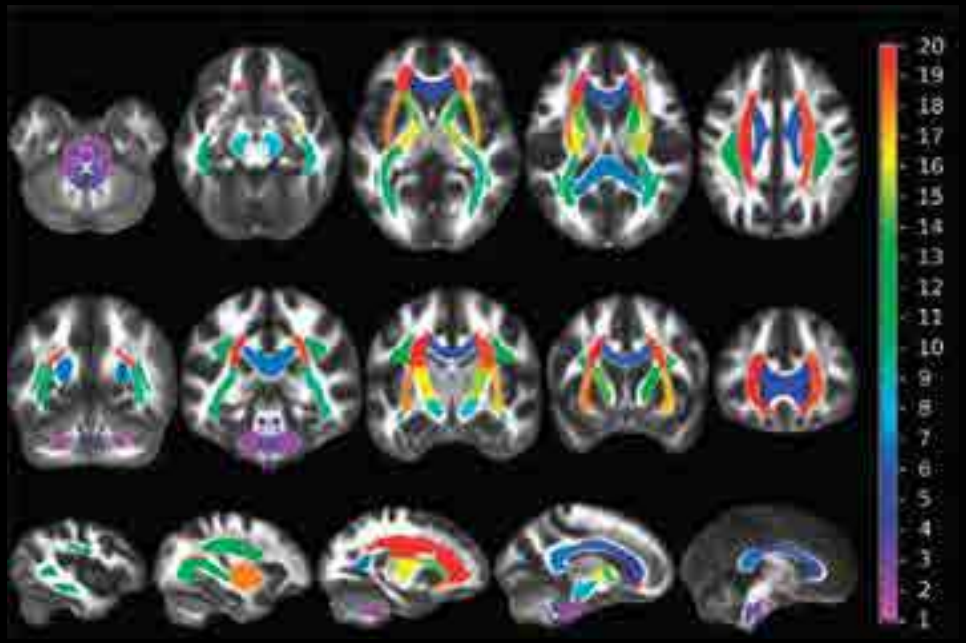


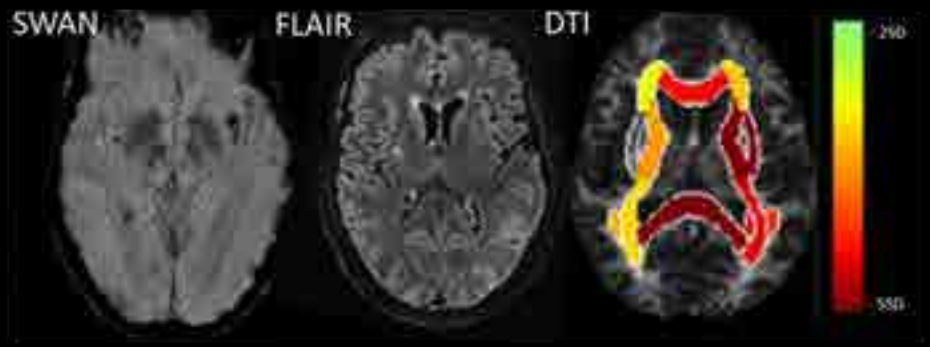


Claassen,… & Rohaut NEJM 2019
Bodien, … Rohaut … Sitt … Naccache … & Schiff NEJM 2024

➔ Multimodal exploration of each patient

.Structural brain-imaging





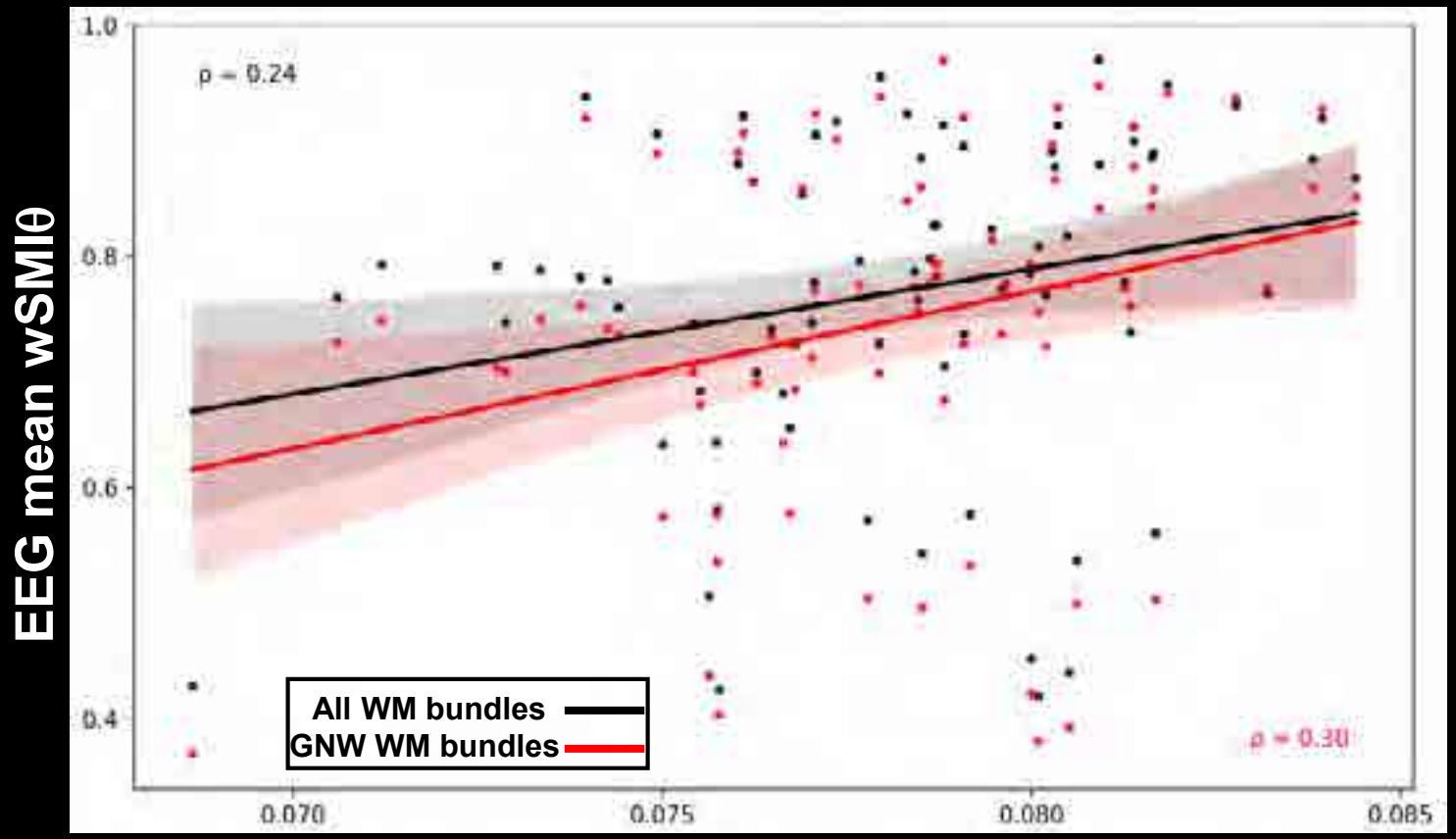
Sangaré,… & Naccache, Brain Sci. 2020

Use of brain diffusion tensor imaging for the prediction of long-term neurological outcomes in patients after cardiac arrest: a multicentre, international, prospective, observational, cohort study

Velly et al., Lancet Neurology 2018

➔ Multimodal exploration of each patient

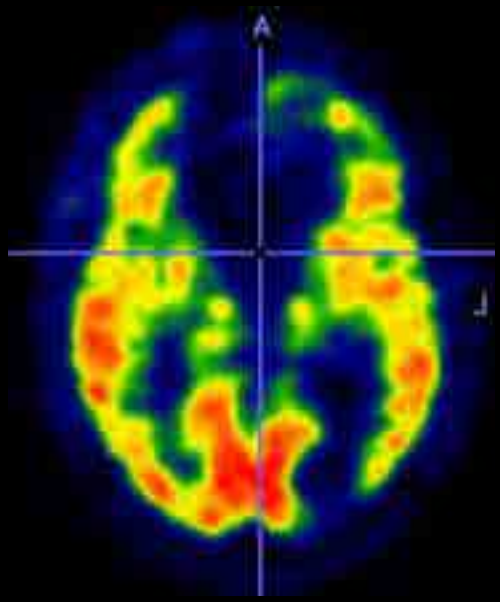
. GNW Structural (DTI) & Functional (EEG) connectivities are correlated

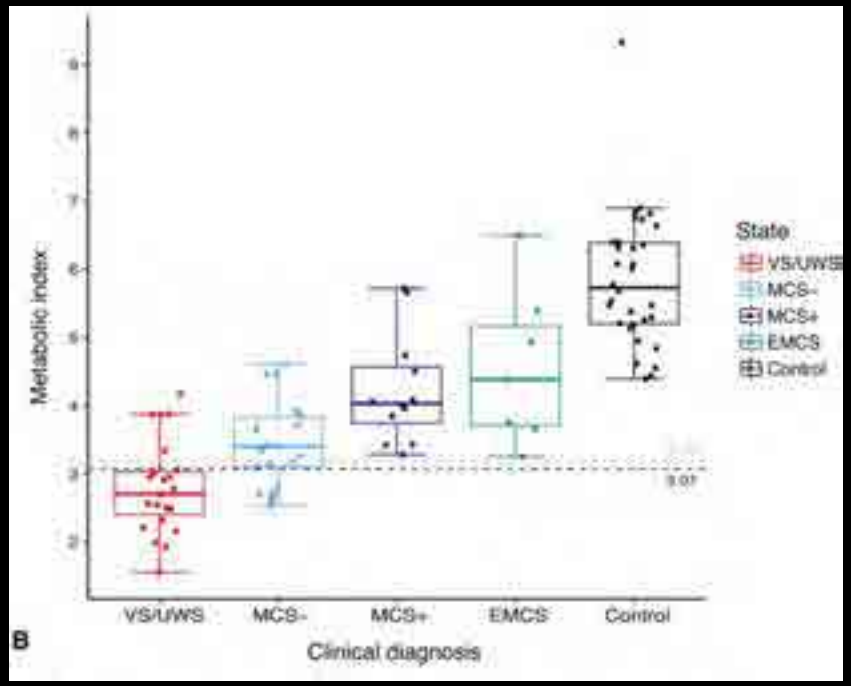


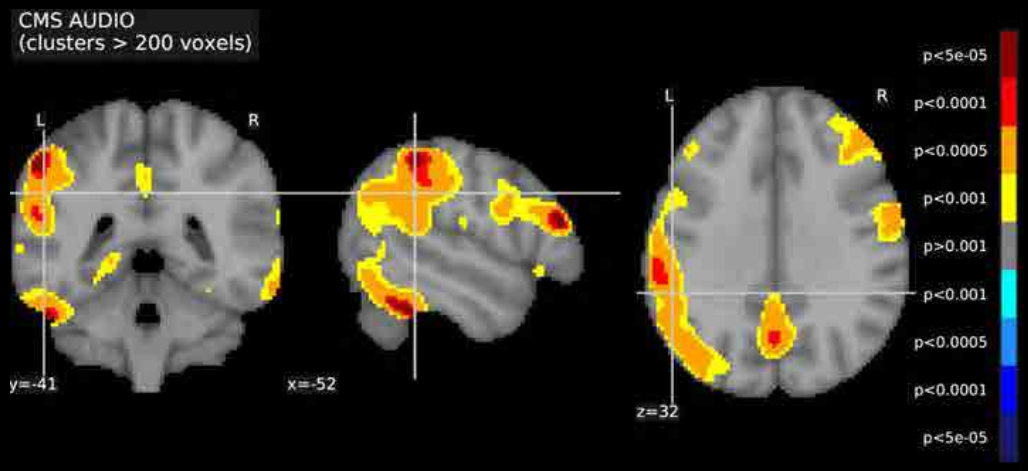
Altmayer et al., Brain Struct. Funct. 2024

➔ Multimodal exploration of each patient

.Metabolic brain-imaging:







Stender et al., Curr. Biol. 2016
Hermann, … & Naccache, Neuroimage Clinical 2021
Hermann,… et Naccache, Neurosc. of Consciousness 2022

Identifying new behavioral signs of CS

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https://academic.oup.com/brain/article/143/7/2154/5862031#supplementary-data

Hermann, … Naccache, Brain 2020

Identifying new behavioral signs of CS

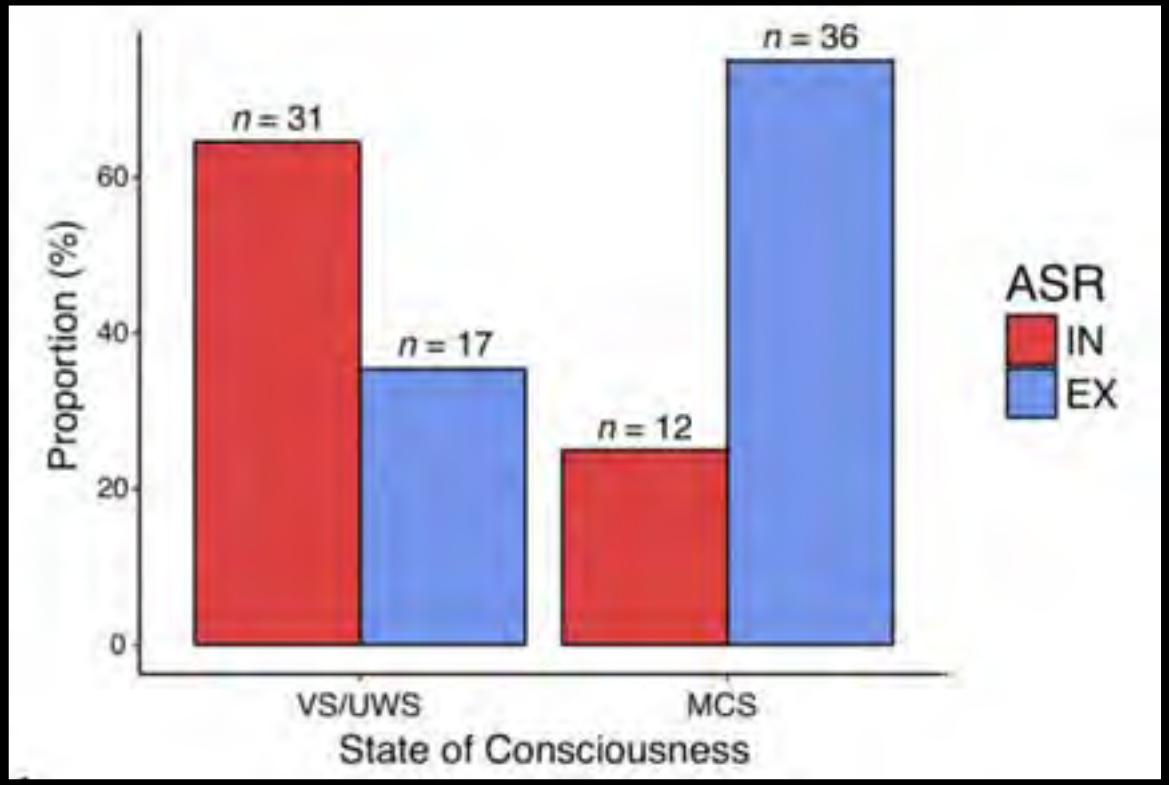
EXTINGUISHABLE
STARTLE REFLEX

download movies from

https://academic.oup.com/brain/article/143/7/2154/5862031#supplementary-data

Hermann, … Naccache, Brain 2020

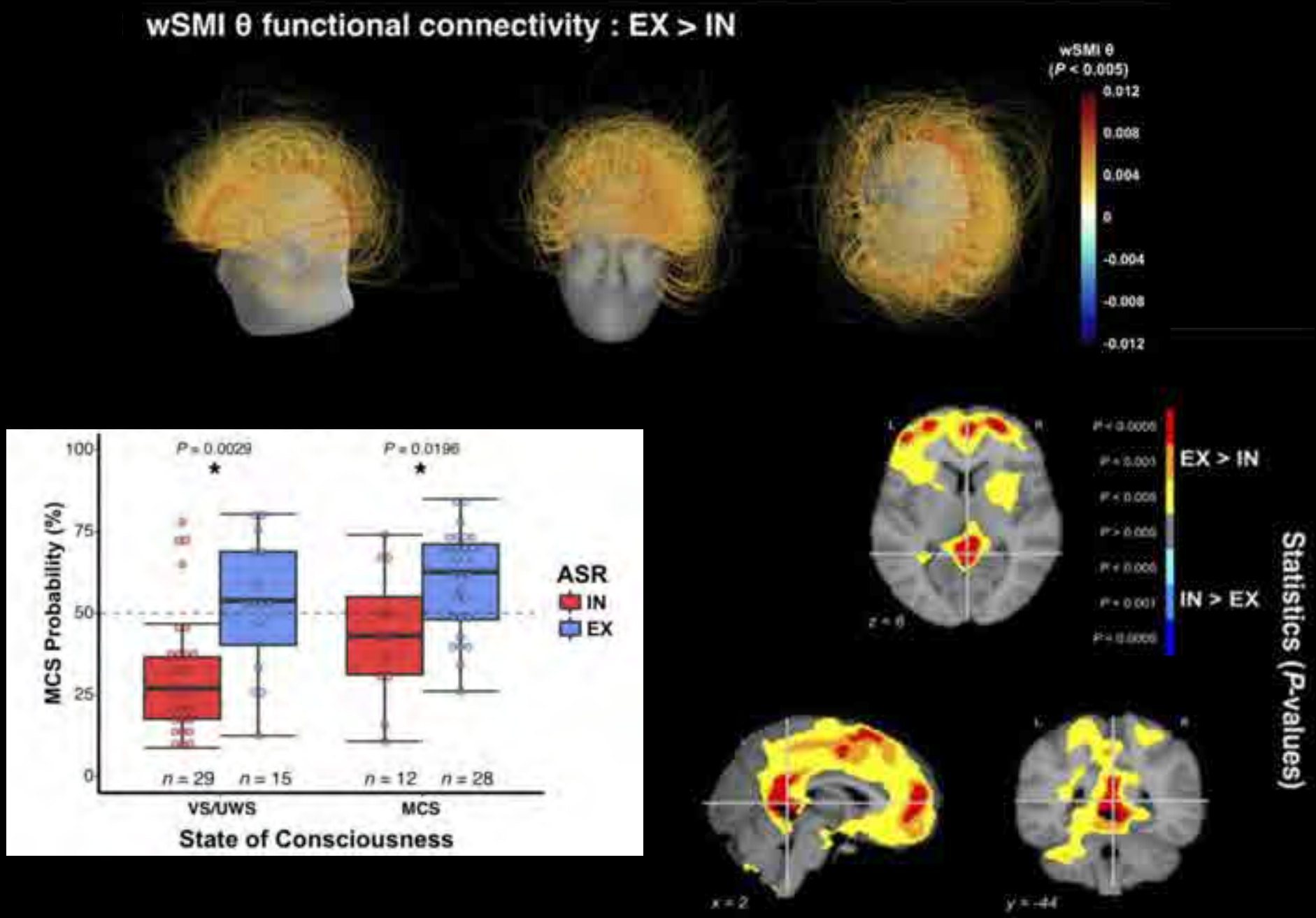
Habituation of auditory startle is a new powerful and behavioral sign of CMS easy to assess at bedside



	Pr (%)	AUC [95% CI]
Habituation of auditory startle reflex		
Exhaustible	55	0.70 [0.60–0.79]
Auditory		
Reproducible (3)	9	0.59 [0.54–0.66]
Systematic (4)	5	0.55 [0.51–0.6]
Visual		
Fixation (2)	6	0.56 [0.52–0.61]
Pursuit (3)	25	0.75 [0.68–0.82]
Localization (4)	2	0.52 [0.5–0.55]
Recognition (5)	5	0.55 [0.51–0.59]
Motor subscale		
Localization (3)	7	0.57 [0.53–0.62]
Manipulation (4)	2	0.52 [0.5–0.55]
Automatic (5)	16	0.66 [0.59–0.72]
Oromotor and verbal subscale		
Verbalization (3)	1	0.51 [0.5–0.53]
Communication subscale		
Intentional (1)	8	0.58 [0.53–0.64]

Acc = accuracy; AUC = area under the ROC curve; N
value; Pr = prevalence; Sen = sensitivity; Sp = specific

Hermann, … Naccache, Brain 2020



Hermann, … Naccache, Brain 2020

Identifying new behavioral signs of CS

https://doi.org/10.1093/braincomms/fcae311 BRAIN COMMUNICATIONS 2024: fcae311 | 1

BRAIN COMMUNICATIONS

Pain anticipation is a new behavioural sign of minimally conscious state

Aude Sangare,[1,2] Esteban Munoz-Musat,[1] Amina Ben Salah,[1] Melanie Valente,[1,2] Clemence Marois,[3] Sophie Demeret,[3] Jacobo Diego Sitt,[1] Benjamin Rohaut[1,3] and Lionel Naccache[1,2]

Illustration of the multimodal approach: a patient with severe TBI at 7 months

EXAMENS CLINIQUES

Examen clinique

CRS-R (Giacino JT, et al. Neurology 2002)

CRS-R du 14/12/2020 : 12 [2-4-2-2-0-2]

CRS-R du 14/12/2020 : 13 [3*-4-2-2-0-2] en présence de son frère, si consignes faisant appel à compréhension situationnelle et non verbales

CRS-R du 15/12/2020 : 13 [3-4-2-2-0-2]

CRS-R du 16/12/2020 : 13 [3-4-2-2-0-2]

CRS-R du 17/12/2020 : 13 [3-4-2-2-0-2]

CRS-R du 18/12/2020 : 13 [3-4-2-2-0-2]

Auditory Startle : Extinguishible

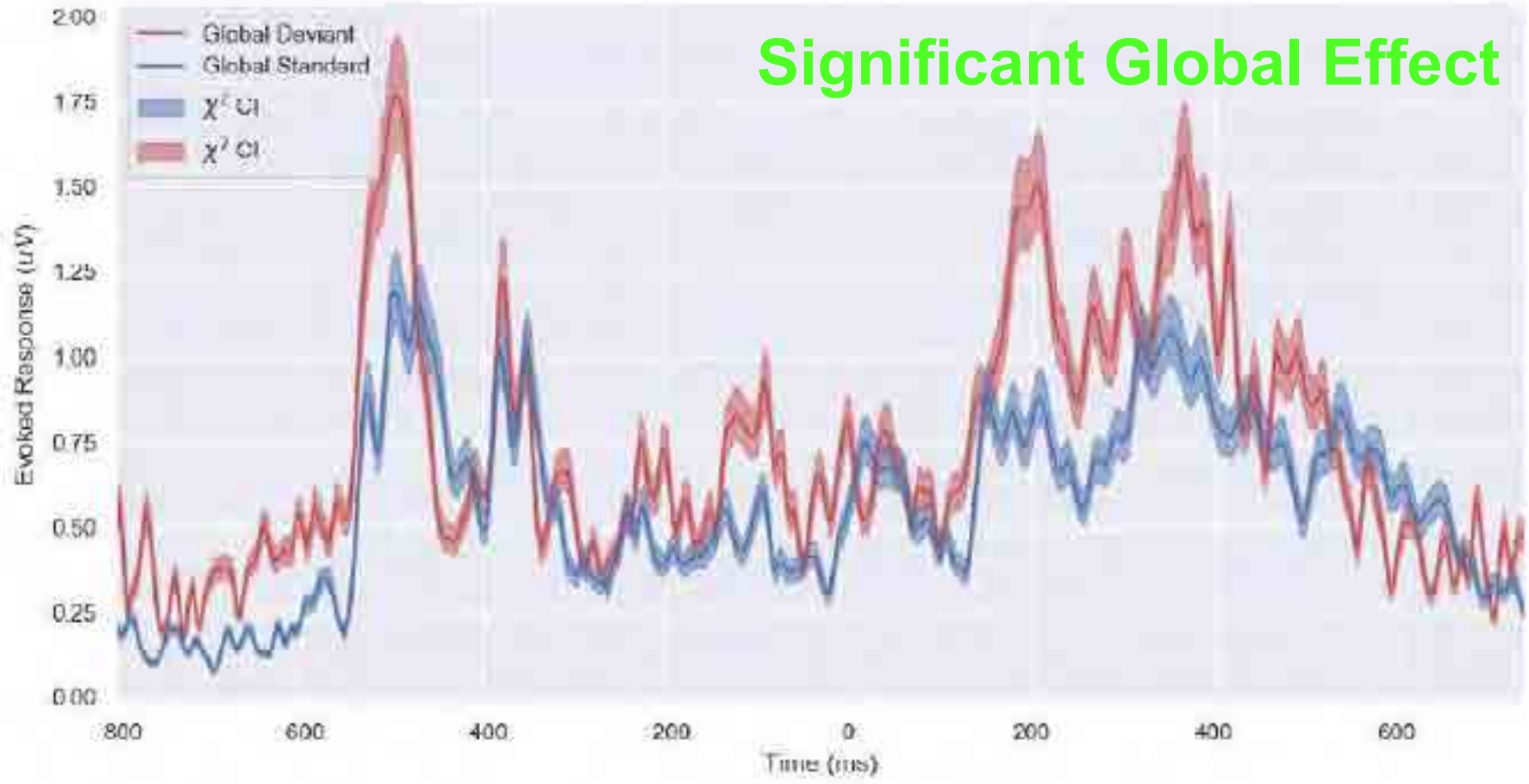
BRAIN

A JOURNAL OF NEUROLOGY

Habituation of auditory startle reflex is a new sign of minimally conscious state

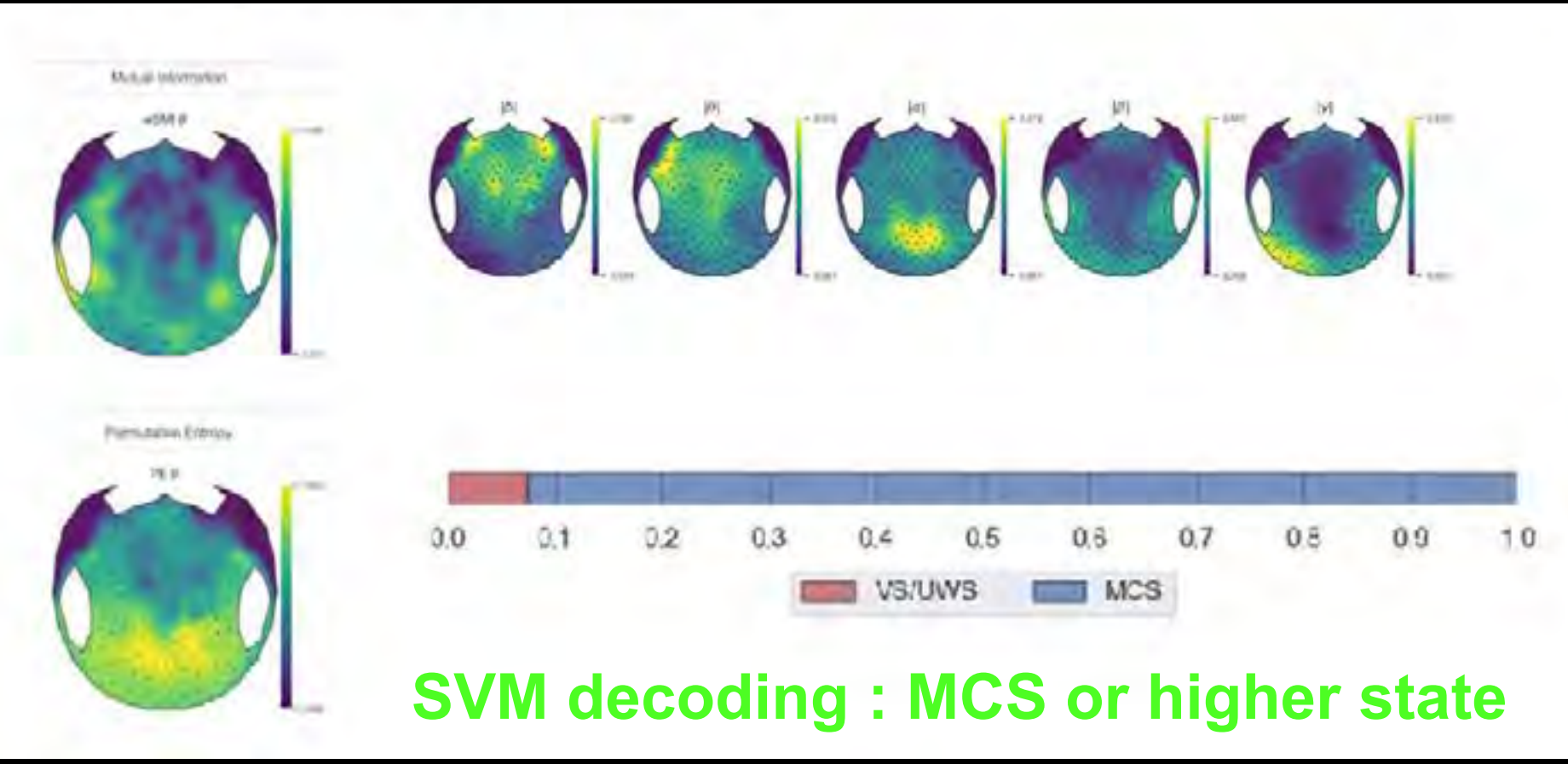
Bertrand Hermann,[1,2,3] Amina Ben Salah,[1] Vincent Perlbarg,[4,5] Mélanie Valente,[1,6] Nadya Pyatigorskaya,[1,3,7] Marie-Odile Habert,[4,8] Federico Raimondo,[1,9,10] Johan Stender,[1] Damien Galanaud,[1,3,7] Aurélie Kas,[4,8] Louis Puybasset,[3,4,11] Pauline Perez,[1] Jacobo D. Sitt,[1] Benjamin Rohaut[1,2,3,12] and Lionel Naccache[1,2,3,6,*]

A patient with severe TBI at 7 months :



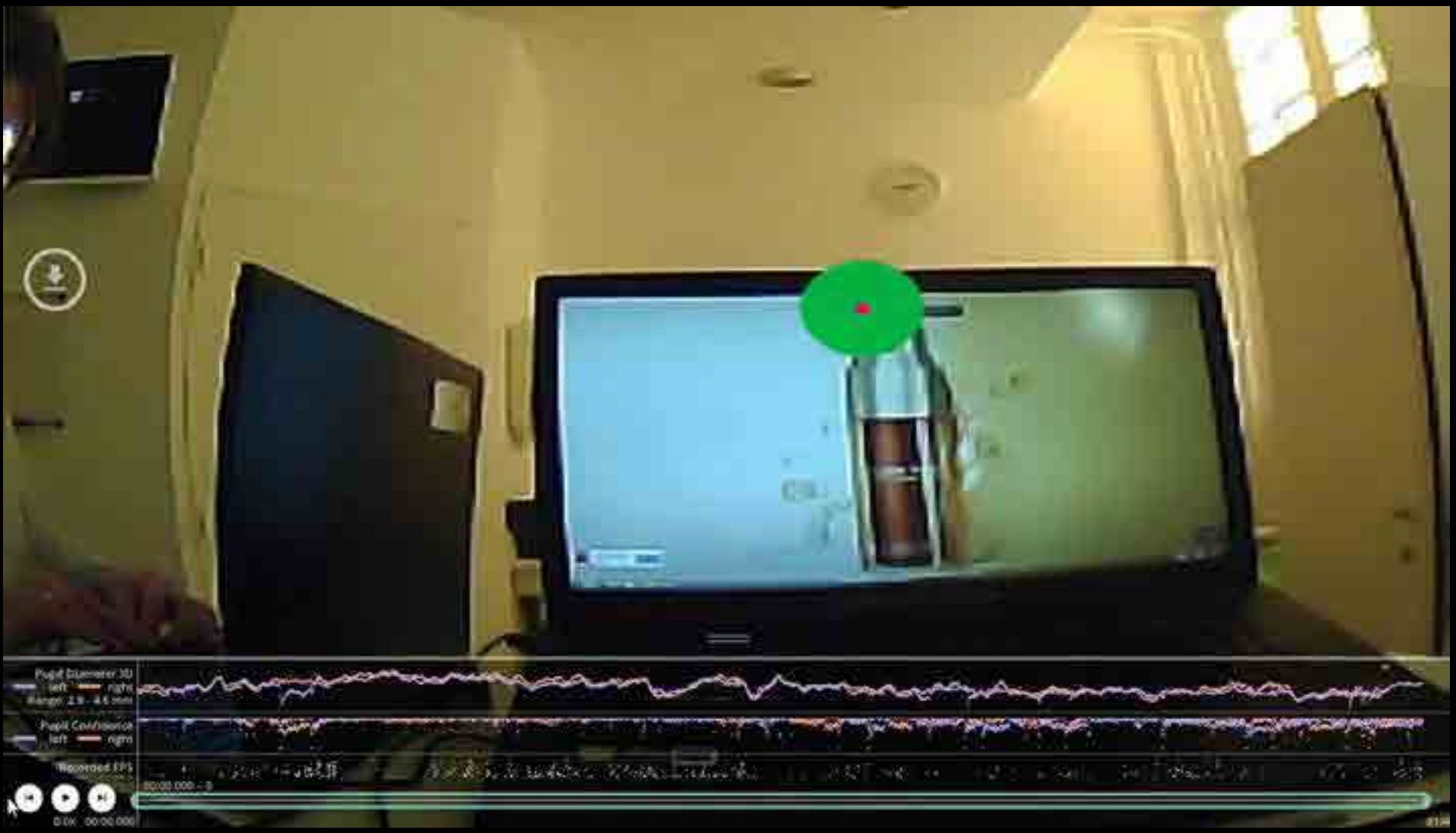
Motor Response with EEG : + (AUC=0,57)

A patient with severe TBI at 7 months :



SVM decoding : MCS or higher state

Eye tracking of faces, text and relevant stimuli



➔Recovery of overt consciousness and of functional communication

Multimodality for DoC patients neuropronostication

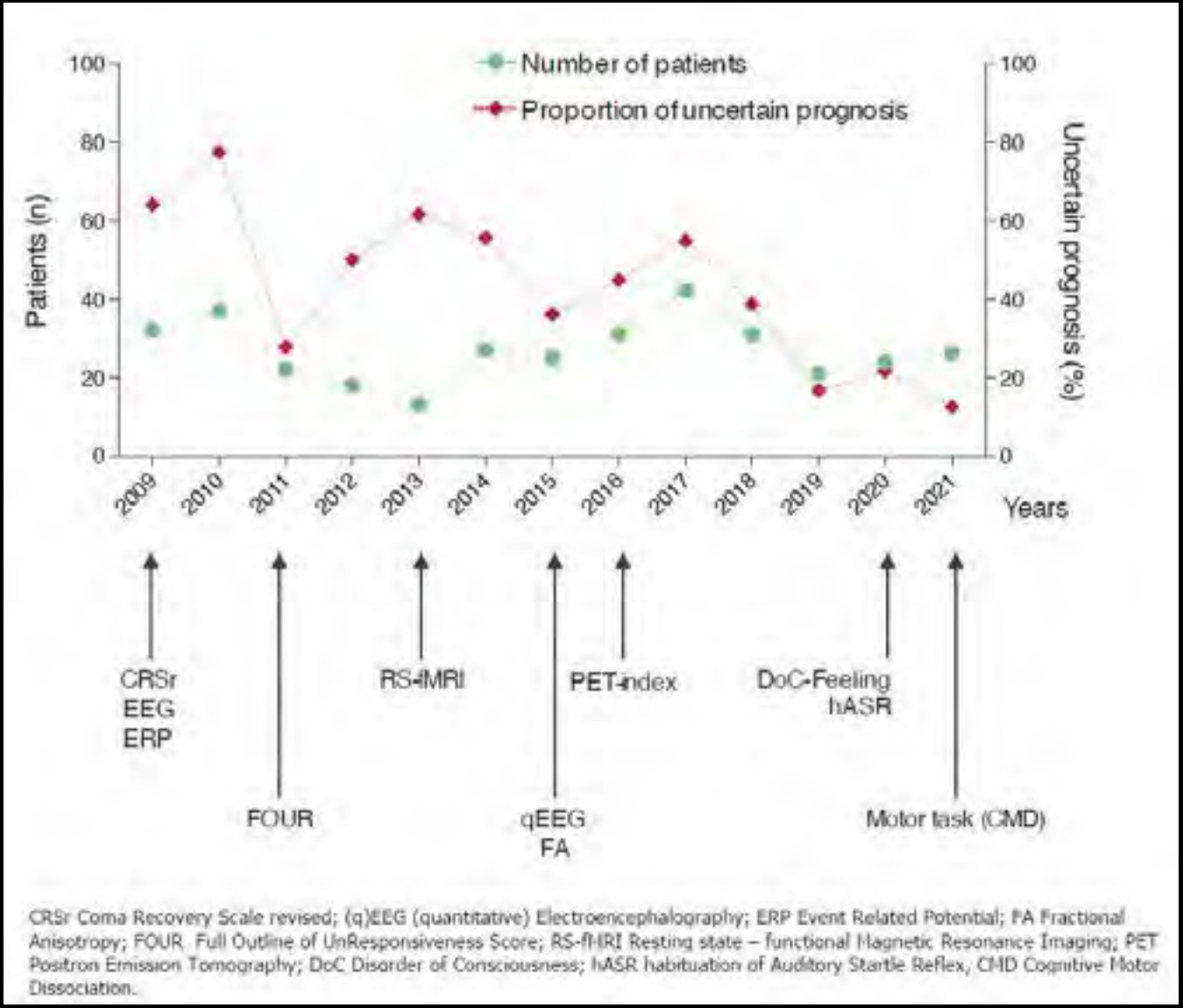
Rohaut, Calligaris, … Sitt & Naccache, *Nature Medicine 2024*

Predicting 'Poor' vs 'Good' outcome

GOS 5-point scale	GOSE 8-point scale	Domain	Criteria
Dead	***1. Dead***		
Vegetative State	***2. Vegetative State***	Consciousness	
Severe Disability (SD)	***3. Lower SD***	Function in home	Unable to look after themselves for 8 hours
Conscious but dependent	***4. Upper SD***	Function in home Function outside the home	Unable to look after themselves for 24 hours OR Unable to shop OR Unable to travel
Moderate Disability (MD) Independent but with limitations in one or more activities	***5. Lower MD***	Work/ study Social & leisure activities Family & friendships	Unable to work/ study OR Unable to participate OR Constant problems
	6. Upper MD	Work Social & leisure activities Family & friendships	Reduced work capacity OR Participate much less OR Frequent problems
Good Recovery (GR) Return to normal life	***7. Lower GR***	Social & leisure activities Family & friendships Symptoms	Participate a bit less OR Occasional problems OR Some symptoms affecting daily life
	8. Upper GR		No problems

Rohaut, Calligaris, … Sitt & Naccache, *Nature Medicine 2024*

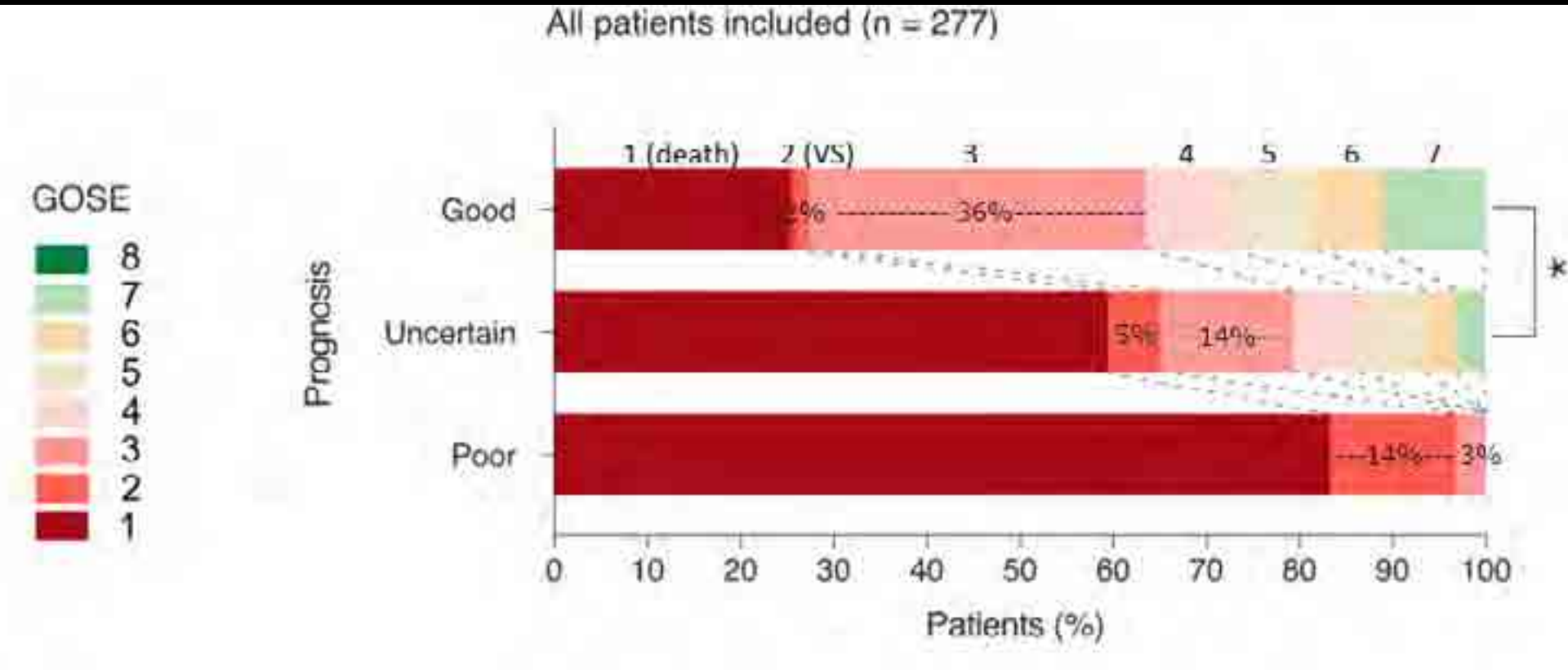
Multimodality improves neuropronostication



CRSr Coma Recovery Scale revised; (q)EEG (quantitative) Electroencephalography; ERP Event Related Potential; FA Fractional Anisotropy; FOUR Full Outline of UnResponsiveness Score; RS-fMRI Resting state – functional Magnetic Resonance Imaging; PET Positron Emission Tomography; DoC Disorder of Consciousness; hASR habituation of Auditory Startle Reflex; CMD Cognitive Motor Dissociation.

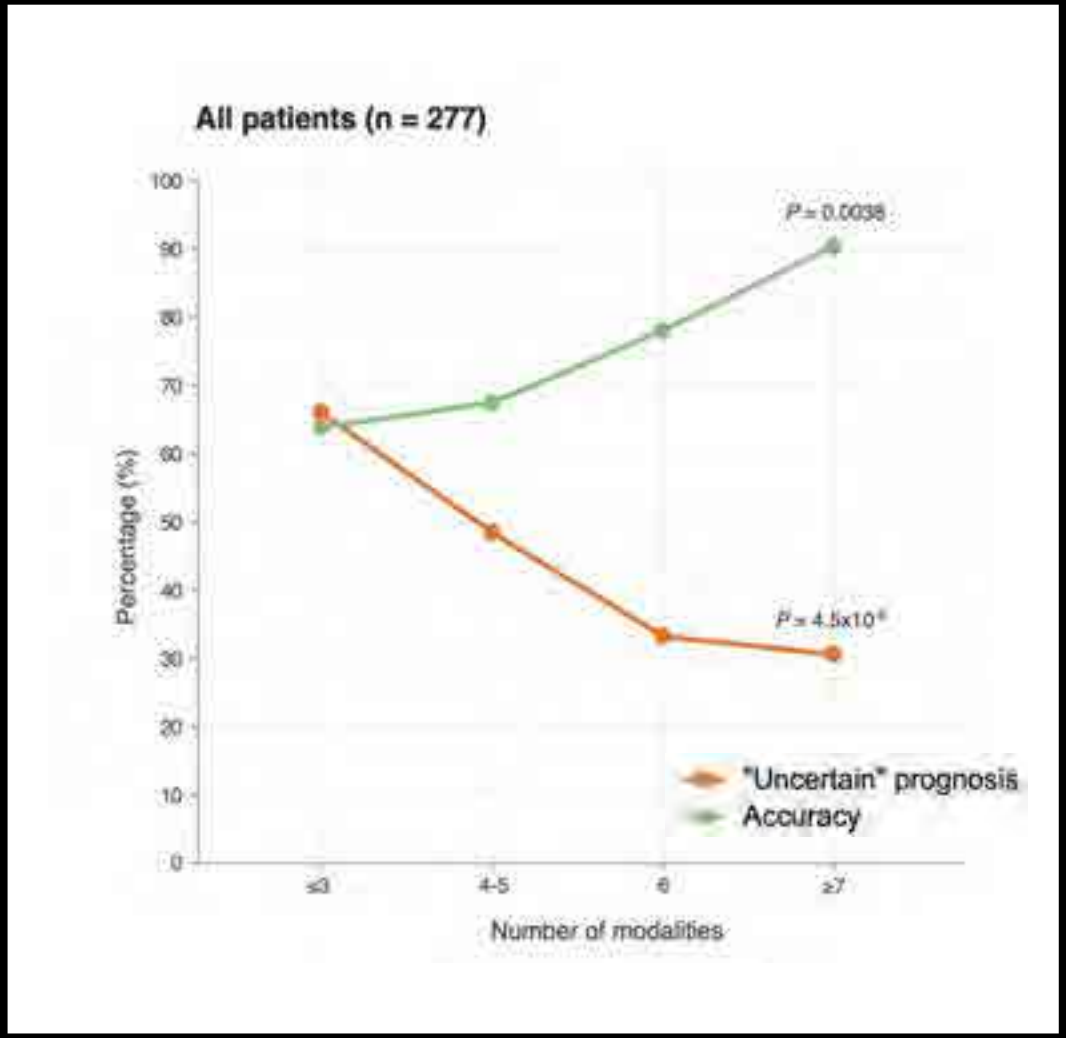
Rohaut, Calligaris, … Sitt & Naccache, *Nature Medicine 2024*

Outcome prediction is possible



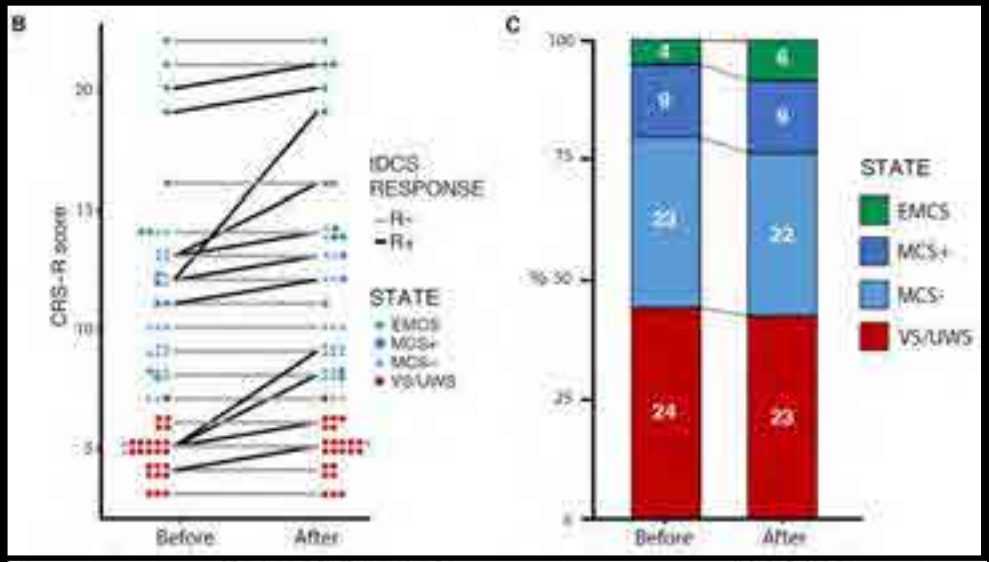
Rohaut, Calligaris, … Sitt & Naccache, *Nature Medicine 2024*

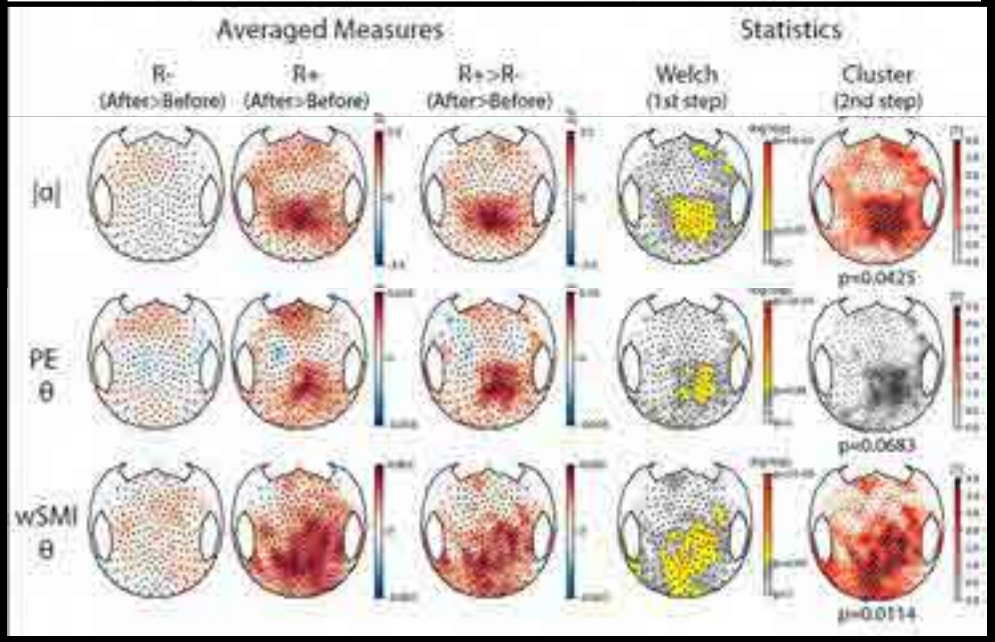
Outcome prediction precision increases with multimodality

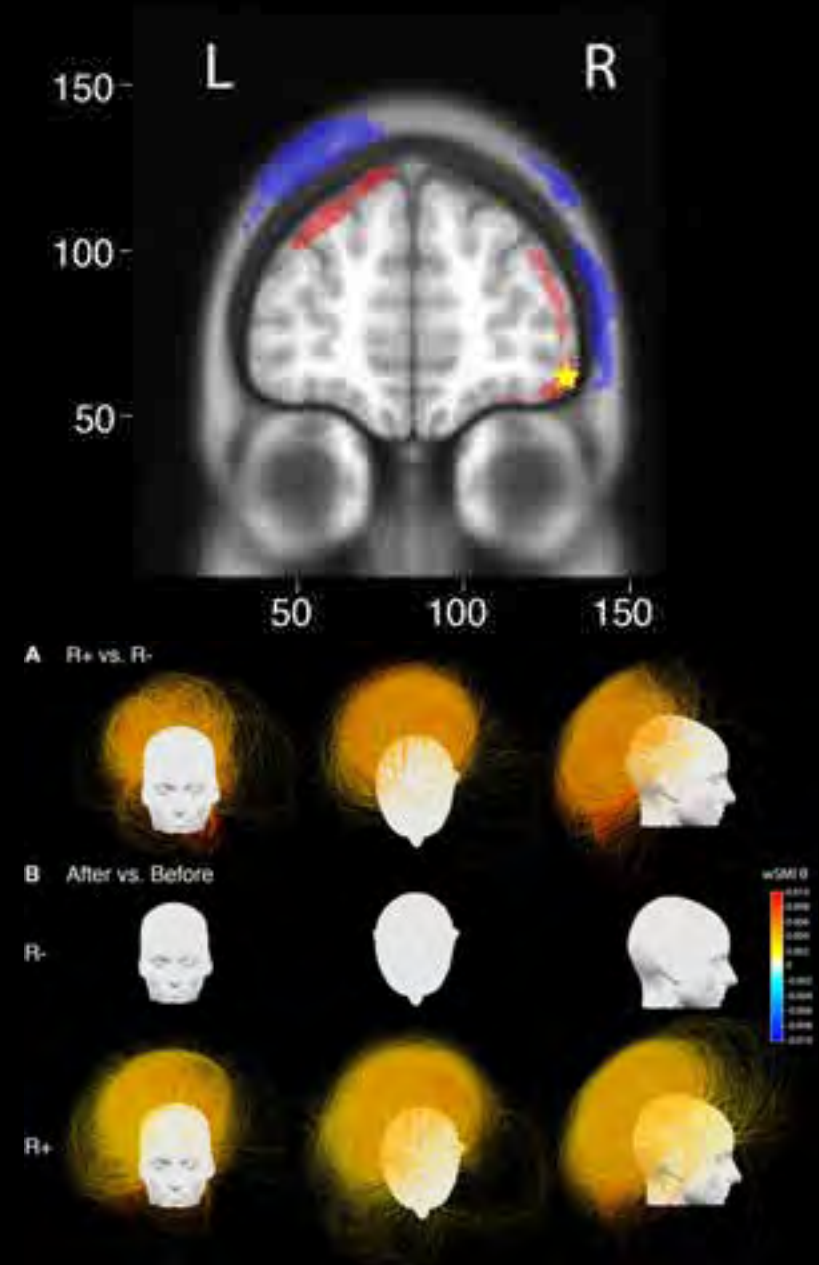


Rohaut, Calligaris, … Sitt & Naccache, *Nature Medicine 2024*

Improving conscious states through DLPFC tDCS

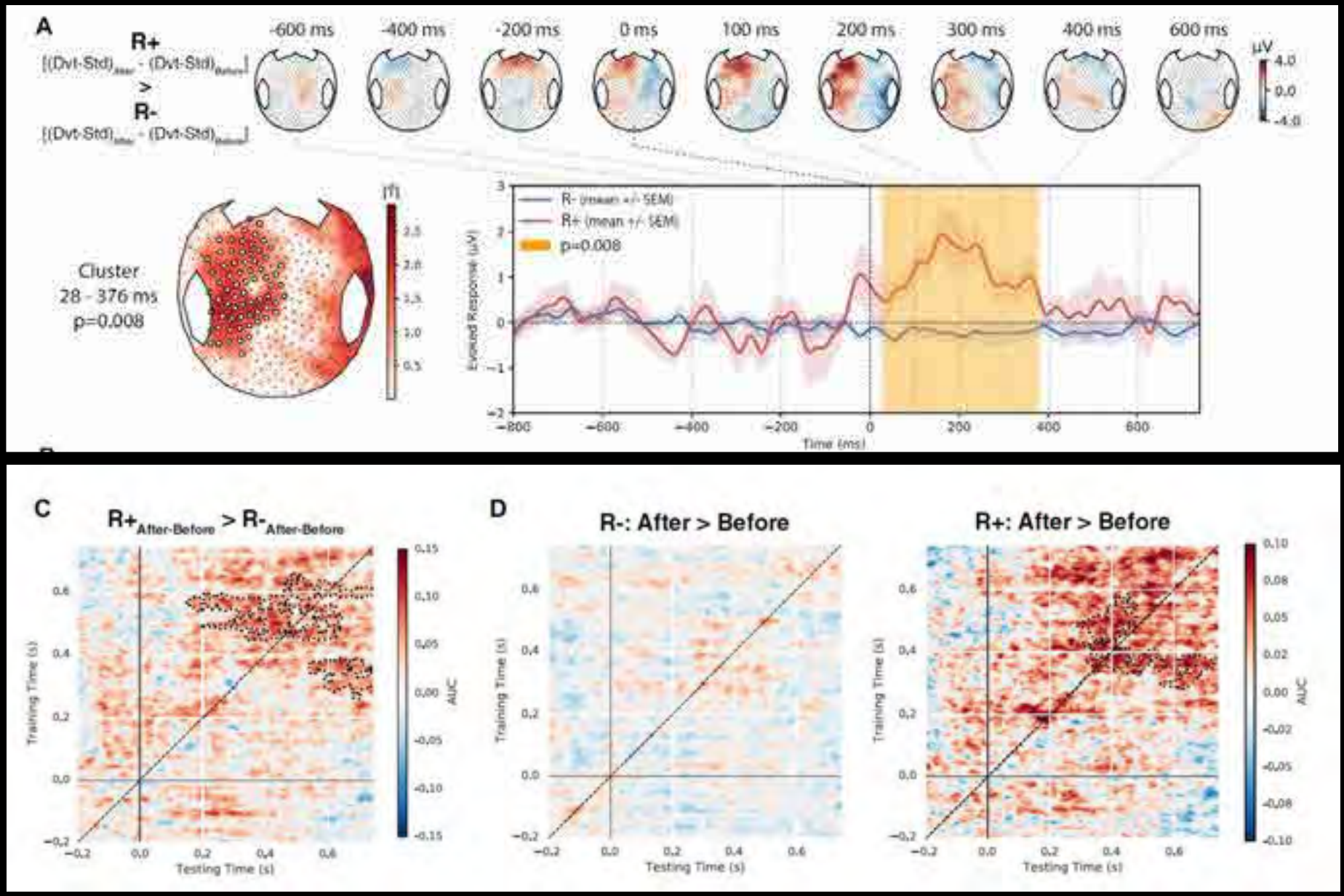






Hermann,… & Naccache, Sci. Rep. 2020
Sangare, … & Naccache, under revision

Improving conscious access with tDCS



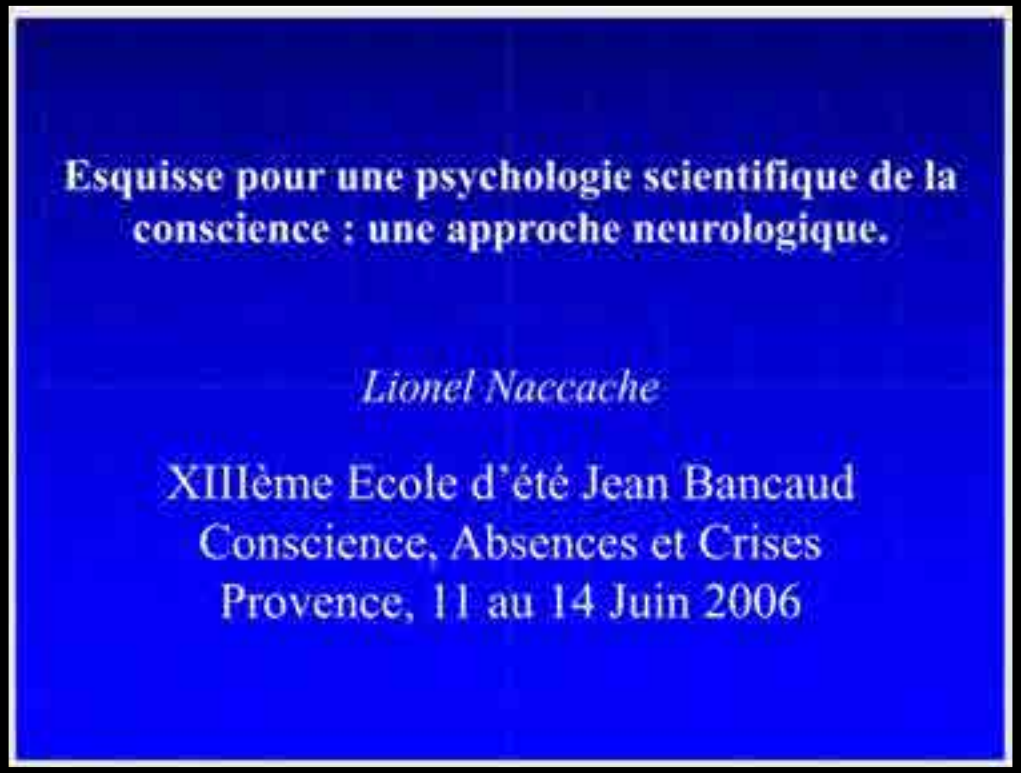
Hermann,… Naccache, Sci. Reports 2020

➔Consciousness requires a complex and coherent long-distance connectivity

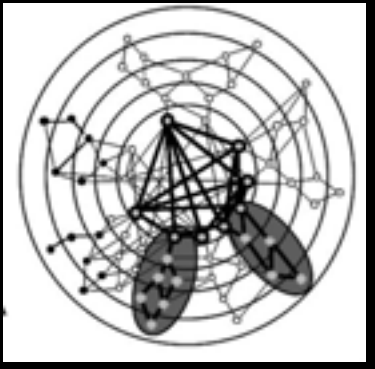
. Loss of consciousness due to an excess of connectivity with a loss of complexity and differentiation

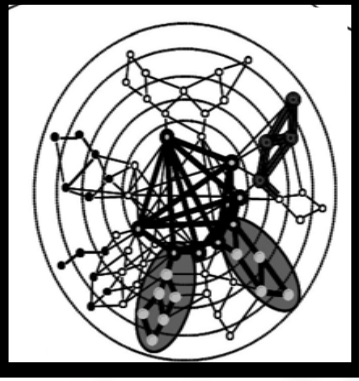
➔Complex partial & Absence epileptic seizures

Almost 20 years ago … June 2006 !
Abbaye Saint Maximin

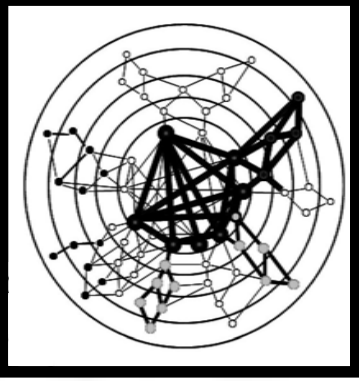


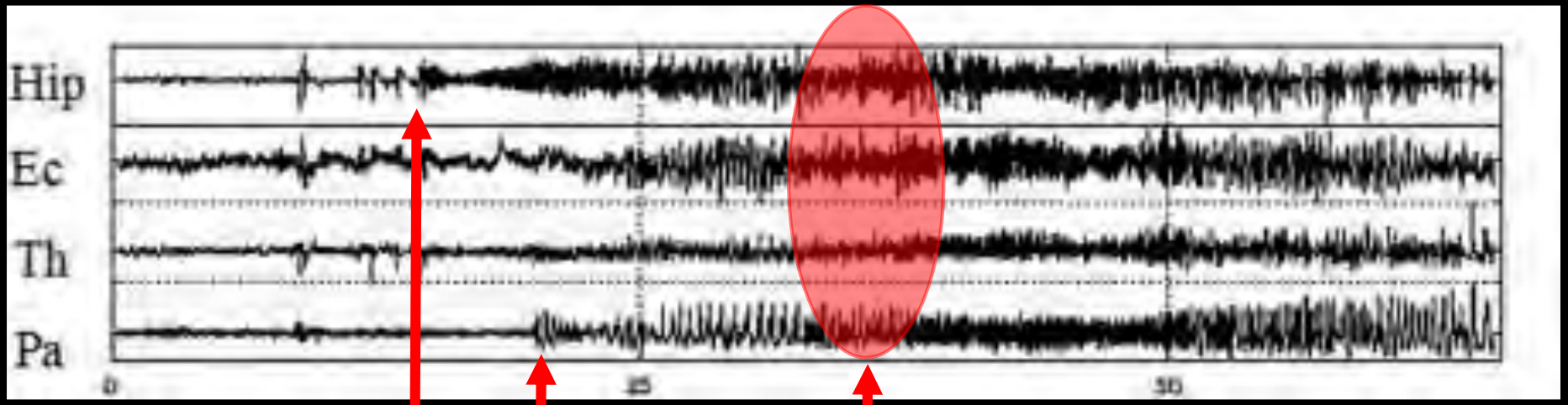
GNWT Prediction :
transition from partial simple seizure (CS) to complex seizure (LOC) should correspond to the epileptic ignition of GNW





Loss of consciousness





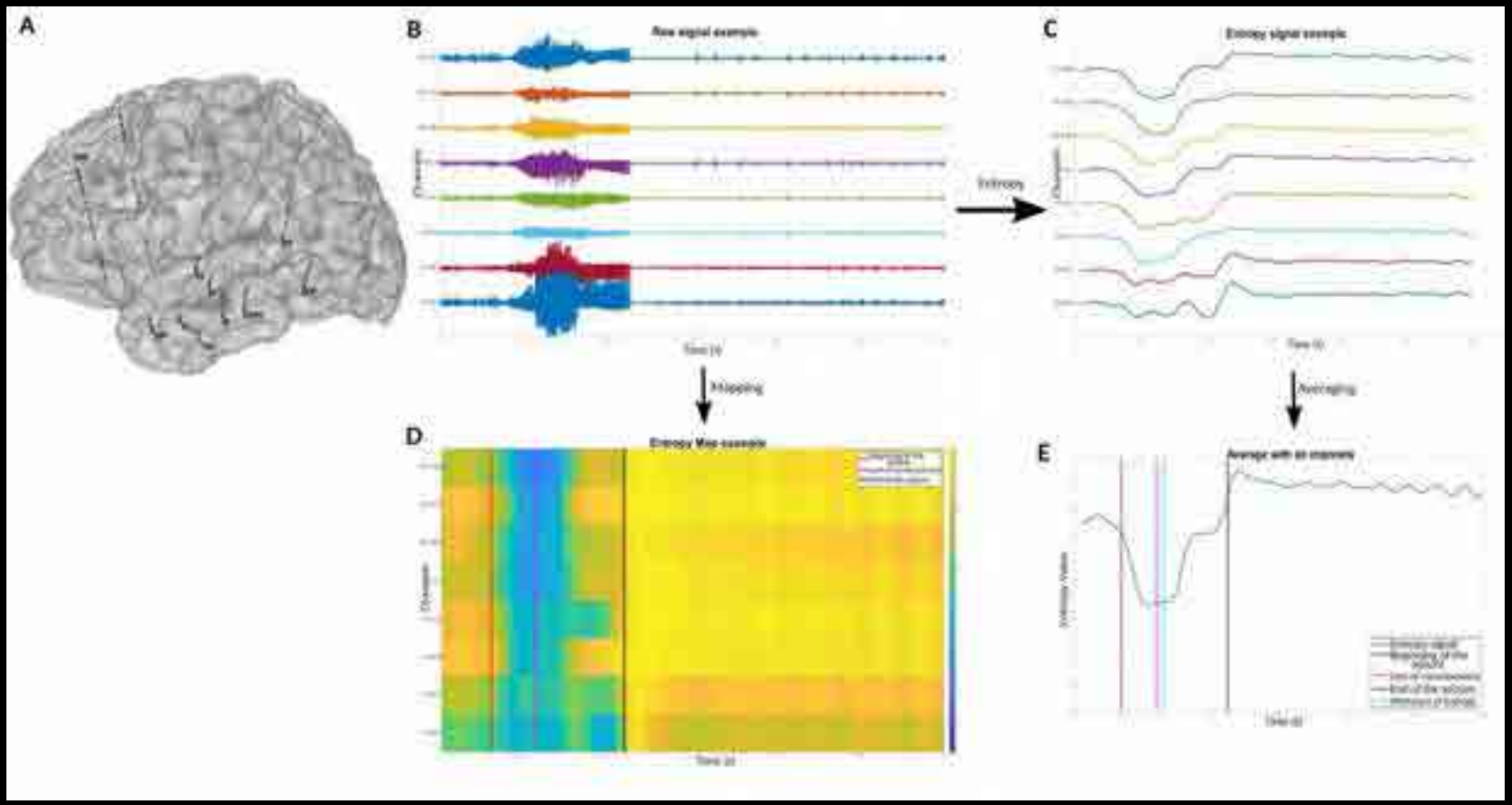
Seizure onset in a local brain circuit

Seizure propagates to other brain circuits

Seizure reaches the conscious global workspace

Arthuis,… Naccache, Bartolomei, Brain 2009
Bartolomei & Naccache, Behav. Neurol. 2011

Epileptic loss of consciousness is associated to a decrease of SEEG complexity within GNW areas



"The loss of signal complexity was diffuse, extending bilaterally and to the associative cortices, in patients with profound alteration of awareness and limited to the temporal mesial structures in patients with no alteration of awareness."

El Youssef, … Naccache, Bénar & Bartolomei, Sci. Rep. 2023

➔Window of FC for a conscious GNW

Too low GNW FC => No global availability & low GNW complexity :VS/UWS

Optimal FC : functional GNW with differentiation of processors => conscious state

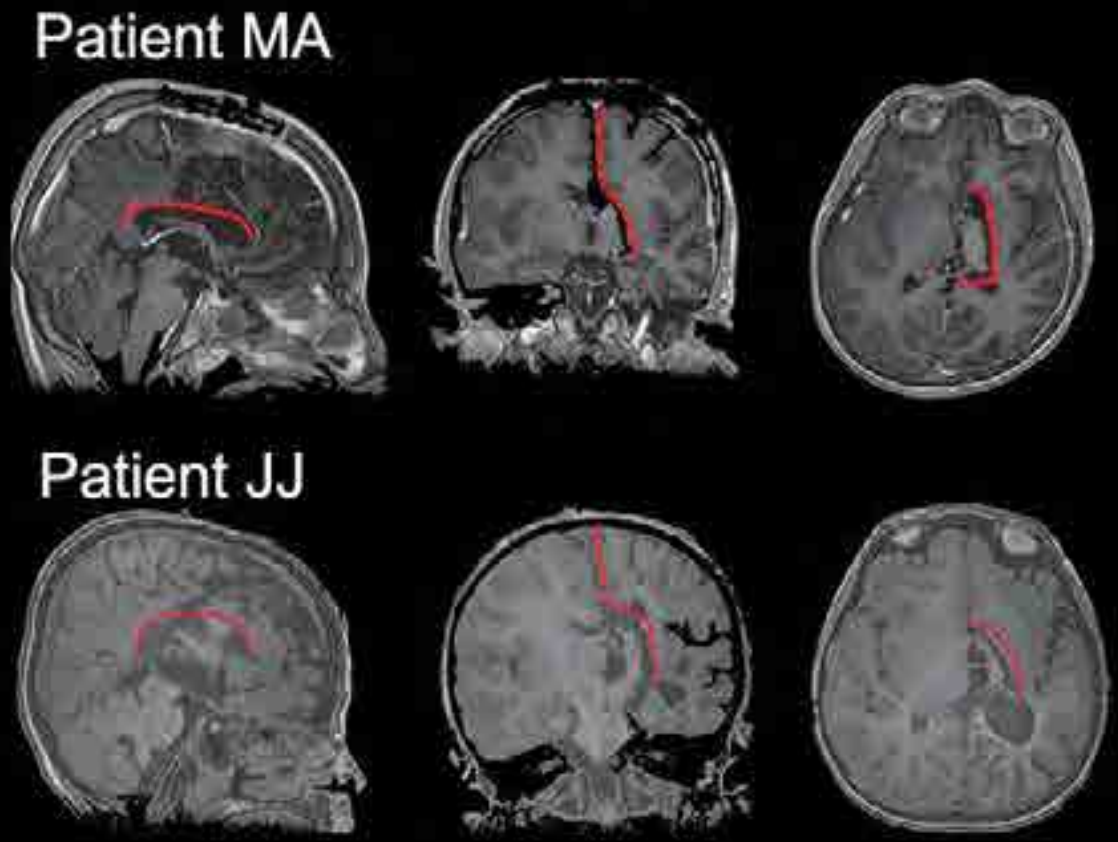
Too high GNW FC => low GNW complexity : Epileptic LOC

➔ **Critical windows of FC & Complexity**

➔ **Other CS states at the edge** (FC/Complexity)? **Psychedelics? Hypnosis? REM? LREM? …**

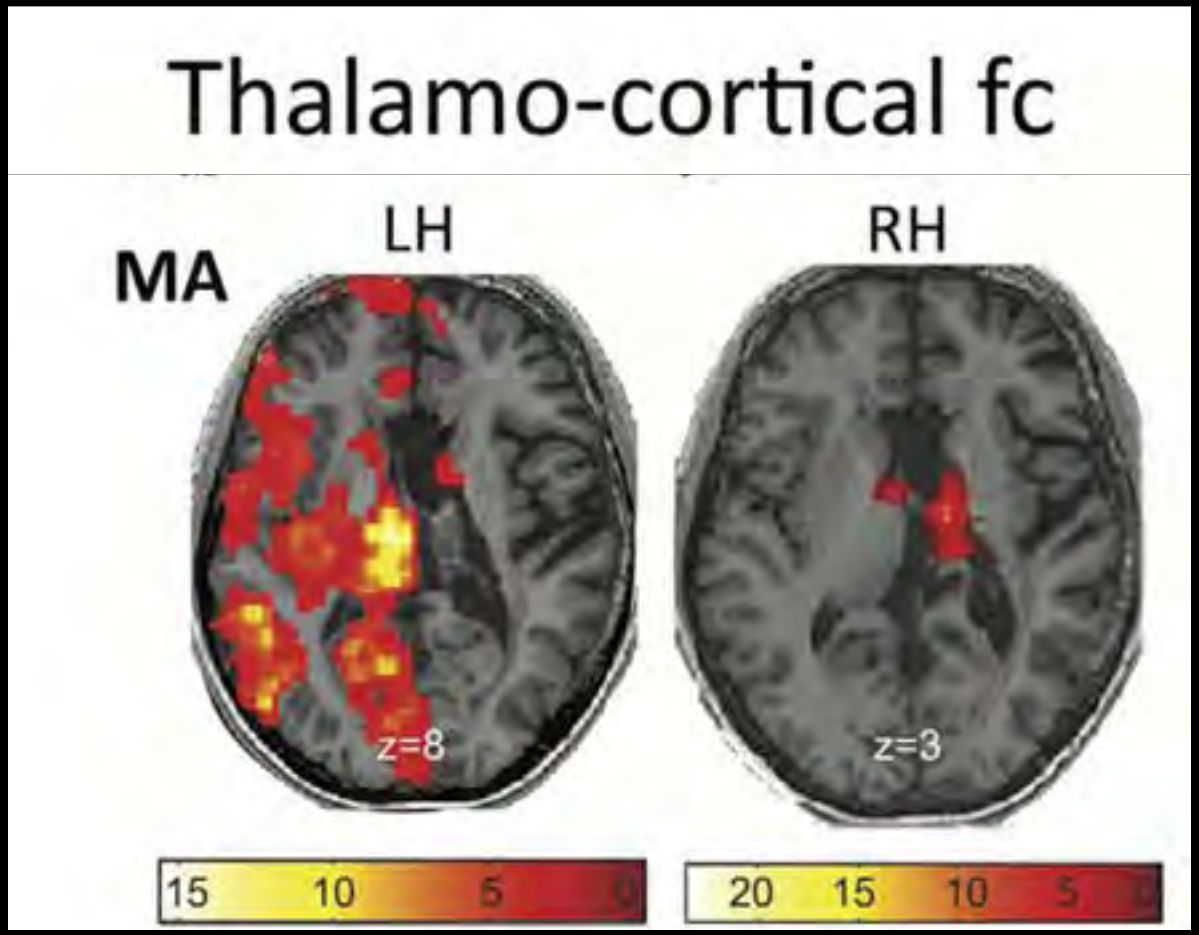
What is the minimal size of a GNW?

. One hemisphere seems enough (split-brain patients)
. Thalamo-cortical architecture required : the case of 'hemispherotomy'



Blauwblomme, Demertzi et al., Epilepsia Open 2020

Another demonstration of thalamus importance for conscious state through hemispherotomy model



Blauwblomme, Demertzi et al., Epilepsia Open 2020

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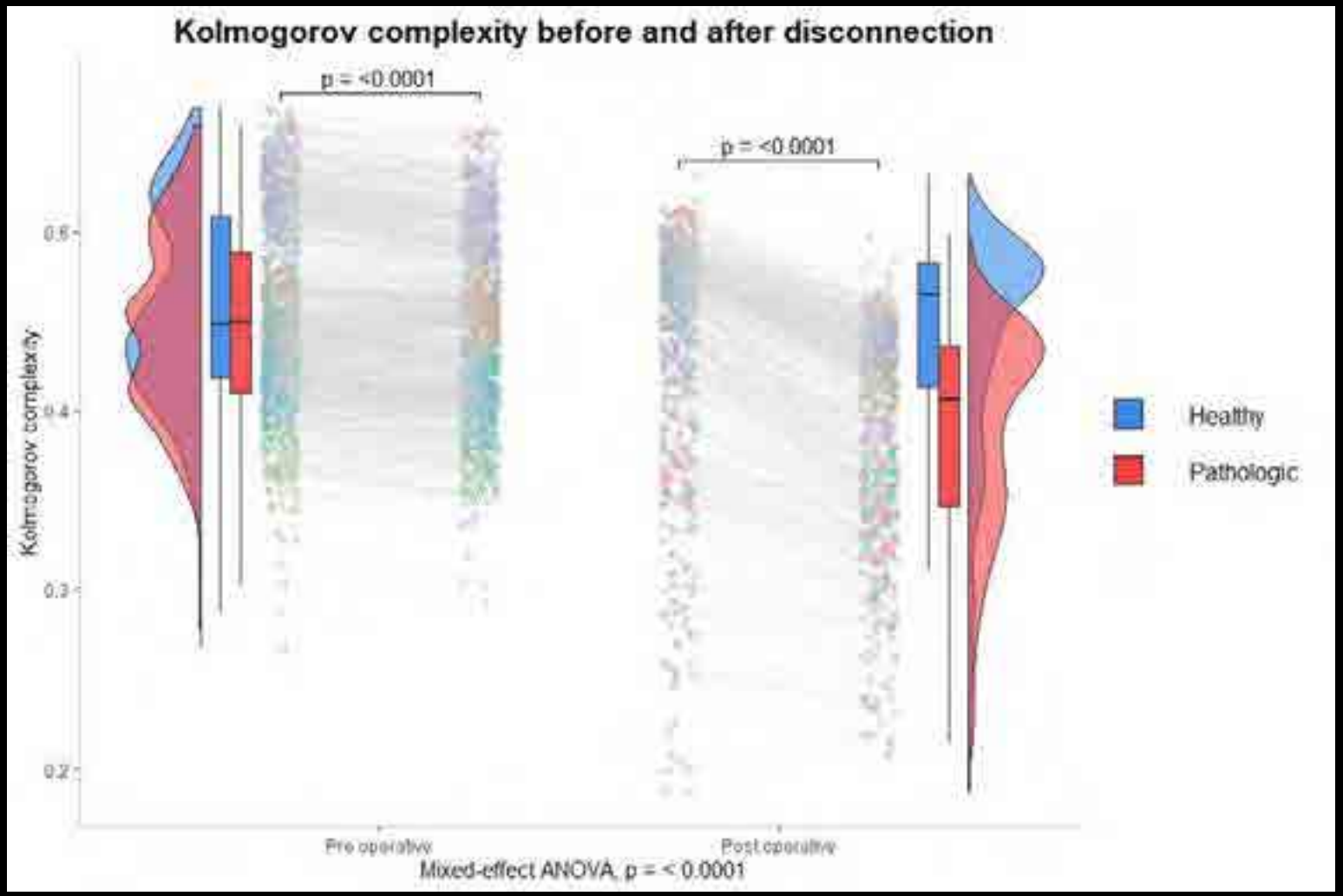


Caudron, … & Naccache, ms in preparation

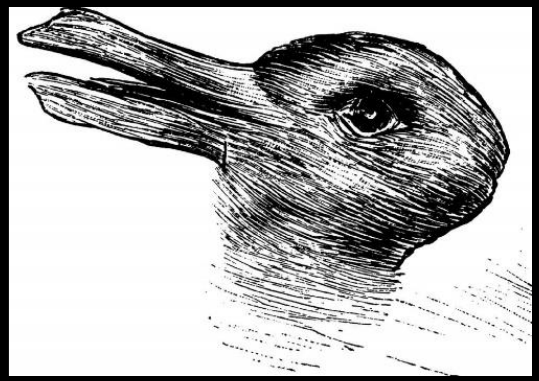
Global Neuronal Workspace

- ***Synthetic résumé of GNW framework***
- ***Questions/Ideas about conscious access***
- ***Questions /Ideas about conscious state***
  with a strong focus on disorders of consciousness
- ***Questions/Ideas about conscious stream***

Conscious stream as an 'Inner Cinema'

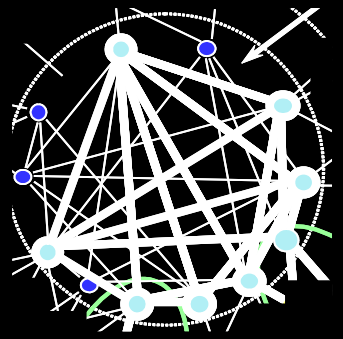
(not a dualistic Cartesian theater ☺)

***At any moment, a single complex representation occupies our* GNW !**



"We have only one thought of the same thing at the same time" *Descartes (Passions of the soul, 1649)*

The mechanism of conscious access: Top-down amplification and *all-or-none* ignition



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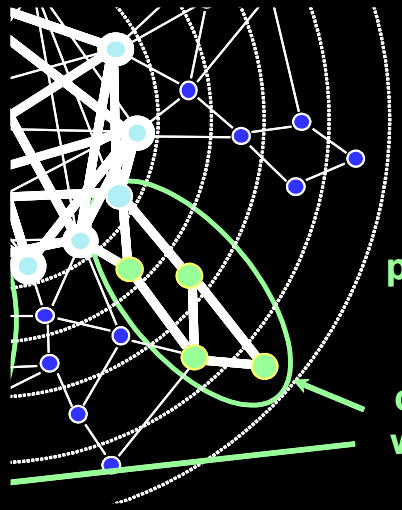


processors mobilized into the conscious workspace

Dehaene & Naccache, Cognition 2001

➔ CONSCIOUS STREAM AS A SUCCESSION OF DISCRETE CONTENTS SUBJECTIVELY EXPERIENCED AS A CONTINUUM

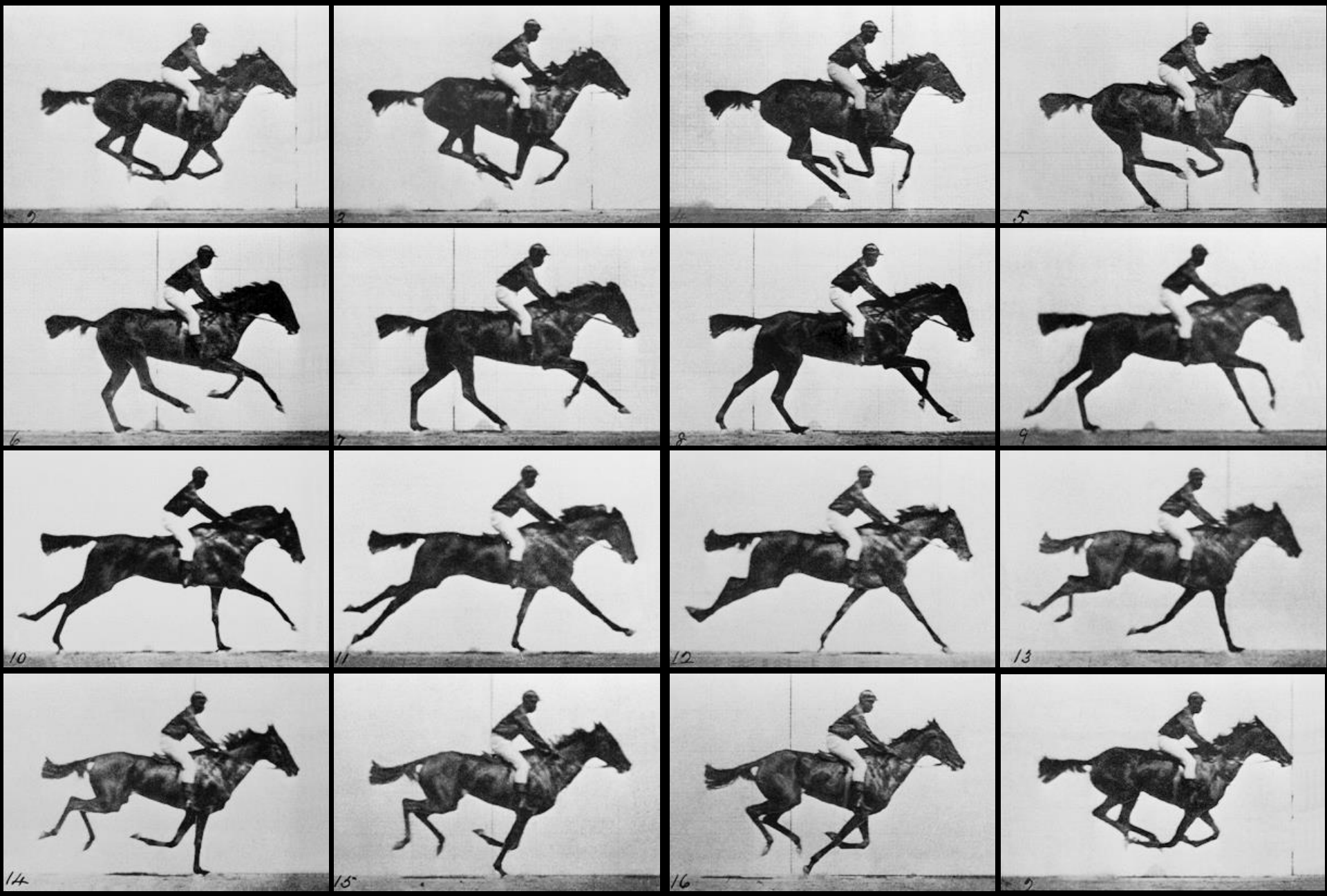
Naccache, Le Cinéma intérieur (2019)
Naccache, Apologie de la discrétion (2022)

MÉLIÈS

LA MAGIE DU CINÉMA

LA CINÉMATHÈQUE FRANÇAISE

FLAMMARION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Proc. Natl. Acad. Sci. USA
Vol. 93, pp. 3693–3697, April 1996
Neurobiology

The wagon wheel illusion in movies and reality

(perception/vision/time/stroboscopic presentation/rotation)

DALE PURVES*, JOSEPH A. PAYDARFAR, AND TIMOTHY J. ANDREWS

Department of Neurobiology, Duke University Medical Center, Durham, NC 27710

Contributed by Dale Purves, December 15, 1995

Purves et al. PNAS 1996
Van Rullen & Koch, TICS 2003

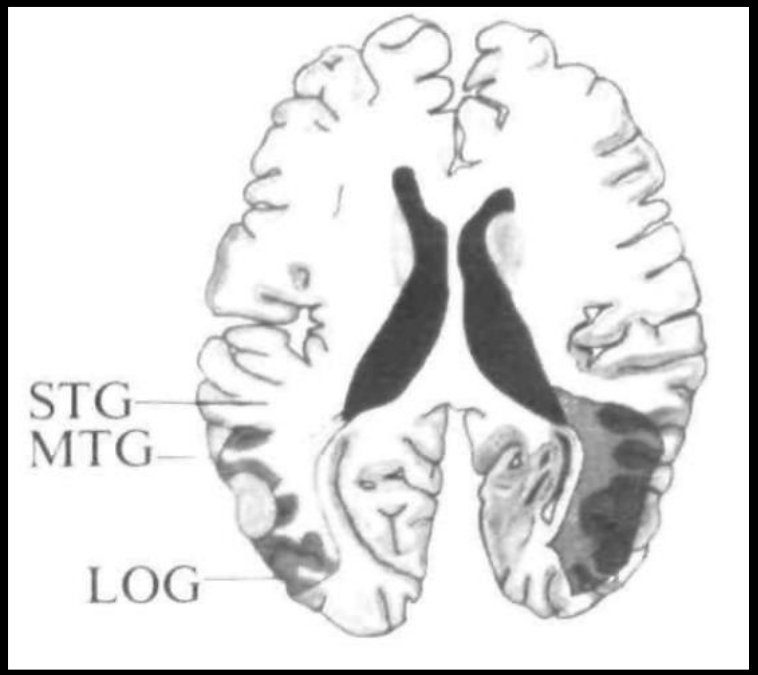
Akinetopsia reveals our 'Inner Cinema' by its perturbations

Brain (1983), **106**, 313–340

SELECTIVE DISTURBANCE OF MOVEMENT VISION AFTER BILATERAL BRAIN DAMAGE

by J. ZIHL, D. VON CRAMON *and* N. MAI

(*From the Max-Planck-Institut für Psychiatrie, Kraepelinstrasse 10, D-8000 München 40, FRG*)

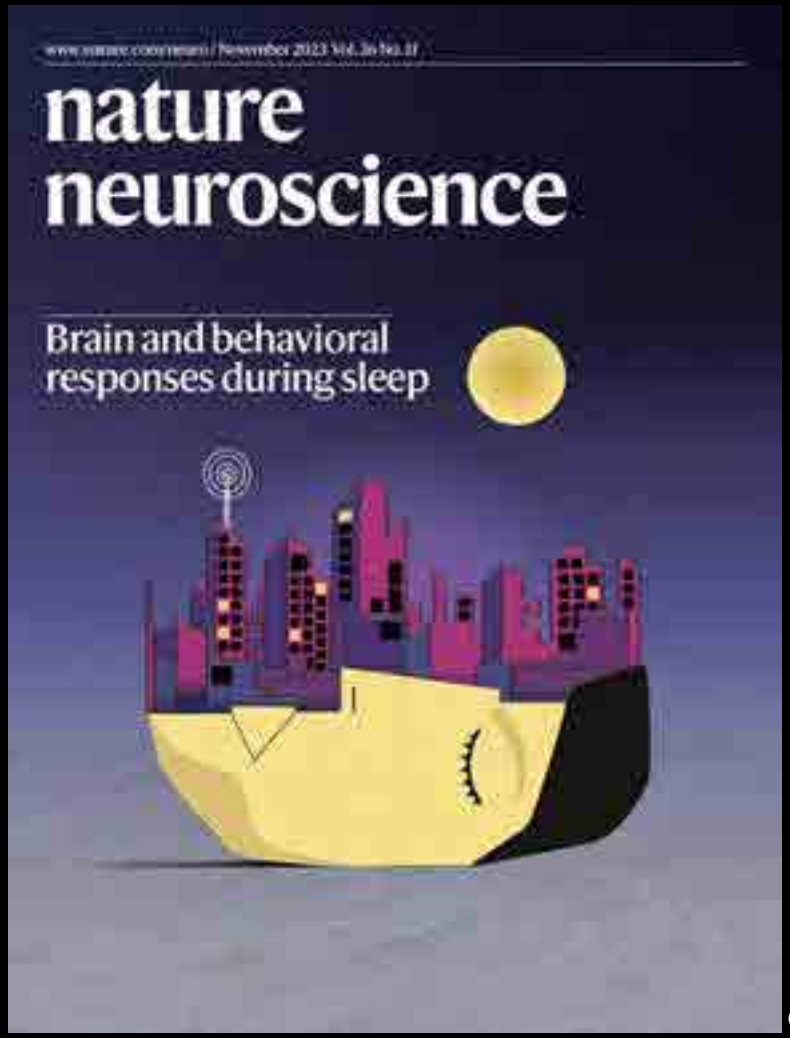


Temporal mosaic of conscious & unconscious states wakefulness?

during conscious wakefulness, a form of high-level filling-in process may join discrete conscious states separated by short periods of unconsciousness into what we subjectively experience as a continuous stream of consciousness.

Naccache, Phil. Trans. Roy. Soc. B 2018

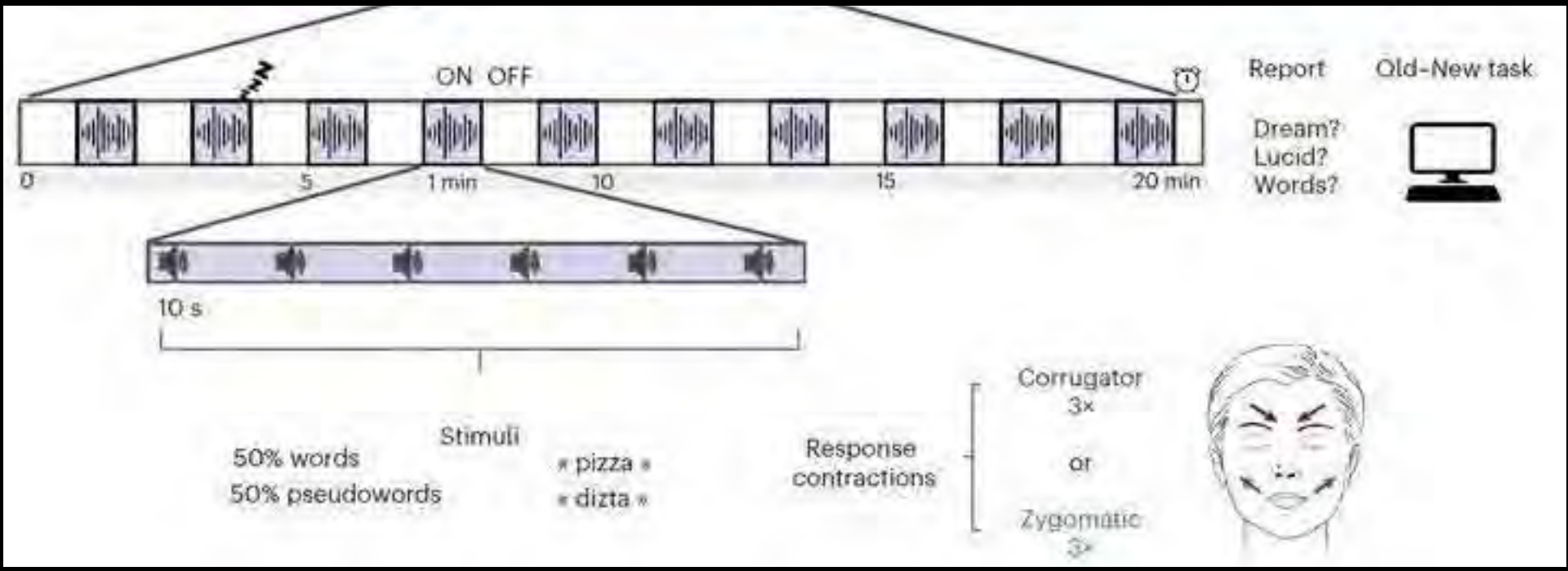
Temporal mosaic of conscious & unconscious states during sleep?



® *Nicolas Decat*

Turker[co-1st], Munoz-Musat[co-1st], Chabani[co-1st]… Naccache[co-last], Arnulf[co-last], Oudiette[co-last] Nature Neuroscience 2023

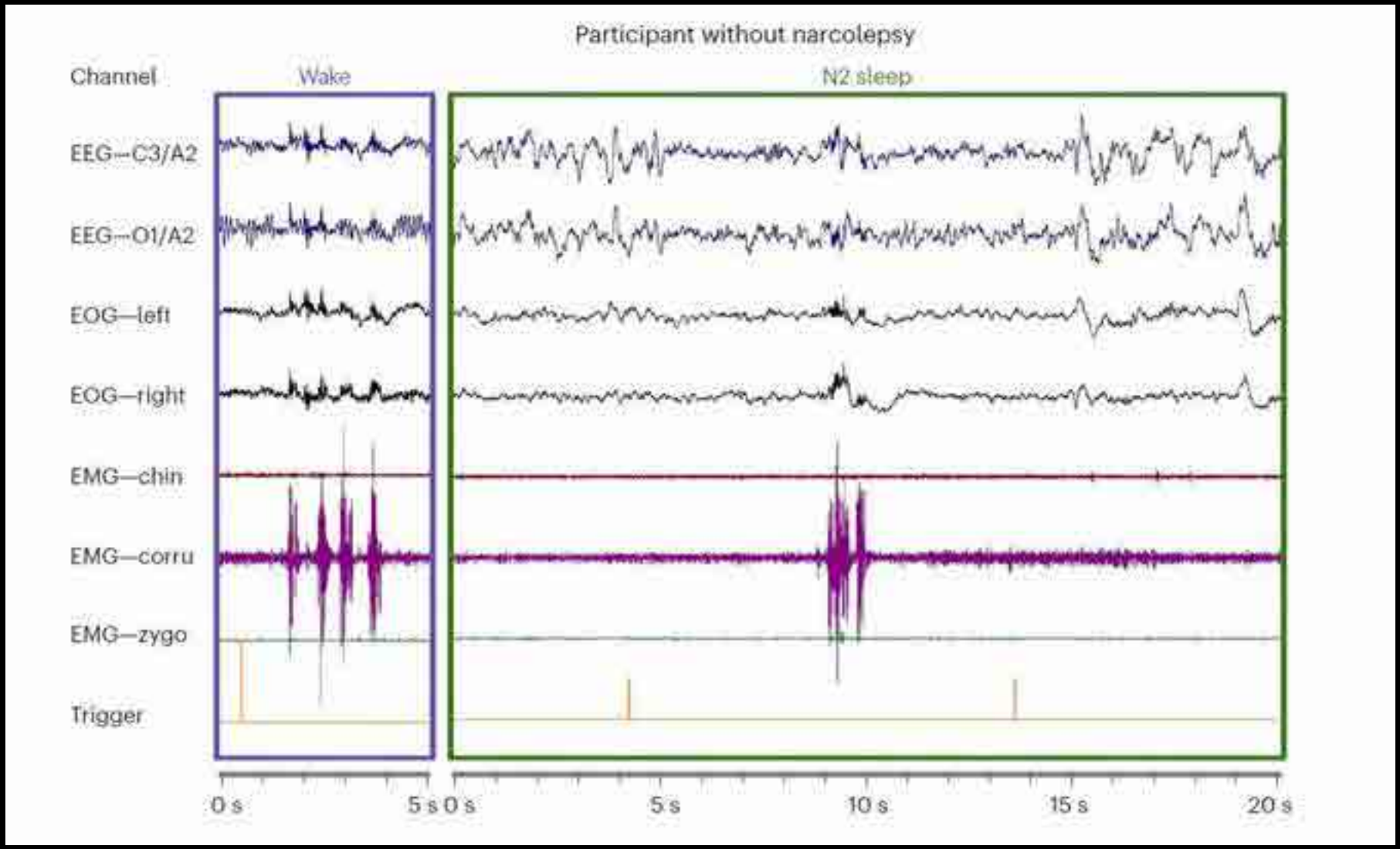
A lexical decision task with a facial motor response code



Turker[co-1st], Munoz-Musat[co-1st], Chabani[co-1st]… Naccache[co-last], Arnulf[co-last], Oudiette[co-last] Nature Neuroscience 2023

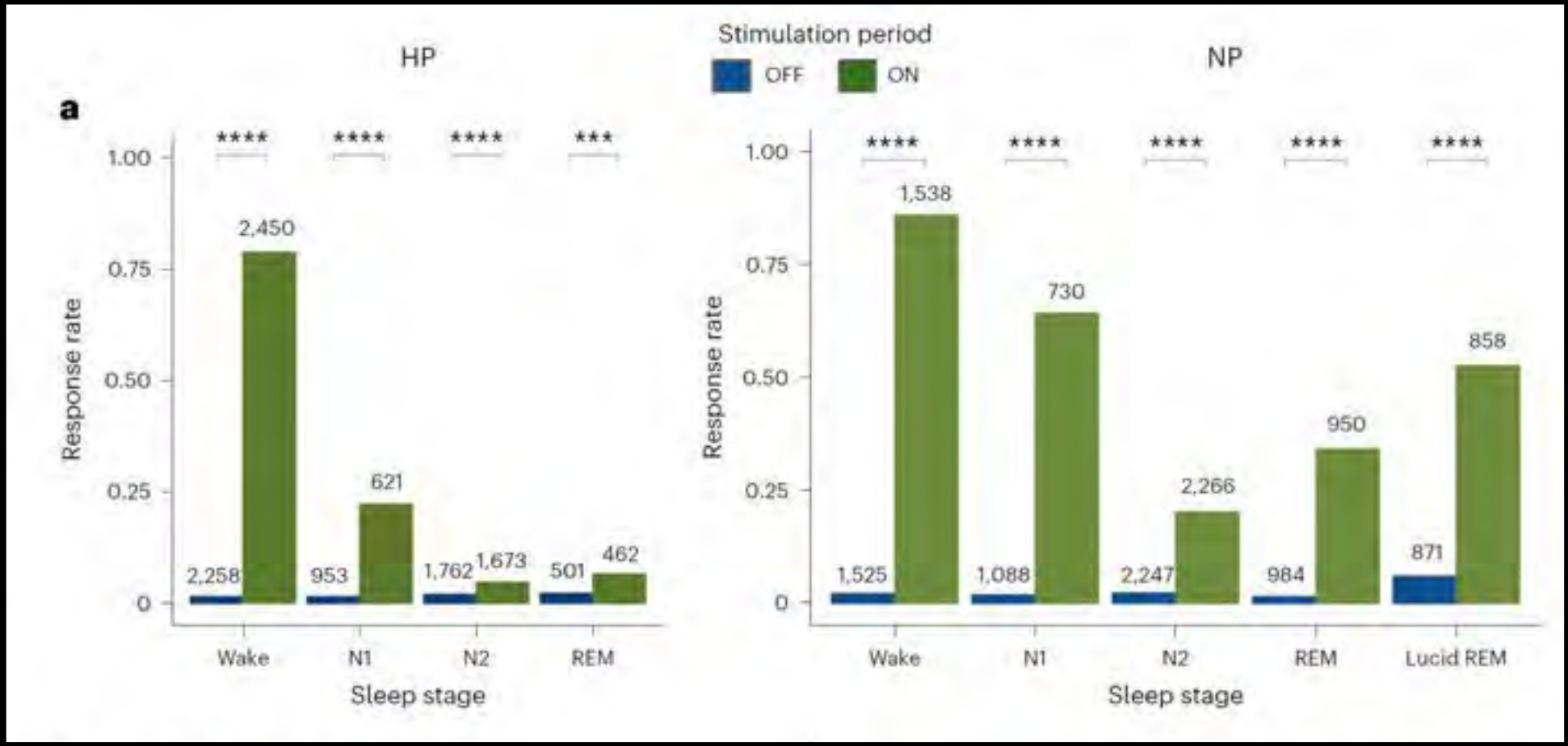
Looking for the presence of conscious voluntary cognitive processes across all sleep stages

A typical trial with a response to stimuli



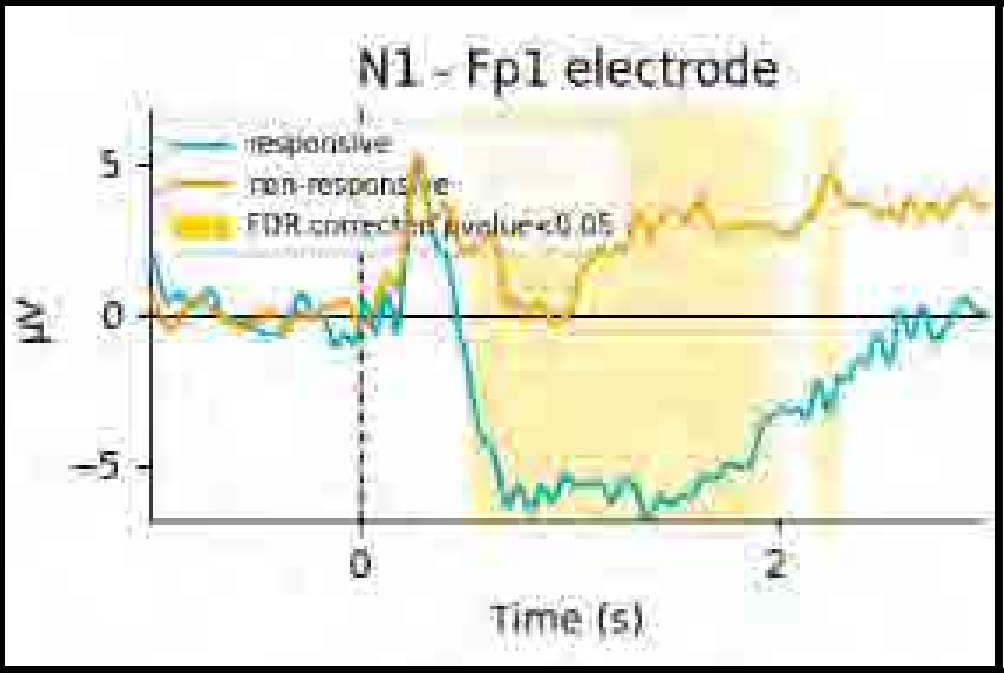
Turker[co-1st], Munoz-Musat[co-1st], Chabani[co-1st]… Naccache[co-last], Arnulf[co-last], Oudiette[co-last] Nature Neuroscience 2023

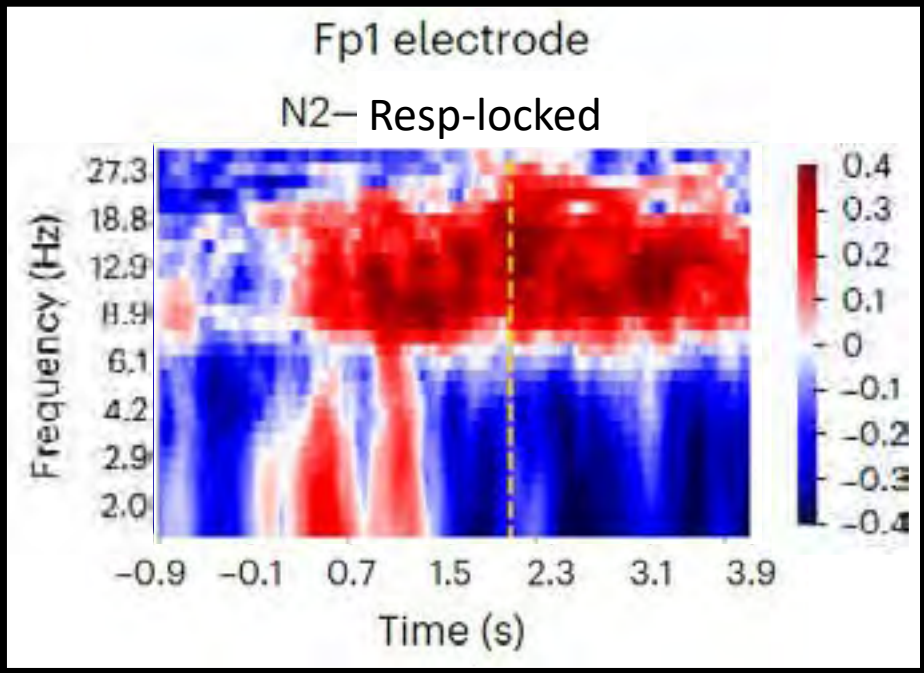
Discovering accurate responses in N1, N2, REM and lucid-REM sleep stages !



Turker[co-1st], Munoz-Musat[co-1st], Chabani[co-1st]… Naccache[co-last], Arnulf[co-last], Oudiette[co-last] Nature Neuroscience 2023

What is the 'neural fate' of responded stimuli as compared to unresponded ones?





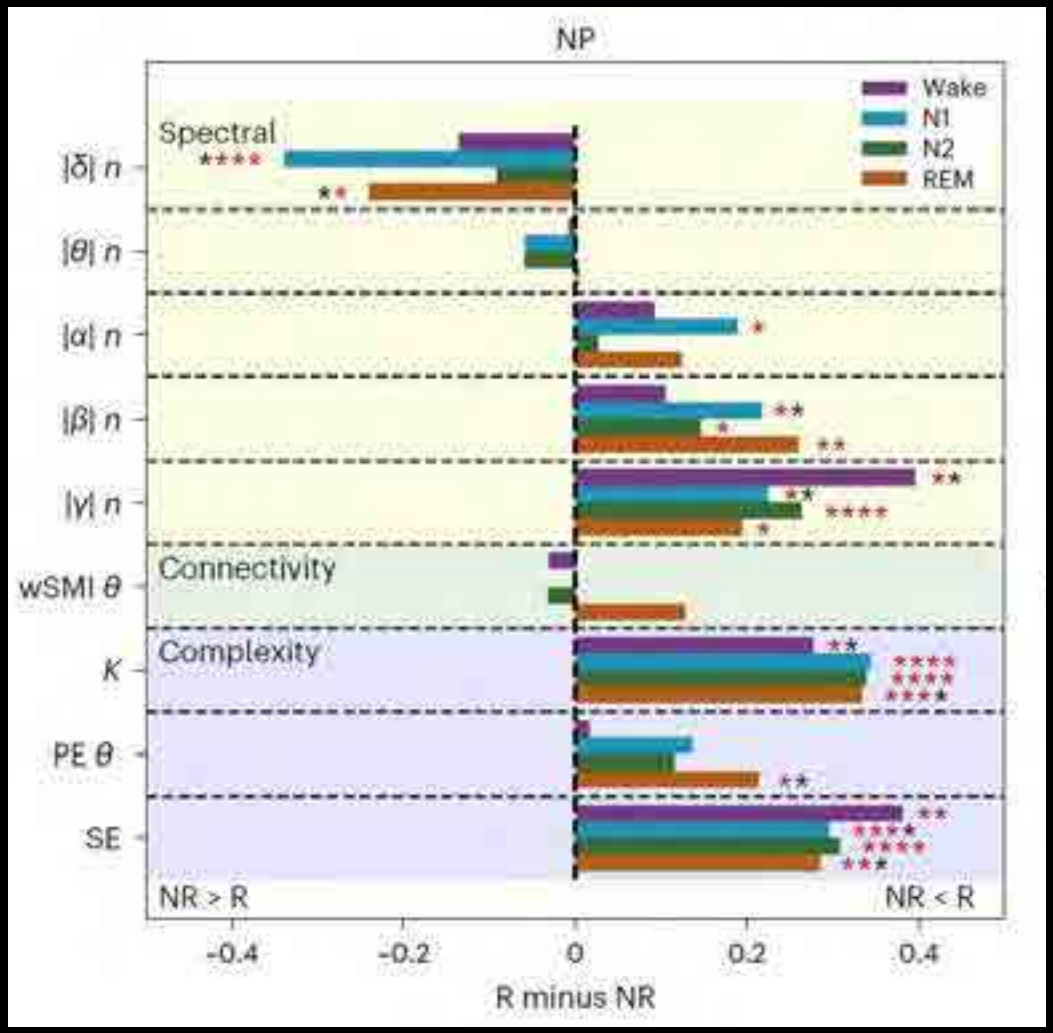
- *Same early cortical processing*
- *Bereitschaftspotential signatures for responded trials only*

Discovering accurate responses in N1, N2, REM and lucid-REM sleep stages !

➔ ***What is the (conscious) status of these responsive periods ?***

Turker[co-1st], Munoz-Musat[co-1st], Chabani[co-1st]… Naccache[co-last], Arnulf[co-last], Oudiette[co-last] Nature Neuroscience 2023

Probing current state immediately prior to stimulus onset : R vs NR

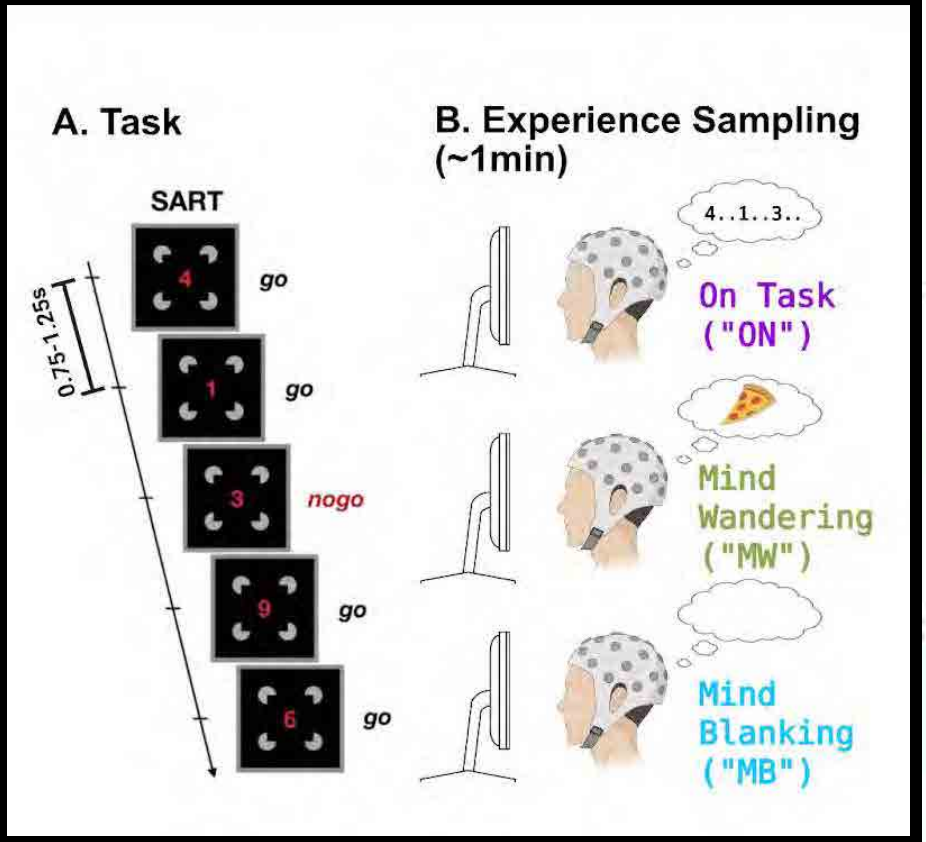


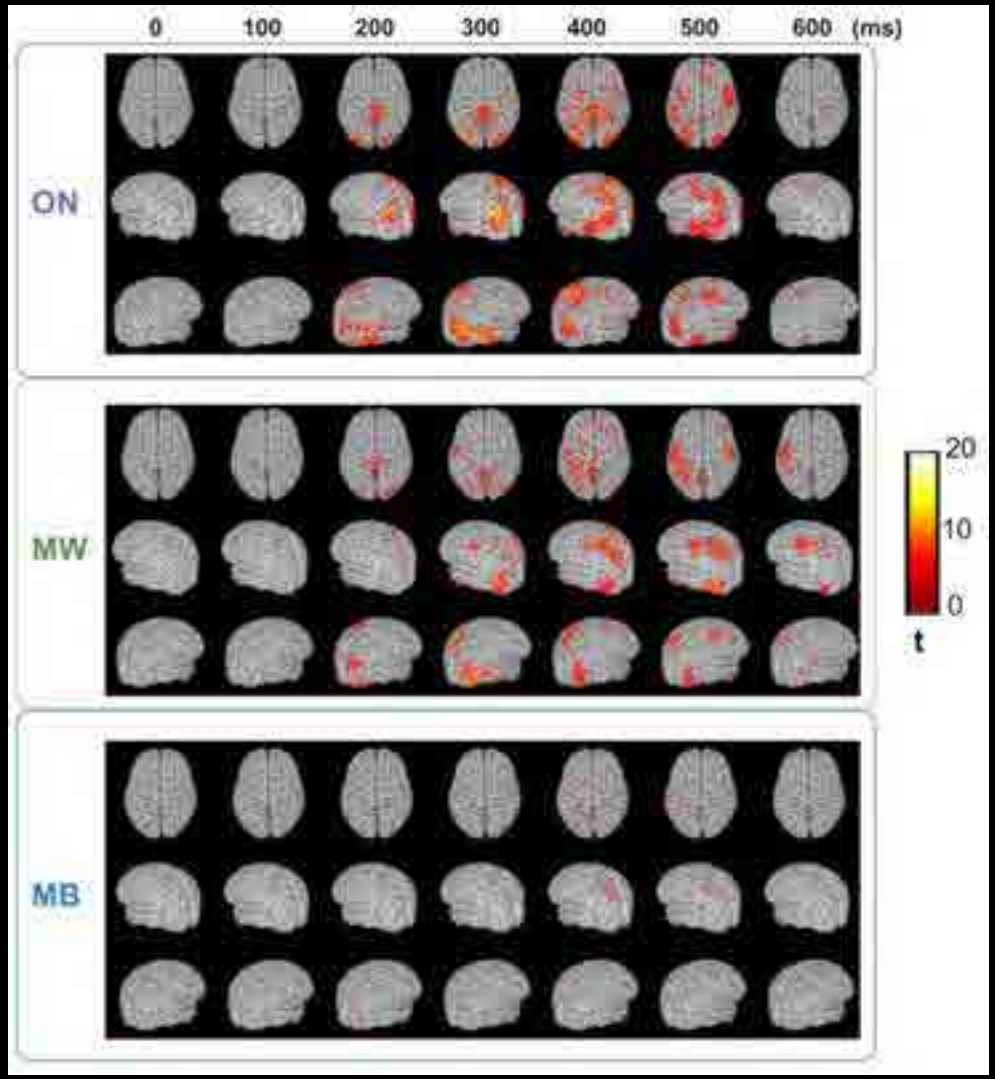
As compared to non responded trials, to be responded trials show:

- ***Low delta power***
- ***High alpha, beta and gamma power***
- ***High-complexity***

➔ Brief moments of conscious state ?

Temporal mosaic of conscious & unconscious states wakefulness?





Munoz-Musat, … Naccache, Andrillon, under revision (listen to Esteban Munoz-Musat's talk ☺)

Mind the blank !

- No conscious access
- Large decrease of GNW FC
- Large decrease of complexity

➔ Brief periods of unconscious state?

What's next ?

Imagining original methods to access the granularity of individual conscious moments without averaging them together or assigning them to a set of predetermined categories.

➔ *Making the 'making-of' of our conscious stream accessible to our own GNWs*

'Thanks!' to the icones of this '*Sperling array*' ☺

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