Human brain mechanisms of subliminal processing and conscious access

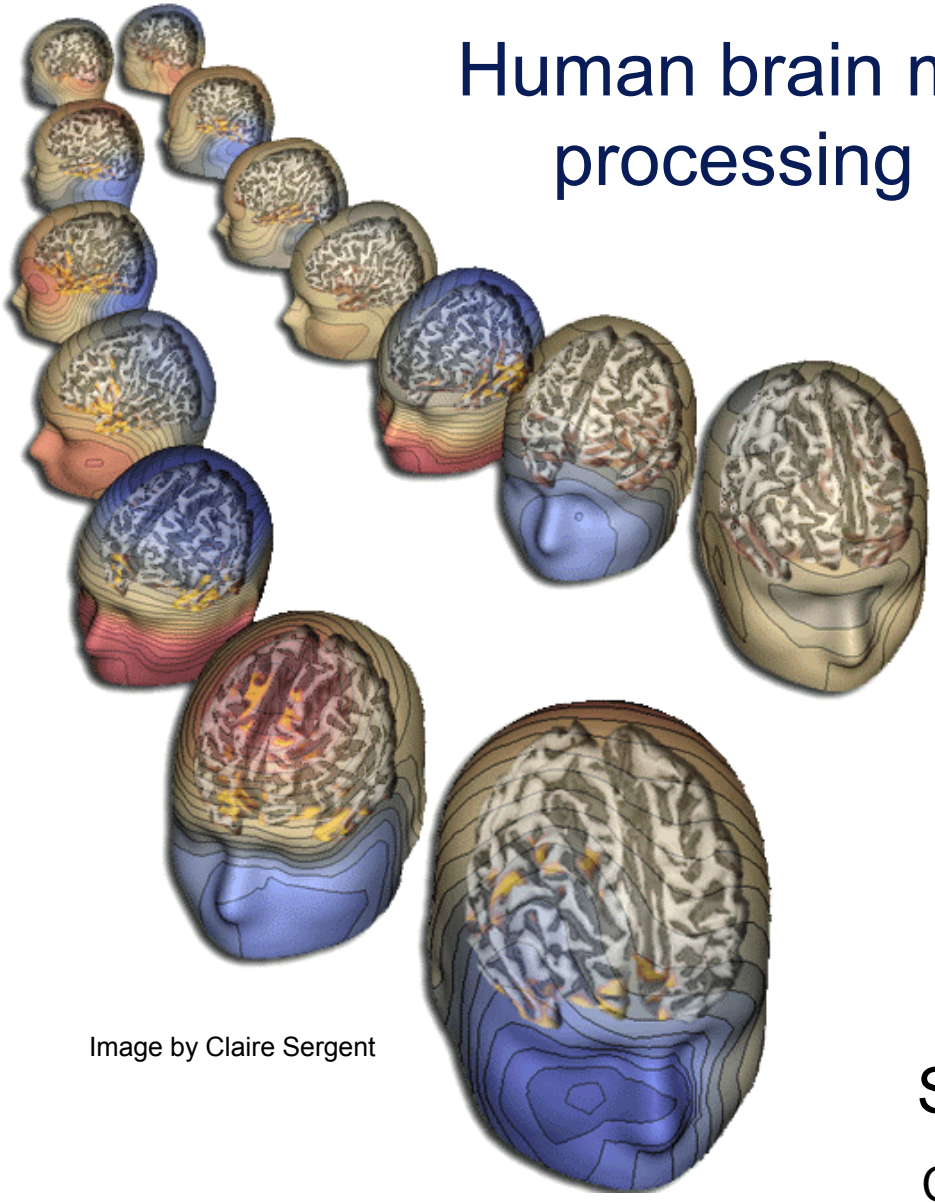


Image by Claire Sergent

Stanislas Dehaene

Collège de France, Paris

INSERM/CEA Cognitive Neuroimaging Unit, Orsay
www.unicog.org

Research strategy

1. The contrastive method: « … contrasting pairs of similar events, where one is conscious but the other is not. » (Baars, 1989)

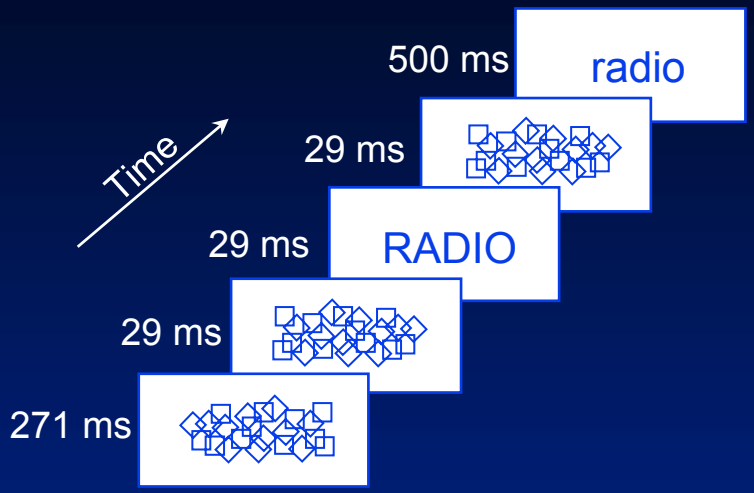
2. The primacy of the subjective: « …the first crucial step is *to take seriously introspective phenomenological reports*. (…) They constitute primary data that need to be measured and recorded along with other psychophysiological observations » (Dehaene & Naccache, 2001)

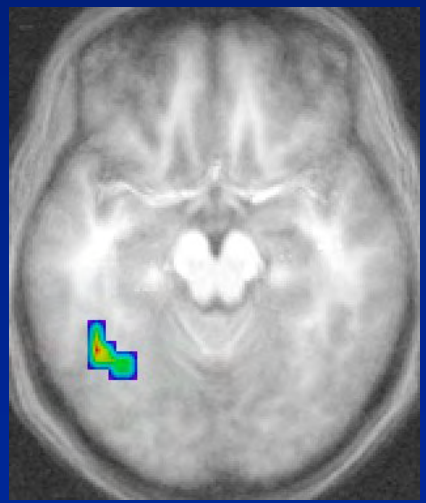
3. Consciousness is a «real, natural, biological phenomenon, litterally located in the brain» (Revonsuo 2001)
Neuro-imaging methods can be used to study access to consciousness.
Look for the objective bases of subjective states

4. Theoretical models are needed to integrate disparate observations and bridge from the neuronal to the psychological level

Subliminal priming in the visual word form area

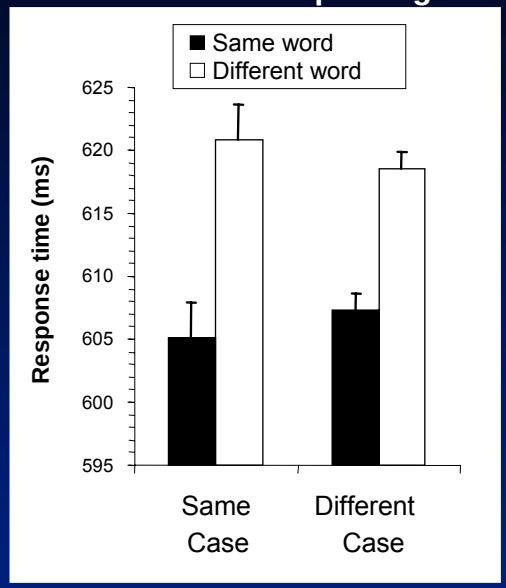
Dehaene et al, *Nature Neuroscience*, 2001; *Psychological Science*, 2004



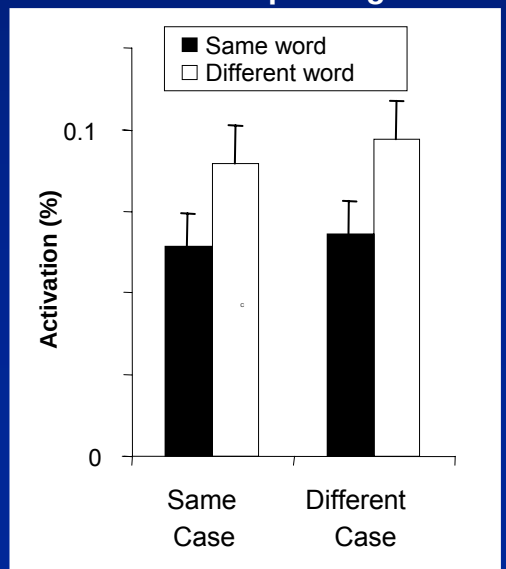


Left fusiform
(-44, -52, -20)

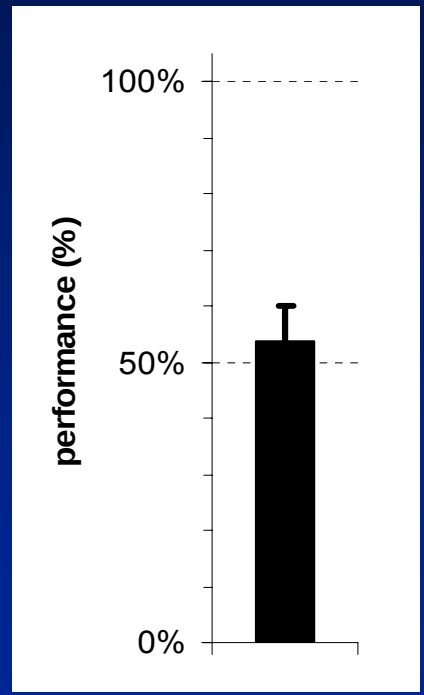
Behavioral priming



fMRI priming



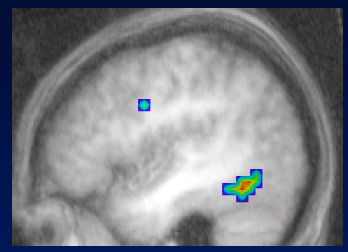
Absence of conscious perception (forced-choice between two words)



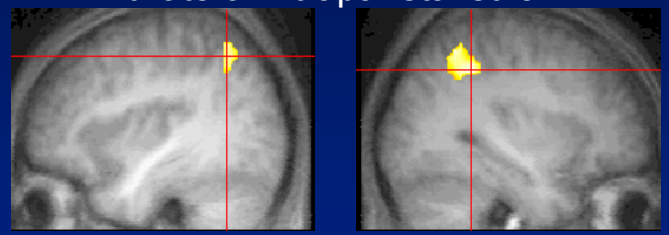
Evidence for extensive subliminal processing using fMRI priming

- Orthographic priming
  - Left fusiform gyrus (Dehaene et al, 2001, 2004; Devlin et al, 2004)
- Semantic priming
  - Numerical proximity in bilateral intraparietal sulci (Naccache and Dehaene, 2001)
  - Semantic proximity of words in left middle temporal gyrus (Devlin et al, 2004; Nakamura, Dehaene et al, 2005)
  - Amygdala activation by masked emotional words (Naccache et al, 2005)
- Motor priming
  - Bilateral motor areas (Dehaene et al., 1998)

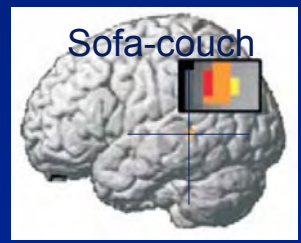
Visual word form area

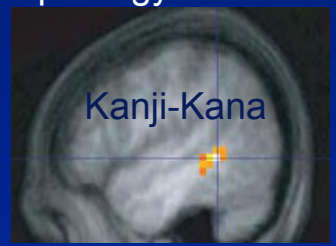


bilateral intraparietal sulci

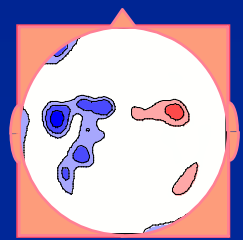


Left middle temporal gyrus



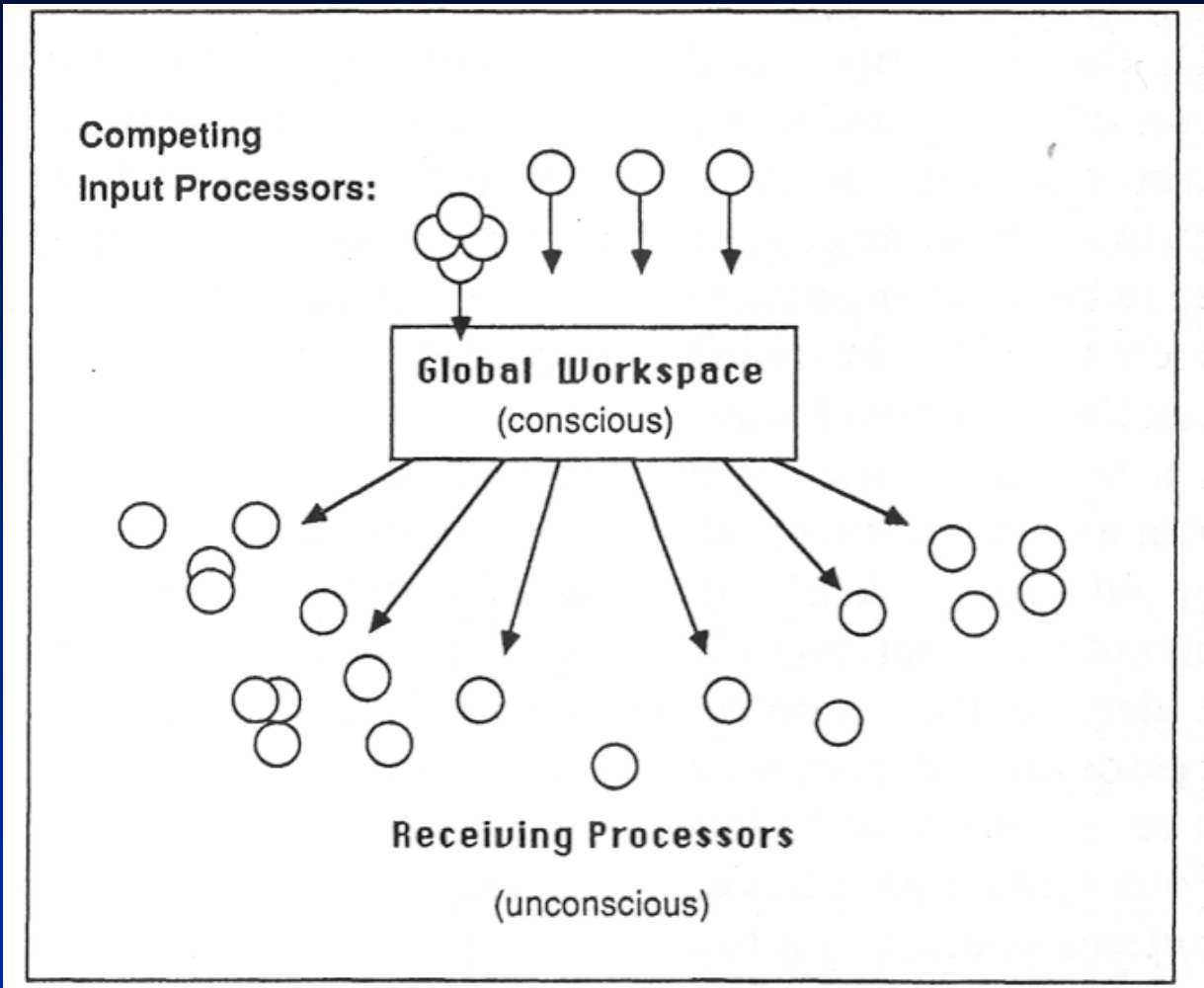


Motor lateralized readiness potential

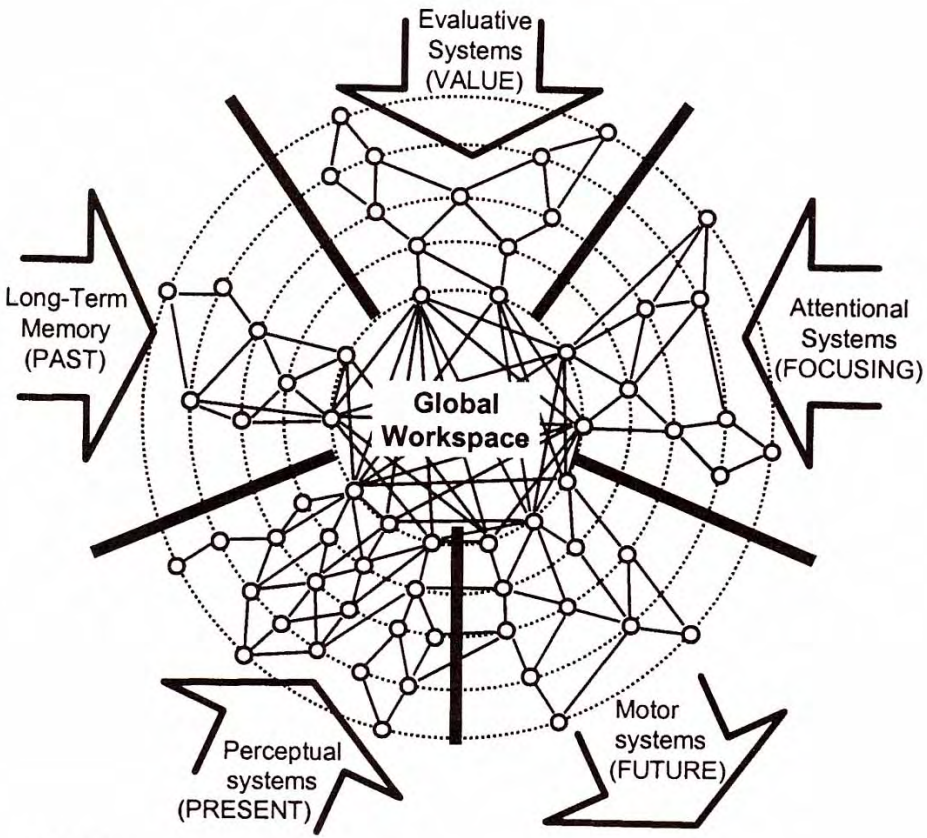


An architecture mixing parallel and serial processing:

Baar's (1989) theory of a **conscious global workspace**



Model 1. A global workspace in a distributed system.

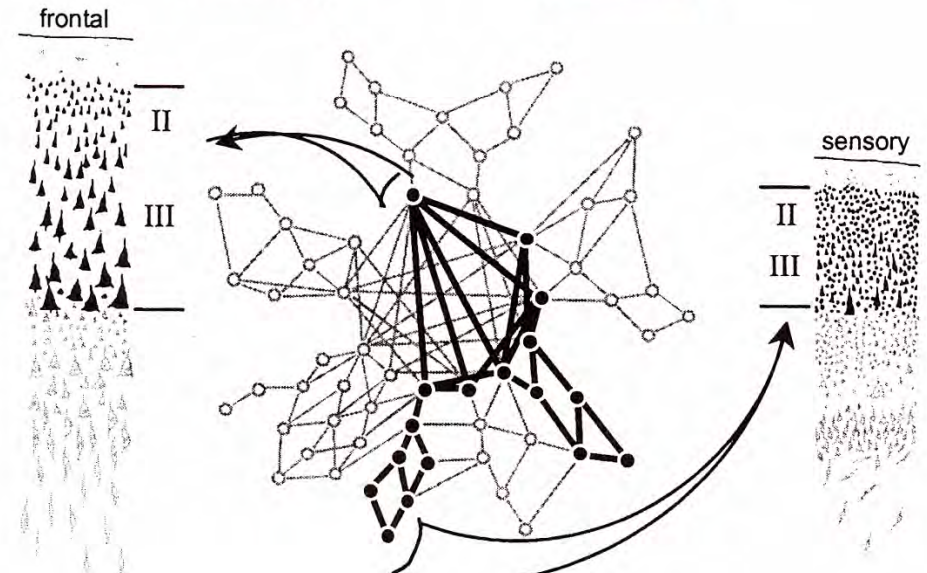


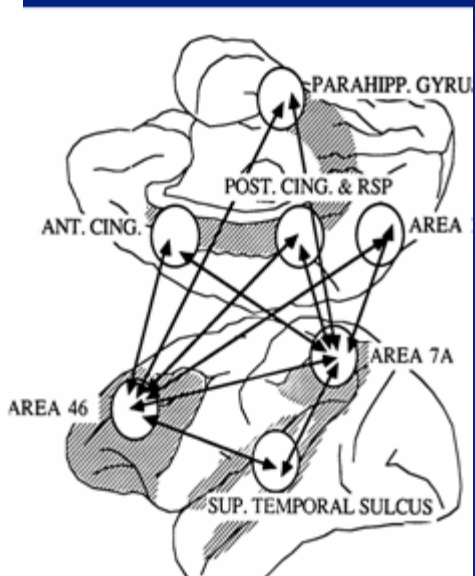
THE NEURONAL WORKSPACE HYPOTHESIS

two computational spaces:

1) specialized processors
modular, encapsulated
& automatic

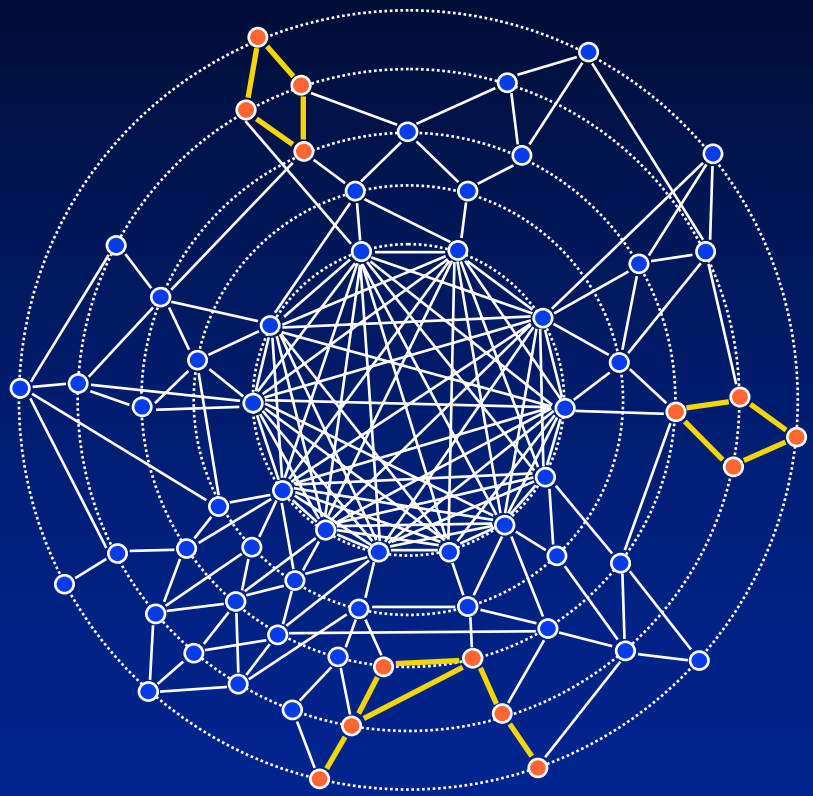
2) *global workspace* with long range axon neurons broadcast signals to multiple areas yielding subjective experience of being conscious & reportability



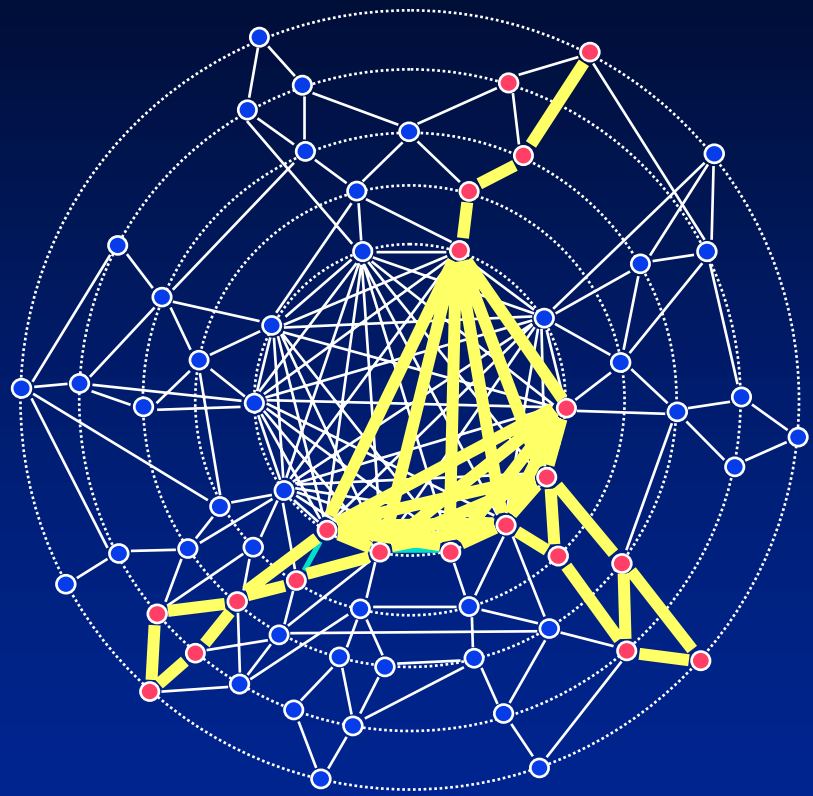


Dehaene, Kerszberg & Changeux, PNAS 1998

SEVERAL AUTOMATIC TASKS



A SINGLE CONSCIOUS TASK

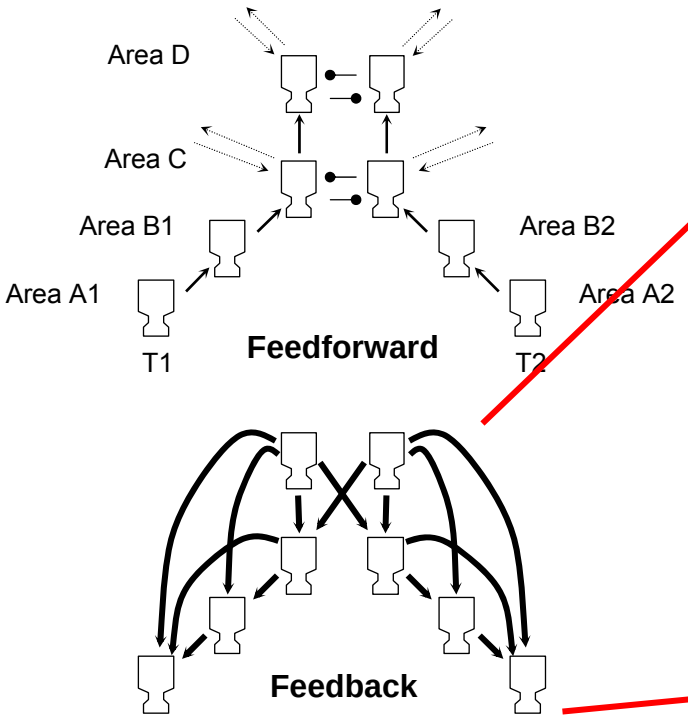


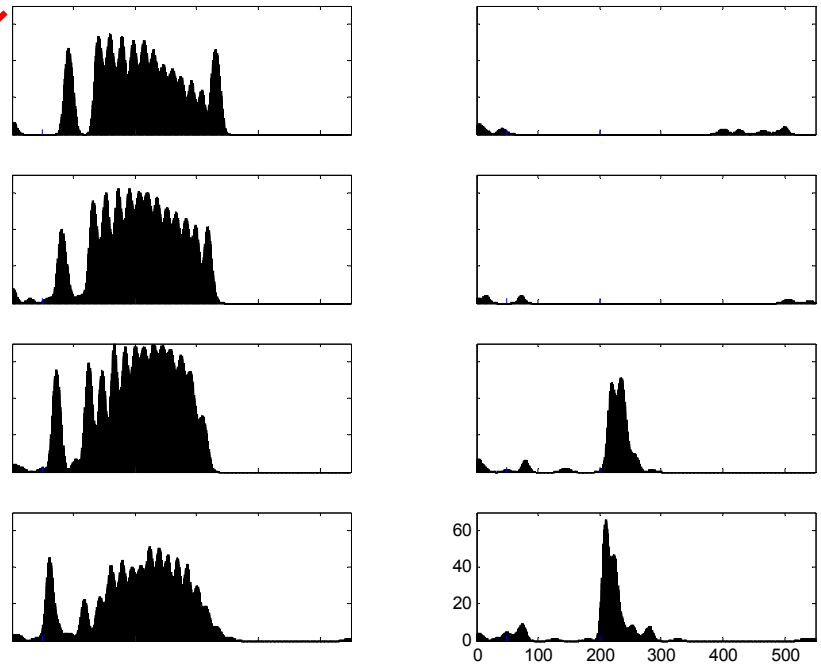
Key postulates of the neuronal workspace model

- The same brain processors may participate in unconscious and conscious processing.
- The conscious mode is characterized by
  - feedforward activation progressively recruiting a large set of distributed workspace neurons with long-distance axons
  - thus forming a brain-scale reverberating assembly that amplifies, in a top-down manner, the subset of processor neurons holding the current conscious content
  - and broadcasting this content to many other areas
- Workspace neurons are particularly dense in prefrontal, parietal and anterior cingulate areas.
- The workspace operates in a top-down manner: even in the absence of inputs, workspace neurons are the seat of a permanent spontaneous activity subject to selection by ascending neuromodulator systems

Detailed simulations of the global neuronal workspace using a semi-realistic network of spiking neurons

(Dehaene et al., *PNAS* 2003, *PLOS Biology, 2005*)

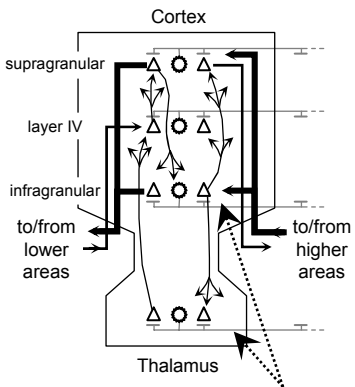




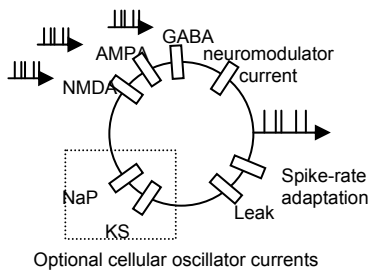
« Ignition » of the global workspace by target T1

Failure of ignition by target T2

Thalamocortical column



Spiking neurons



Dehaene, Sergent, & Changeux, *PNAS,* 2003

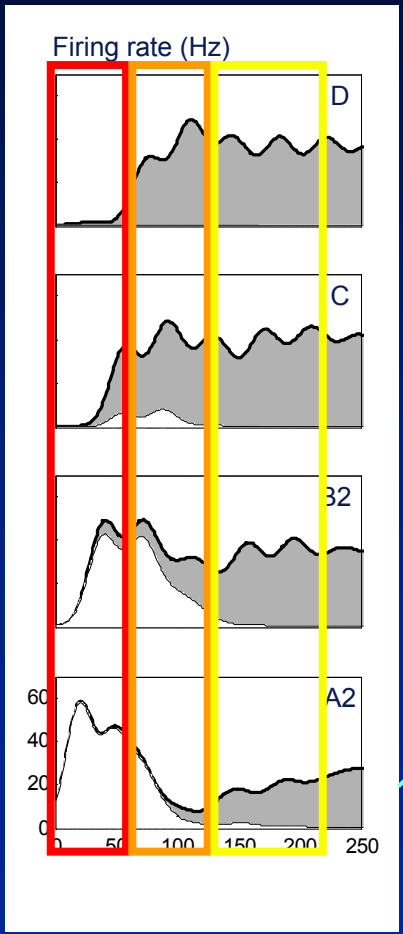
Predicted dynamics of conscious access

1. Subliminal feedforward activation

2. Sudden divergence

3. All-or-none conscious reverberation

Simulation

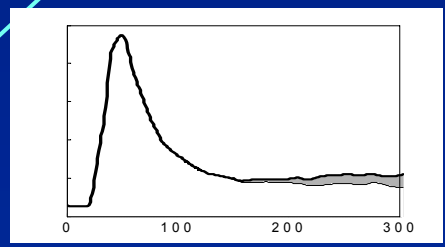


Area D active
Area D inactive

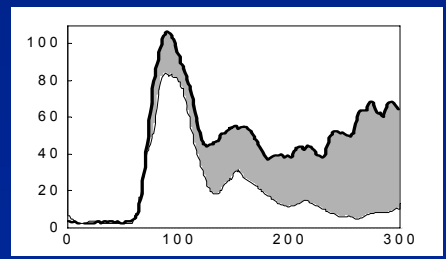
Highest areas:
(prefrontal, parietal, cingulate)

All-or-none conscious ignition

Sensori-motor areas:
Initial subliminal processing followed by conscious amplification

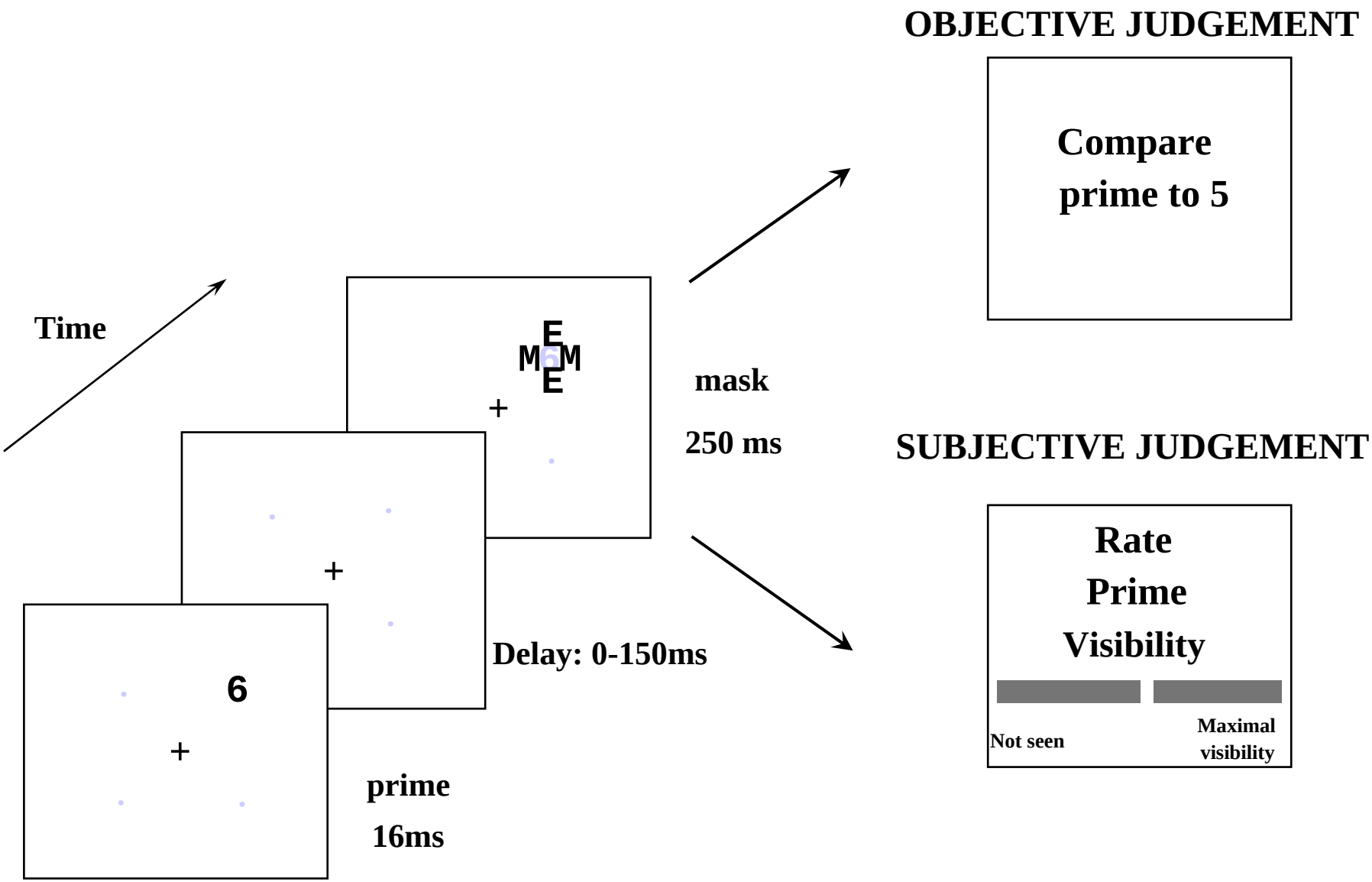


V1 (Roelfsema et al., 1999)
attended
unattended



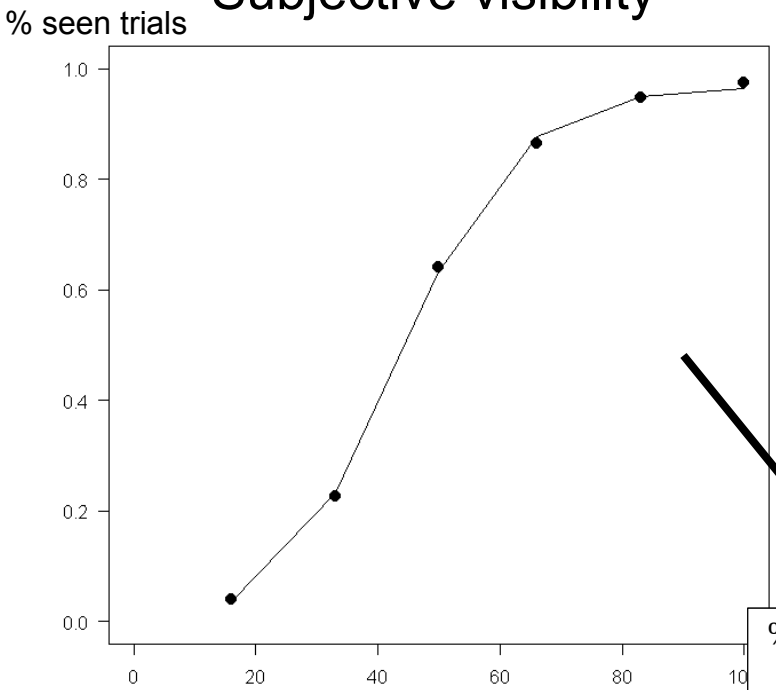
FEF (Thompson & Schall, 1999)
detected
undetected

DIGIT MASKING PARADIGM

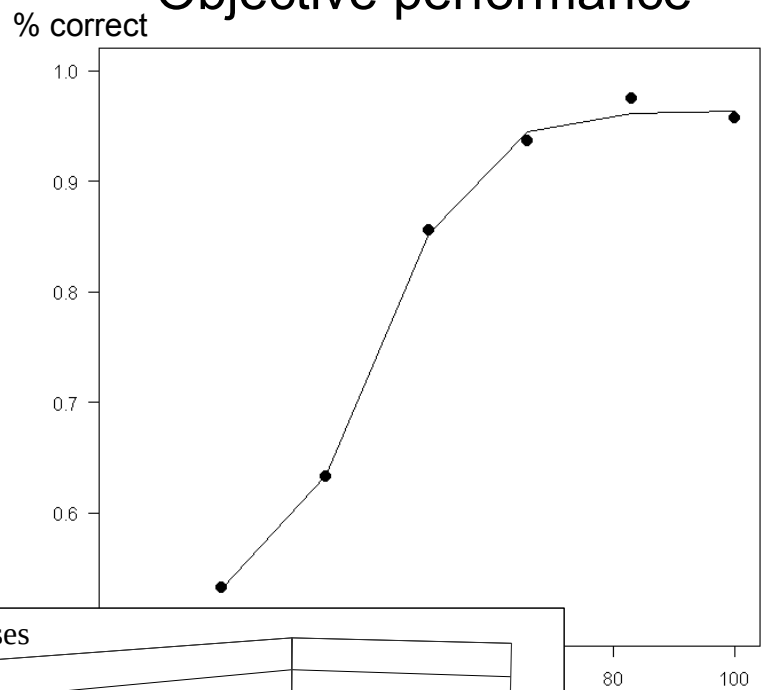


A well-defined threshold for conscious access

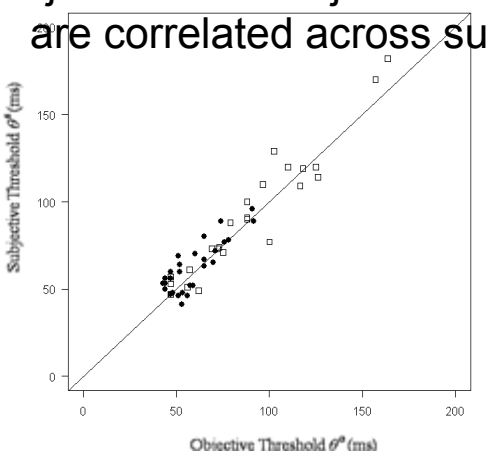
Subjective visibility

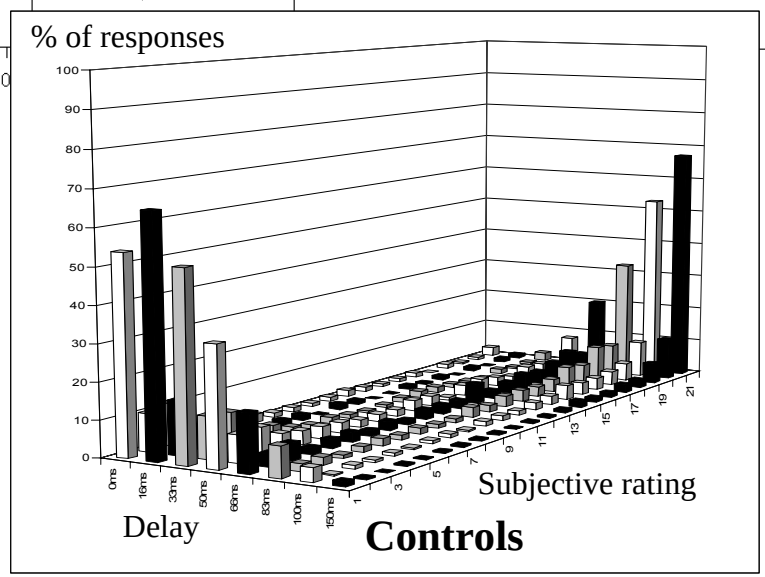


Objective performance



Objective and subjective thresholds are correlated across subjects

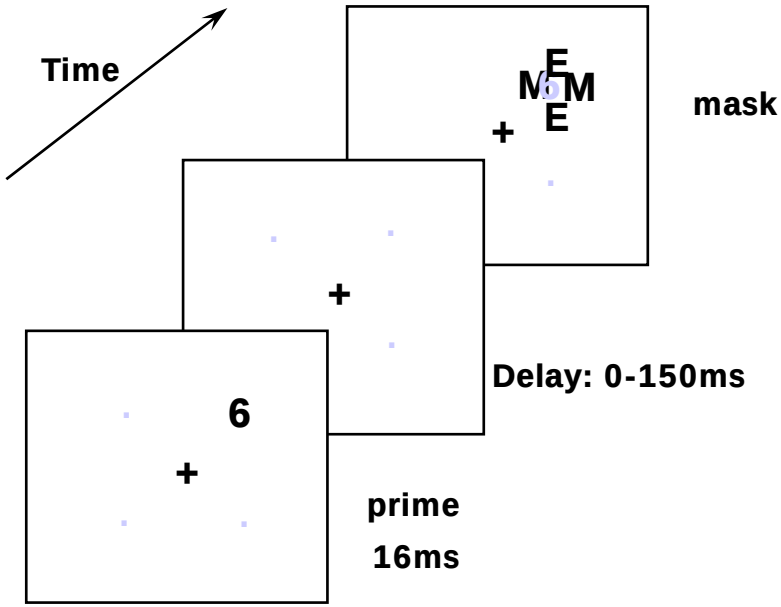


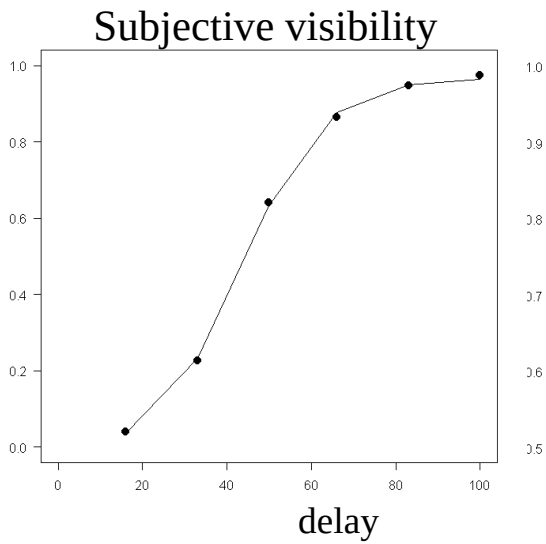


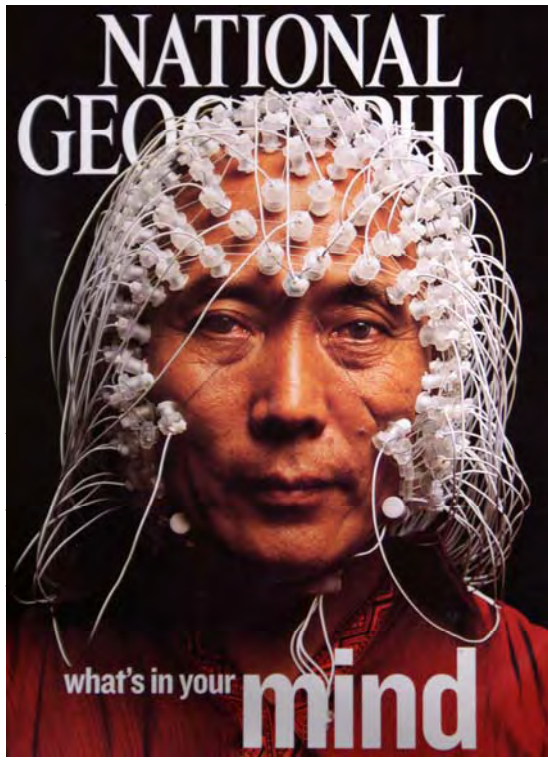
visibility judgements are bimodal, « all-or-none »

Exploring the cerebral mechanisms of the non-linear threshold in conscious access

(Del Cul and Dehaene, submitted)



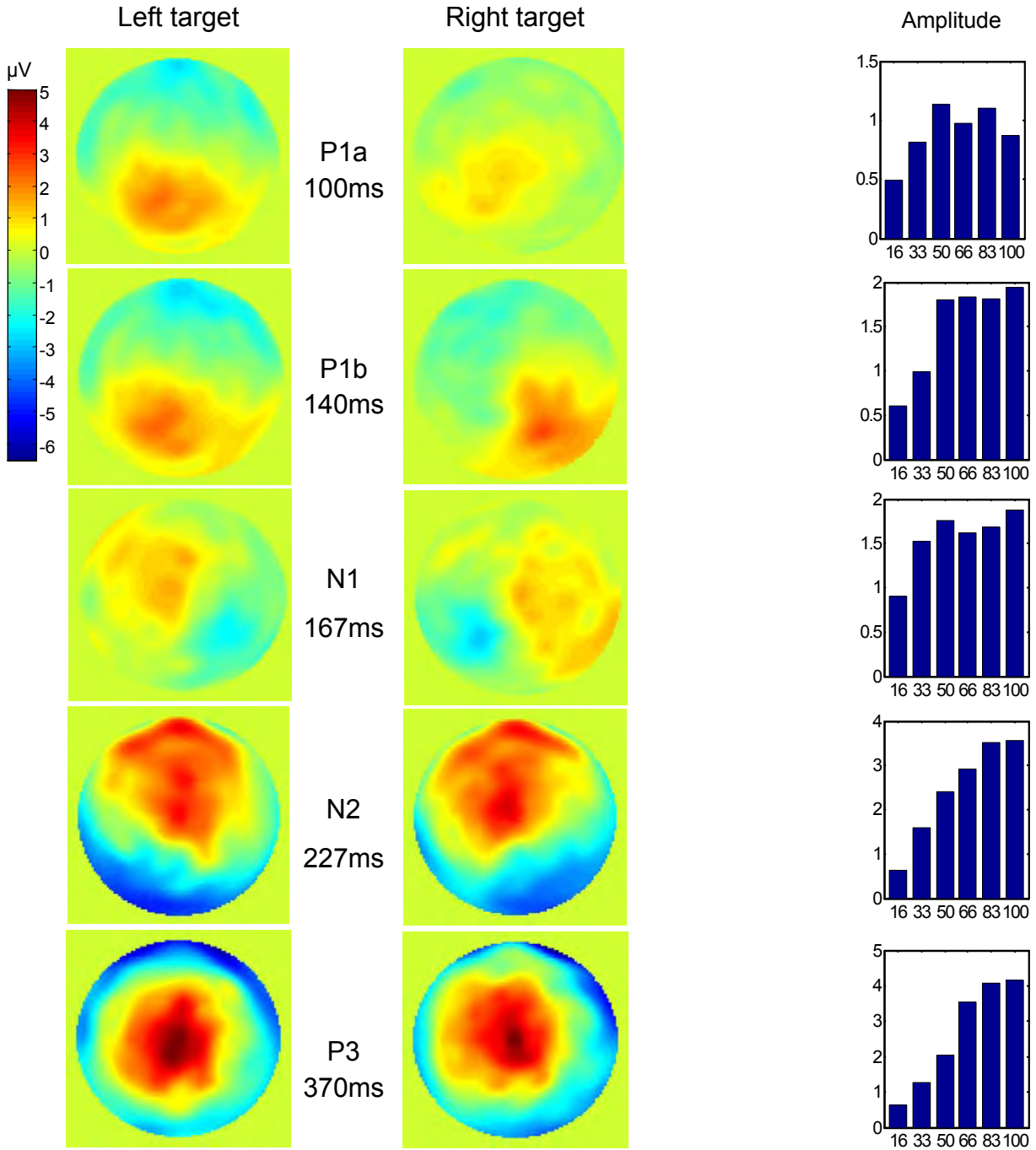




Logic = Use this sigmoidal profile as a « signature » of conscious access. Which ERP components show this profile?

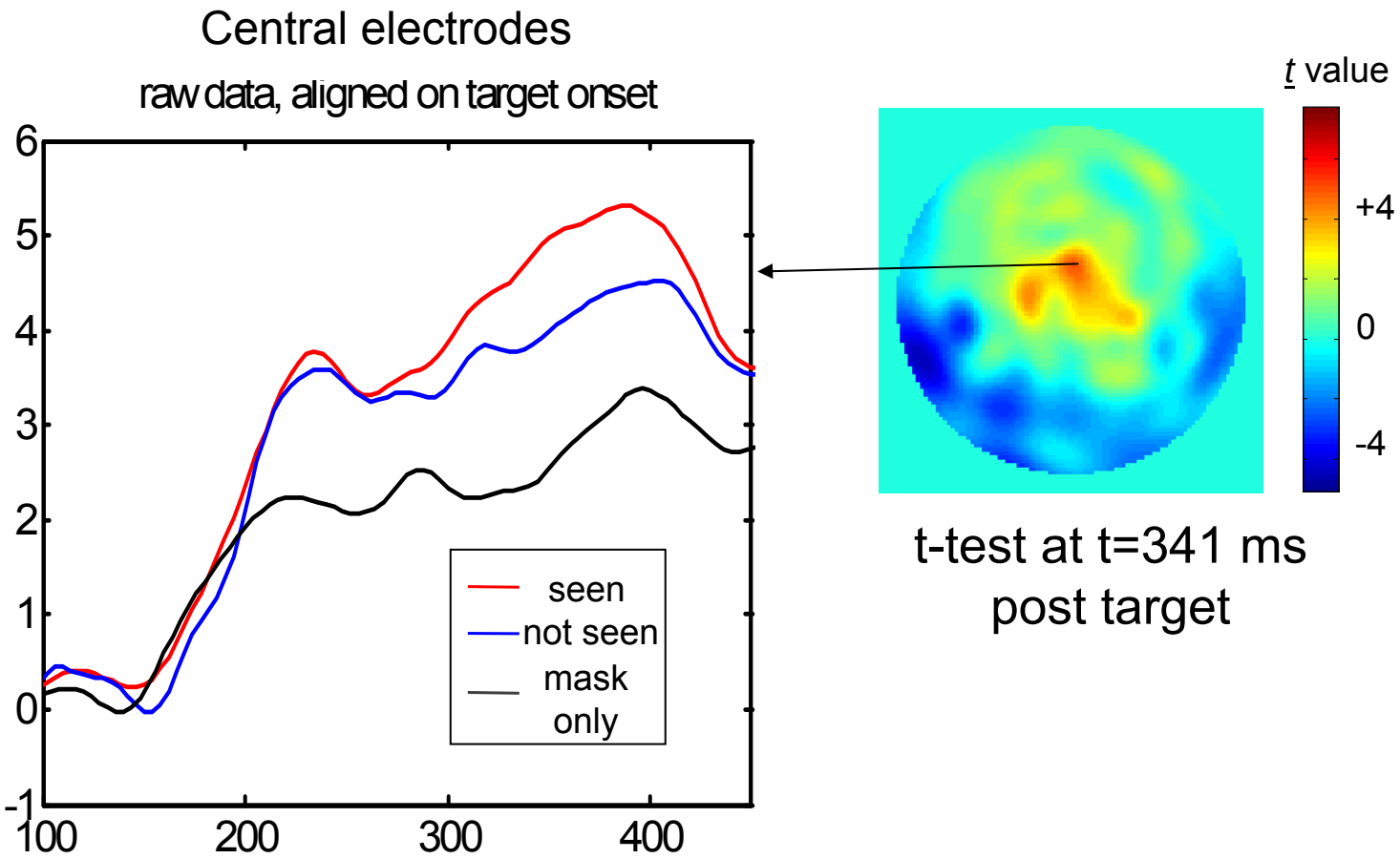
-Targets evoke a well-defined sequence of ERP components

- Which of these correlate with the subjective profile?



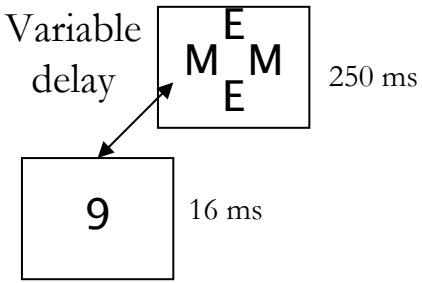
The amplitude of the P3 also distinguishes seen versus not-seen trials at an intermediate delay (50 ms)

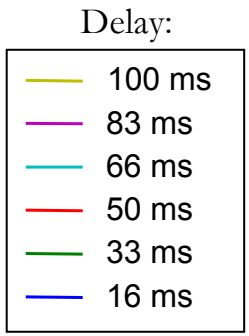
(9 subjects only)



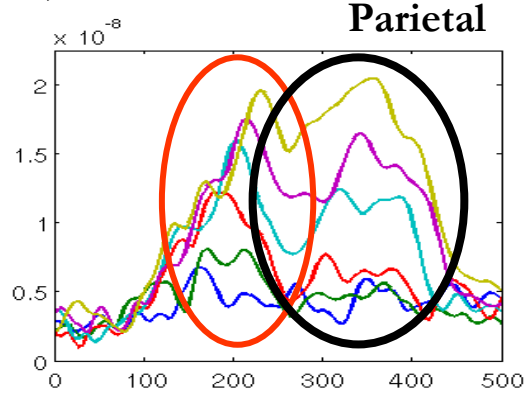
A late non-linearity underlying conscious access during masking

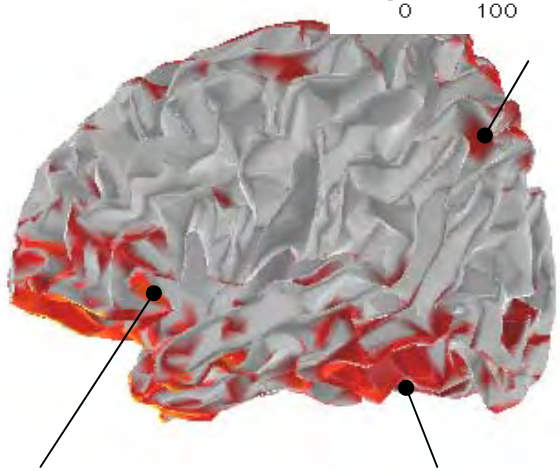
(Del Cul et Dehaene, submitted)



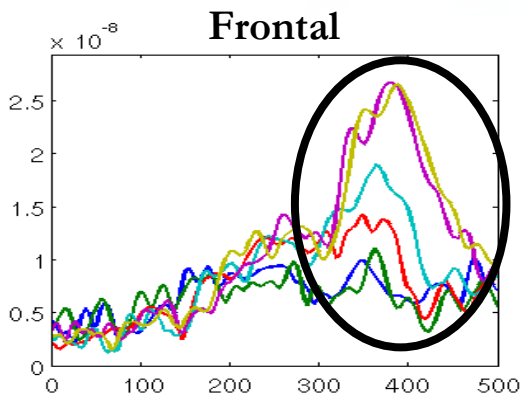


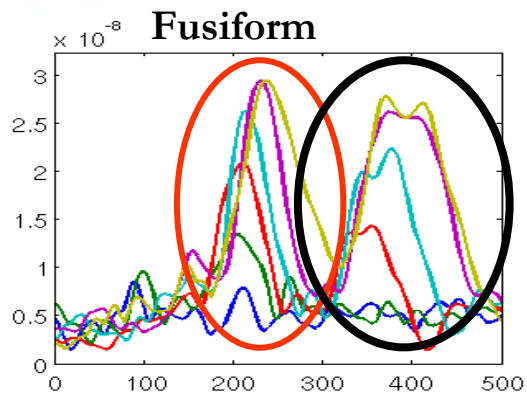
First phase: local and linear



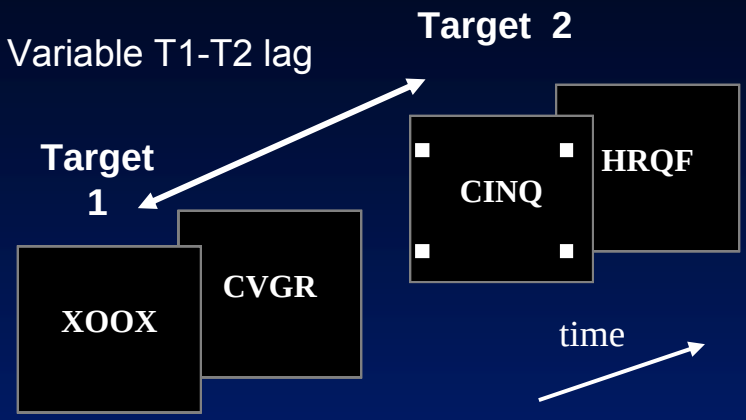


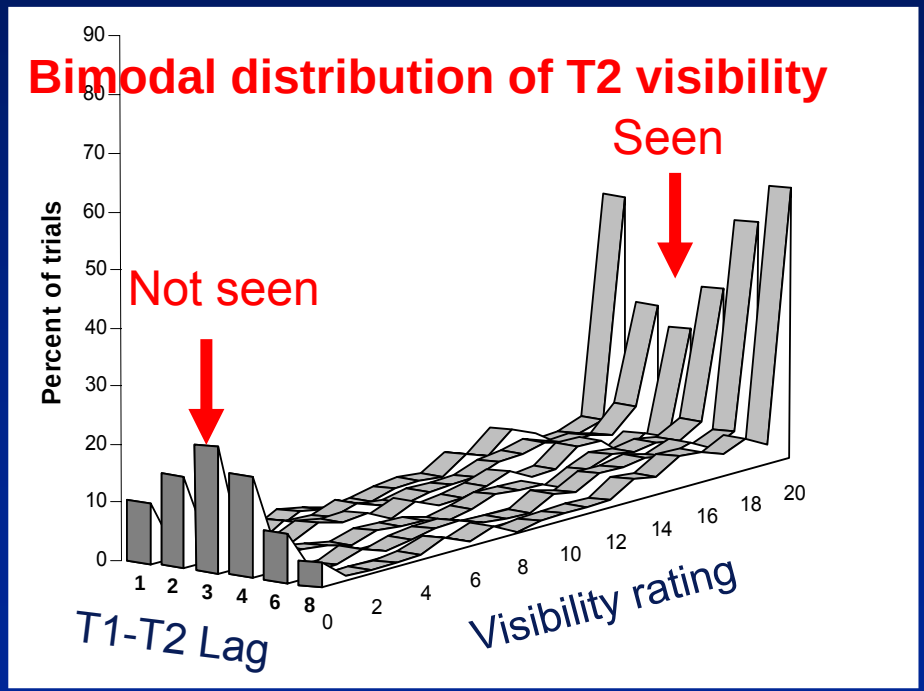
Second phase: global and non-linear (amplification)





Conscious access and non-conscious processing during the attentional blink





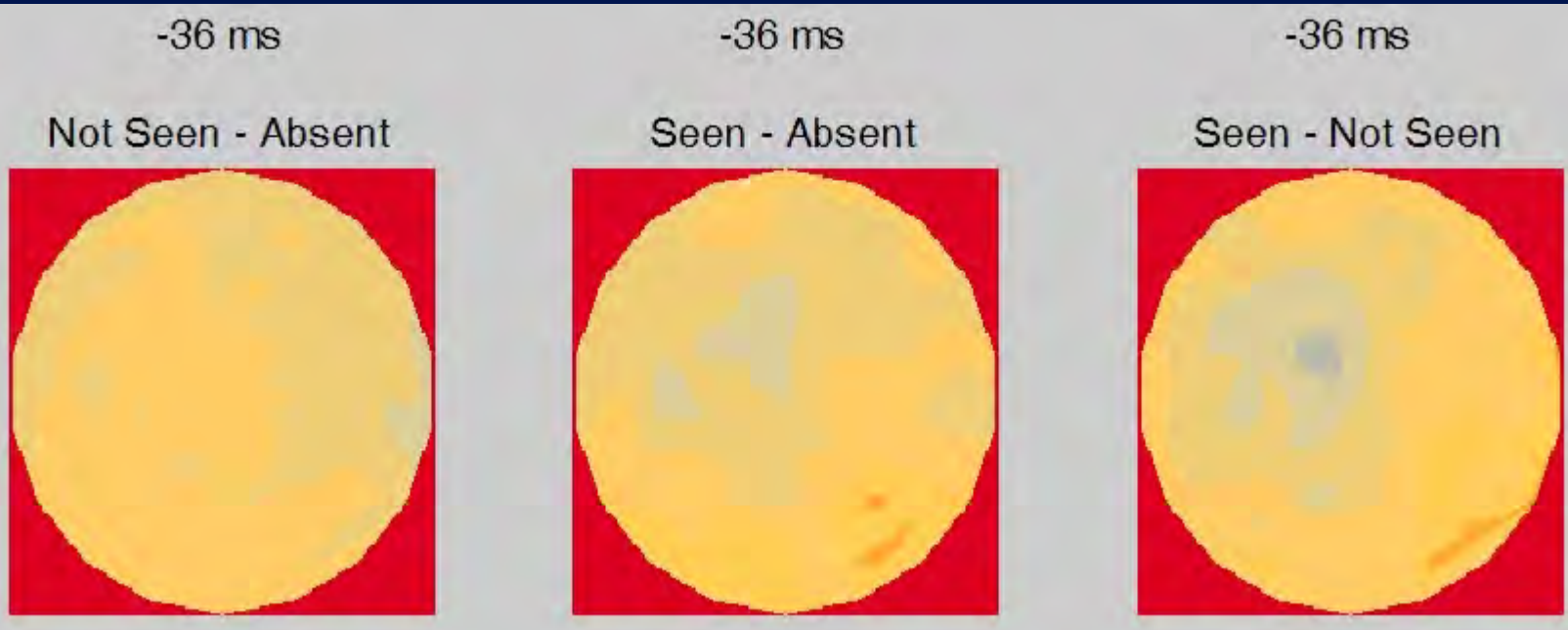
Sergent, Baillet & Dehaene, *Nature Neuroscience*, 2005

Time course of scalp-recorded potentials during the attentional blink

UNSEEN T2
(minus T2-absent trials)

SEEN T2
(minus T2-absent trials)

DIFFERENCE

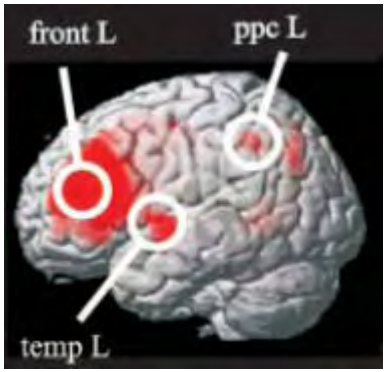


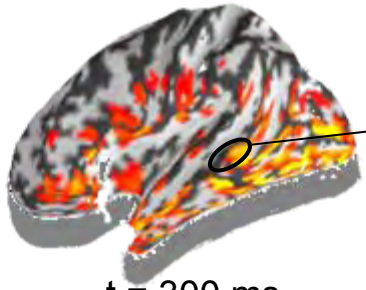
Sergent et al., *Nature Neuroscience,* 2005

Difference between seen and not seen trials

Recording of ‘virtual sources’ at various cortical locations

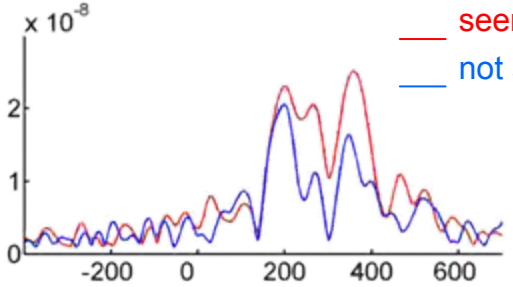
MEG:
Gross et al,
PNAS 2004



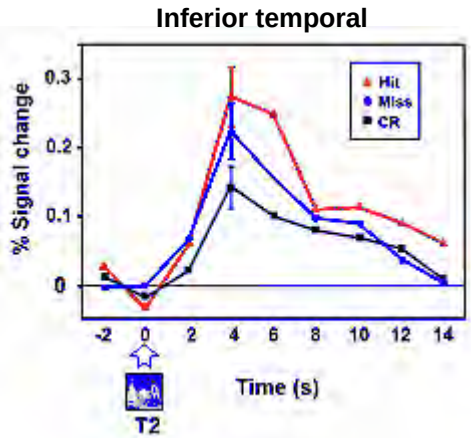


t = 300 ms

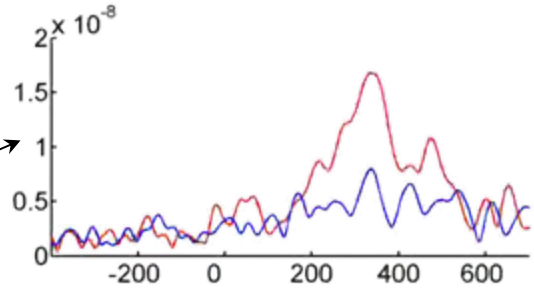
Middle temporal



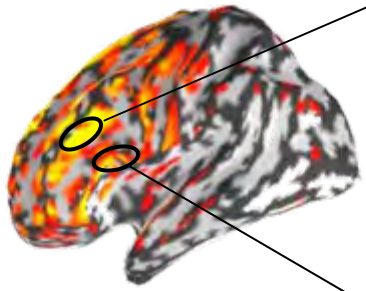
Inferior temporal



Inferior frontal

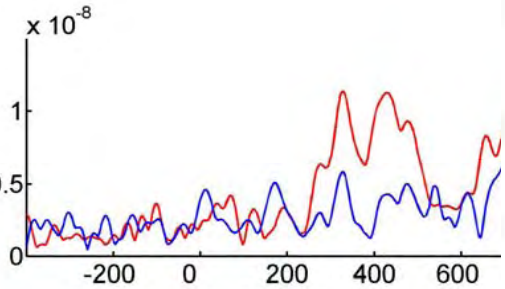


fMRI:
Marois et al,
Neuron 2004

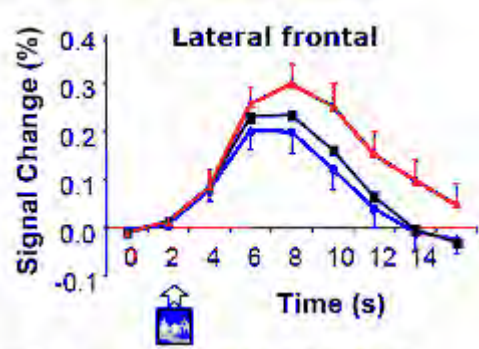


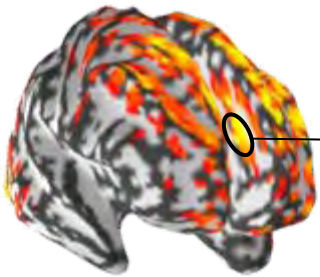
t = 436 ms

Dorsolateral prefrontal



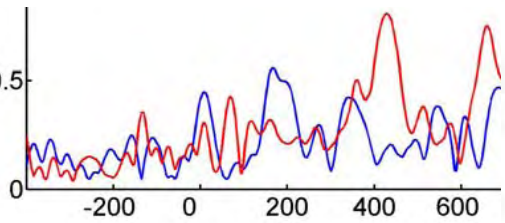
Lateral frontal

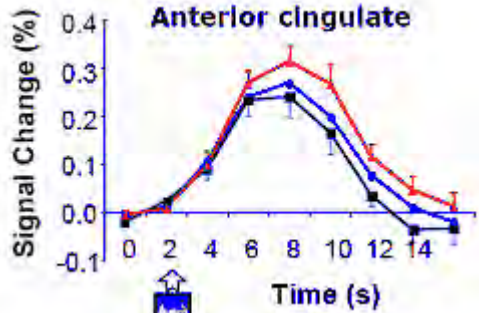




t = 436 ms

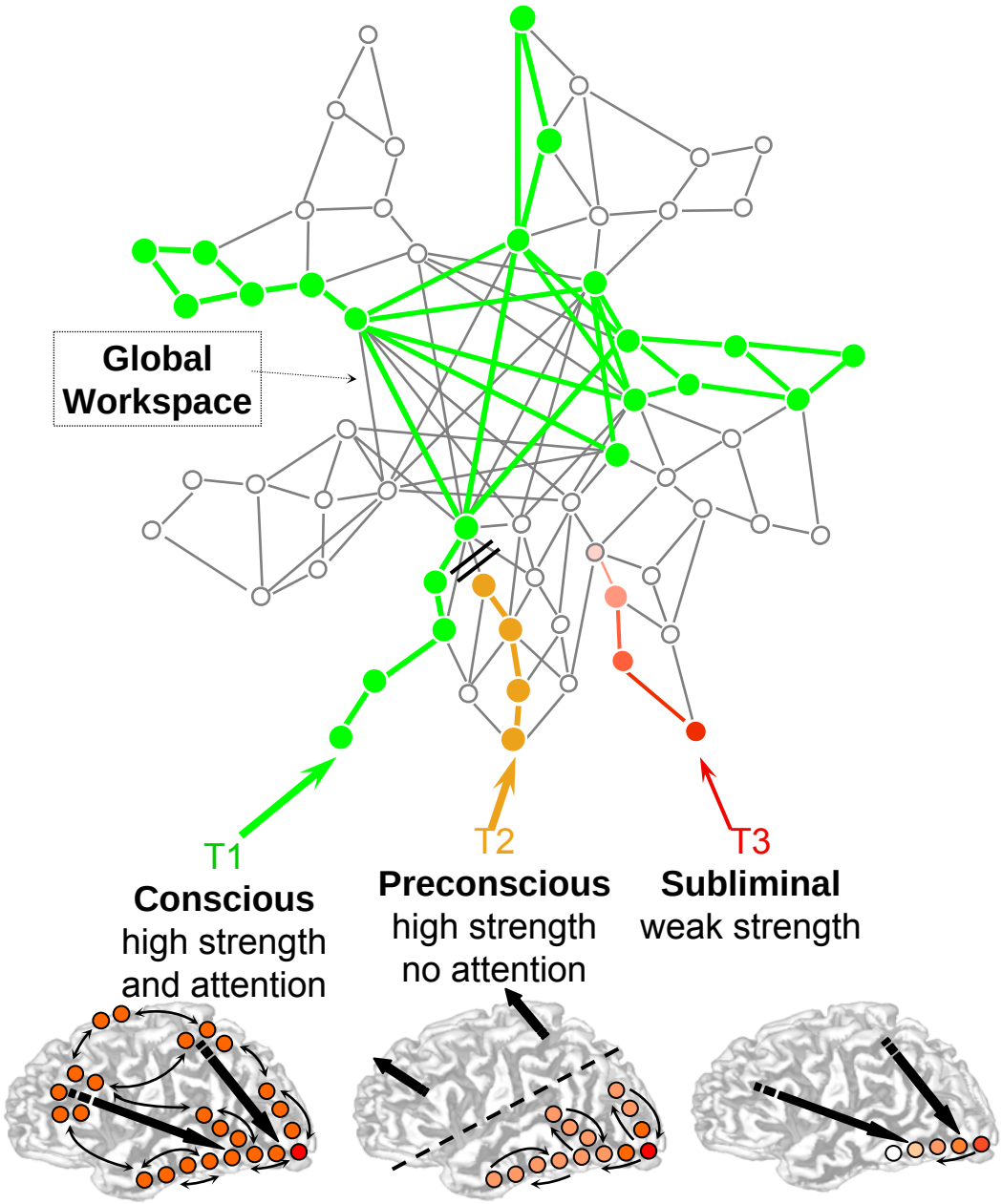
Anterior cingulate





Subliminal, **preconscious** and **conscious** processing

Dehaene, Changeux, Naccache, Sackur, & Sergent, TICS, 2006[2]



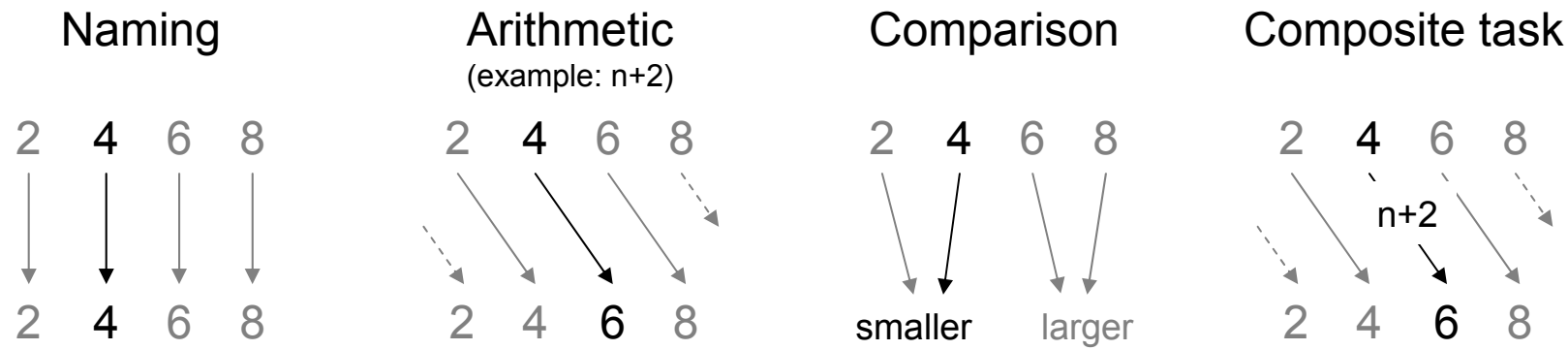
Conclusion: Towards a neuronal understanding of consciousness

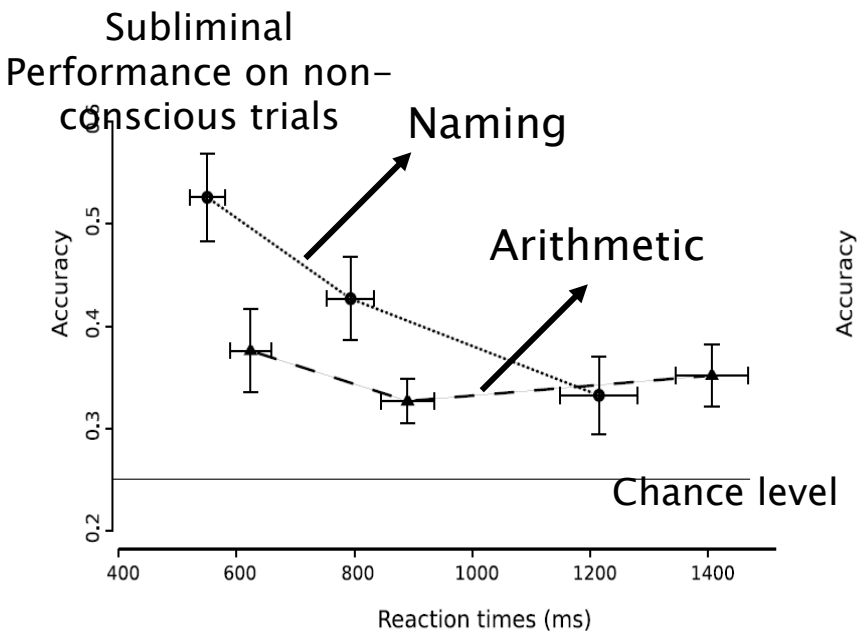
- Non-conscious processing is extensive in the human brain
- Brain activity can remain non-conscious for at least two reasons:
  - bottom-up strength is insufficient (e.g. masking)
  - Top-down attention is distracted (e.g. attentional blink)
- A representation becomes conscious whenever it wins the central competition and activates a distributed, self-sustained assembly of neurons in prefrontal, cingulate and other cortical association areas
- Conscious access corresponds to a sharp and relatively late (~270 ms) dynamical transition in neural network activity.
- The conscious workspace may have evolved as a response to the need to exchange information across processors and to chain several mental operations, thus implementing a rudimentary 'Turing Machine' and giving us access to a new cognitive niche (recursive functions).

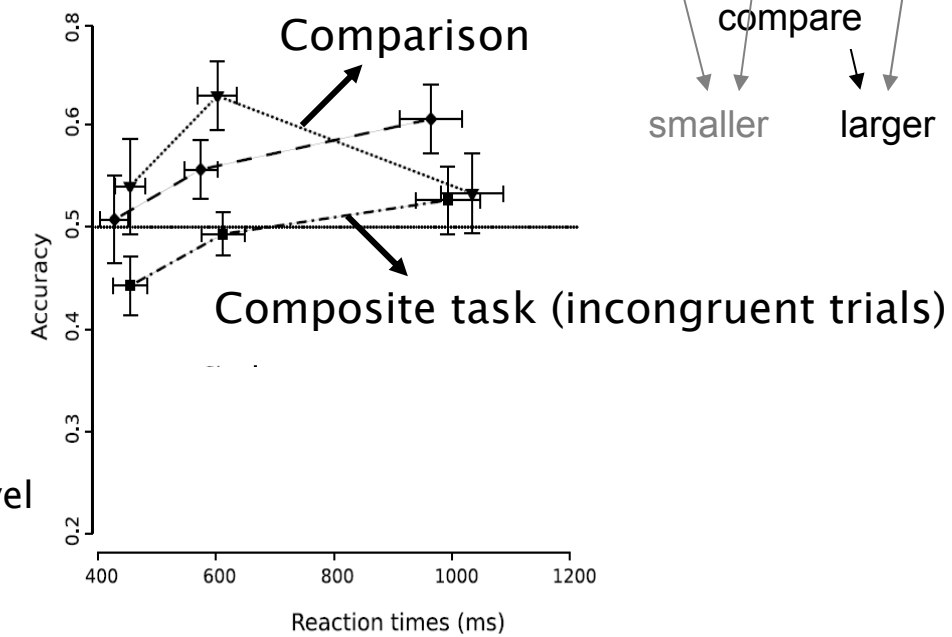
Consciousness is needed for chaining of two operations

(Sackur and Dehaene, submitted)

- Presentation of a masked digit (2, 4, 6, ou 8) just below threshold
- Four tasks



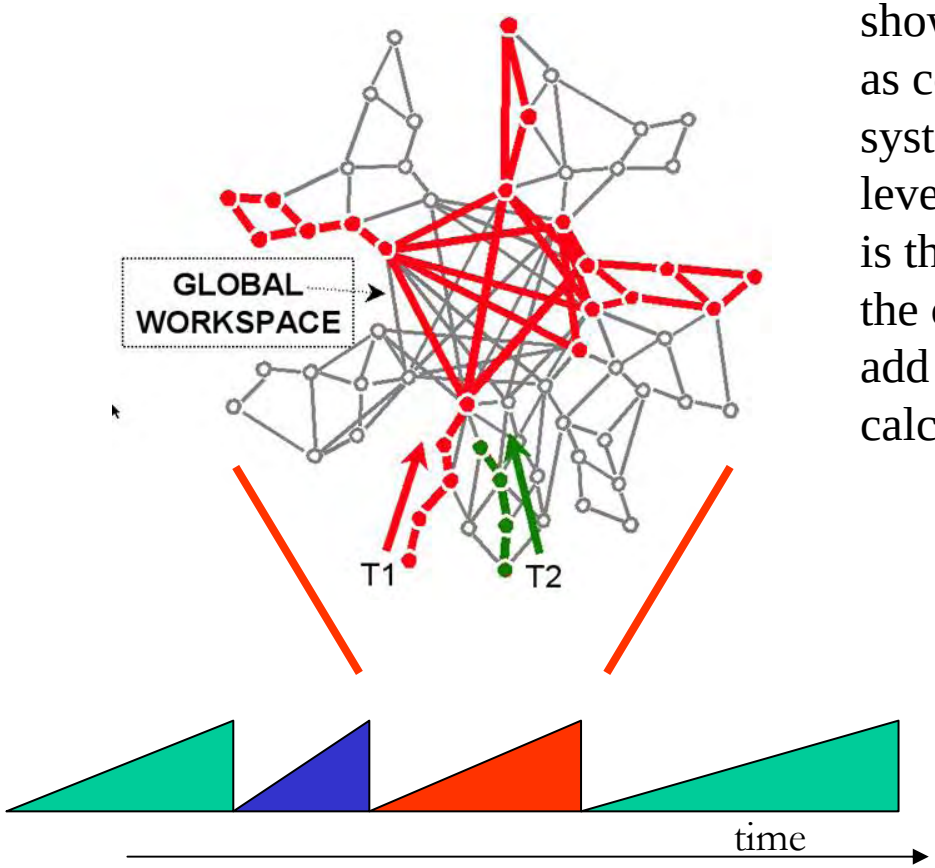




A hypothetical scheme for the « human Turing machine »

• The workspace can perform complex, consciously controlled operations by **chaining** several elementary steps

•**Each step** consists in the **top-down recruitment**, by a fronto-parietal network, of a set of specialized processors, and the **slow accumulation of their inputs** into categorical bins, which allows to reach a **conscious decision** with a fixed, predefined degree of accuracy.



Sigman & Dehaene, *PLOS:Biology*, 2005

« All experience with computing machines shows that if a computing machine has to handle as complicated arithmetical tasks as the nervous system obviously must, facilities for rather high levels of precision must be provided. The reason is that calculations are likely to be long, and in the course of long calculations, not only do errors add up but also those committed early in the calculation are amplified by the latter parts of it »