Cours 2025-2026:

Qu'est-ce que la conscience et quels sont ses mécanismes cérébraux ?

What is consciousness, and what are its neuronal mechanisms?

Stanislas Dehaene
Chaire de Psychologie Cognitive Expérimentale

Cours n°6

Relation entre conscience et mémoire de travail

The relationship between consciousness and working memory

The relations between working memory and consciousness

Short-term memory is the ability to maintain information over time for a few seconds.

Working memory is a short-term memory buffer that allows us to manipulate information mentally.

What are the neural mechanisms of both forms of memory ?

Can both forms operate without consciousness?

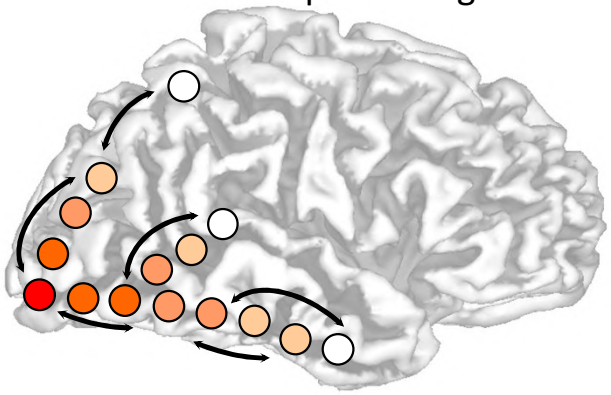
Do subliminal stimuli leave a memory trace?

Is conscious access the gateway to working memory?

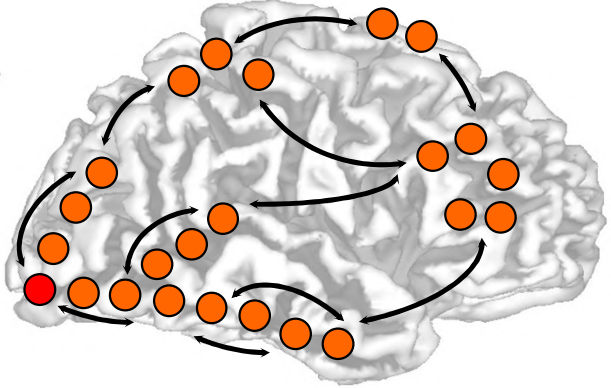
Global workspace predictions :

- A bout of non-linear ignition should be present, even if briefly, whenever conscious perception occurs, even in the absence of a task or working memory (see course 4)
- If needed, this metastable state of GNW activity can be maintained for an arbitrar duration, thus bridging into the working memory period.
- During conscious perception or working memory delay, the **neural code** should allow to faithfully decode the contents of the subject's mind.
- Whenever this neural code becomes inactive and vanishes from the GNW, the representation becomes non-conscious – even it can be restored later : concept of **latent or activity-silent working memory**.

subliminal processing



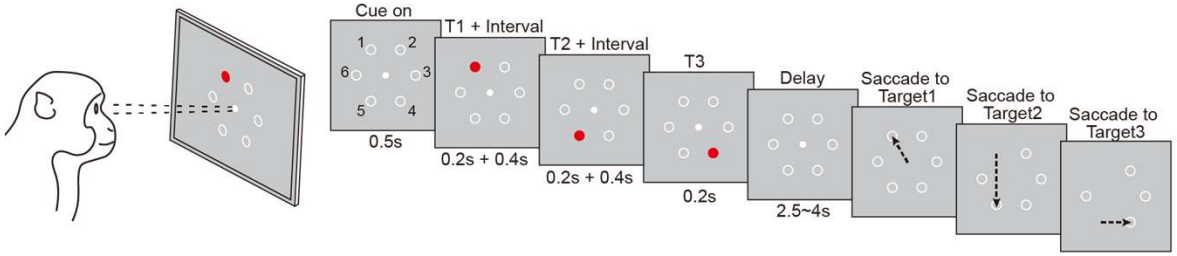
conscious processing

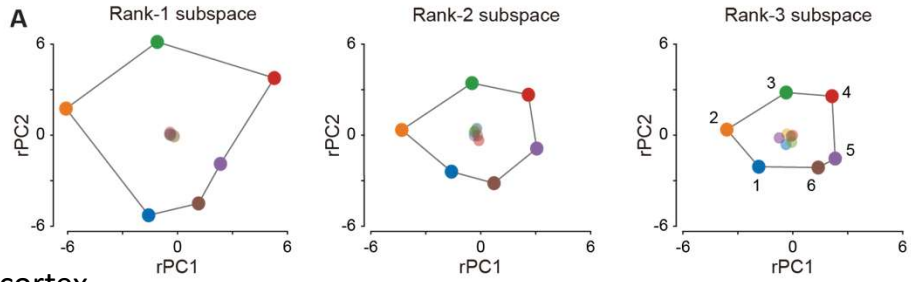


The neural code for spatial working memory in monkeys

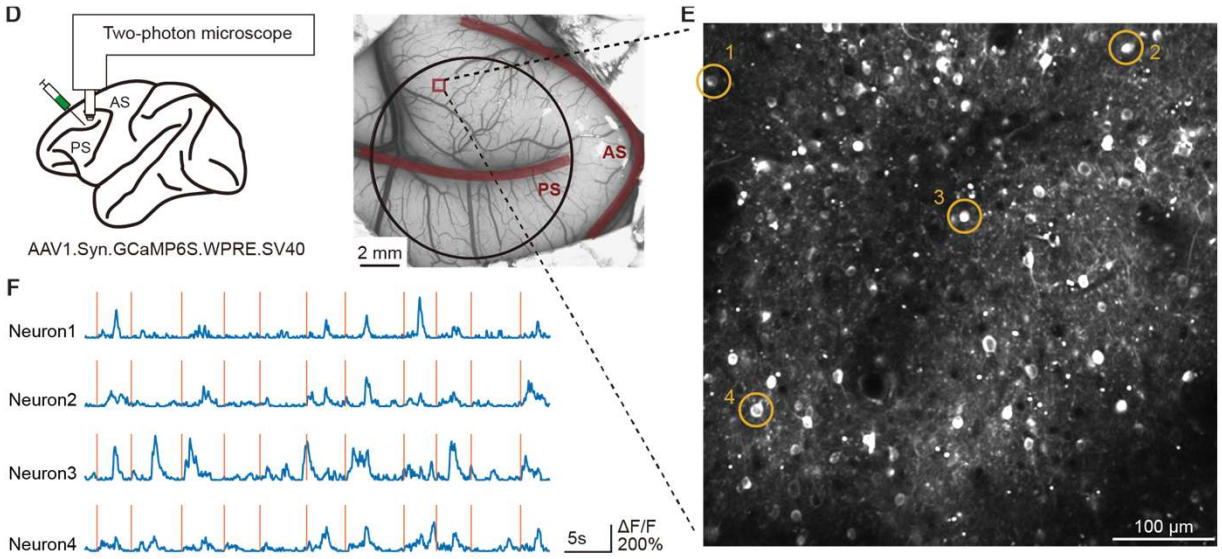
Xie, Hu, Li, Chen, Song, Wang, Yang, Dehaene, Tang, Min, and **Liping Wang** ,
Geometry of Sequence Working Memory in Macaque Prefrontal Cortex. *Science*, 2022

Liping Wang

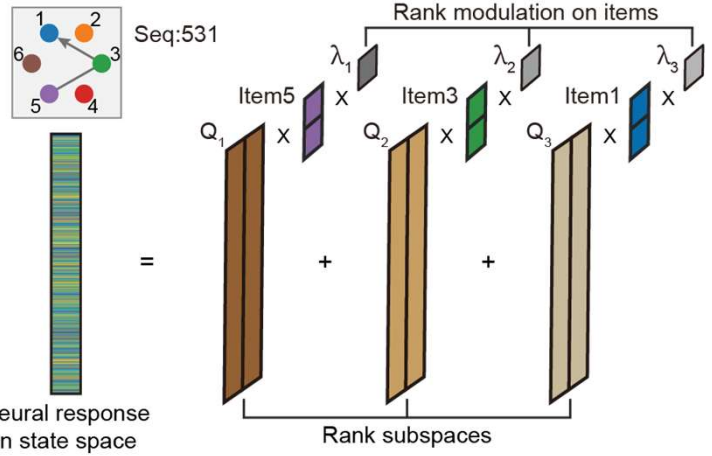




Thousands of neurons recorded using 2-photon calcium imaging in the prefrontal cortex of awake macaque monkeys performing a delayed spatial sequence reproduction task



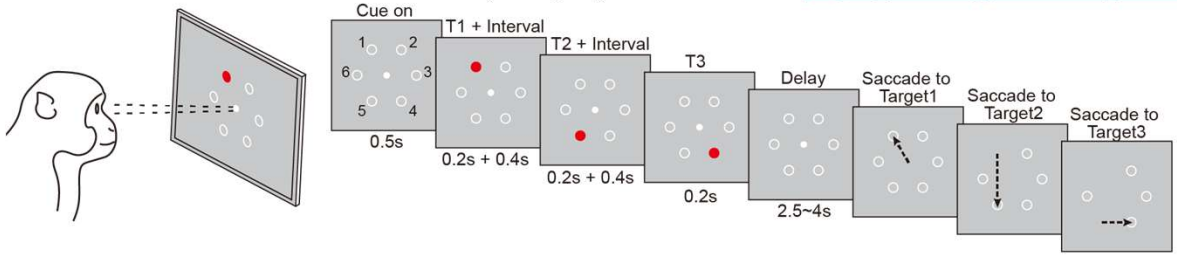
The neural state **during the delay** is the sum of **three superimposed 2-D subspaces**, each storing the spatial location at a given ordinal rank. This code generalizes to new sequences and explains monkey behavior

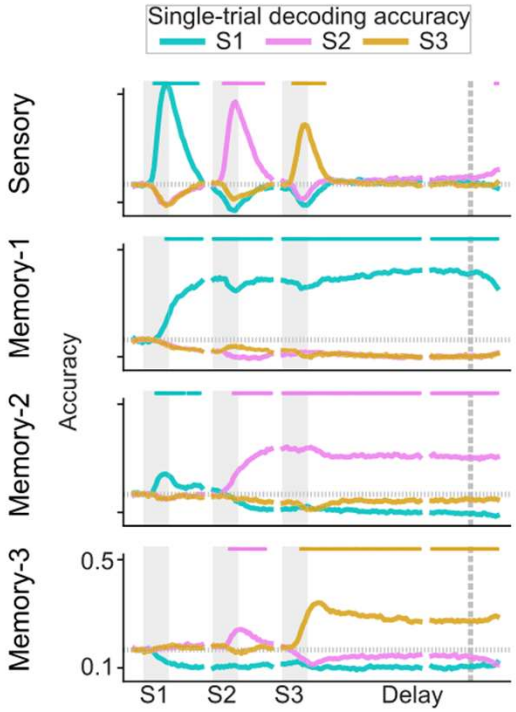


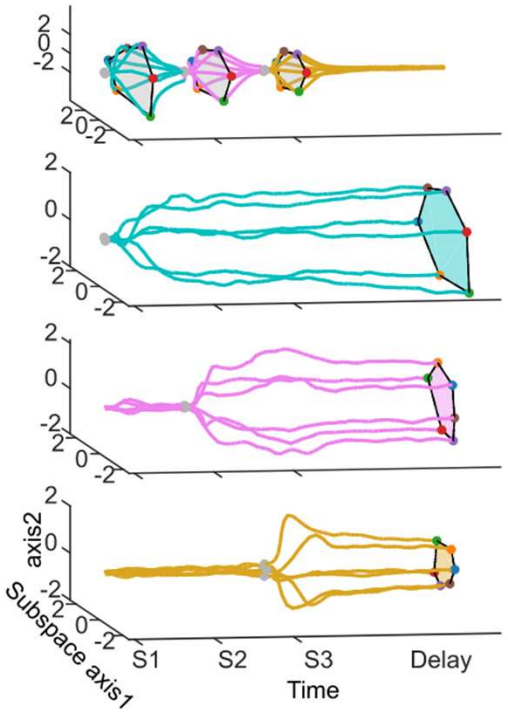
Working memory loading during sequence presentation

Chen, J., Zhang, C., Hu, P., Min, B., & Wang, L. (2024). Flexible control of sequence working memory in the macaque frontal cortex. Neuron, 112(20), 3502-3514.e6. https://doi.org/10.1016/j.neuron.2024.07.024

Liping Wang





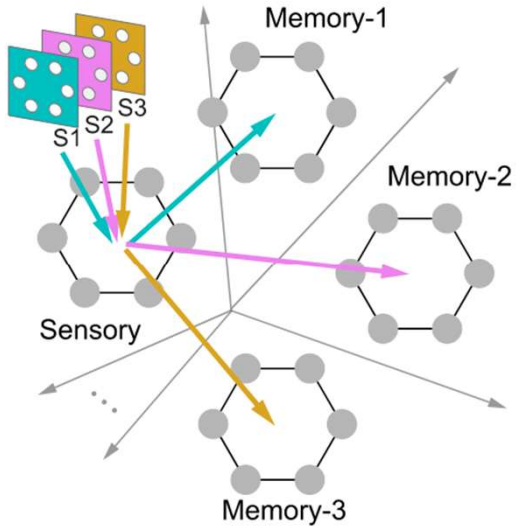


Electrophysiology allowed to follow the three successive spatial stimuli as they entered prefrontal cortex.

→ All stimuli are initially encoded in a transient "**entry subspace**" that encodes spatial location at any rank.

→ Then the **spatial information is routed in the corresponding rank subspace**, and held active there.

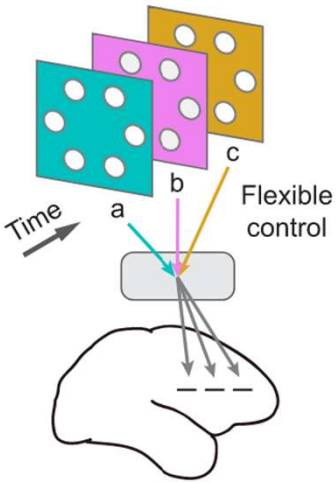
→ Remarkably, the **same neural population in PFC** contributes to both sensory and memory subspaces.



Flexible control of entry into working memory

Chen, J., Zhang, C., Hu, P., Min, B., & Wang, L. (2024). Flexible control of sequence working memory in the macaque frontal cortex. Neuron, 112(20), 3502-3514.e6. https://doi.org/10.1016/j.neuron.2024.07.024

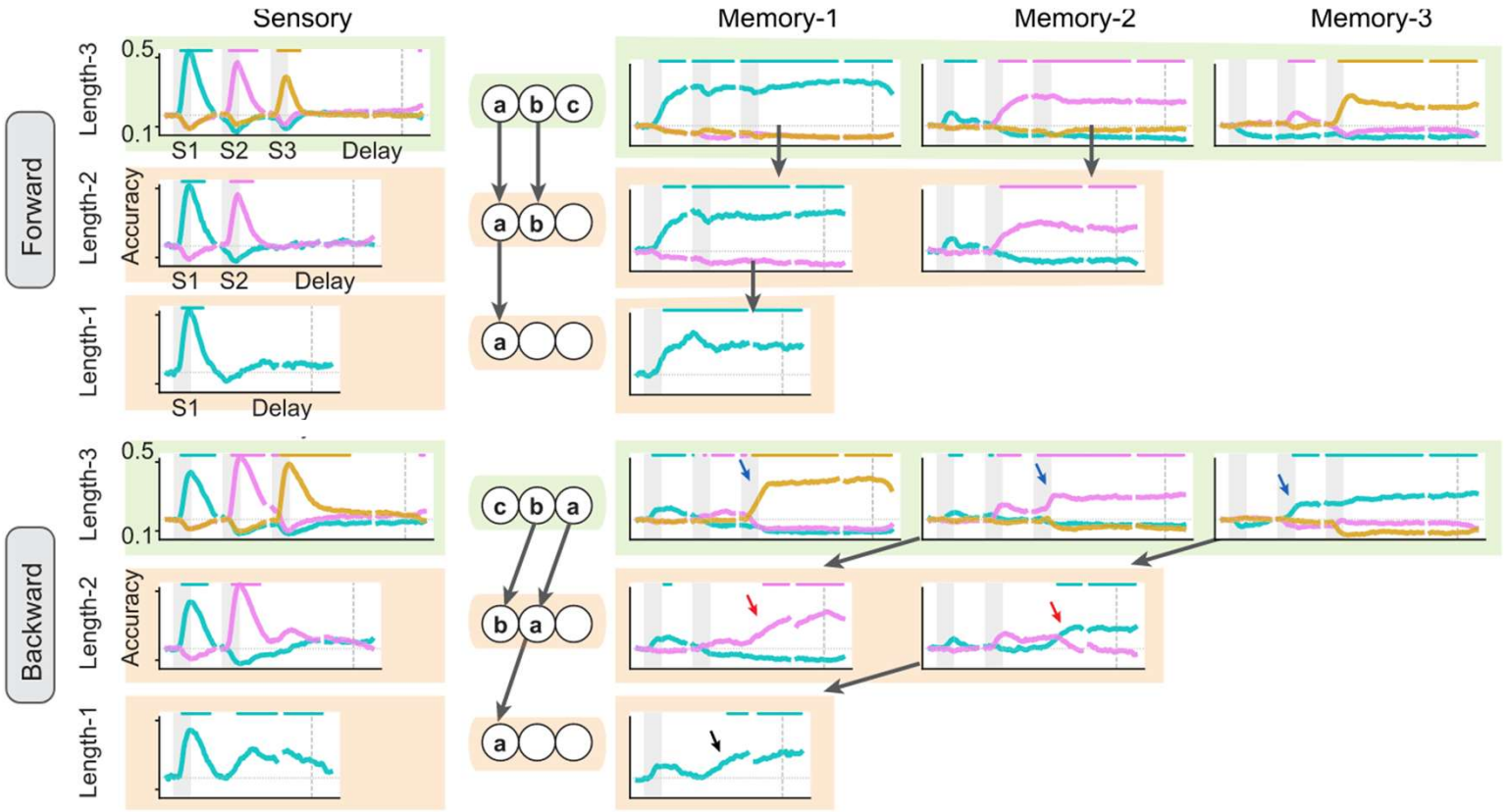
Liping Wang



Sensory information is NOT passively transmitted to each memory subspace, but is cleverly **gated**

- When monkeys have to reproduce the sequence forwards, each item is routed to its corresponding rank subspace.
- When reproducing the sequence **backwards,** the gating is reversed, and its timing depends on sequence length.

Which of these systems can be activated by a masked, unseen stimulus?
GNW theory predicts that flexible routing and working memory should depend on consciousness, and therefore show a non-linear ignition.

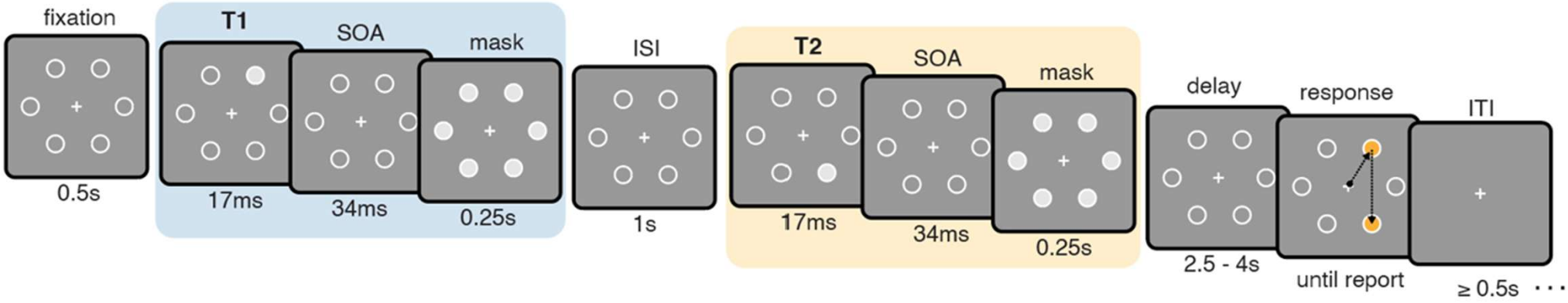


Can an unseen masked sequence enter working memory?

Hao Zhou, Wen Fang, Guobin Fu, Yiteng Zhang, Bin Min, Stanislas Dehaene, Liping Wang, in preparation

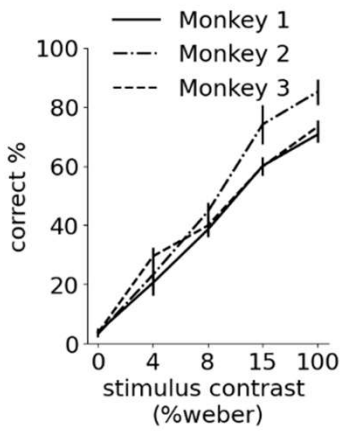
Liping Wang

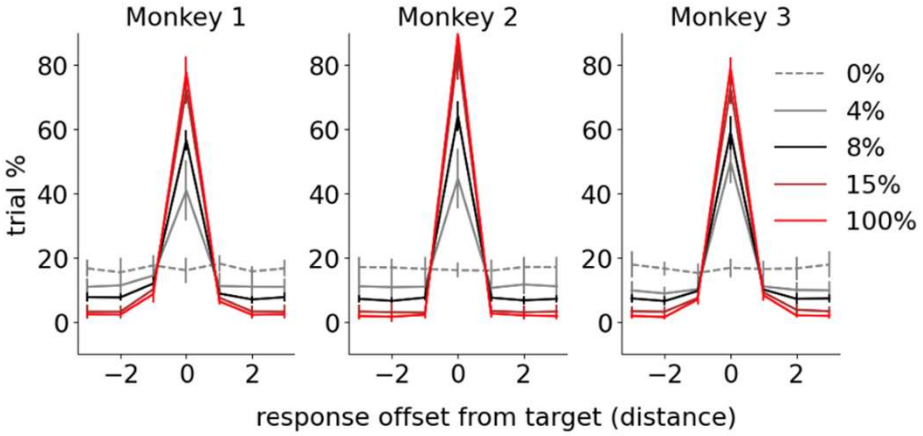
In this new version of the task, a sequence of two locations is presented, each for only 17 ms followed by a mask.



Contrast is systematically varied, including zero contrast (no stimulus).

Behavioral improves steadily with contrast in three monkeys. However they all make about 60% errors at the lowest contrast.





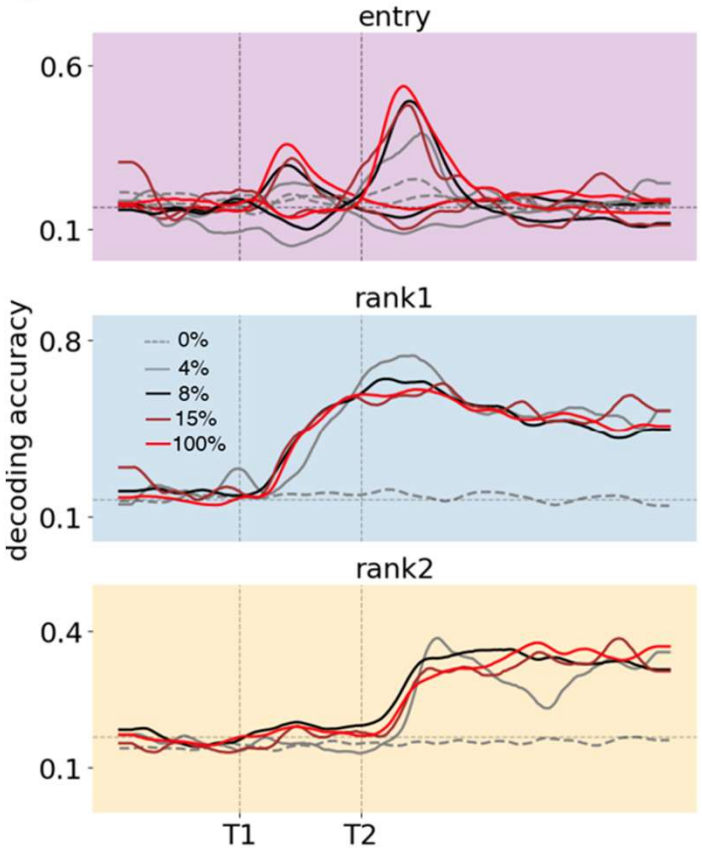
Can an unseen masked sequence enter working memory?

Hao Zhou, Wen Fang, Guobin Fu, Yiteng Zhang, Bin Min, Stanislas Dehaene, Liping Wang, in preparation

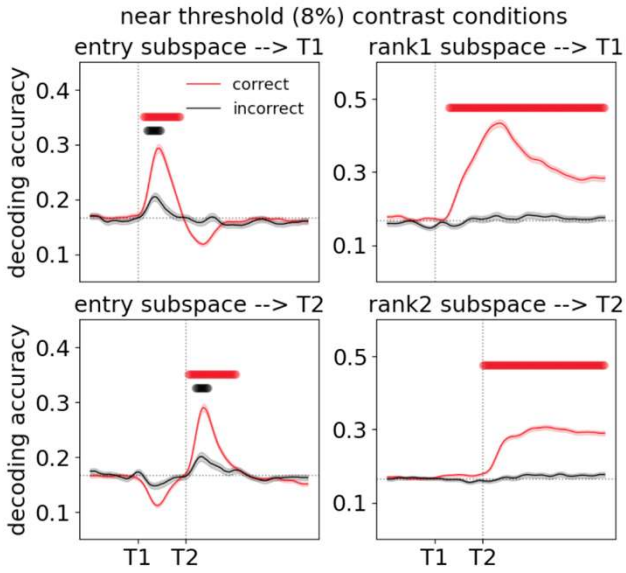
Liping Wang

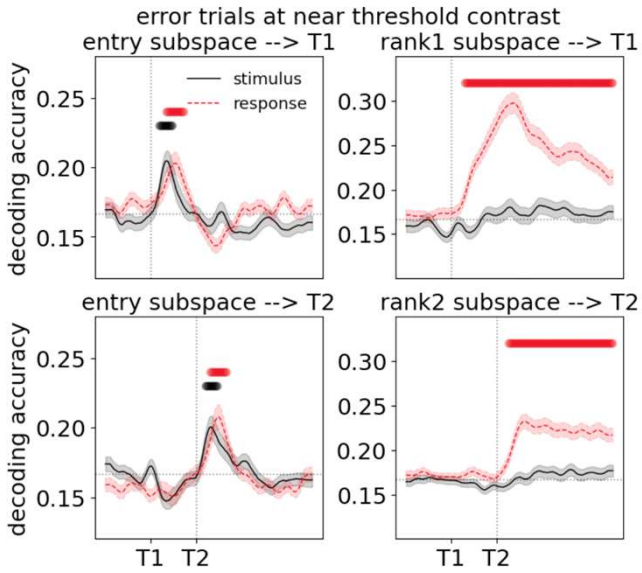
A sequence of linear followed by non-linear (ignition) stages **within prefrontal cortex.**

- Activity in the entry subspace is **linearly related** to stimulus contrast.
- Activity in both WM rank subspaces is non-linear and shows an ignition on correct trials.



The entry activation is significant on both correct and error trials, thus reflecting **subliminal processing** (failed ignition).
However, on error trials, there is **zero transmission** of this activity to WM subspaces.
Sorting according to the **response** explains what happens on error trials : there is already an activation of that location in the entry, competing with the stimulus.





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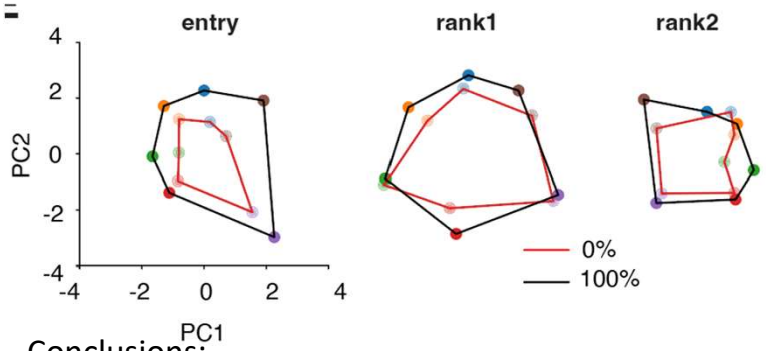
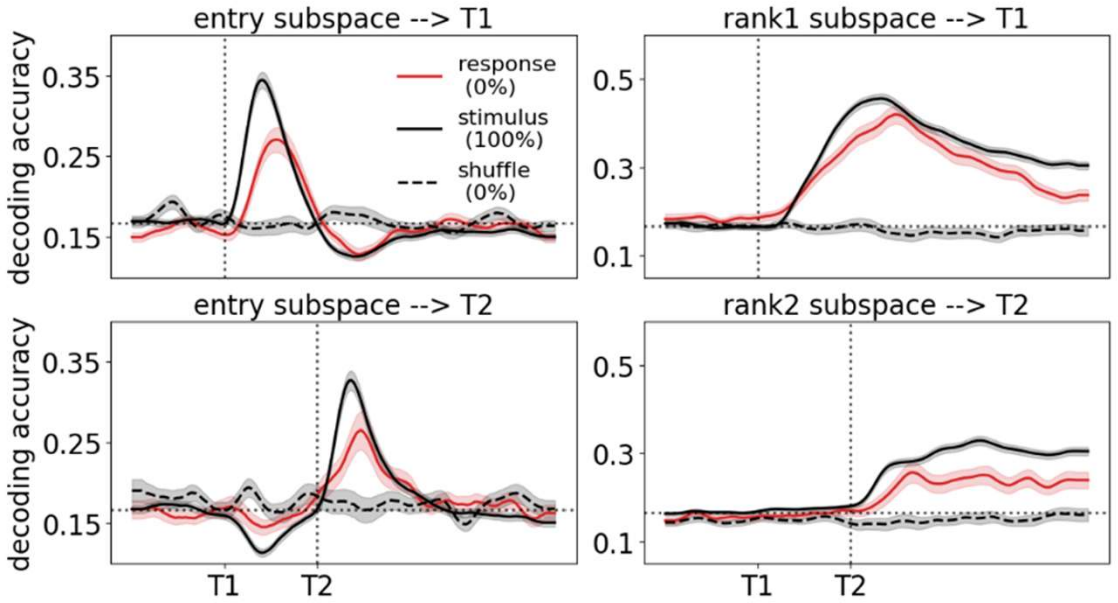


What happens when there is no stimulus at all (0% contrast)?
We see the same sequential activation of the same subspaces.

Again, the location that will ultimately be reported by the animal shows a pre-activation in the entry subspace, and this activity gets transmitted to WM.
→ The animal may "hallucinate" a stimulus at an non-stimulated location.

Conclusions:
This study beautifully confirms the two stages of processing: (1) linear stimulus processing, in parallel across all locations, followed by (2) non-linear access to working memory (ignition).
Surprisingly, **both stages** occur in PFC.
The status of entry subspace activity remains uncertain. PFC activity at this moment may just be a faithful reflection of inferotemporal and parietal neural firing, thus a **purely non-conscious stage** of competition for access to consciousness.
Alternatively, it might reflect the fleeting consciousness of having seen a vague stimulus, while being unsure.
The status of working memory slots, however, is clear : they are only accessed in an all-or-none manner, thus showing the signature of consciousness.

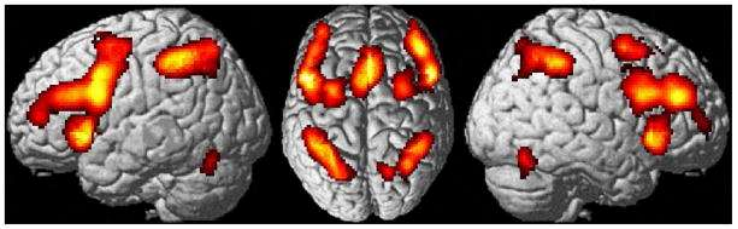


Human studies of unconscious working memory: A new challenge

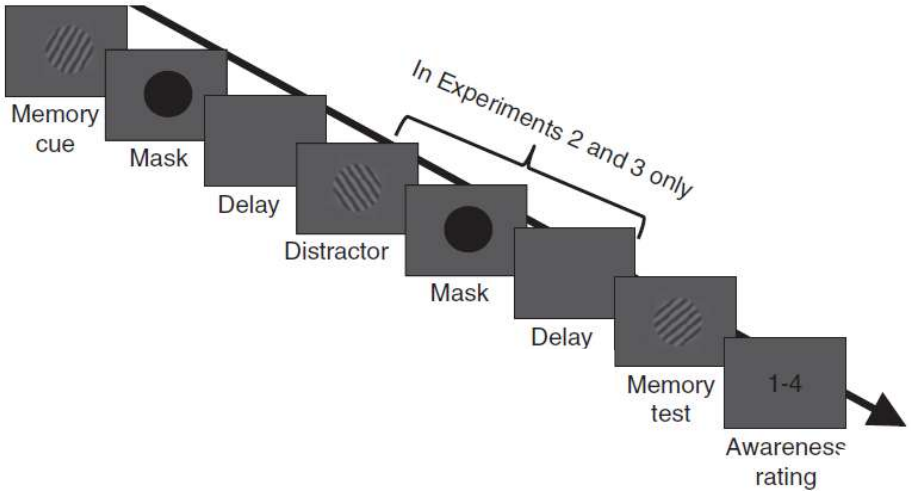
Is access to consciousness equivalent to access to working memory?

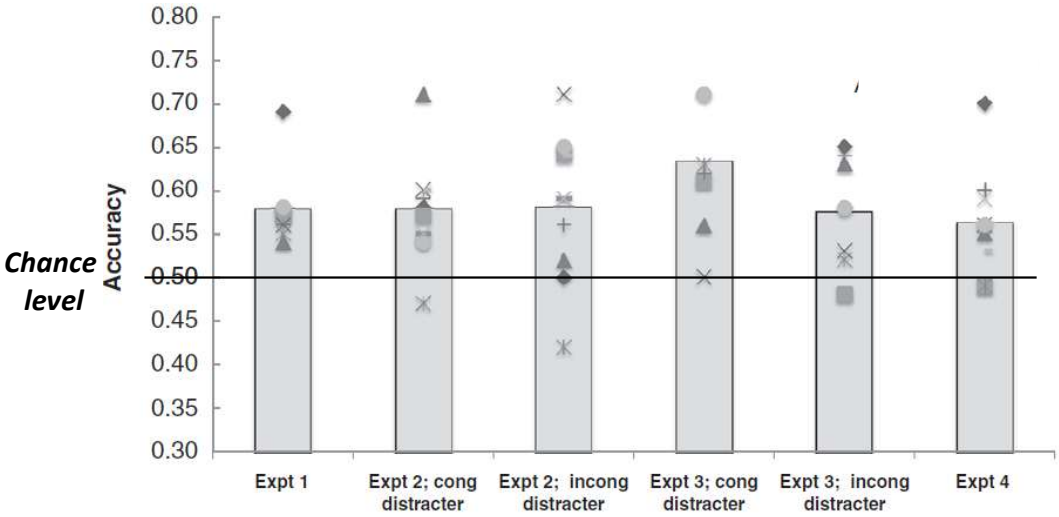
Many common features

- Durability, metastability
- Reportability
- Similar neural correlates



- However, several papers recently reported above-chance performance after a delay of several seconds, in the absence of consciousness (e.g. Soto et al., *Curr Biol*, 2011; 2-5 seconds delay)



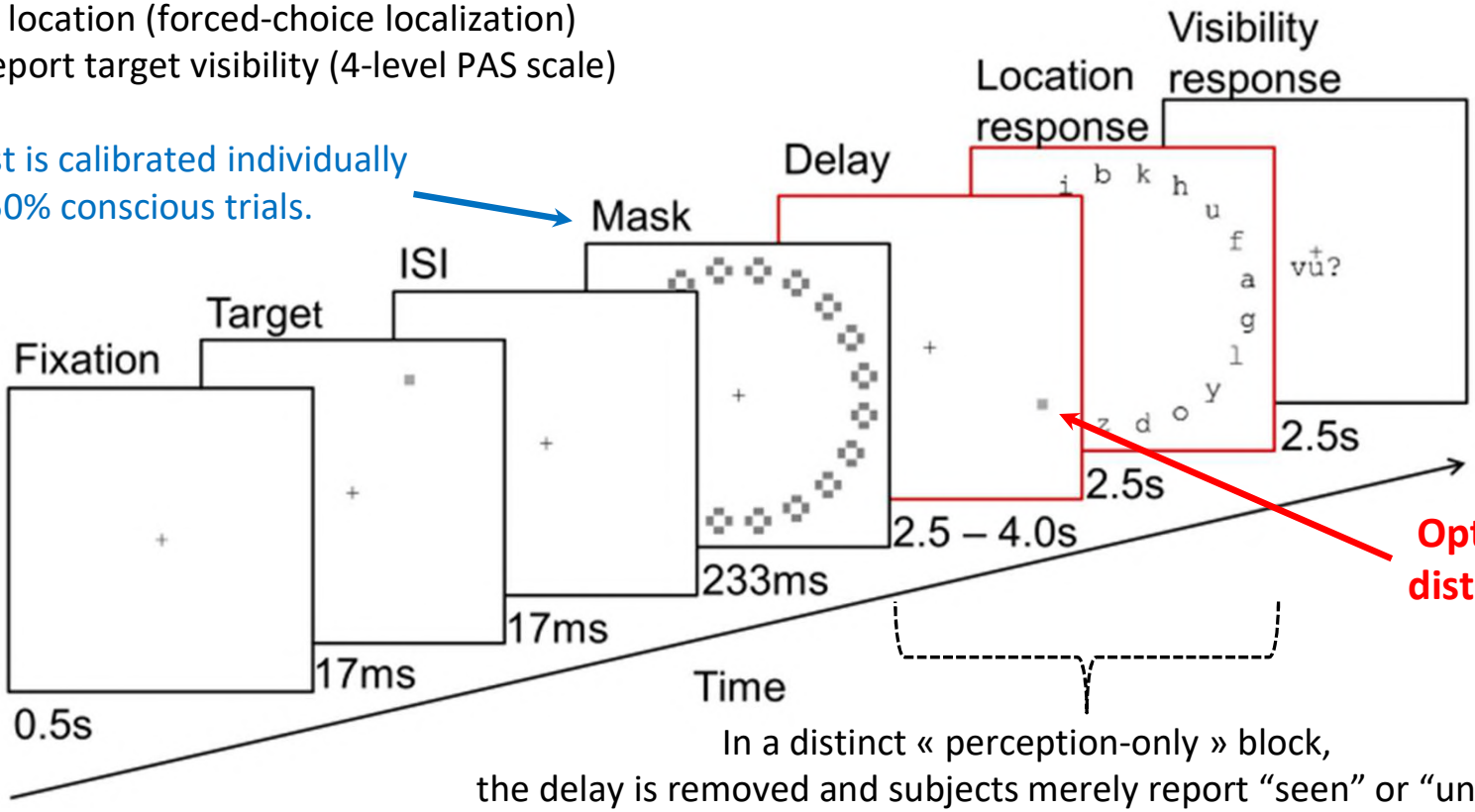


A spatial working memory task with a high level of blindsight

Trübutschek, D., Marti, S., Ojeda, A., King, J.-R., Mi, Y., Tsodyks, M., & Dehaene, S. (2017). A theory of working memory without consciousness or sustained activity. *eLife*, *6*, e23871. https://doi.org/10.7554/eLife.23871

- On each trial, a small dot is flashed at one of 24 locations at a fixed excentricity, then masked
- after a long delay (2.5 to 4 seconds), subjects report the identity of the letter at the target location (forced-choice localization)
- then they report target visibility (4-level PAS scale)

Mask contrast is calibrated individually to achieve ~50% conscious trials.

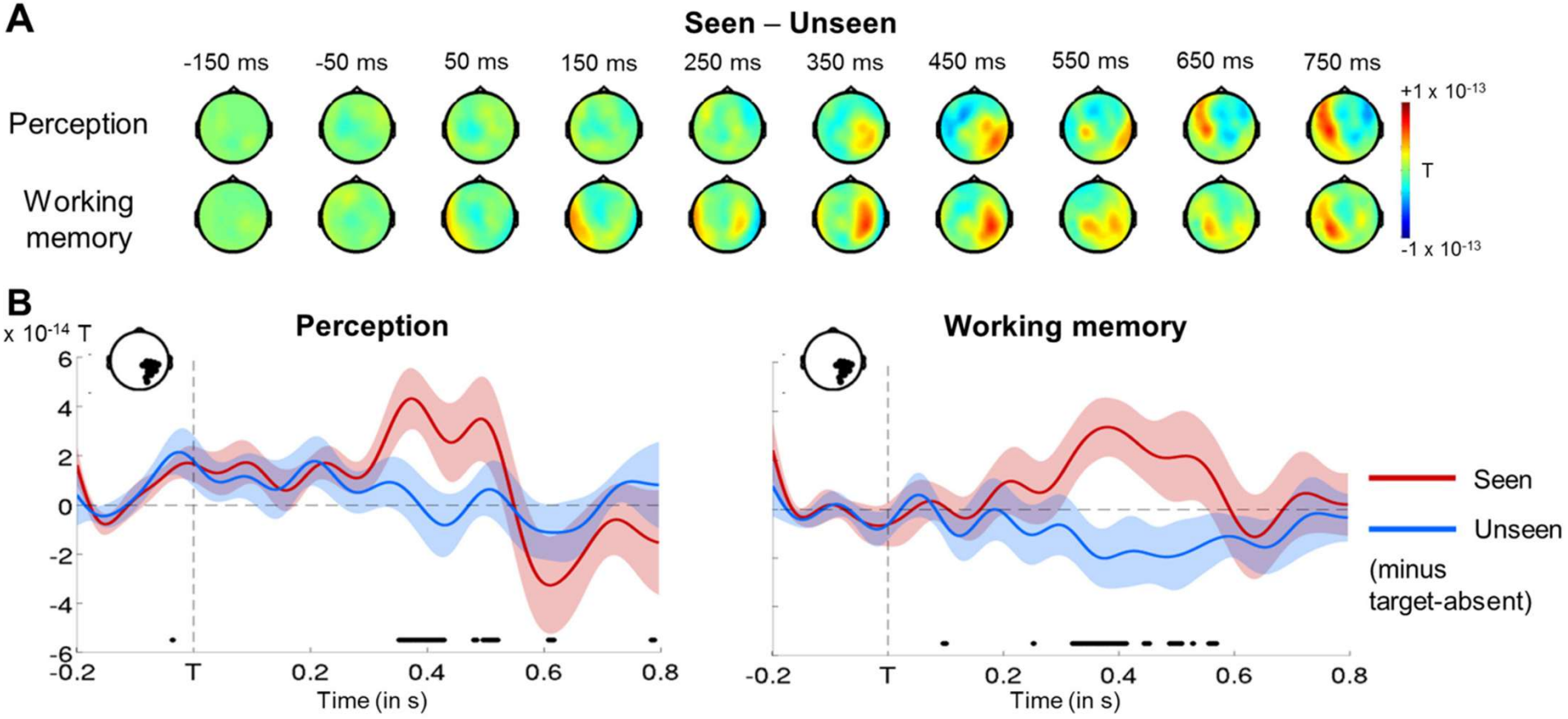


In a distinct « perception-only » block,
the delay is removed and subjects merely report “seen” or “unseen”.
This part allows to test the idea that WM is just a prolongation of conscious access.

Conscious access and conscious working memory are similar

Trübutschek, D., Marti, S., Ojeda, A., King, J.-R., Mi, Y., Tsodyks, M., & Dehaene, S. (2017). A theory of working memory without consciousness or sustained activity. *eLife*, *6*, e23871. https://doi.org/10.7554/eLife.23871

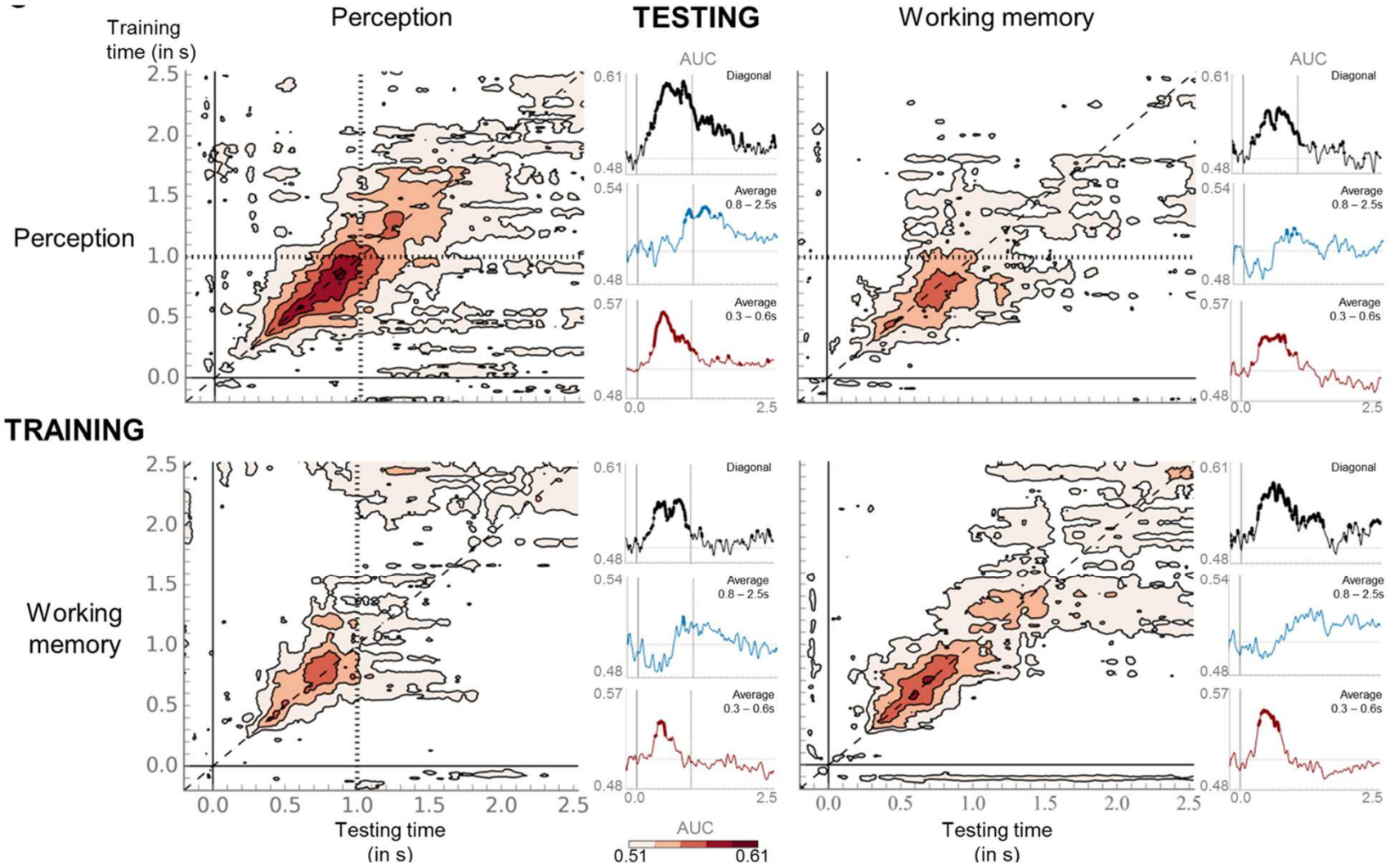
The difference between seen and unseen trials is quite similar on mere report versus working memory trials: a sudden divergence around 300 ms, more durable on WM trials.



Comparison of conscious access and conscious working memory

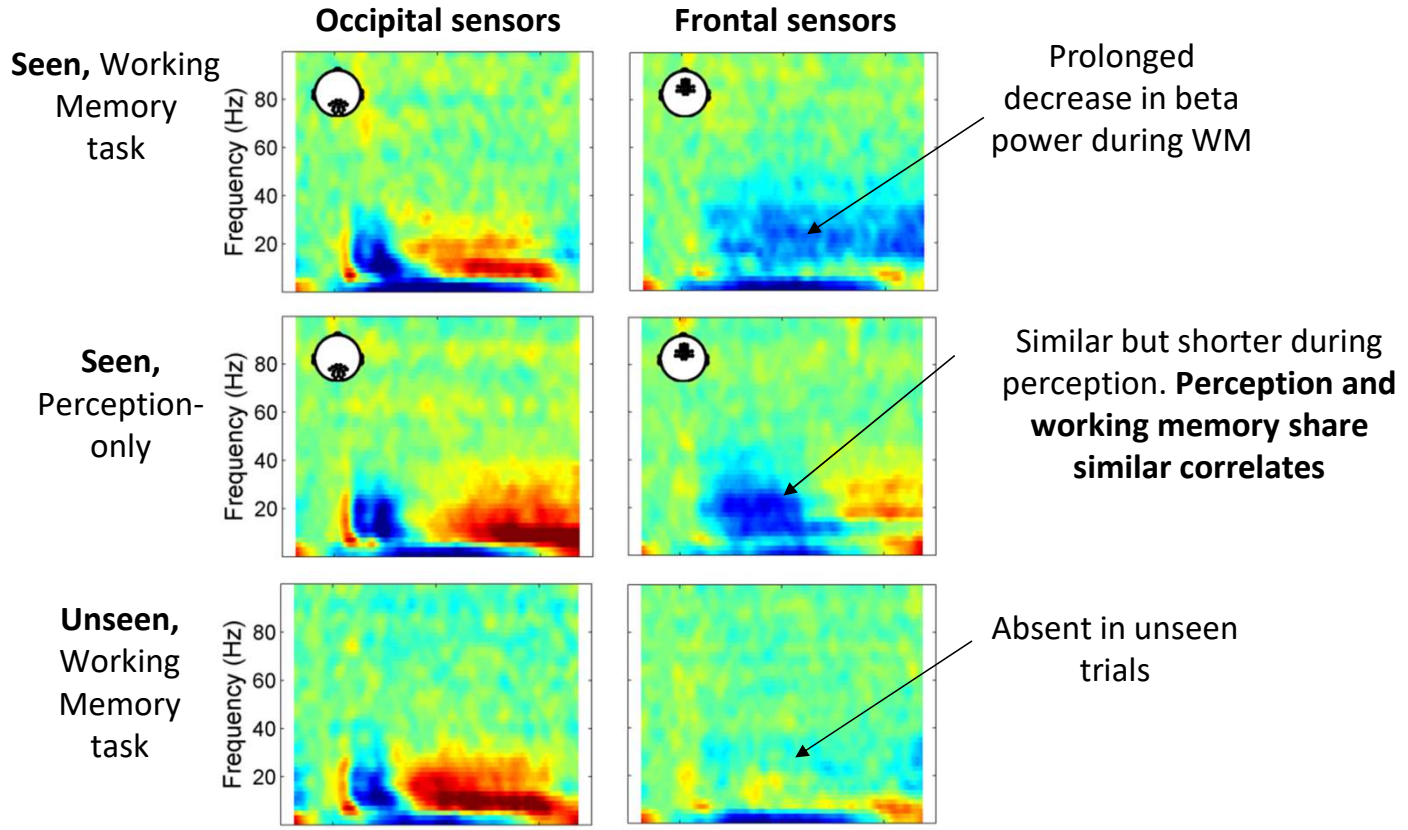
Most crucially, a decoder trained to distinguish seen vs unseen trials on mere report trials generalizes to WM trials, and vice-versa.

Note the pale square decoding pattern : activity is sustained, but quite weak (and this is an average over many trials – it could be sparse on individual trials).

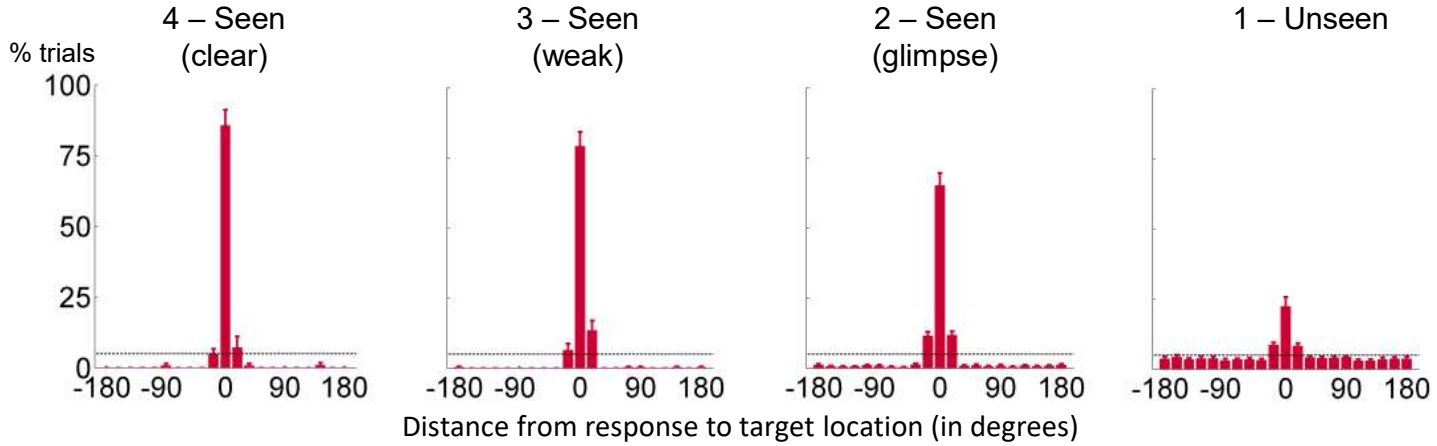


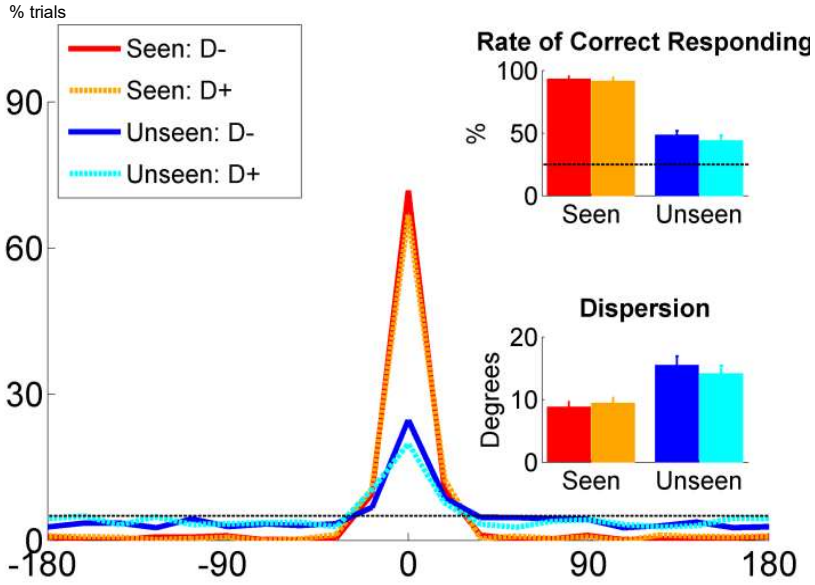
Conscious working memory is distinguished by a more sustained decrease in alpha/beta power

Trübutschek, D., Marti, S., Ojeda, A., King, J.-R., Mi, Y., Tsodyks, M., & Dehaene, S. (2017). A theory of working memory without consciousness or sustained activity. *eLife*, *6*, e23871. https://doi.org/10.7554/eLife.23871



Performance remains above chance regardless of visibility





Subjects select the correct response way above chance level

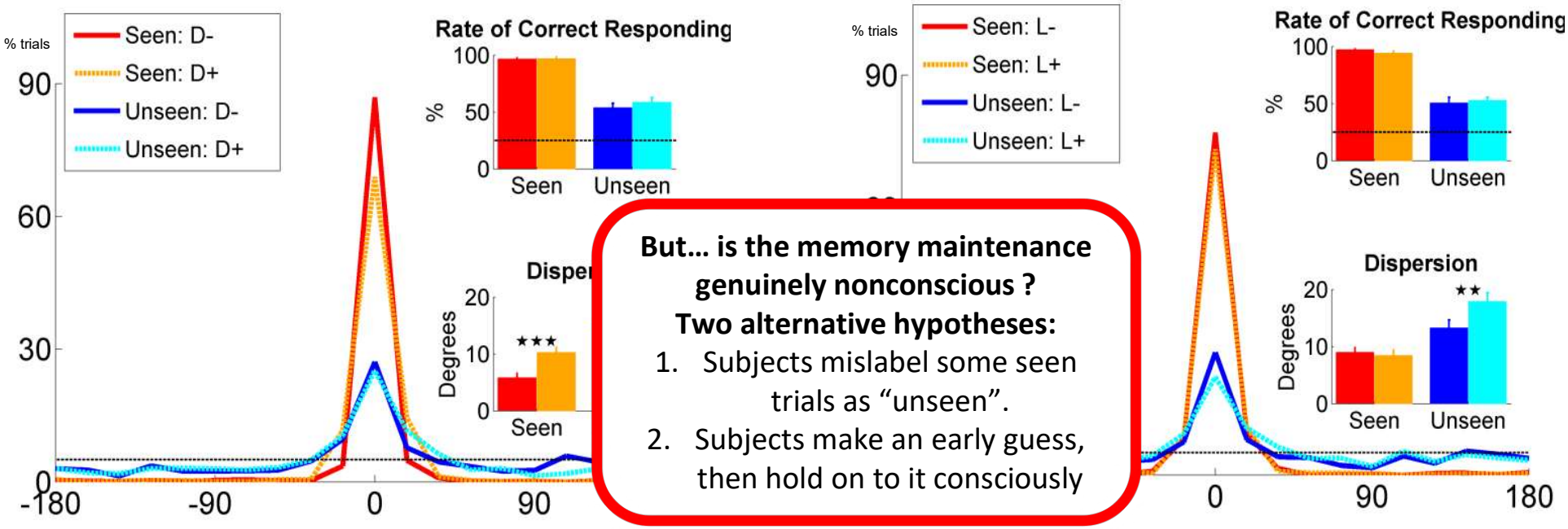
- even in the presence of a distractor.

- nonconscious working memory is noisier than conscious working memory.

Unconscious working memory is replicable

Effect of DELAY :
Unconscious performance remains significant after a long delay, up to 4 seconds.

Effect of LOAD :
Unconscious performance remains significant in the presence of a prior memory load (5 digits memorized prior to target presentation)



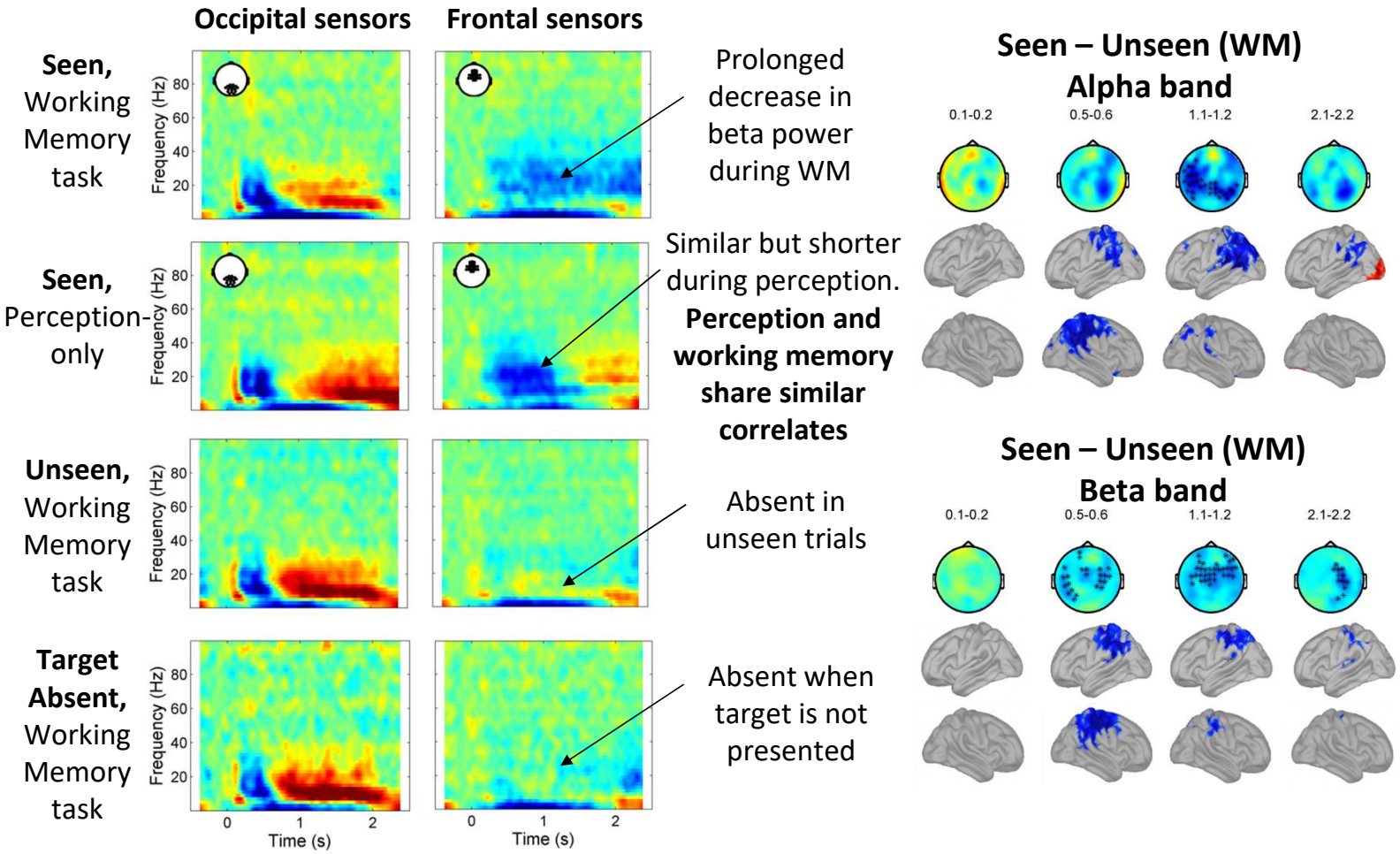
But… is the memory maintenance genuinely nonconscious ?
Two alternative hypotheses:

1. Subjects mislabel some seen trials as “unseen”.
2. Subjects make an early guess, then hold on to it consciously

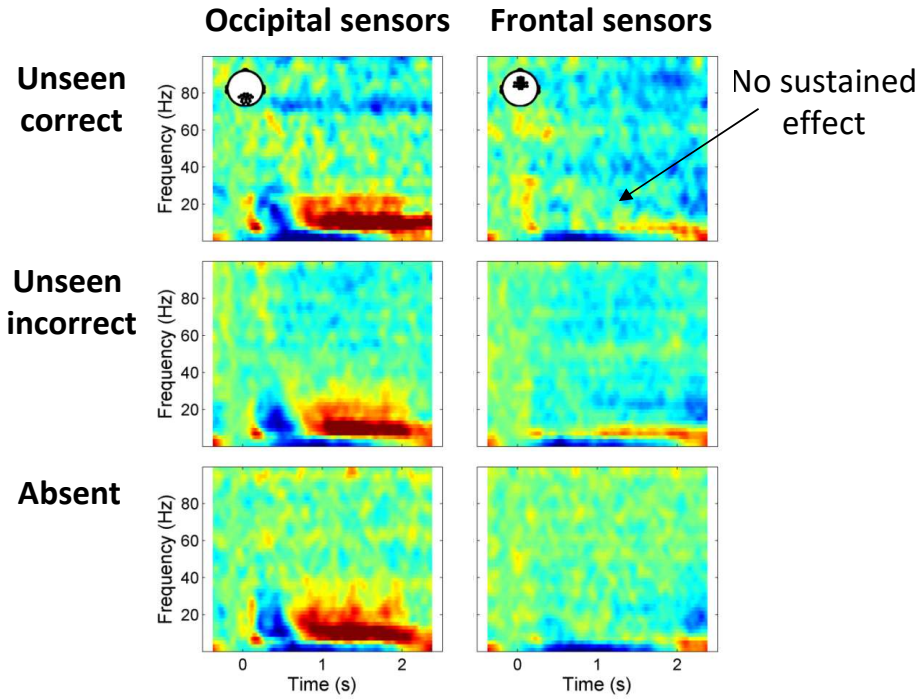
Also, we replicated the unconscious memory in a task with two locations, and show unconscious memory for temporal order.

Trübutschek, D., Marti, S., & Dehaene, S. (2019). Temporal-order information can be maintained in non-conscious working memory. *Scientific Reports*, *9*(1), 6484. https://doi.org/10.1038/s41598-019-42942-z

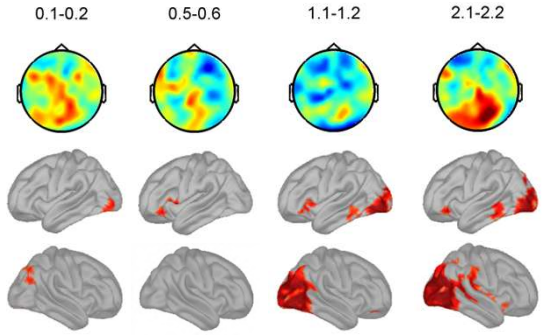
If subjects mislabeled trials as “unseen”, then we should see the signatures of consciousness on some unseen trials



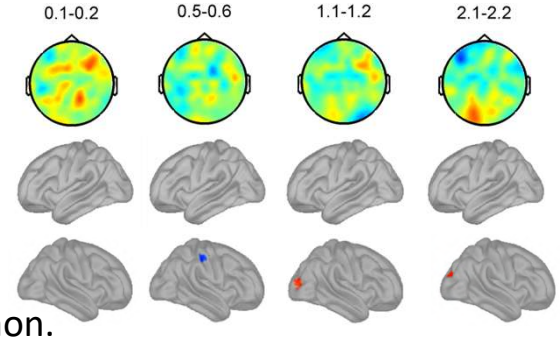
Crucially, this signature of conscious working memory is absent even on *unseen correct* trials



Unseen Correct – Unseen Incorrect
Alpha band



Unseen Correct – Unseen Incorrect
Beta band



Rejection of alternative hypothesis 1:
Unseen correct trials are not just seen trials that are erroneously reported as « unseen ».
Unconscious working memory is a distinct phenomenon.

Rejecting the hypothesis of an early guess

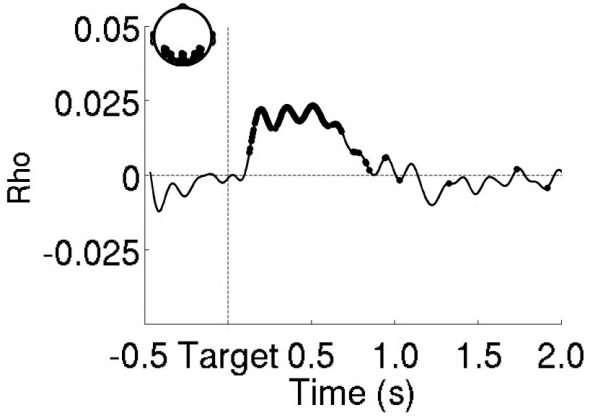
Conceivably, subjects could achieve **above-chance working memory** performance on **unseen** trials by making a forced-choice guess as soon as the target appears, and holding to that choice in conscious working memory

However, if that was true

- We would see signatures of conscious working memory throughout the epoch
- We would be able to decode the **response** location on all trials, even the incorrect ones

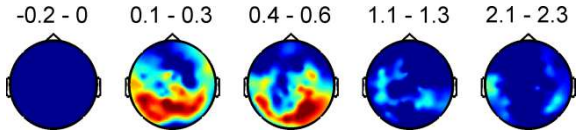
Tracking conscious and nonconscious working memories

Circular-linear correlation between MEG activity and target location :



(all trials, seen and unseen)

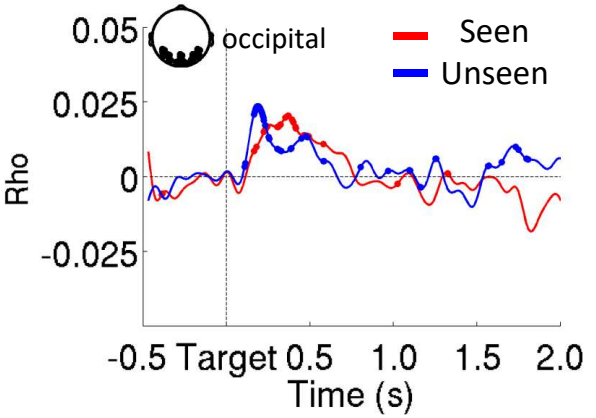
Occipital, parietal and temporal sensors contain decodable information about target location



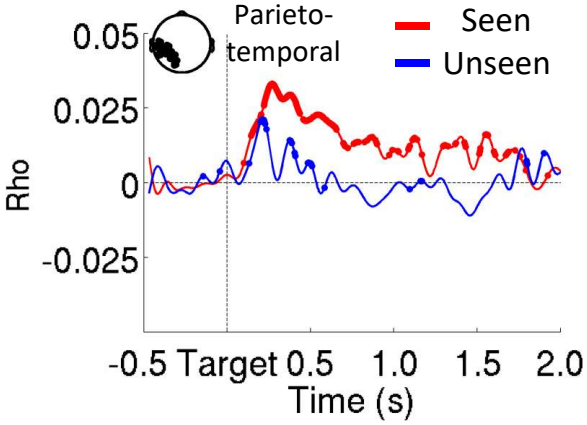
Circular-linear correlation (all trials)

Target location
is transiently encoded in occipital cortex on both seen and unseen trials.

Circular-linear correlation with **target** location



The location code
- Shows a longer duration in parieto-temporal cortex on seen trials
- is transient on unseen trials



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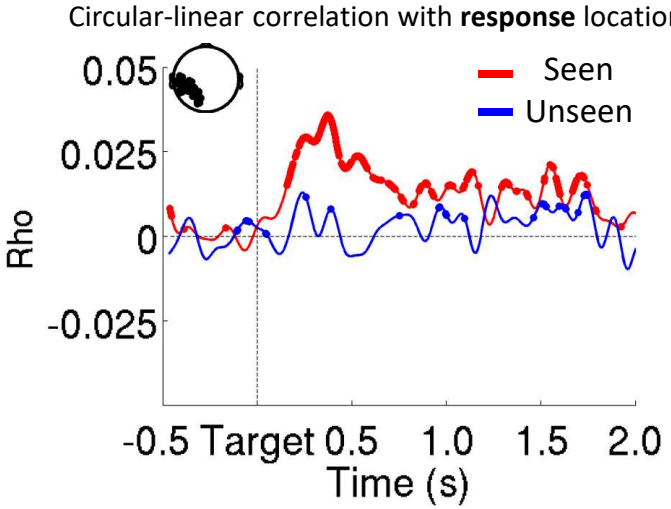
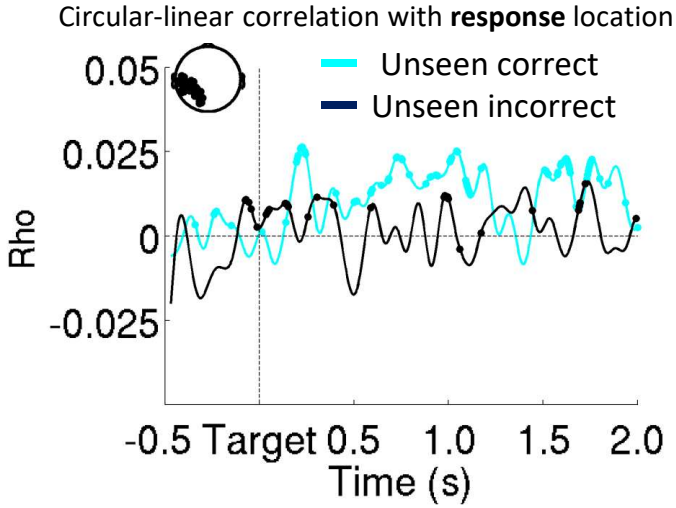
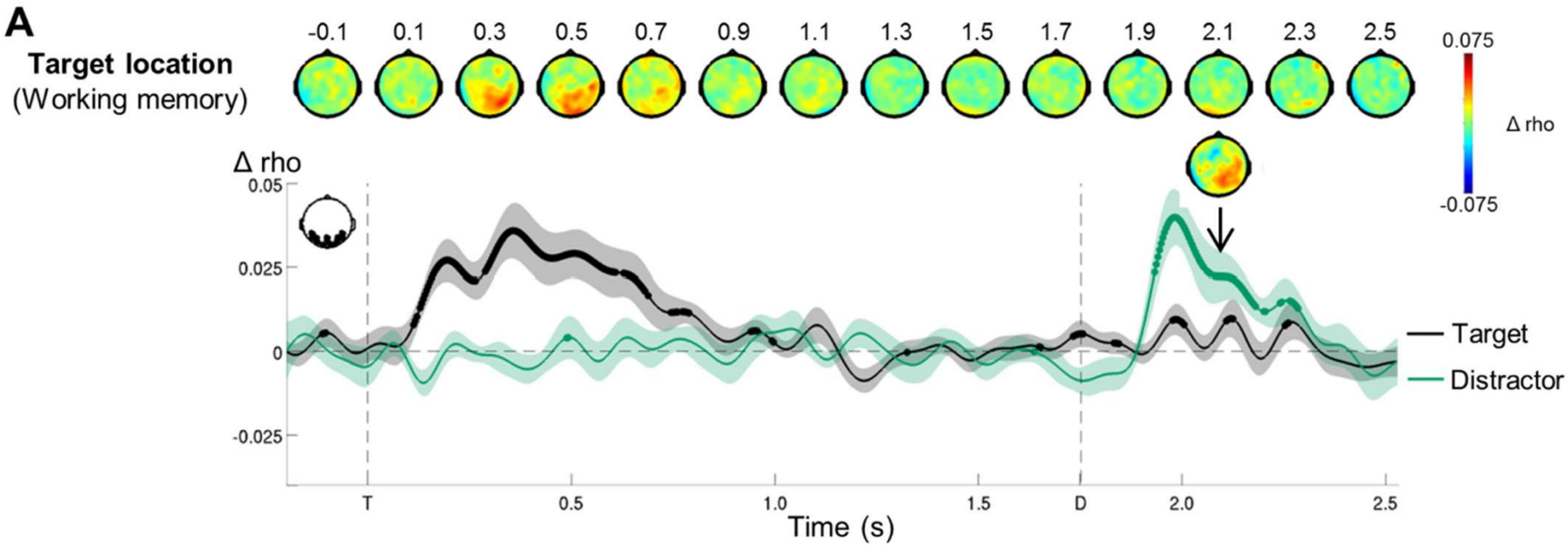




- No conscious storage of an early guess (or it concerns only a minority of trials)
- Unconscious working memory differs from conscious working memory.

Even on conscious working memory trials, the location code is not fully sustained

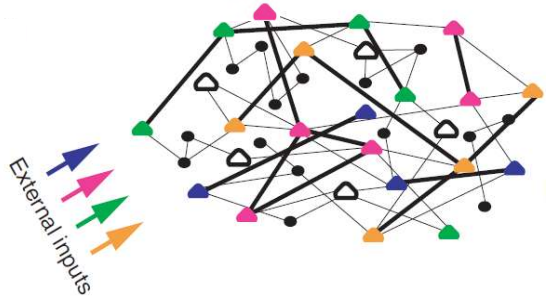
The location is decodable for about 1 second, then it decays to a non-detectable level.
But… the distractor appears, the target location also seems to be re-awakened.

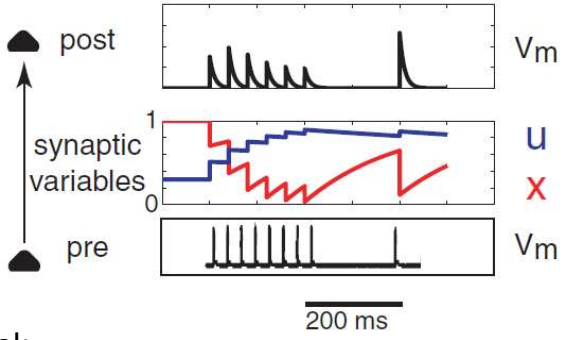


Could there be **activity-silent working memory ?** (Mongillo, Barak & Tsodyks, Science, 2008; Stokes, 2014)

One possible interpretation: « Activity-silent » working memory

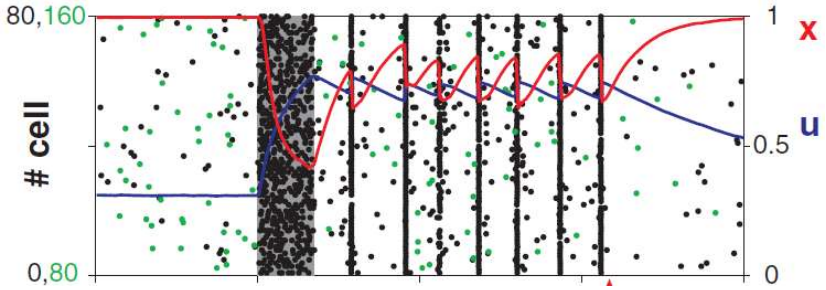
Mongillo, Barak & Tsodyks, Synaptic theory of working memory (Science, 2008)



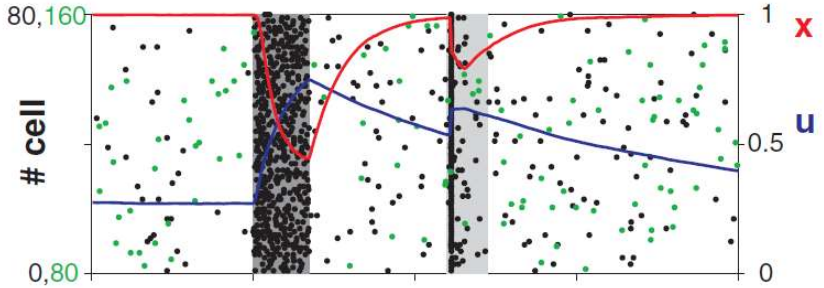


Each content of working memory is coded by one cell assembly.
However, these assemblies do not have to be permanently active during the delay period. Rather, memory can be maintained by short-term changes in synaptic efficacy (variable u)
Reactivation can occur spontaneously during the delay period, thus refreshing the weights (« conscious rehearsal »).
The (nonconscious) assembly can also be reactivated by a non-specific read-out signal.
Hypothesis: Such retrieval is what happens at the end of the delay.

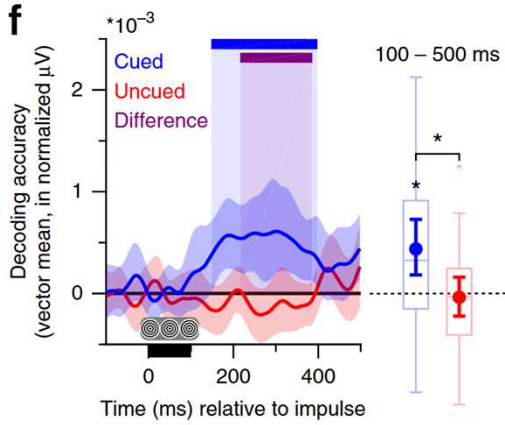
Conscious rehearsal:



Retrieval of a dormant nonconscious memory:



Wolff… & Stokes (Nature Neuroscience, 2017): Once decodability of a memorized item decayed to zero, it can be reactivated by a non-specific pulse of visual or auditory noise (or TMS, see Rose et al. Science 2016).

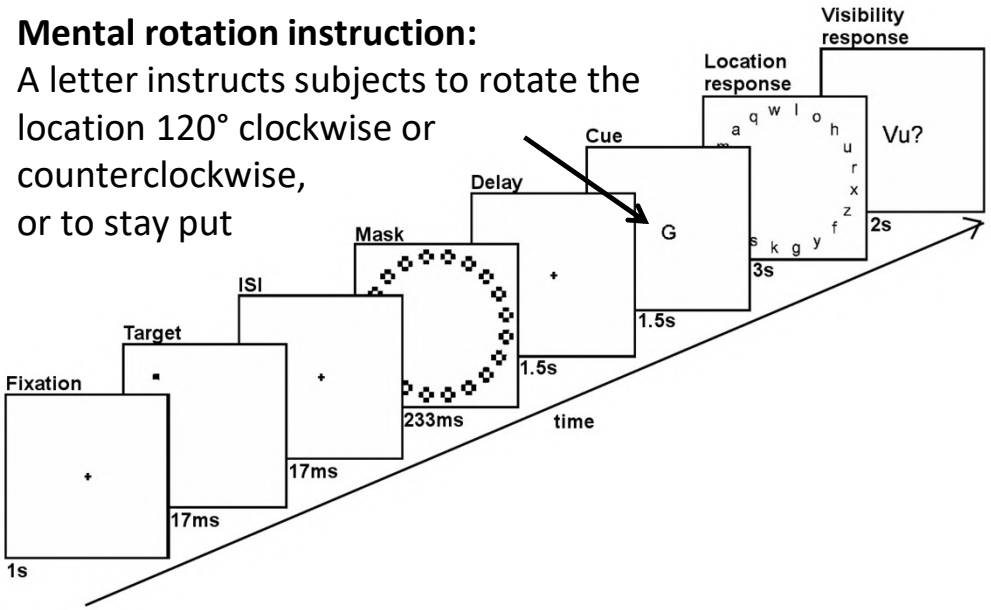


Can there be a non-conscious and yet genuinely “working” memory ?

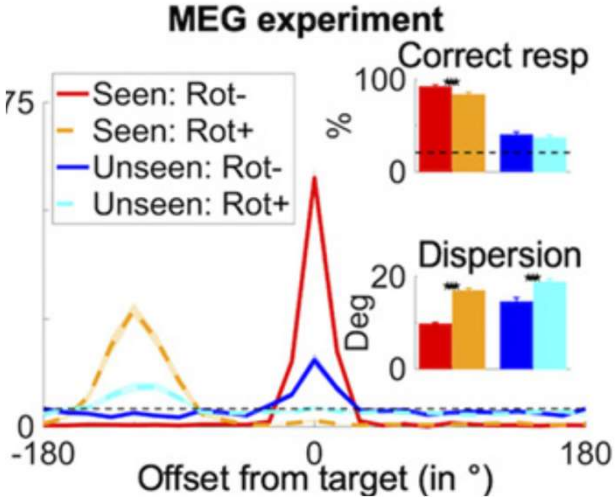
Trübutschek, D., Marti, S., Ueberschär, H., & Dehaene, S. (2019). Probing the limits of activity-silent non-conscious working memory. *PNAS*, 201820730. https://doi.org/10.1073/pnas.1820730116

Prediction of the model: a static code can remain dormant, but it cannot be mentally manipulated.
If the task requires mental manipulation, then we should see an explicit reactivation in the conscious workspace.

Mental rotation instruction:
A letter instructs subjects to rotate the location 120° clockwise or counterclockwise, or to stay put



Behavior is better than chance on all trials, whether seen or unseen, and whether rotation is required or not



Is this better-than-chance behavior on unseen trials due to a genuine unconscious computation?
The GNW rather predicts that the signatures of consciousness should reappear at the time of the cue, *on both seen and unseen trials*

Can there be a non-conscious and yet genuinely “working” memory ?

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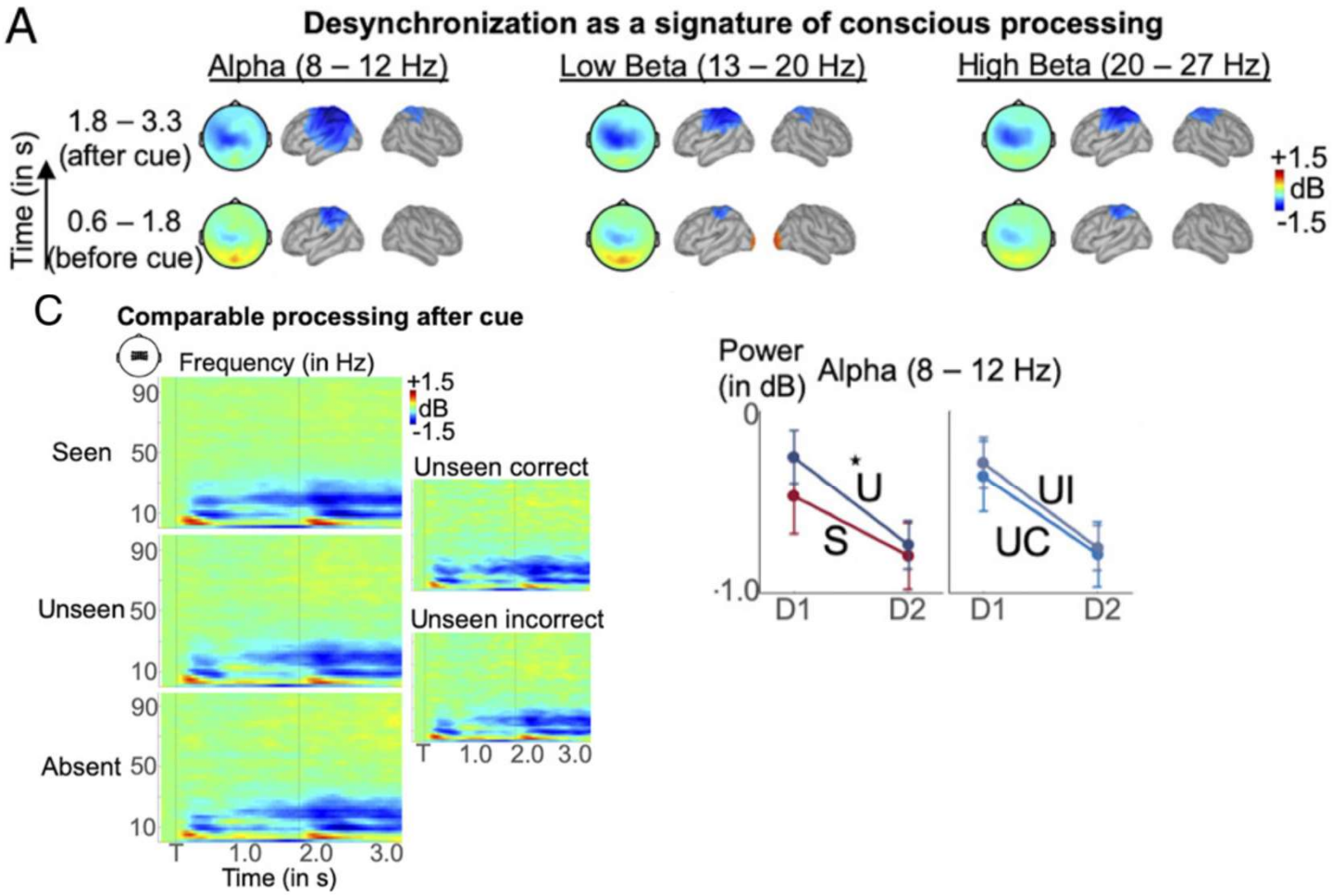
As explained earlier, a sustained desynchronization in the alpha-beta band is a signature of consciousness.
Indeed, before the cue (first delay period D1), power in the beta band decreases much more on seen than on unseen trials.
However, crucially, after the cue (in the second delay period D2), a massive decrease in power, going even beyond the seen case, is seen on **both** seen and unseen trials.
→ A conscious attempt to recover the unseen location and to rotate it consciously.
→ Now, the unconscious memory cannot stay dormant, because it needs to be manipulated.



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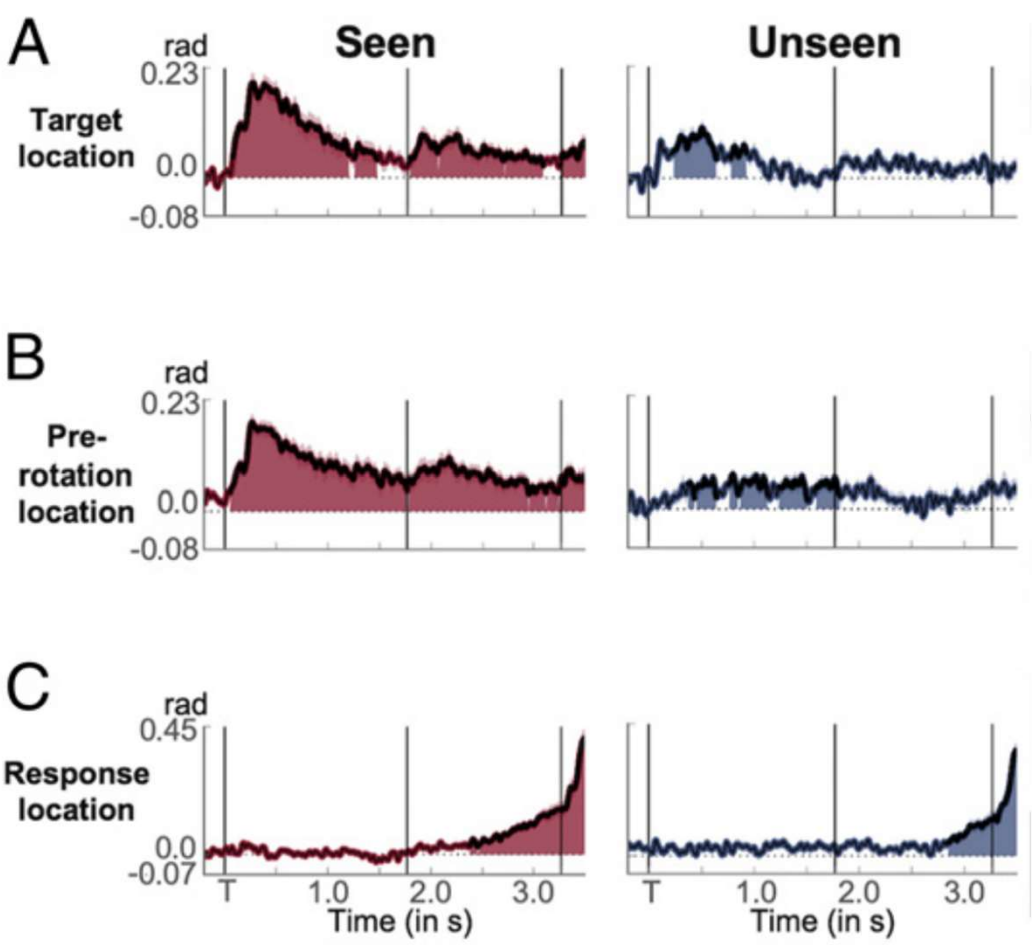
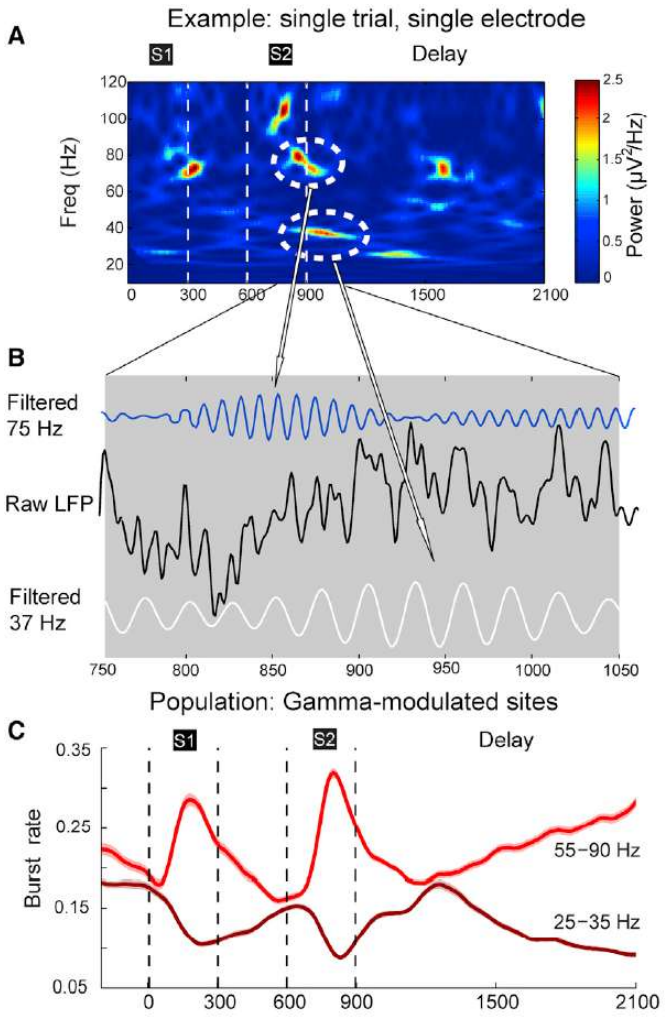


This conclusion is comforted by the decoding of locations: During the first delay, the decoding of the target location decays almost to zero, especially on unseen trials.
But around the time of the cue, we see the rise of the pre-response location (the location that, when rotated, would predict the ulterior response)
And then we see it rotate to the response location, **identically on seen and unseen trials.**

Mental representation by occasional bursts of gamma activity



Lundqvist, M., Rose, J., Herman, P., Brincat, S. L., Buschman, T. J., & Miller, E. K. (2016). Gamma and Beta Bursts Underlie Working Memory. Neuron, 90(1), 152–164.

Claim : the observation of **sustained** firing in **average** working delay activity is misleading. **On single trials**, activity need not be sustained. Each item in a working memory task is encoded by a **transient** gamma burst, with a corresponding **decrease in beta**-burst probability.
The neural code is probabilistic, with a burst probability that increases towards the end of the working-memory delay.

Consequences of these ideas:

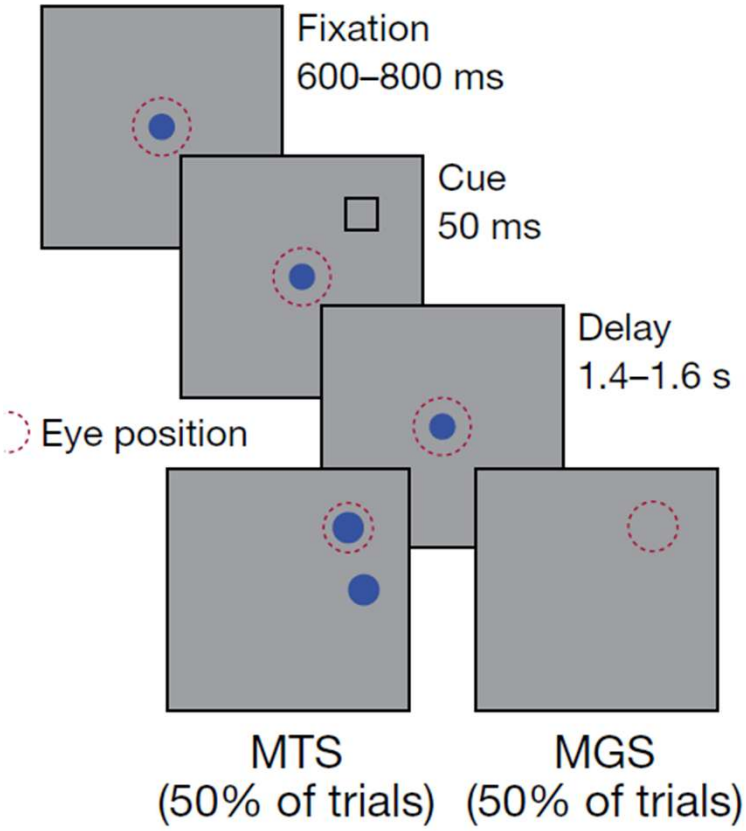
- Working memories are nonconscious most of the time.
- Even items reported as “seen” are not always « in mind » -- they can go dormant.

Problems of such studies:

- perhaps a single electrode goes silent, but the memory remains supported by sustained firing in other neurons.
- Can we detect the predicted short-term change in synaptic strength?

Recent evidence in favor of activity-silent working memory

Panichello, M. F., Jonikaitis, D., Oh, Y. J., Zhu, S., Trepka, E. B., & Moore, T. (2024). Intermittent rate coding and cue-specific ensembles support working memory. *Nature*, *636*(8042), 422-429. https://doi.org/10.1038/s41586-024-08139-9

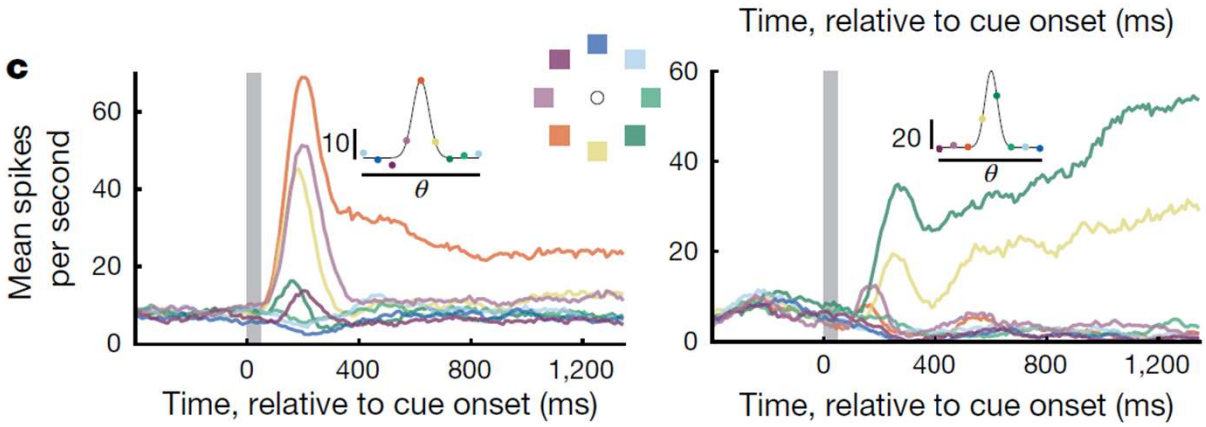


3 monkeys are engaged in classic working-memory tasks: they must memorize a 50-ms location cue for ~1.5 s, in order to either

- choose the corresponding target (match to sample, MTS)
- or move the eyes to to that location (memory guided saccade, MGS)

Many neurons, such as those below, show

- A tuning curve indicating a preference for certain locations
- Sustained activity throughout the delay **once averaged across trials**



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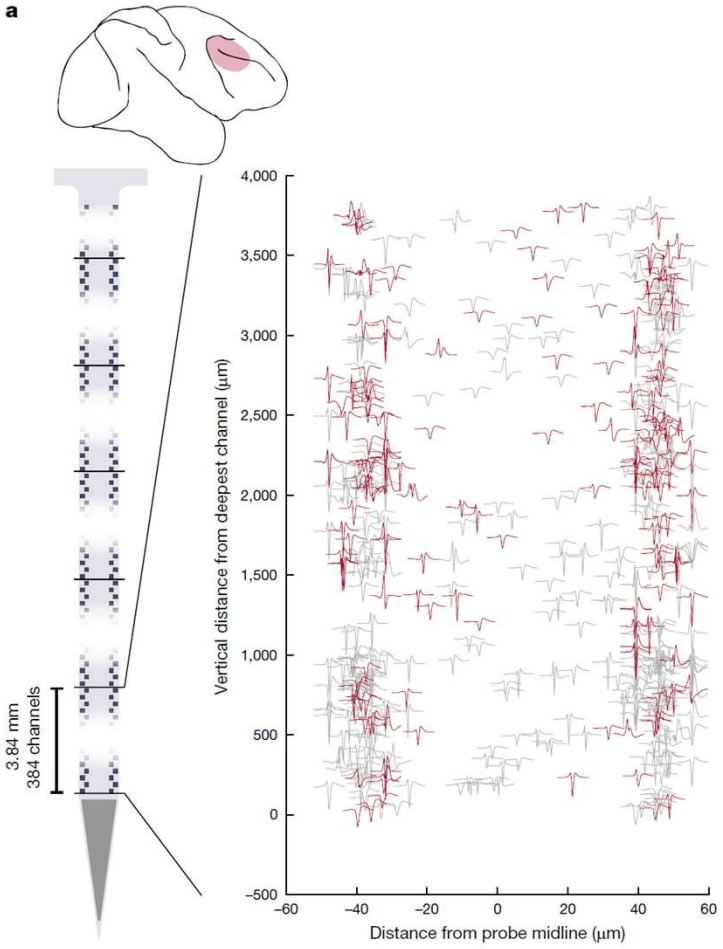
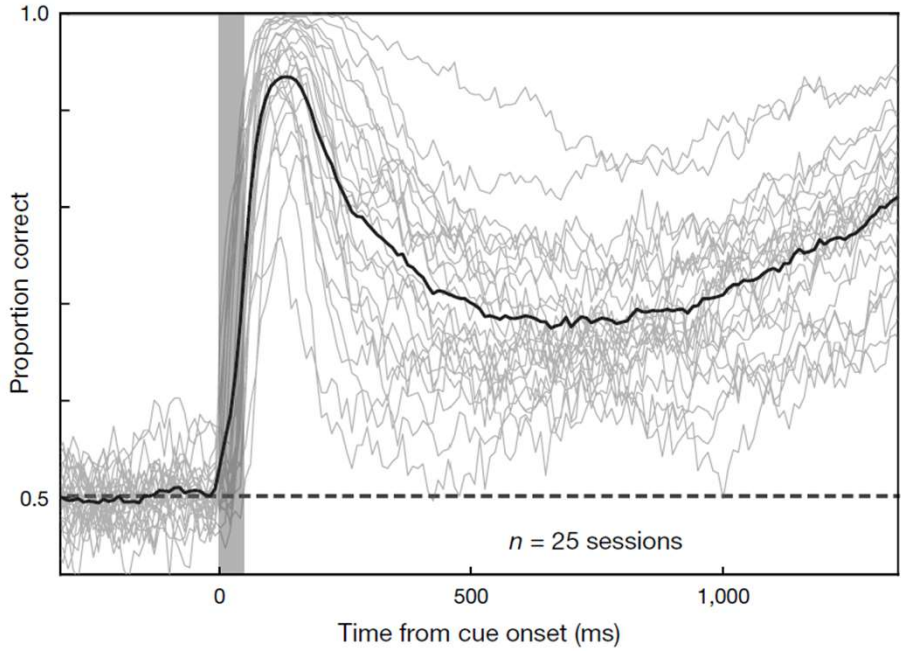


Simultaneous recordings with neuropixel probes (384 contacts on the tip) permit to record hundreds of tuned cells in dorsolateral prefrontal cortex. In turn, this allows to train a decoder that performs way above chance in decoding, **on average**, the location of the memorized item (binary classifier for opposite locations, chance = 50 %).



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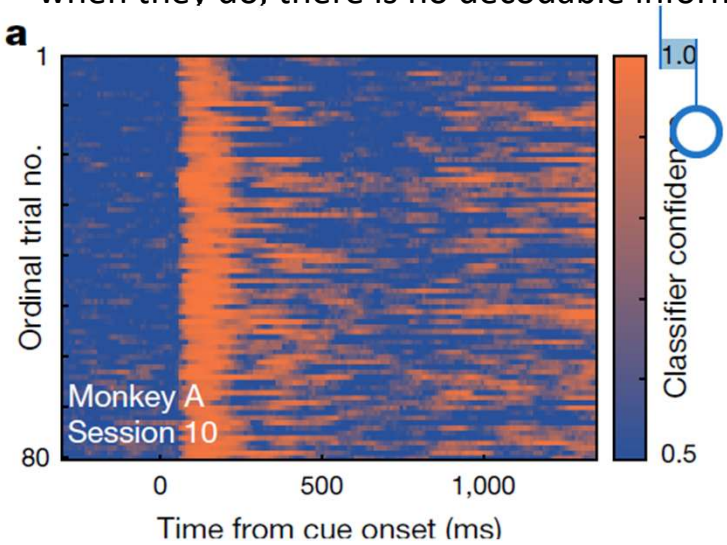
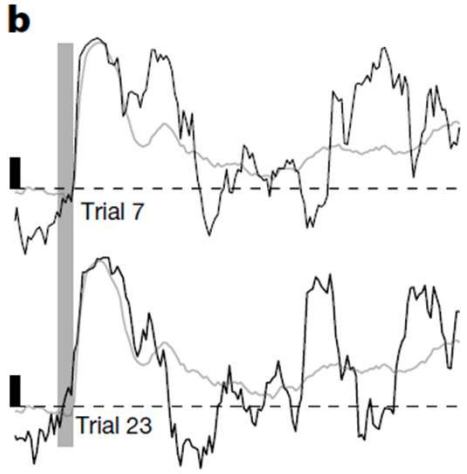
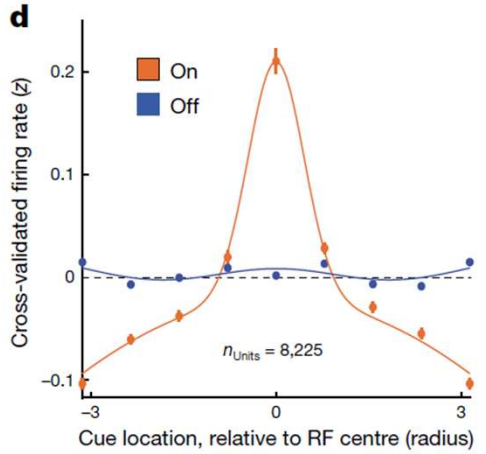
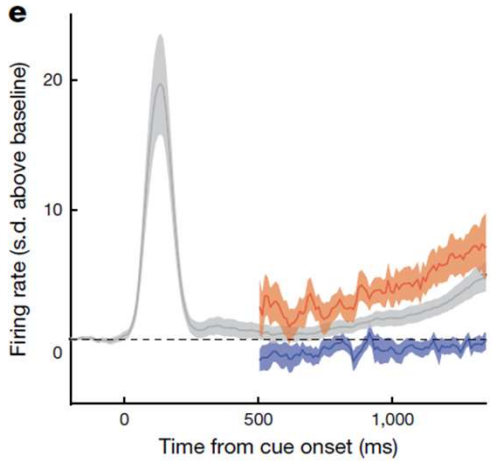
Now looking at **single trials**: the confidence of the detector fluctuates widely across time. WM does not seem to be sustained on every trial !
Bayesian modeling shows that the data goes against a single-state model (where confidence would fluctuate around a single mean) and instead favors **a two-state model**, with an **on-state** (high confidence) and an **off-state** (low confidence).
Crucially, those states are **coordinated across multiple electrodes:** all sites go off, and when they do, there is no decodable information in the neurons' remaining spikes.





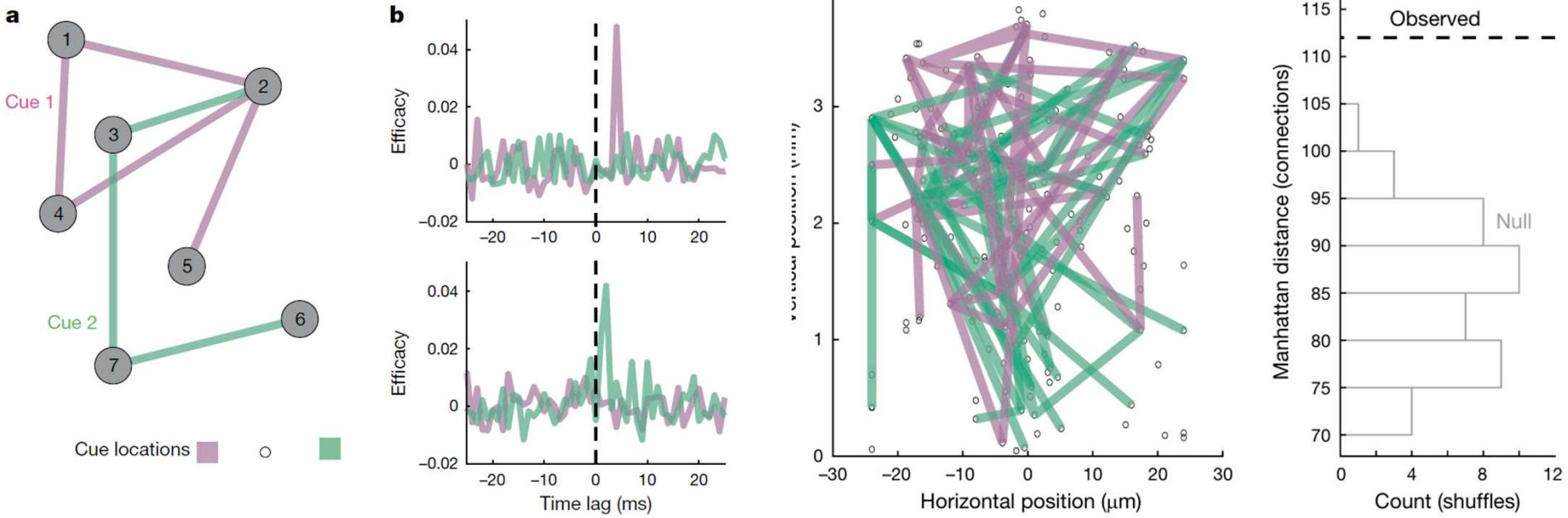




How is working memory maintained when PFC neurons go silent?

Panichello, M. F., Jonikaitis, D., Oh, Y. J., Zhu, S., Trepka, E. B., & Moore, T. (2024). Intermittent rate coding and cue-specific ensembles support working memory. *Nature*, *636*(8042), 422-429. https://doi.org/10.1038/s41586-024-08139-9

Is there a change in synaptic weights, as predicted by the Tsodyks model?
The massive recordings allow to find many pairs of putatively monosynaptic connections
– and their efficacy does change depending on which location cue is being memorized!
Each of the memorized locations leads to a partially specific set of cross-neuron synaptic enhancements.

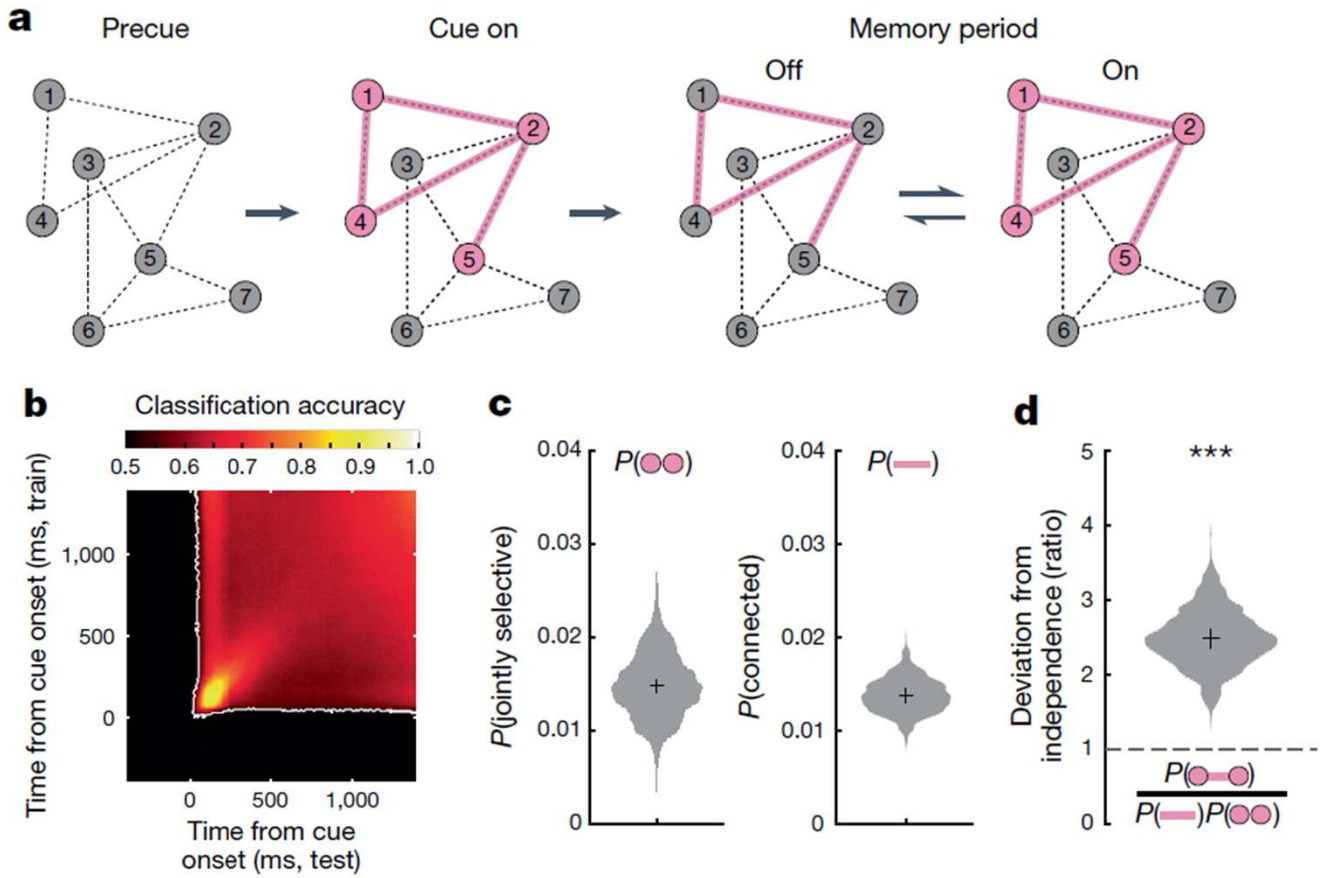


Active neuronal states seem to be turned into activity-silent synaptic states

Panichello, M. F., Jonikaitis, D., Oh, Y. J., Zhu, S., Trepka, E. B., & Moore, T. (2024). Intermittent rate coding and cue-specific ensembles support working memory. *Nature*, *636*(8042), 422-429. https://doi.org/10.1038/s41586-024-08139-9

The model predicts that the neurons activated by the cue also reinforce their mutual connections. They can then go off, and be reinstated by those high connections.

Predictions:
- The active firing pattern for a given memory should remain the same from cue to delay period (no rotating or time-changing code)
- The neurons that fire together during the cue period should have a higher probability of wiring together during the off period.
Indeed they are 2.5 times more likely to coincide than if those two things were independent of each other.



Conclusion: The relation between working memory and consciousness

Working memory corresponds to the active maintenance of information in prefrontal cortex.

Prediction of global neuronal workspace theory : an item which is active in working memory is always consciously reportable.

Conscious perception corresponds to the entry of information into active working memory (a global neuronal workspace).

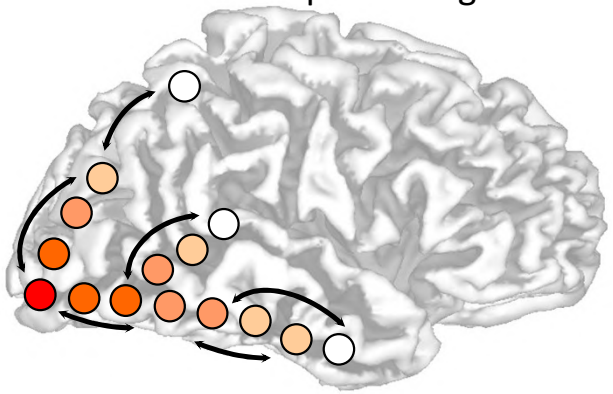
However, during a long memory delay, the WM representation can go dormant (and therefore unconscious), and yet still be reactivated into a conscious, active representation

Short-term memory is the ability to maintain information over time for a few seconds. It can be based on a dormant representation, relying on short-term changes in synaptic weights (and thus bridging into long-term memory).

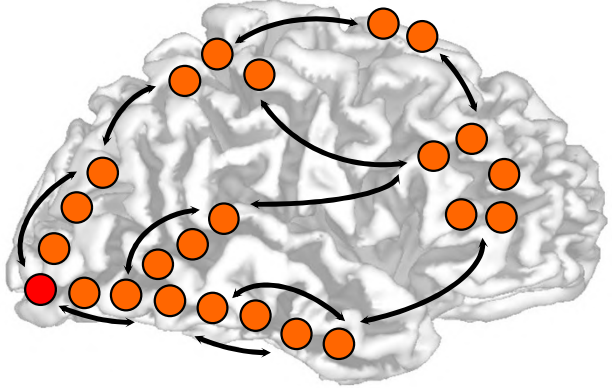
Even a brief nonconscious, which fails to trigger a full ignition, may leave a small dormant representation in short-term memory

A dormant representation cannot be mentally manipulated. Only active representations can.

subliminal processing

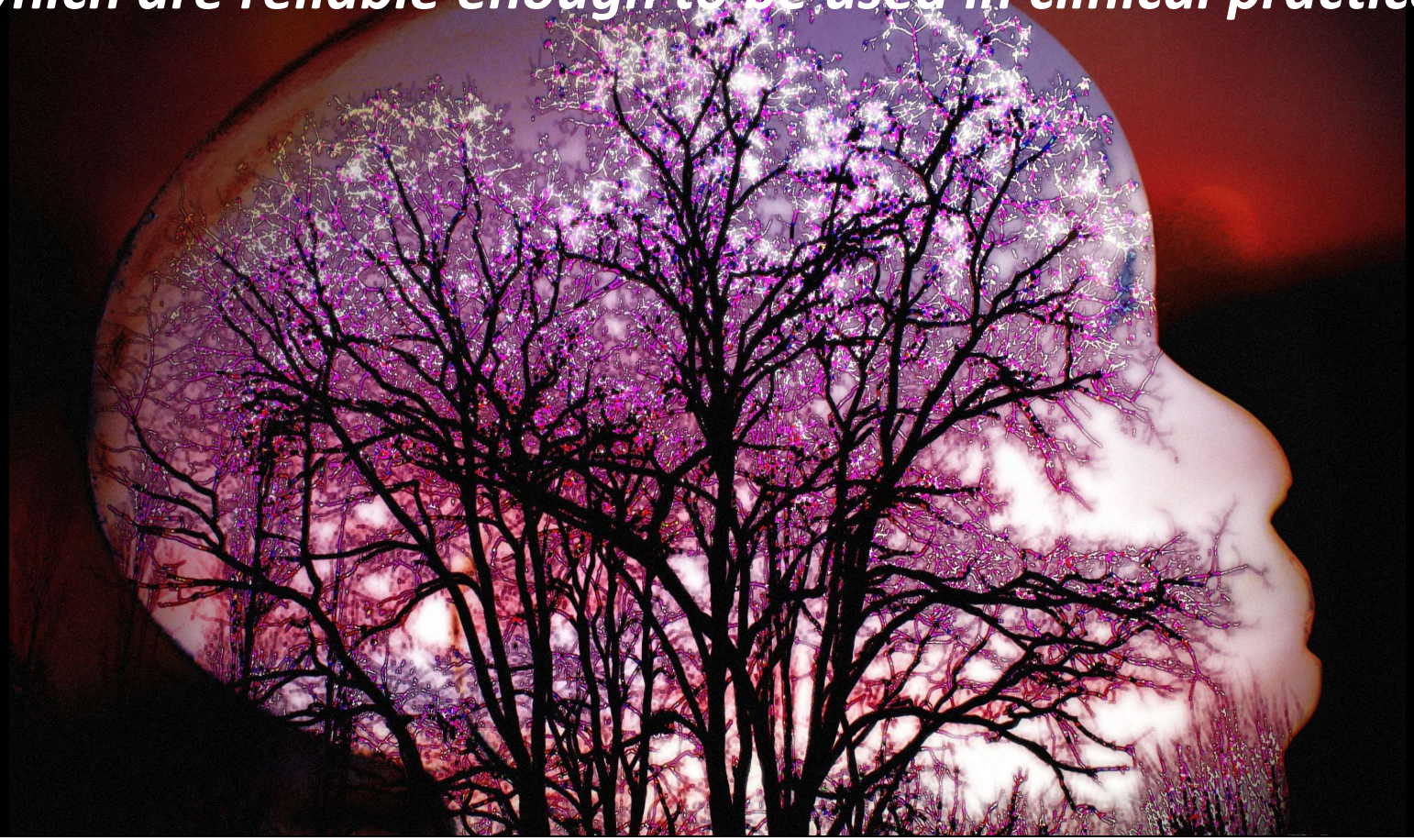


conscious processing



Conclusions of the course:

We now have many neural « signatures » of consciousness, which are reliable enough to be used in clinical practice.



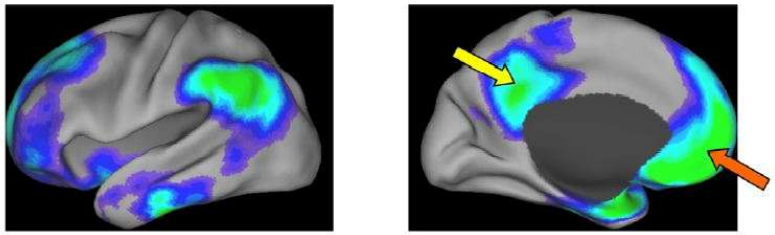
Spontanous activity: The restless brain

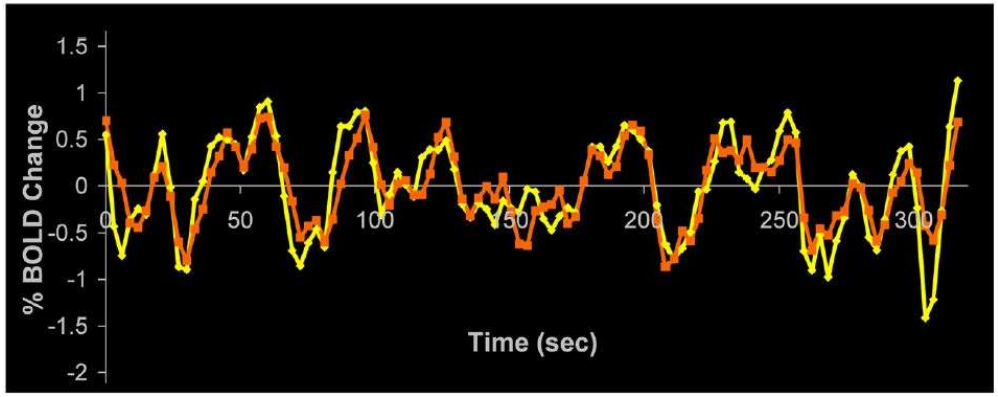
The global workspace is never silent, and does not require external inputs to be activated.

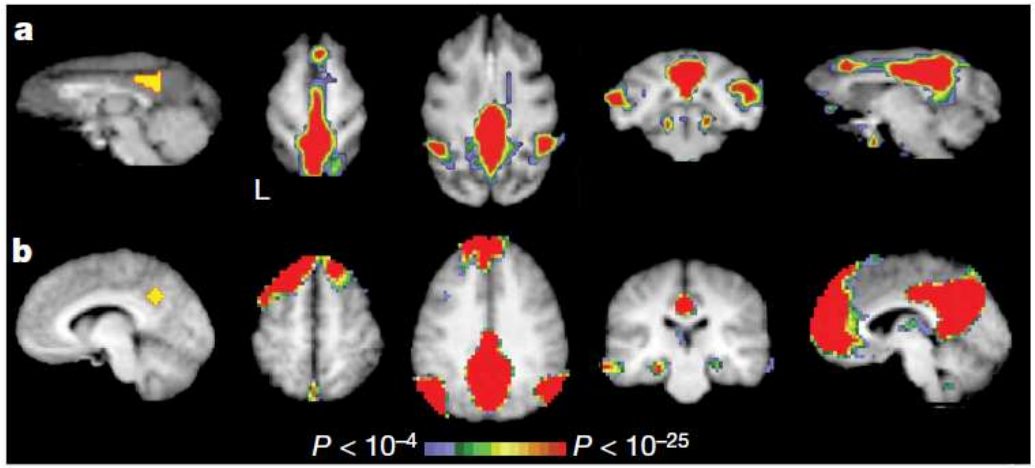
Even at rest, the conscious brain is constantly traversed by structured activity formed global patterns.

These « resting-state » patterns can partially predict the content of consciousness, e.g. whether a subject is imagining or mind wandering (Christoff, 2009; Mason, 2007) or what is the focus of attention (Barttfeld, 2012).

A paradox, however, is that these networks continue to be observed during anesthesia (Vincent, 2007).



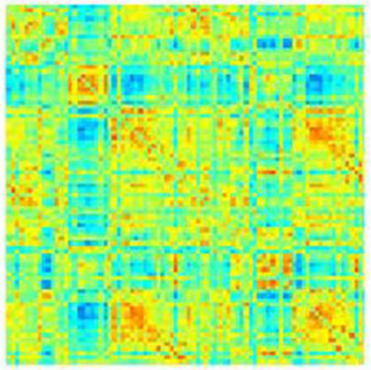


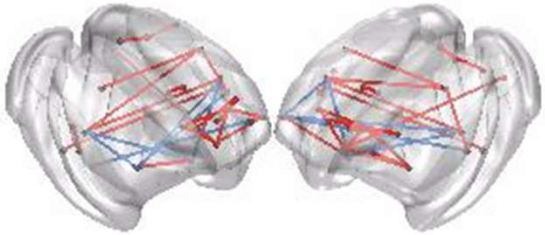


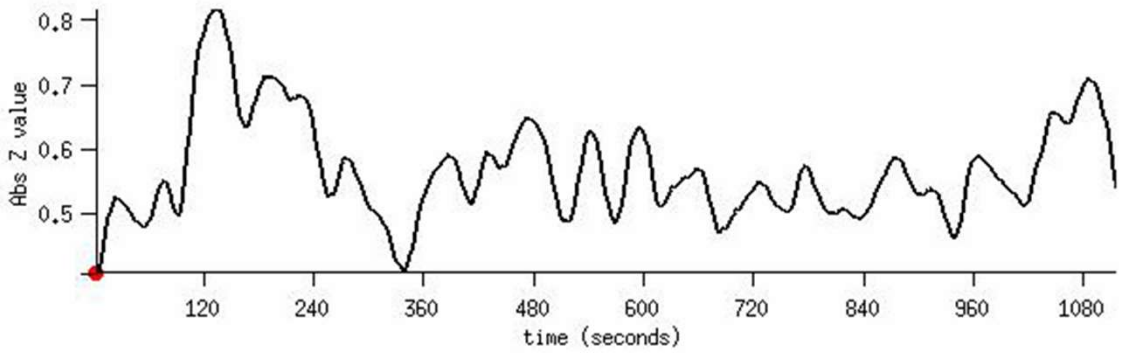
Resolving the paradox of spontaneous activity

Pablo Barttfeld, Lynn Uhrig, Bechir Jarraya et al., PNAS 2015

- Resting-state fMRI in monkeys during wakefulness and two levels of propofol anesthesia.
- Analysis of the dynamics of resting-state activity





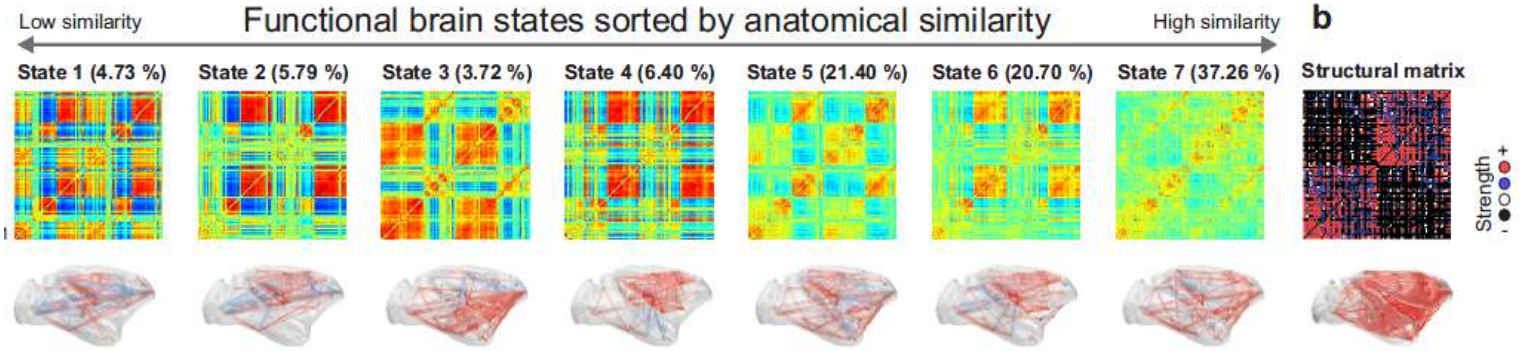


Resolving the paradox of spontaneous activity

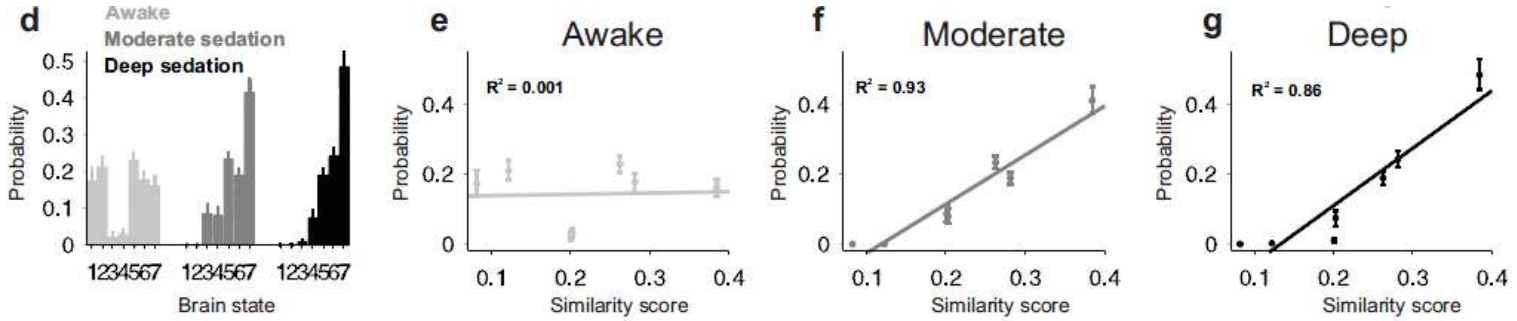
Barttfeld, Uhrig, Sitt, Sigman, Jarraya & Dehaene, PNAS 2015

We replicate the presence of long-distance functional connectivity during anesthesia, but…

- During the conscious state, functional connectivity is dynamic and ceaseless varies.



- A **greater diversity of states** is present during consciousness than during anesthesia
- The states that persist during anesthesia are most similar to **anatomical connectivity.**



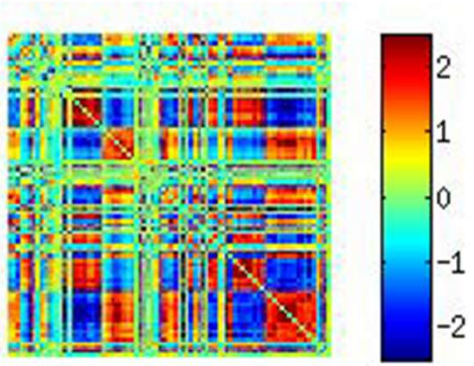
→ During anesthesia, the anatomical network is traversed by random spikes.

→ During wakefulness, global workspace dynamics self-organizes into a series of fluctuating states.

Jacobo Sitt

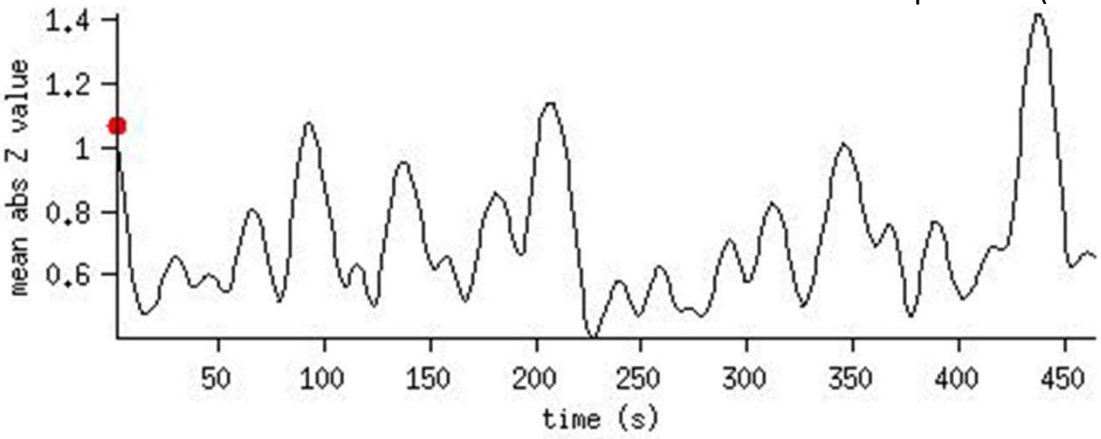
fMRI dynamics of resting-state activity: A signature of consciousness that also works in humans

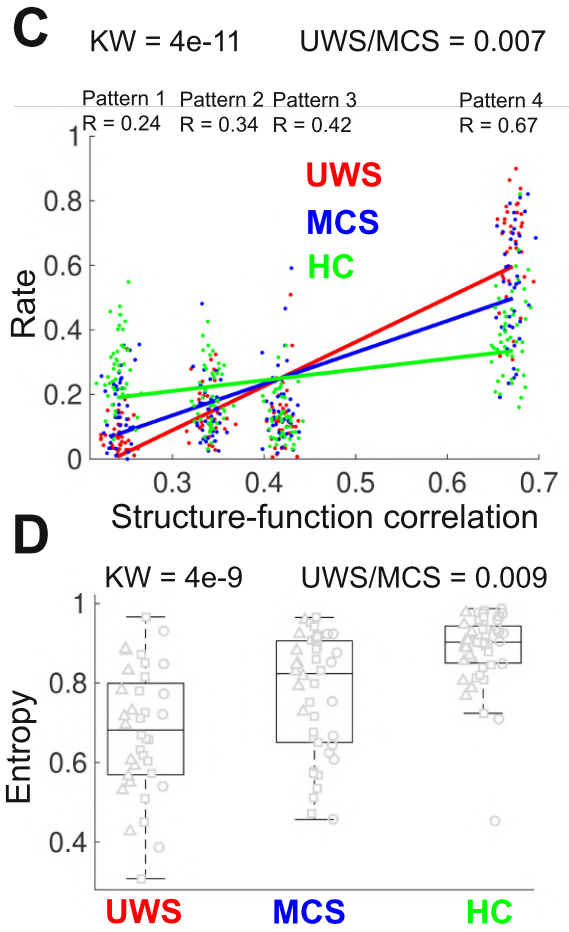
Demertzi et al., with Niko Schiff, Adrian Owen, Steven Laureys, Lionel Naccache and Jaco Sitt, Science Advances 2019



125 Multi-centric recordings of healthy controls (HC) and patients in minimal consciousness (MC) or unresponsive wakefulness syndrome (UWS)

- Liège: 21 healthy controls, 40 patients (23 MCS, 17 UWS)
- Paris: 15 healthy controls, 22 patients (9 MCS, 13 UWS)
- New York: 11 healthy controls, 16 patients (10 MCS, 6 UWS)



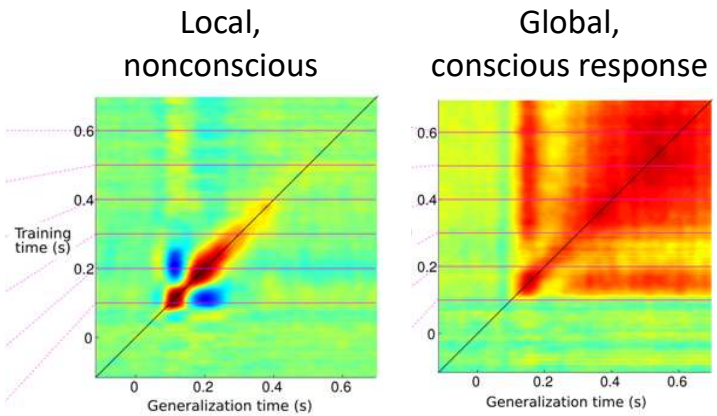


Towards clinical applications

The available signatures of consciousness are beginning to help diagnose patients in **vegetative state (UWS)** or **minimal consciousness (MC)**.

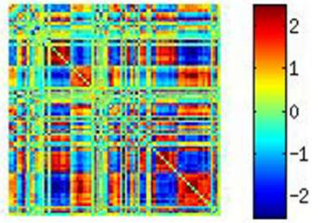
Late global metastable responses to deviant sequences

are only present in patients with residual consciousness or who are soon to recover.

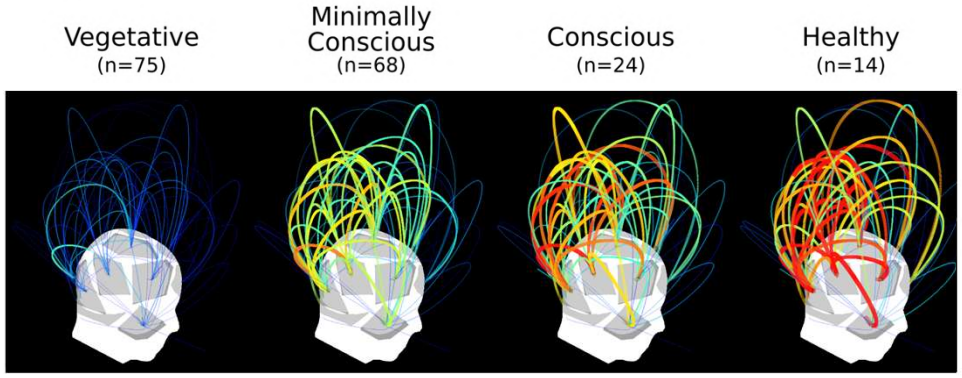


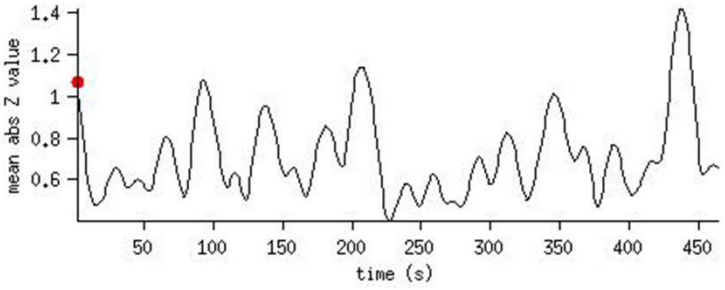
Jacobo Sitt

In fMRI: the diversity of dynamic states during rest indexes consciousness in both anesthesized monkeys and human patients



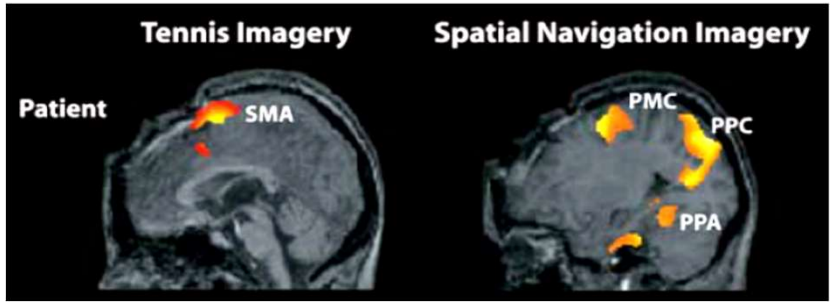
Global brain-scale communication in the theta band (as measured by weighted symbolic mutual information, wSMI) indexes the state of consciousness





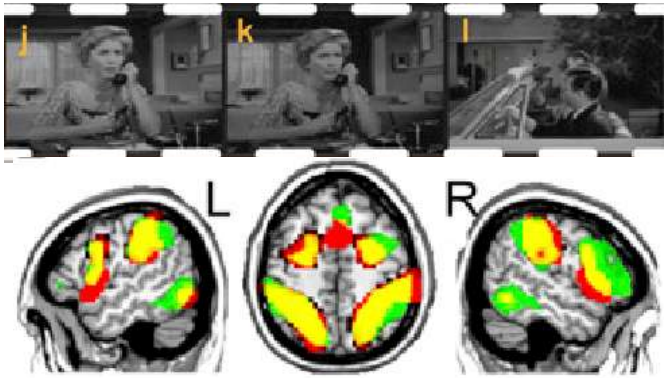
Many other methods may detect residual consciousness

fMRI during mental imagery



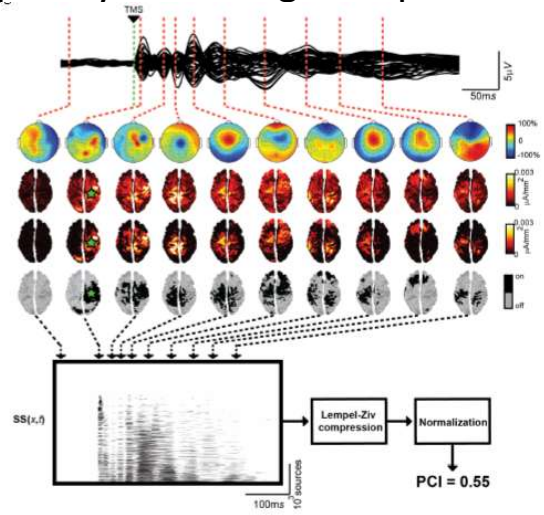
Owen et al, *Science* 2006

fMRI during a Hitchcock movie



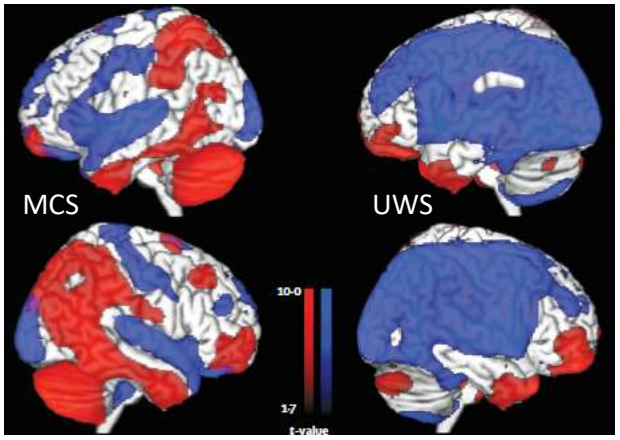
Naci et al, *PNAS* 2014

EEG complexity after magnetic pulse



Casali et al, *Science Translational* 2013

Brain metabolism

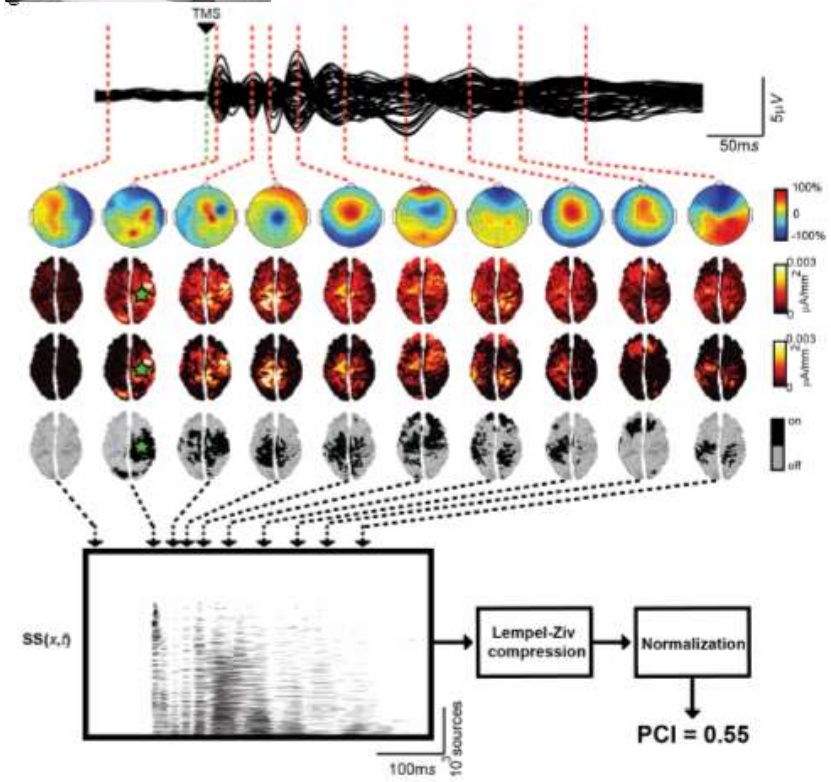


Stender et al, *Lancet* 2014

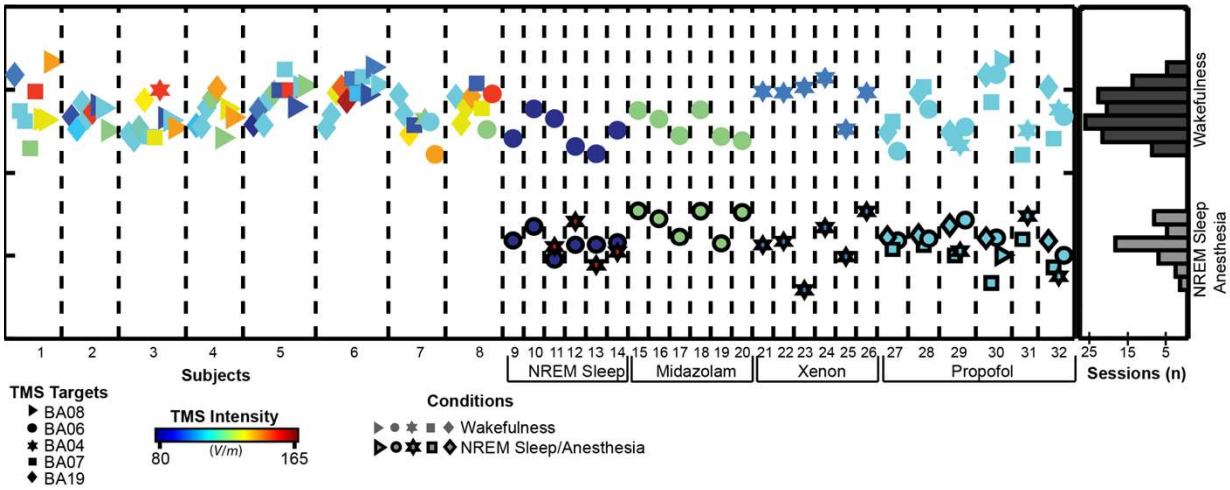
Perturbational complexity as a marker of consciousness

Casali, A. G., Gosseries, O., Rosanova, M., Boly, M., Sarasso, S., Casali, K. R., Casarotto, S., Bruno, M.-A., Laureys, S., & Tononi, G. (2013). A theoretically based index of consciousness independent of sensory processing and behavior. *Science translational medicine*, *5*(198), 198ra105-198ra105.

A Transcranial Magnetic Stimulation (TMS) pulse is used to trigger an event-related spectral evoked response in simultaneous EEG recordings



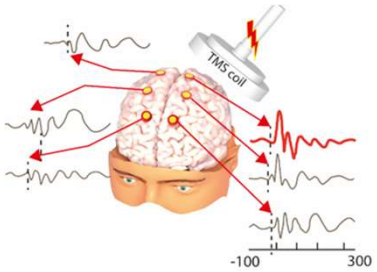
The normalized complexity of that response, as indexed by its compressibility (Lempel-Ziv), called Perturbational Complexity Index (PCI), nicely separates awake and asleep states.



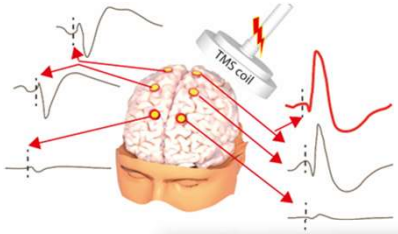
With thanks to Massimo Massimini

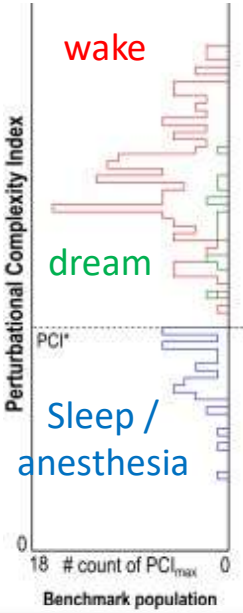
The same measure is then applied to patients, as a function of their Coma Recovery Scale (CRS-revised)

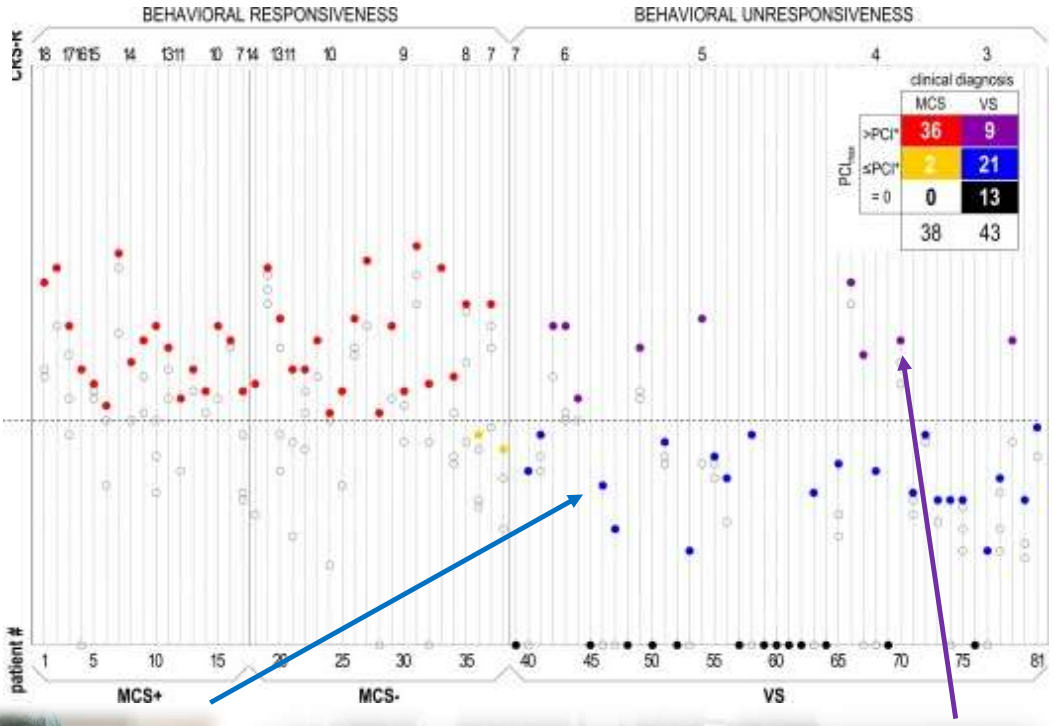
WAKE/DREAMING



SLEEP/ANESTHESIA





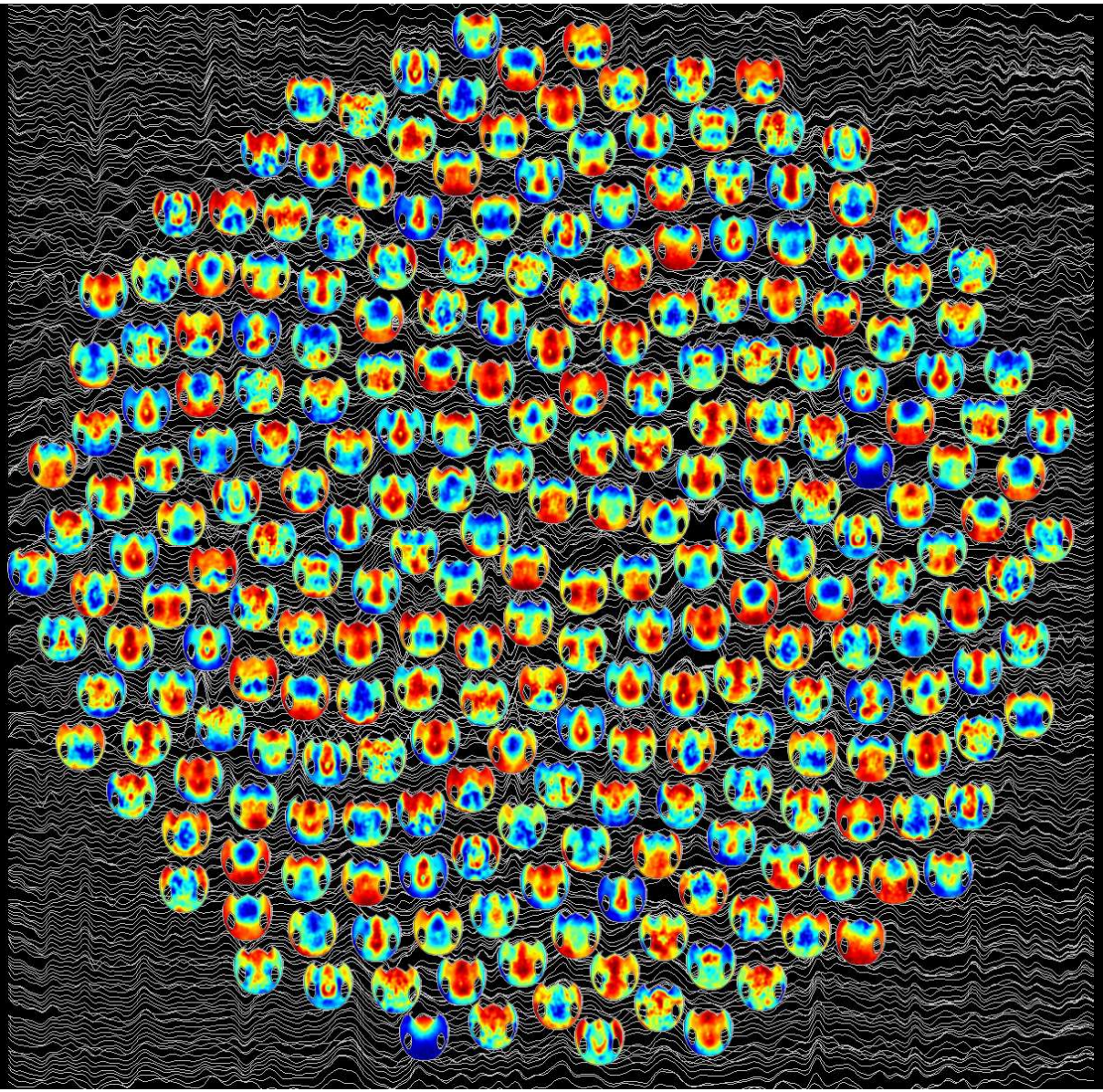


Red = MCS patients (~conscious)
Blue = VS patients with low PCI (~non-conscious)
Purple = VS patients who may still be conscious

White = lower PCI values obtained from other non-max stimulation sites.

Black = patients in whom no response was elicited by TMS

With thanks to Massimo Massimini



92 potential markers of consciousness from EEG alone!

(1) event-related potentials versus ongoing EEG activity
(2) local responses versus information exchange
(3) spectral patterns versus information complexity
(4) average versus fluctuations

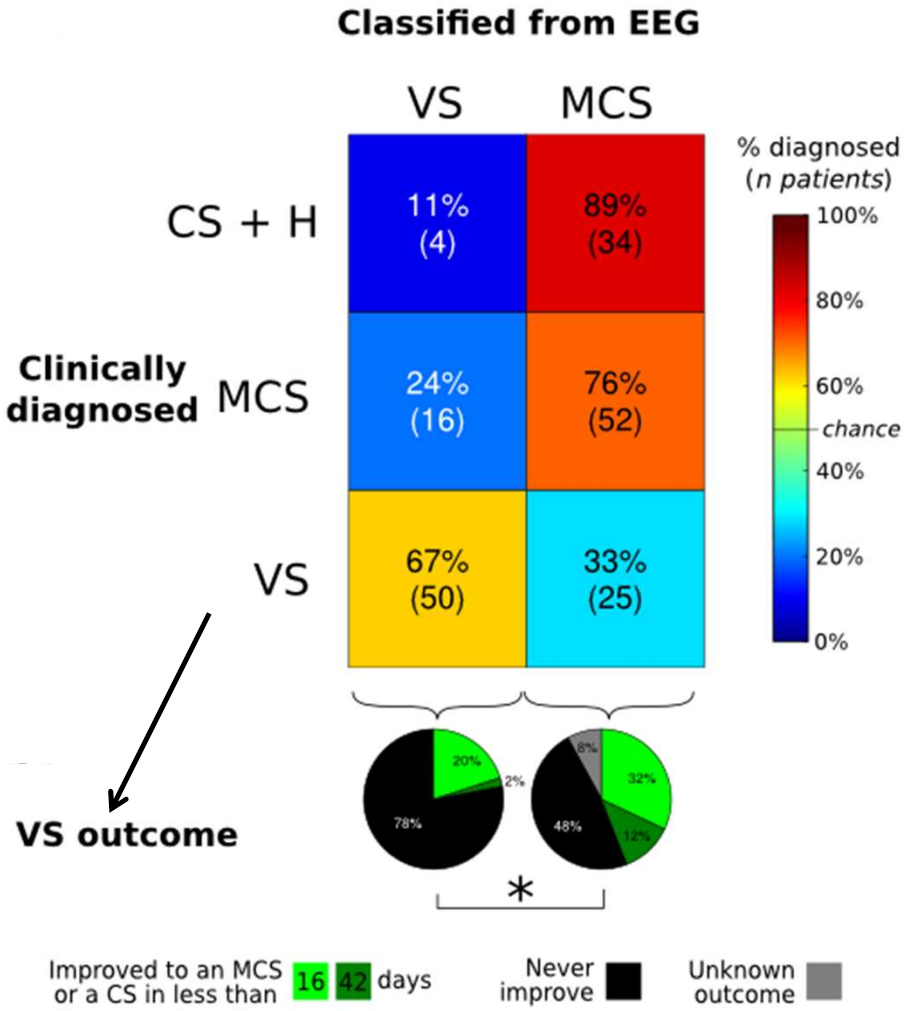
Automatic classification of patients from multiple EEG markers

Sitt et al., Brain 2014; Engemann et al., Brain 2018

A combination of 94 EEG markers can facilitate clinical diagnosis and predict recovery.

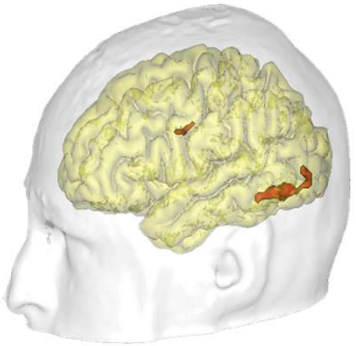
The most informative markers of consciousness are:

- **Long-distance information sharing** (theta band)
- **Late and long-lasting ignition to auditory novelty**
- **High and stable EEG complexity**
- **Increased power in higher, attention-dependent frequencies** (alpha and theta) and **reduced slow waves** (delta)

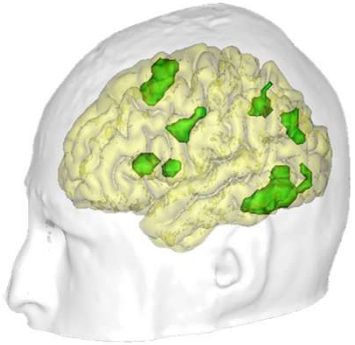


28 years of Global Neuronal Workspace

Invisible words



Visible words




Lionel Naccache


Ghislaine Dehaene


Jean-Pierre Changeux


Luc


Sid Kouider


Darinka Trübutschek


Jérôme Sackur


Pieter Roeflsema

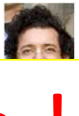

Bechir Jarraya


Jean-Rémi King


Sébastien Marti


Mariano Sigman

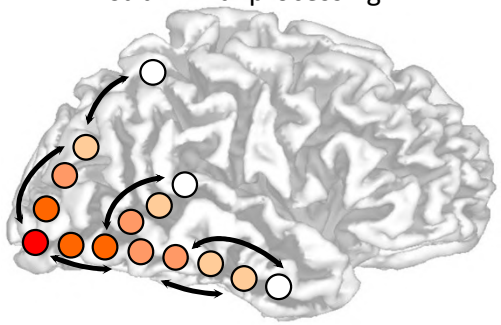

Claire Sergent


er

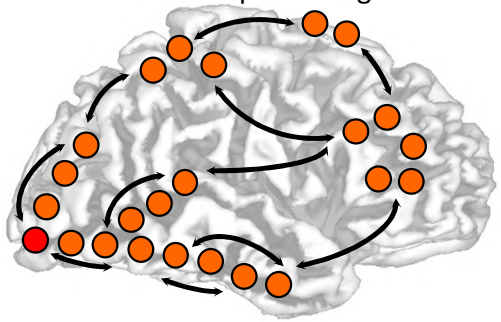

Jacobo Sitt


Moti Salti

subliminal processing

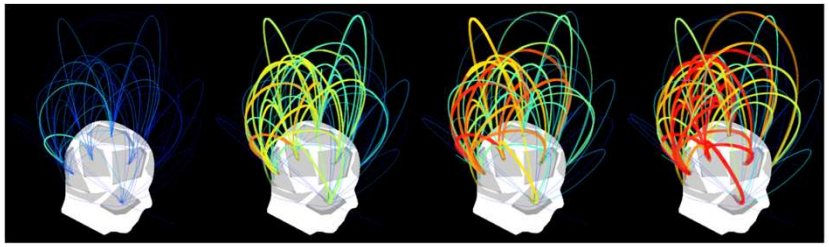


conscious processing

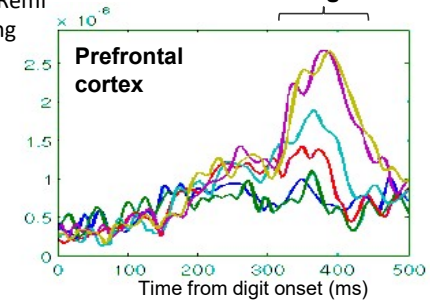


Merci de votre attention !

Symbolic mutual information



All-or-none ignition



1. Linear accumulation **2. All-or-none ignition**