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
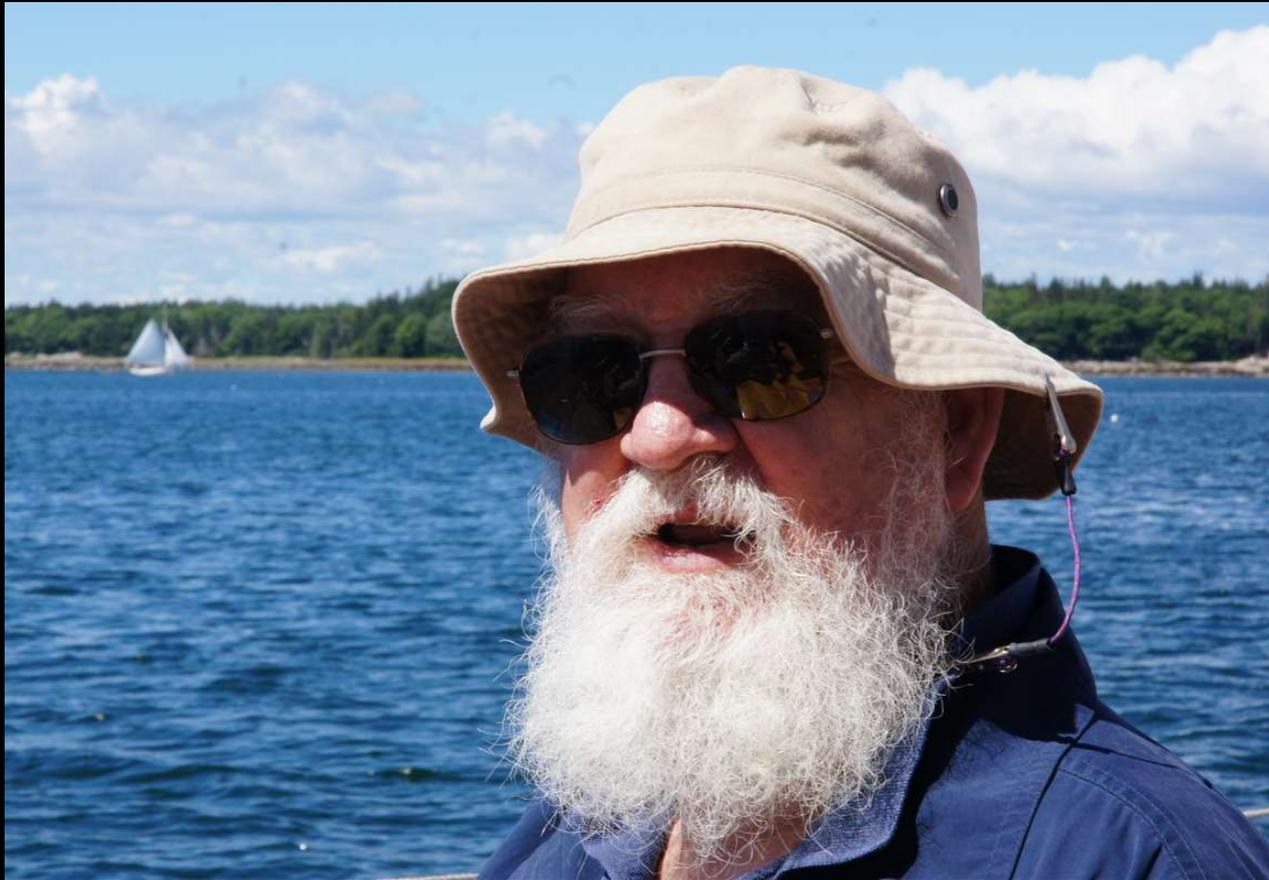Chaire de Psychologie Cognitive Expérimentale
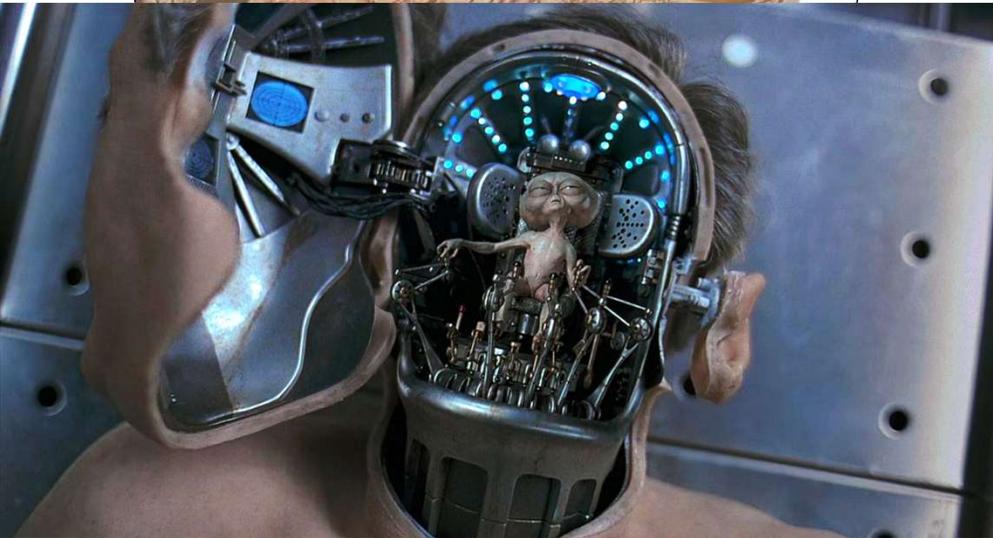
Cours n°5

La temporalité du traitement conscient
The timing of conscious processing

Explaining Consciousness: A brief homage to Dan Dennett

One of the Ten Best Books of the Year—New York Times

CONSCIOUSNESS EXPLAINED

DANIEL C. DENNETT
Author of Brainstorms and coauthor of The Mind's I

Consciousness as a functional property

No Cartesian theater nor any homunculus…

"One discharges fancy homunculi from one's scheme by organizing armies of idiots to do the work."

Heterophenomenology as a method of investigating subjective states.

Multiple drafts : mental representations are progressively edited, refined, and propagated through the brain:
Consciousness can be likened to « **fame in the brain** »

The time dimension is just like
any other mental representation :
The timing of subjective consciousness is a reconstruction
that can be decoupled from physical time.

Consciousness as a late, retrospective reconstruction, often discrete (« all-or-none ») and whose timing may not correspond to perceived time

Kolers, P. A., & von Grunau, M. (1975). Visual construction of color is digital. Science, 187(4178), 757–9.
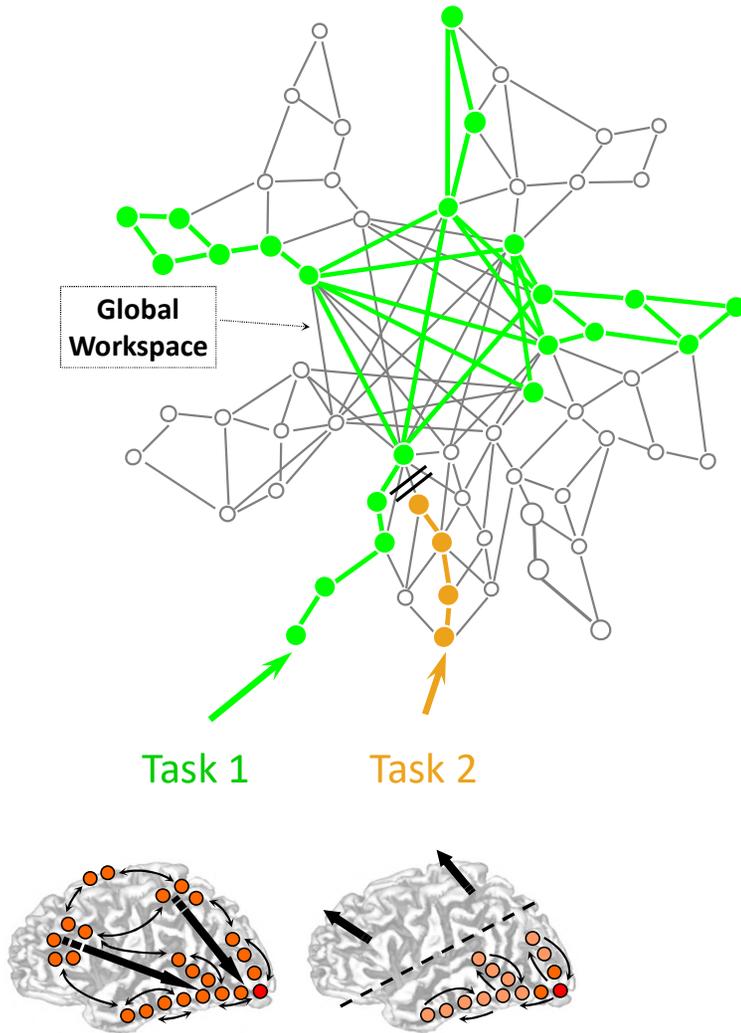

What is Actually Shown

Time
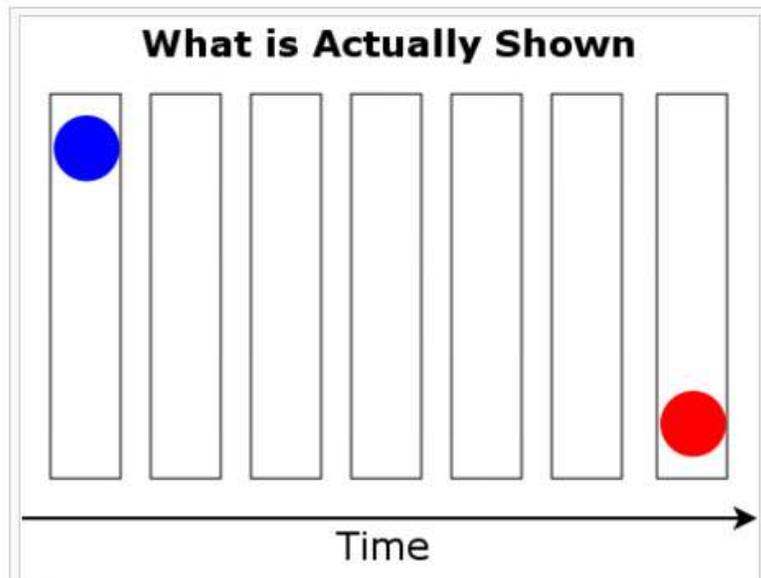
What is actually shown: First a blue dot is shown at the top of the screen, followed by a period of blank screen. Finally a red dot is shown at the bottom of the screen.

What Subjects Report

Time
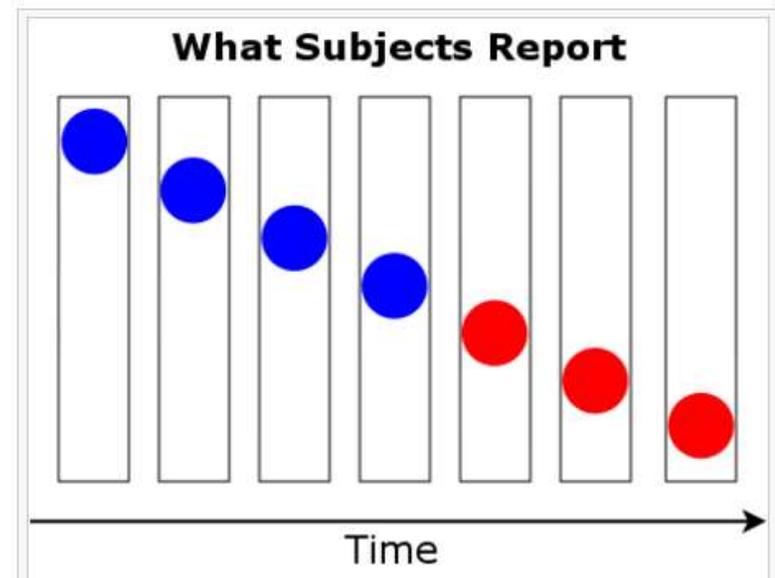
Subjects report seeing a dot that moves from the top to the bottom. The dot changes color midway through its path.

Collisions in consciousness
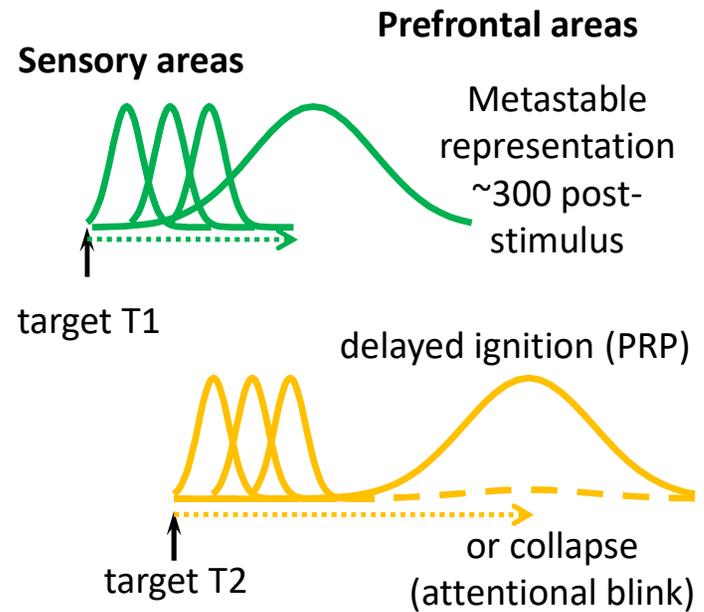

Global Workspace

Task 1   Task 2

Prediction:

During **a dual-task collision**, only the late part of the activation should :

- **be delayed** (Psychological Refractory Period, PRP)
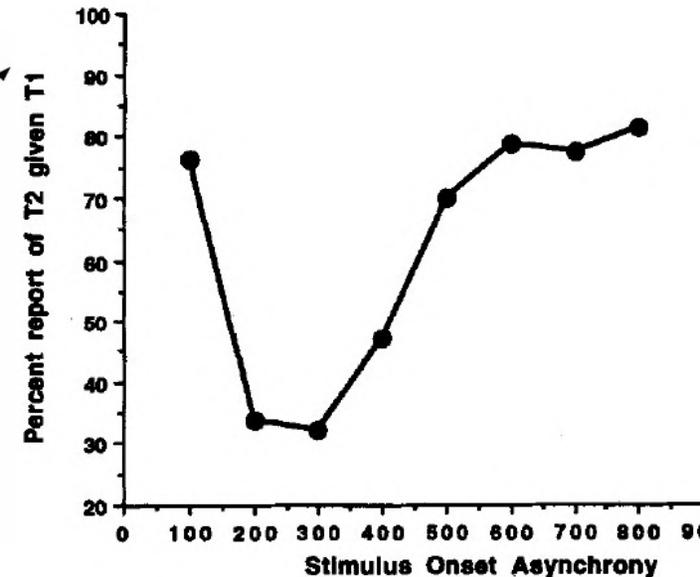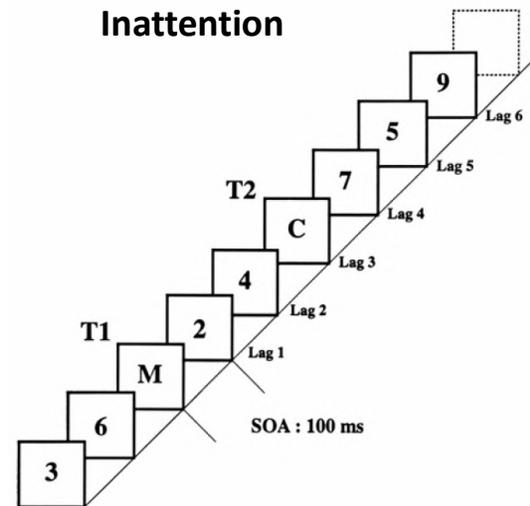- or **collapse** (Attentional Blink, AB)

Prefrontal areas

Sensory areas

Metastable representation ~300 post-stimulus

target T1

delayed ignition (PRP)

target T2

or collapse (attentional blink)

What is the attentional blink ? And the psychological refractory period ?

The **attentional blink** (Broadbent & Broadbent, 1987; Raymond, Shapiro et Arnell, 1992): In a series of successive stimuli, detection of a first target T1 impedes the subsequent detection of a second target T2, within about ~400 ms.

The subject loses all consciousness of T2 (as if it hadn't been presented; Sergent et al. 2005).

No T1 task is needed – the minimal condition for the blink to occur is conscious perception of T1. When T1 is at threshold, the blink only occurs when T1 is consciously perceived, not when it remains subliminal (Nieuwenstein., Van der Burg, Theeuwes, Wyble & Potter, 2009)
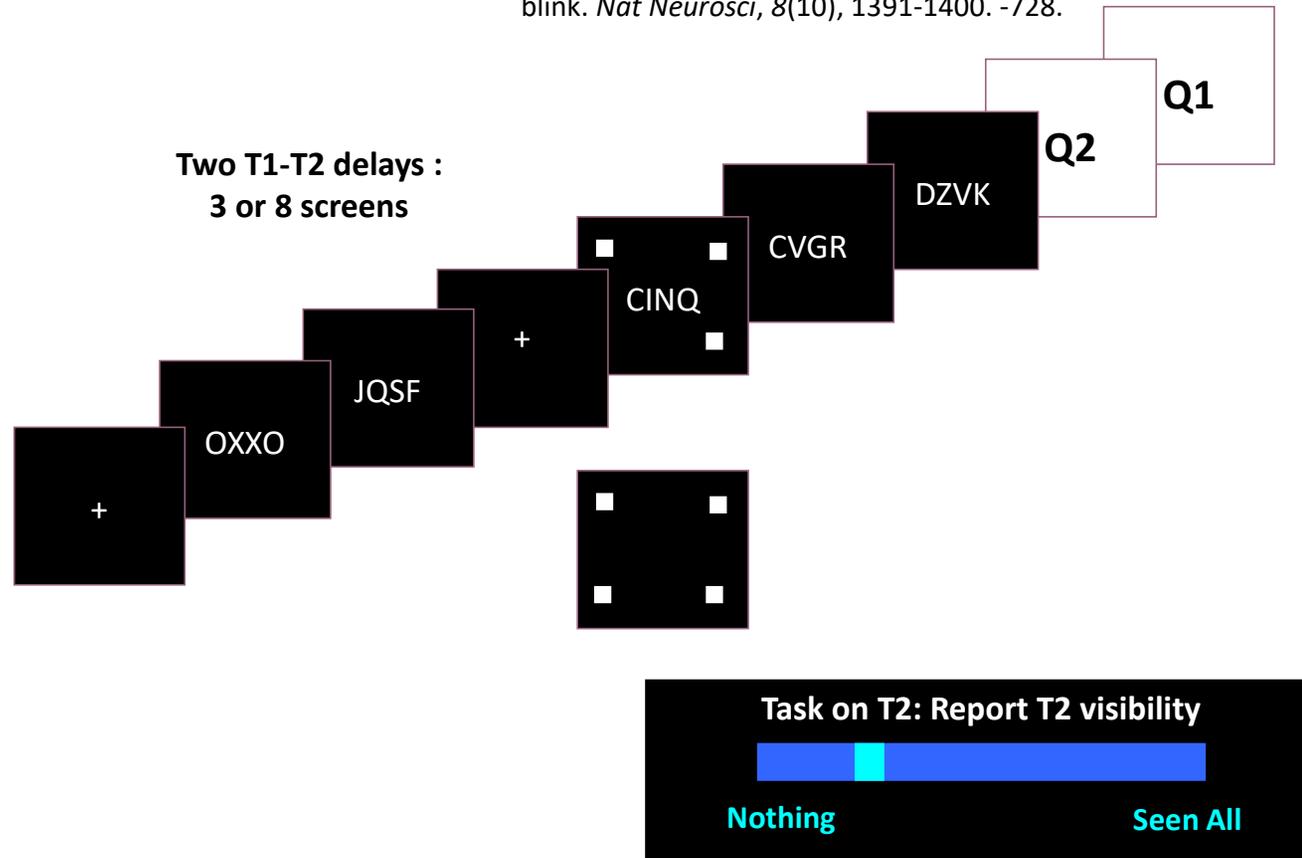
Dual-tasking induces a suppression, a delay and a diffusion of conscious access

Subjects are asked to report the letter(s) surrounded by circle.
For the second letter, performance drops dramatically during the time window of T1 processing (Black curve = attentional blink).
If a letter is reported, it is pushed outside of this interval.

Performance on the first letter (T1)

Performance on the second letter (T1)

Brain imaging of the attentional blink

Sergent, C., Baillet, S., & Dehaene, S. (2005). Timing of the brain events underlying access to consciousness during the attentional blink. *Nat Neurosci*, *8*(10), 1391-1400. -728.

**Two T1-T2 delays :**
3 or 8 screens

Q1

Q2

DZVK

CVGR

CINQ

JQSF

OXXO

+

+

Task on T2: Report T2 visibility

Nothing   Seen All

The bimodal, all-or-nothing nature of conscious perception

Sergent, C., Baillet, S., & Dehaene, S. (2005). Timing of the brain events underlying access to consciousness during the attentional blink. *Nat Neurosci*, *8*(10), 1391-1400. -728.
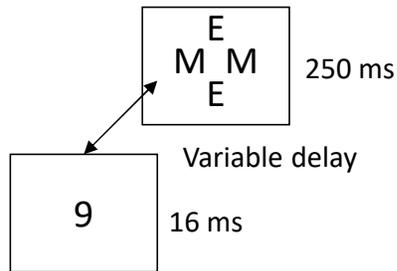
Masking
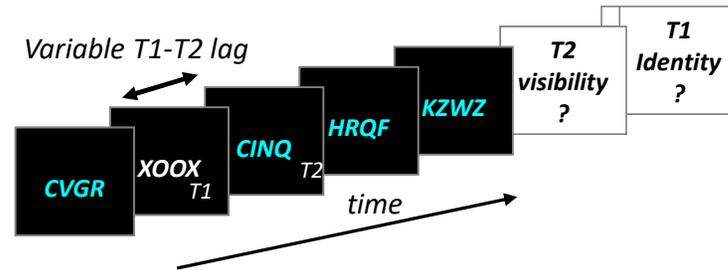
Attentional blink
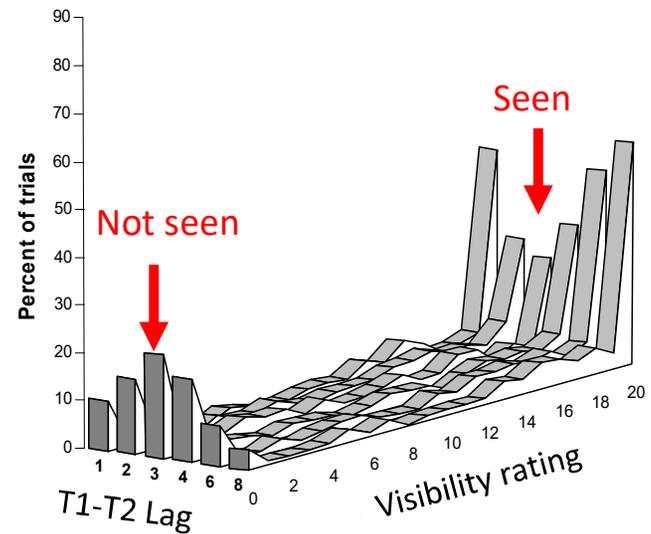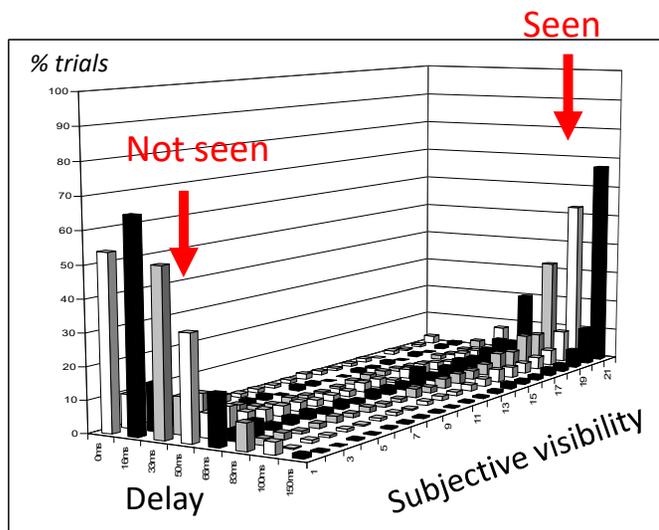
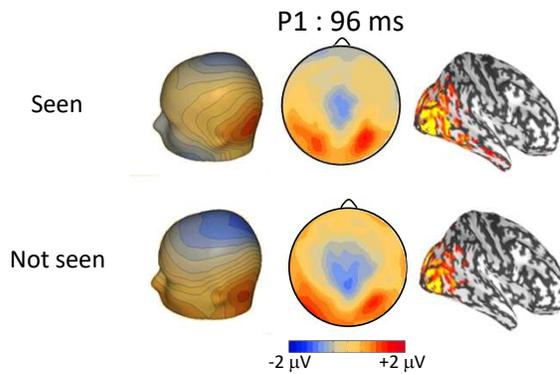# Source reconstruction of non-conscious versus conscious brain activity

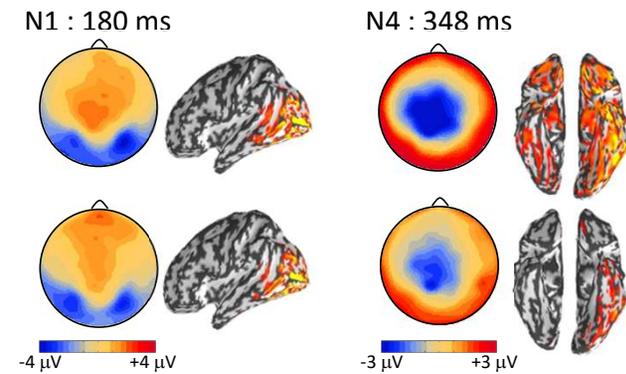Sergent, C., & Dehaene, S. (2004). *Psychol Sci*, *15*(11), 720-728 ; Sergent, C., Baillet, S., & Dehaene, S. (2005). *Nat Neurosci*, 8(10), 1391-1400.
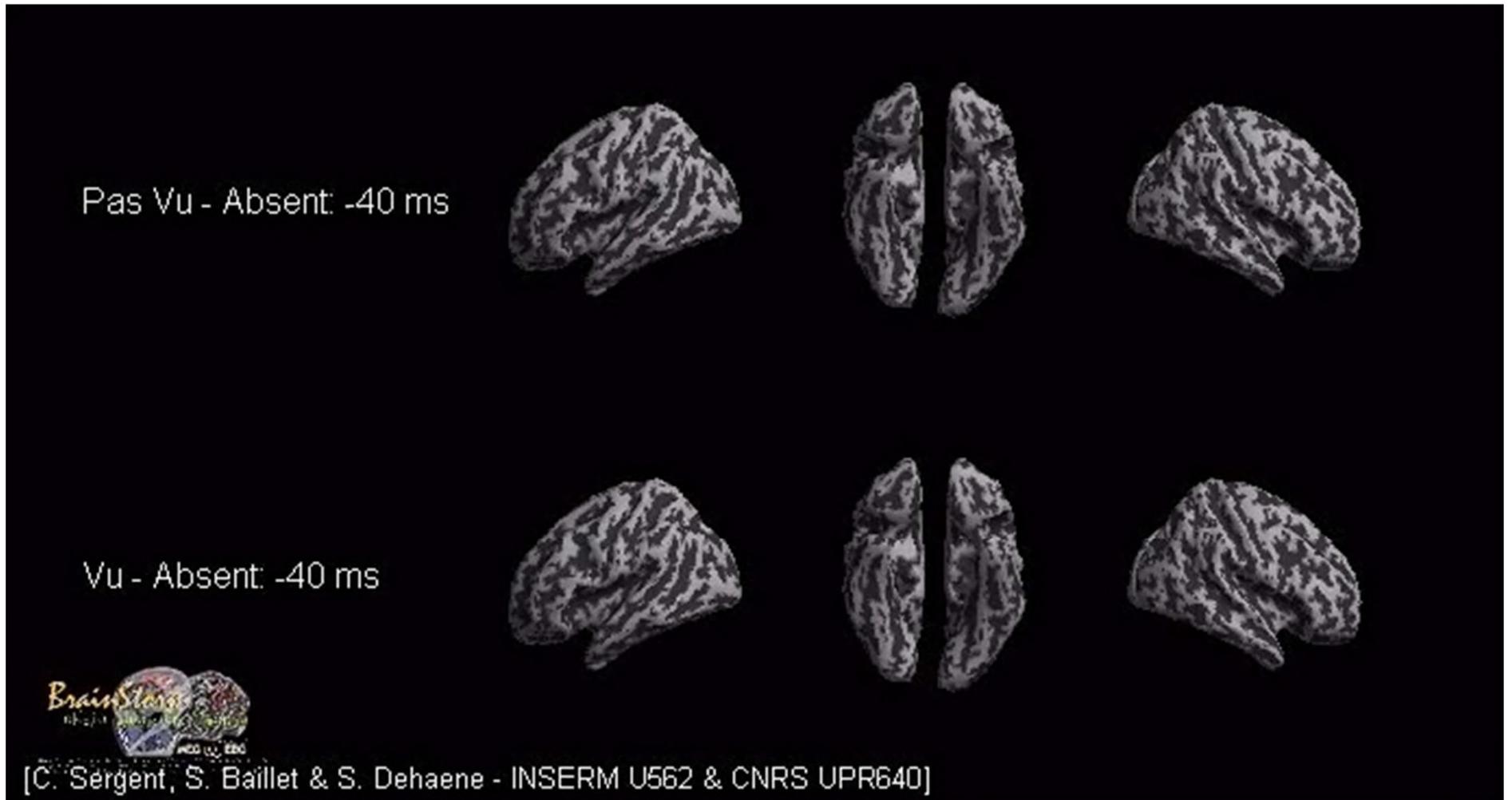
Time course of the divergence between seen and unseen trials
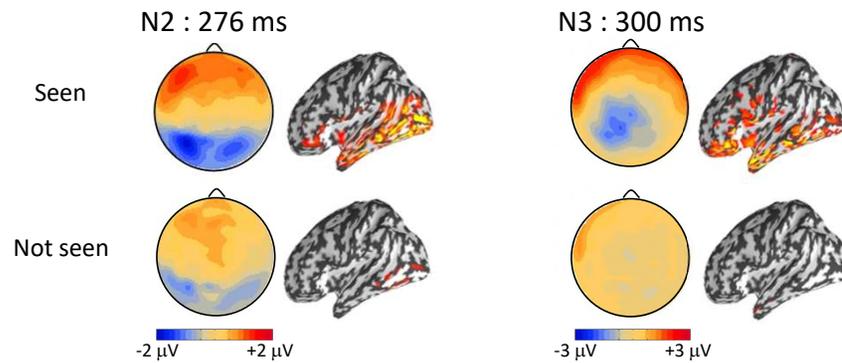
Sergent et al., *Nature Neuroscience* 2005

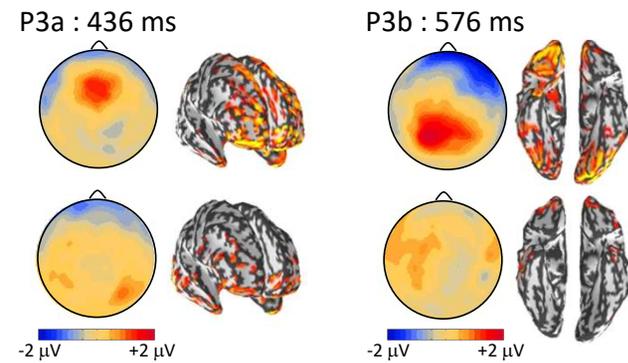Early occipital processing is identical

Even late events (N170, N400) can be fully or partially preserved in unseen trials.

A sudden divergence around 270 ms
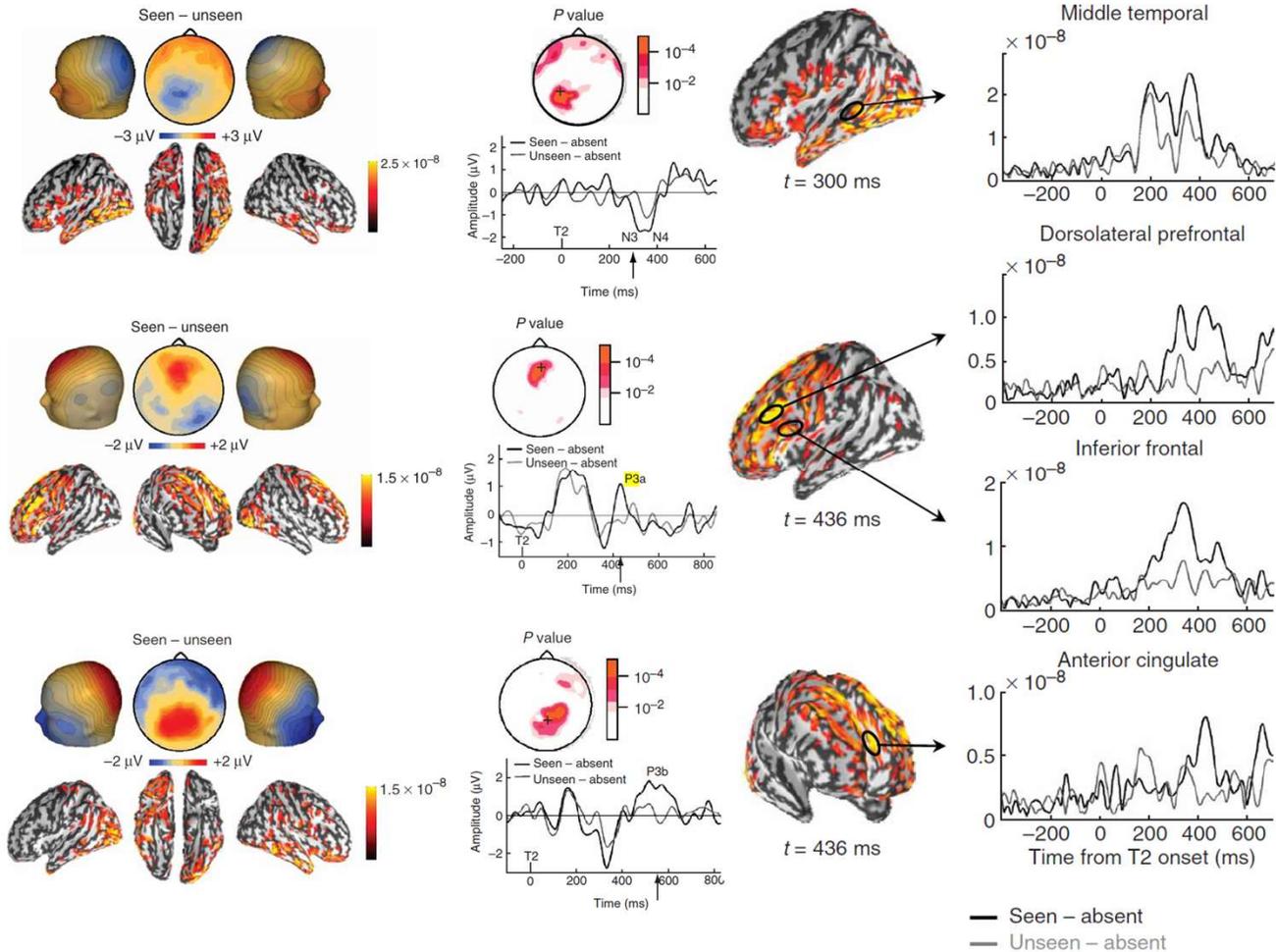
Which becomes all-or-none in the late positivities

A finer view of seen versus unseen trials

Sergent, C., Baillet, S., & Dehaene, S. (2005). *Nat Neurosci*, 8(10), 1391-1400.

Attentional blink

Event-related potential (ERP) peaks can be subdivided into two categories
- Some are present independently of visibility level (P1, N1 N4)
- Some vary drastically with visibility (N3, P3a, P3b)

Source reconstruction of non-conscious versus conscious brain activity

Sergent, C., Baillet, S., & Dehaene, S. (2005). *Nat Neurosci*, 8(10), 1391-1400.
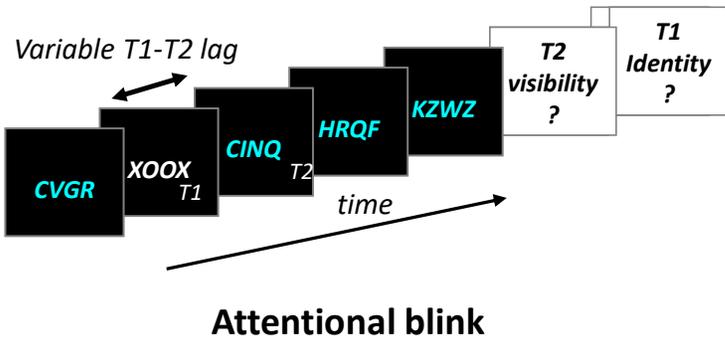
"Whether this perception is available for conscious report seems to depend mostly on the optional triggering of "bimodal" waves (such as N3, P3a and P3b) that match the bimodal distribution of visibility ratings."
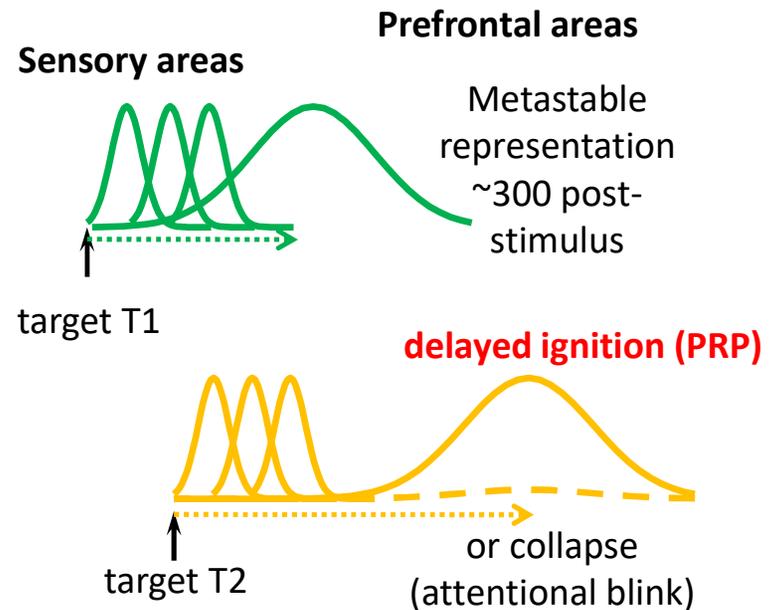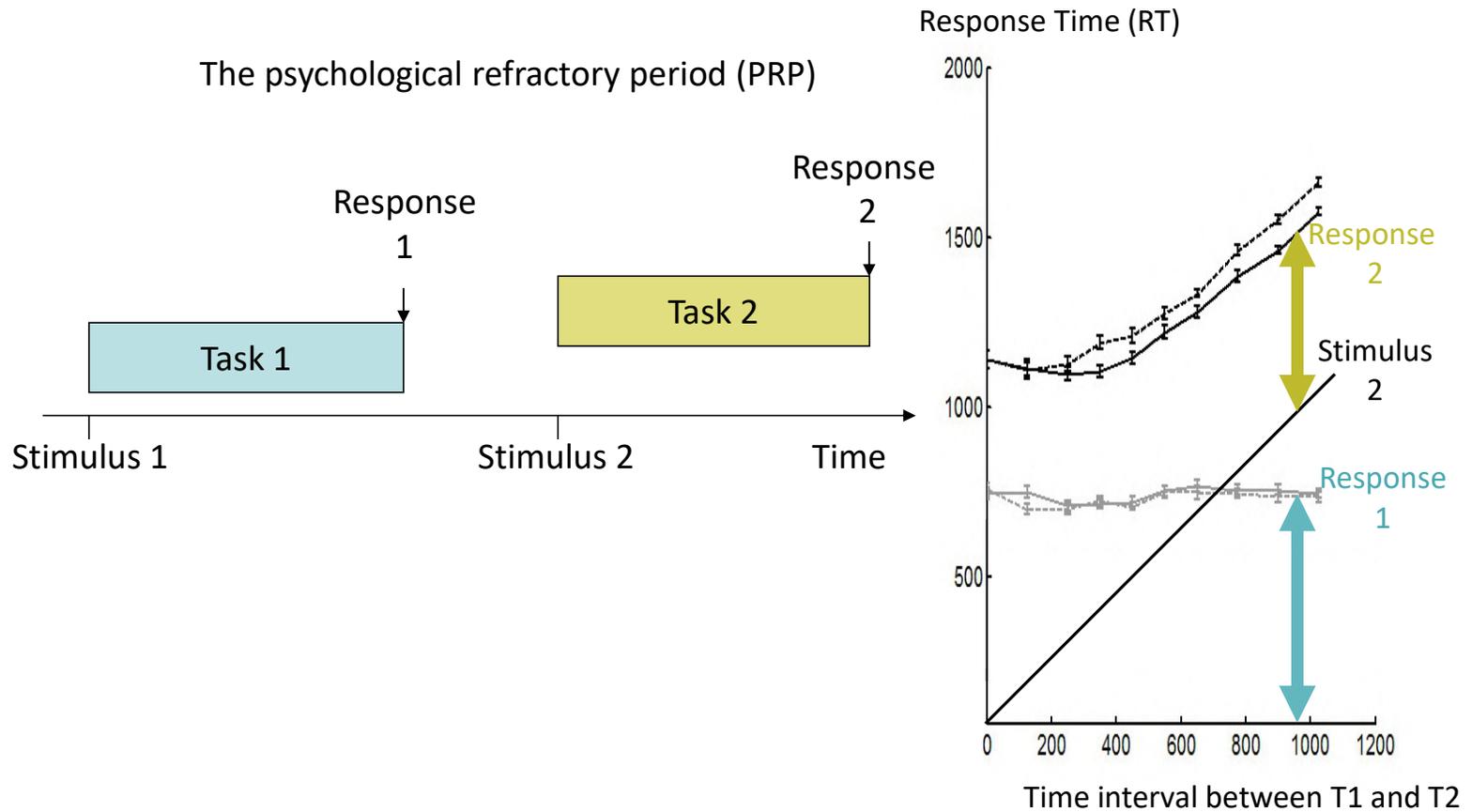
Collisions in consciousness

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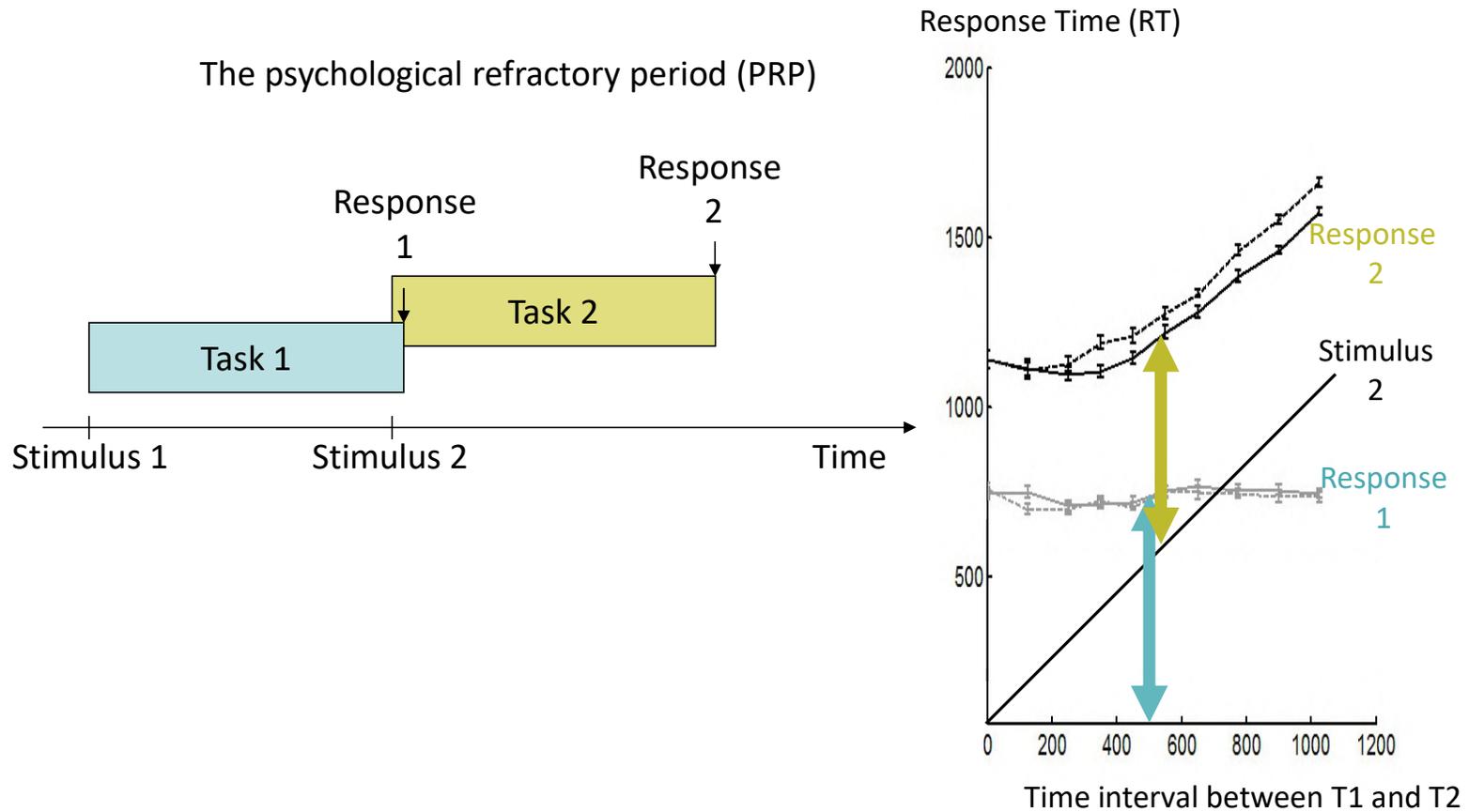- or **collapse** (Attentional Blink, AB)

Prefrontal areas

Sensory areas

Metastable representation ~300 post-stimulus

target T1

delayed ignition (PRP)

target T2

or collapse (attentional blink)

When T2 is unmasked, it is visible, but not immediately processed

The psychological refractory period (PRP)

Response Time (RT)

Time interval between T1 and T2

M. Sigman

When T2 is unmasked, it is visible, but not immediately processed

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M. Sigman

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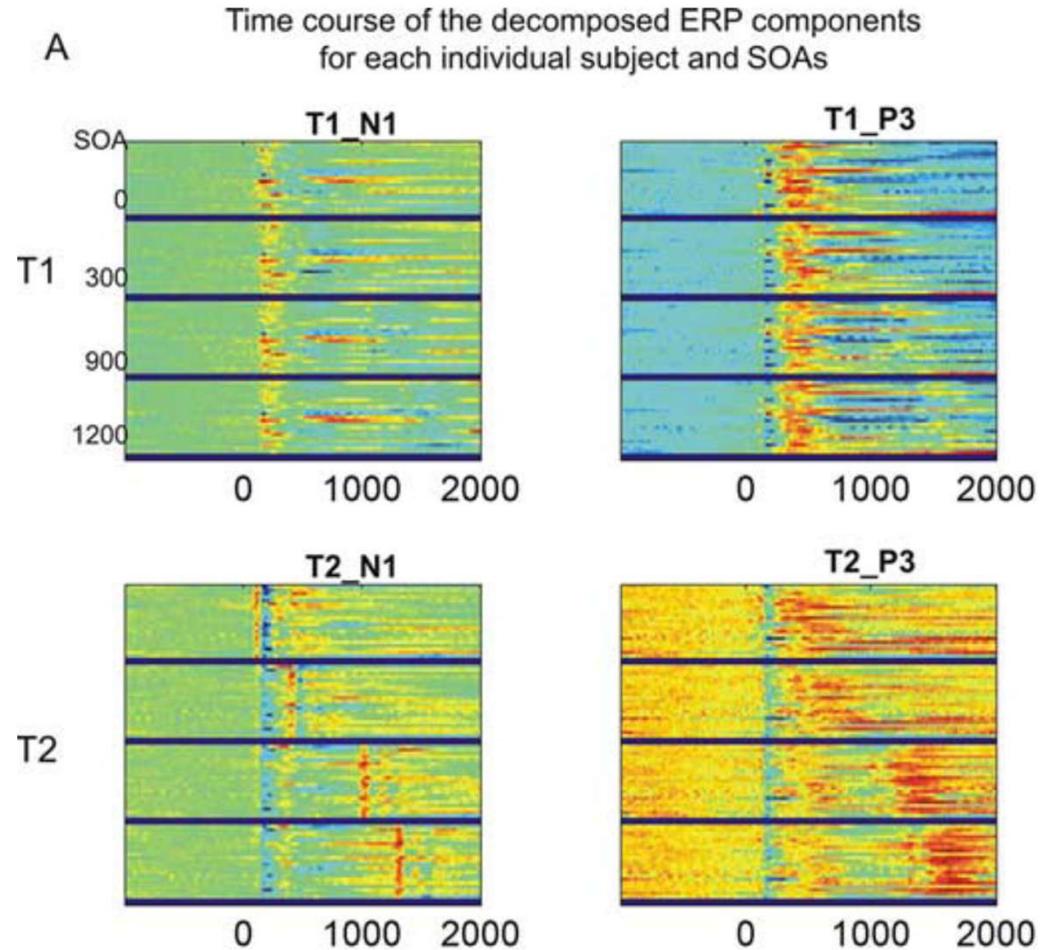The psychological refractory period (PRP)

Response Time (RT)

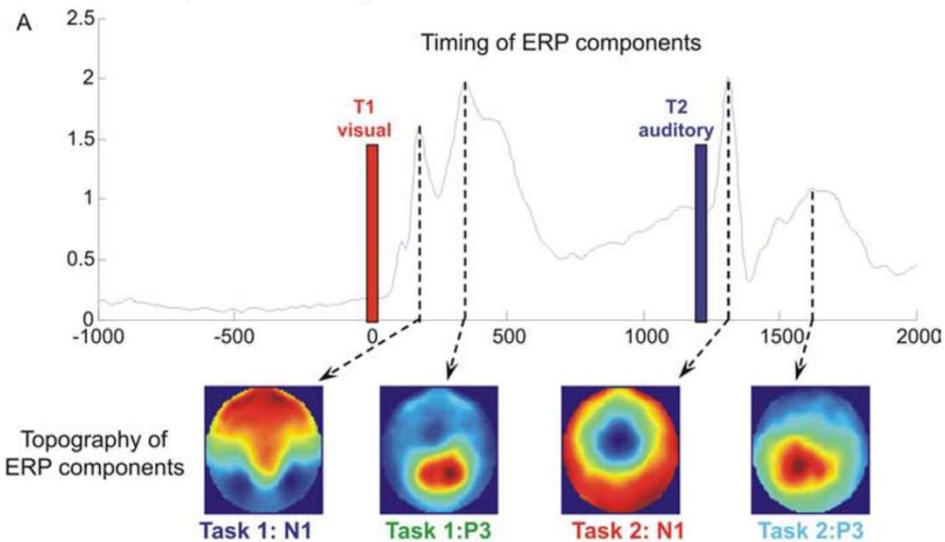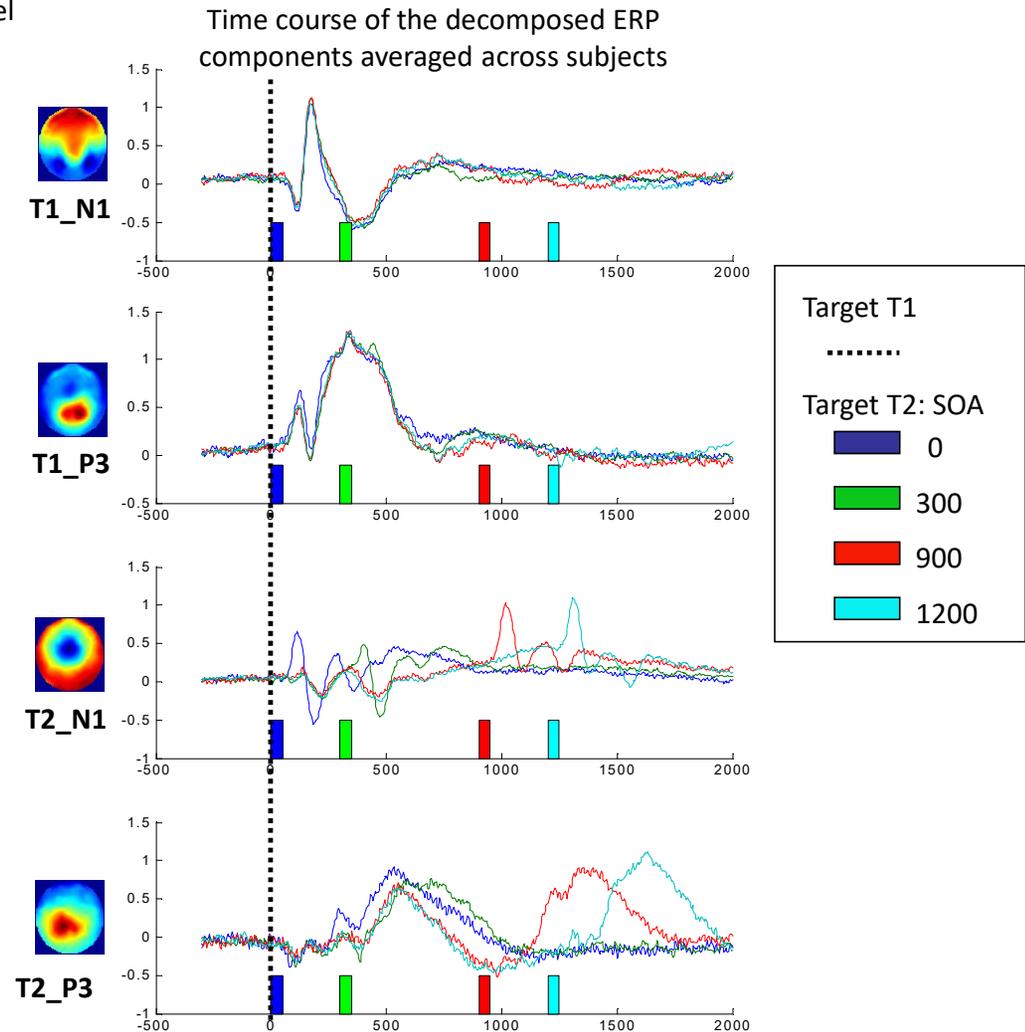Time interval between T1 and T2

M. Sigman

Delayed P3b during dual-task performance

Sigman, M., & Dehaene, S. (2008). Brain mechanisms of serial and parallel processing during dual-task performance. *J Neurosci*, *28*(30), 7585-7598.

Subjects were engaged in two consecutive tasks:
- first a visual task (number comparison, right hand)
- second an auditory (pitch judgement, left hand)
with 4 delays between the two stimuli: 0, 300, 900 or 1200 ms.
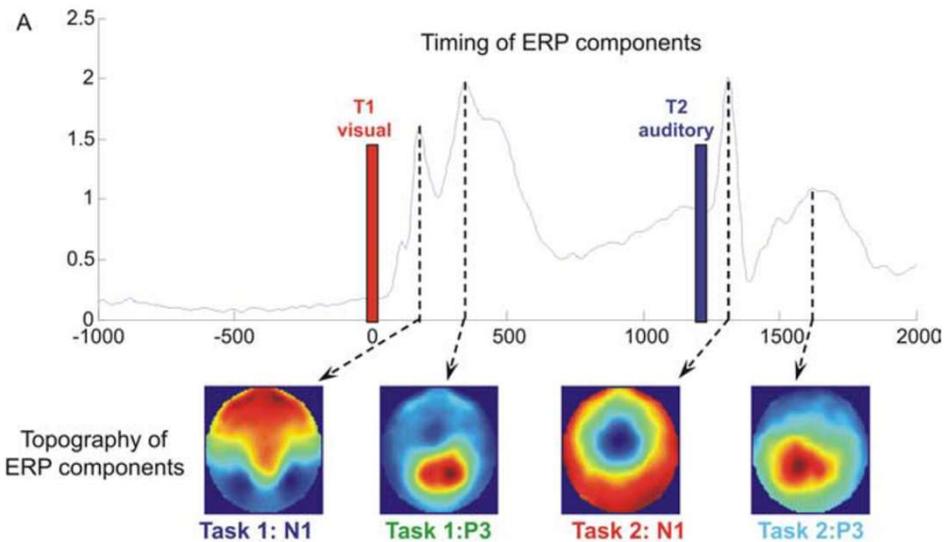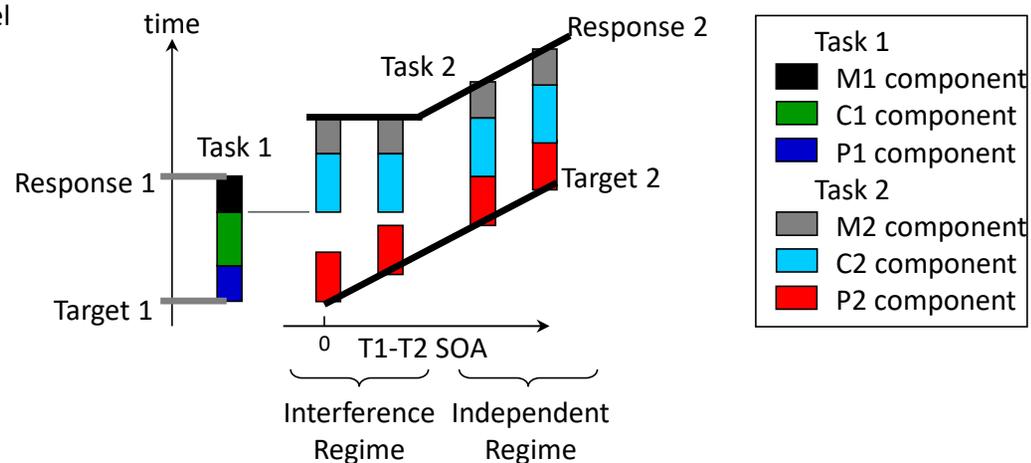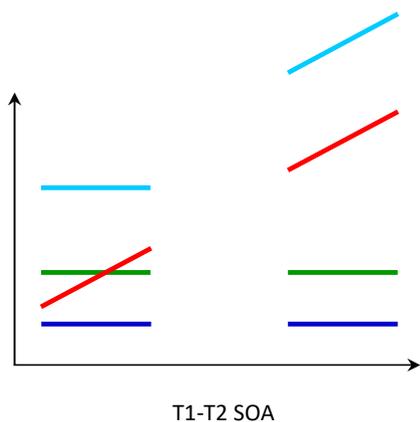
Delayed P3b during dual-task performance

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Subjects were engaged in two consecutive tasks
- first a visual task (number comparison, right hand)
- second an auditory (pitch judgement, left hand)
with 4 delays between the two stimuli: 0, 300, 900 or 1200 ms.

4 distinct early negativities and late positivities were identified for each task.
On single trials, only the Task 2 P3 was massively delayed and diluted by dual tasking at short SOAs.

Timing of ERP components

Topography of ERP components

Task 1: N1   Task 1:P3   Task 2: N1   Task 2:P3

Time course of the decomposed ERP components for each individual subject and SOAs

Delayed P3b during dual-task performance

Sigman, M., & Dehaene, S. (2008). Brain mechanisms of serial and parallel processing during dual-task performance. *J Neurosci*, *28*(30), 7585-7598.

The average time courses show very clearly how
- Task 1 is strictly unchanged, regardless of when the second auditory stimulus occurs.
- The task 2 negativity is nicely time-locked to the second auditory stimulus
- the task 2 positivity is delayed by the simultaneously performance of task 1 (SOA = 0 ms)

Timing of ERP components

Topography of ERP components

Time course of the decomposed ERP components averaged across subjects
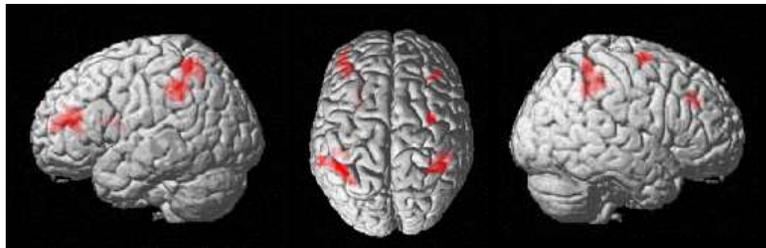
Delayed P3b during dual-task performance

Sigman, M., & Dehaene, S. (2008). Brain mechanisms of serial and parallel processing during dual-task performance. *J Neurosci*, *28*(30), 7585-7598.

The GNW predicts that only the central stage is specifically delayed.

The N1 and P3 evoked by target 2 fit exactly with those predictions.
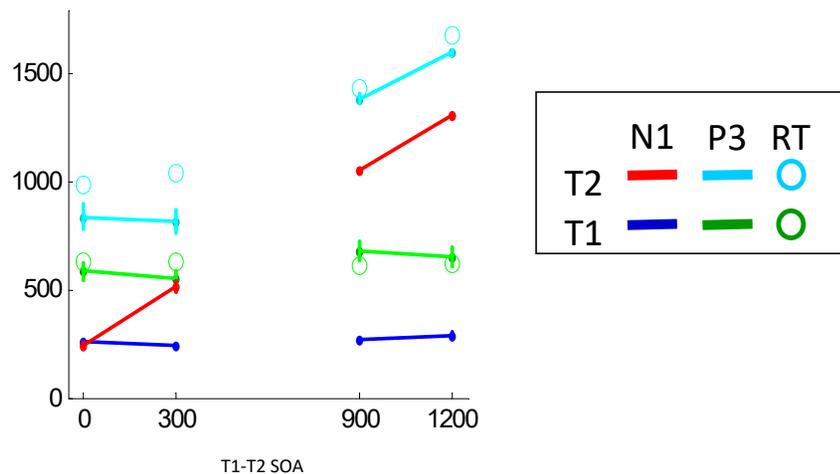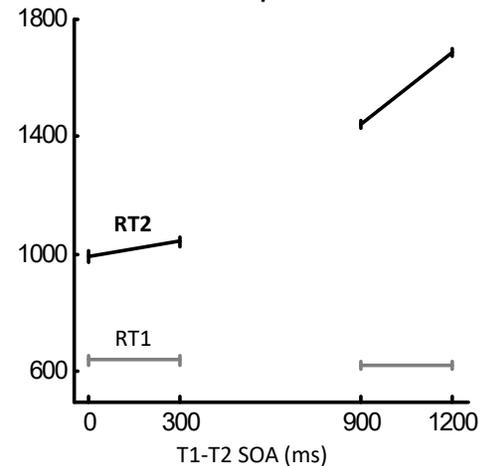
Delayed prefrontal activation during dual-task performance

Sigman, M., & Dehaene, S. (2008). Brain mechanisms of serial and parallel processing during dual-task performance. *J Neurosci*, *28*(30), 7585-7598.

These delays are measurable even in fMRI!

Linear Phase Dependence
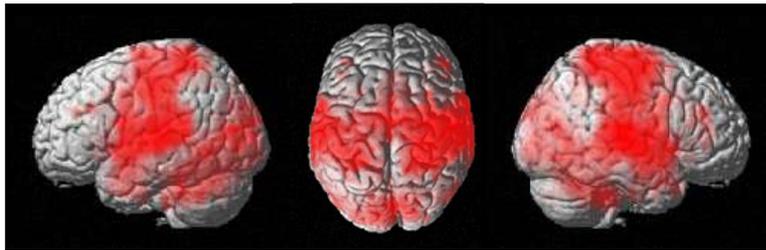
Non-Linear Phase Dependence
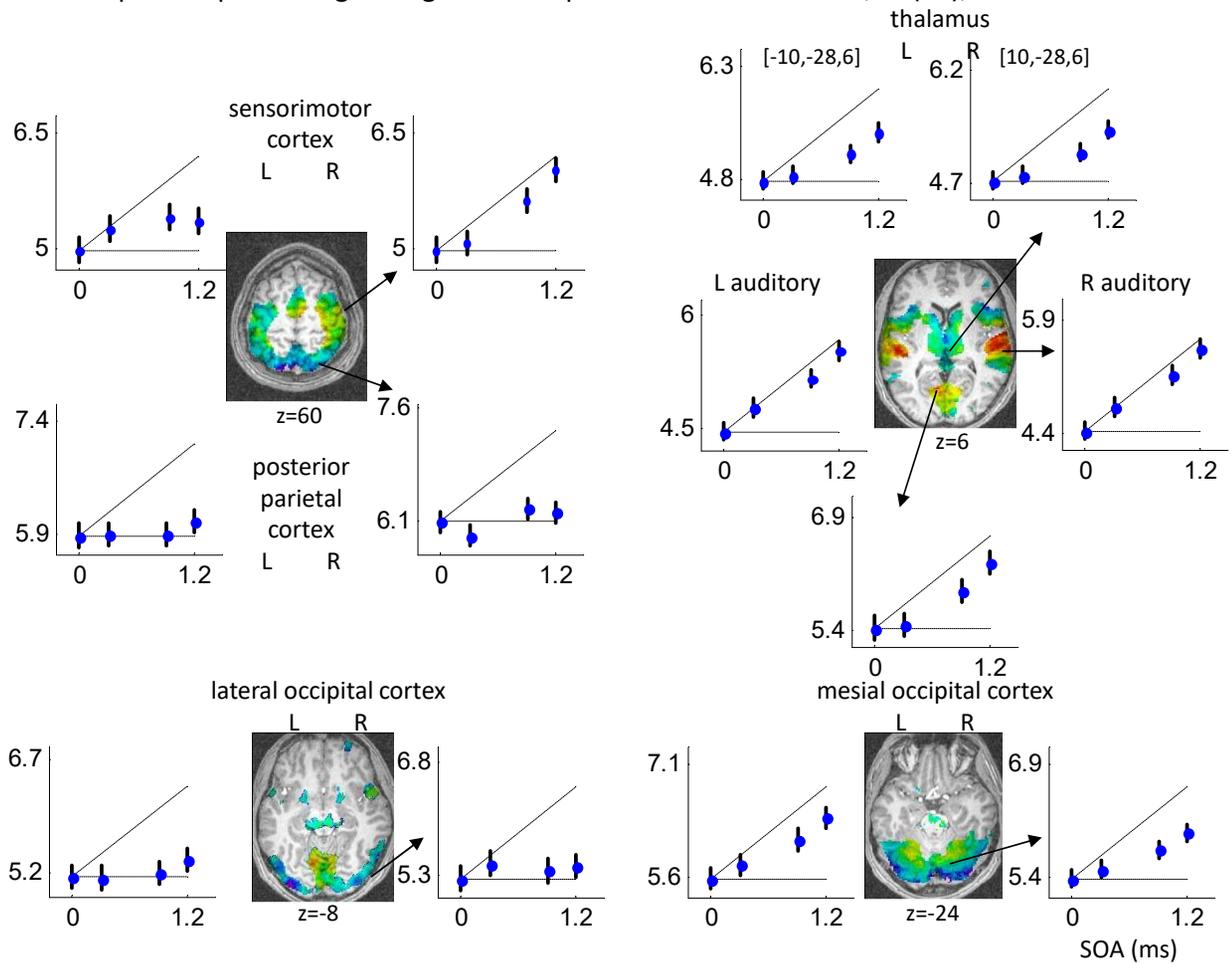
Delayed prefrontal activation during dual-task performance

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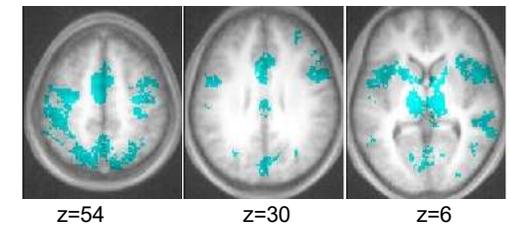
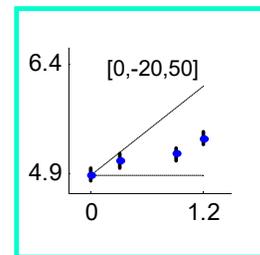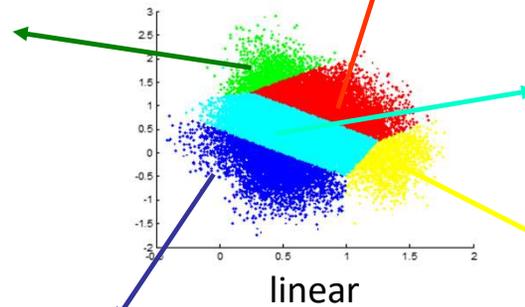5 different networks can be separated according to their response profiles :
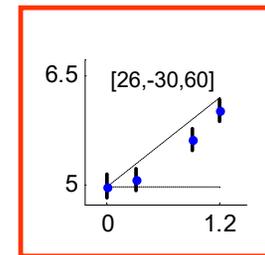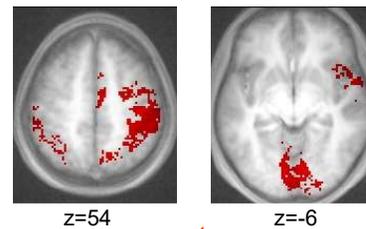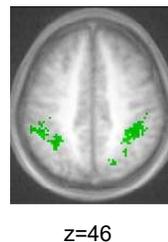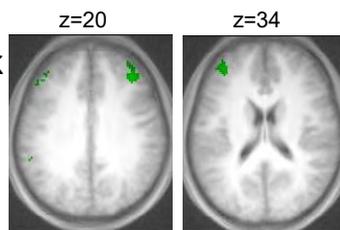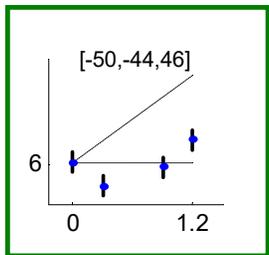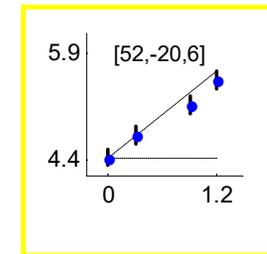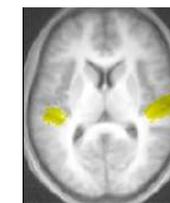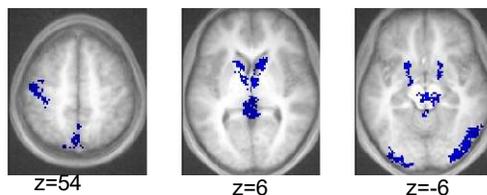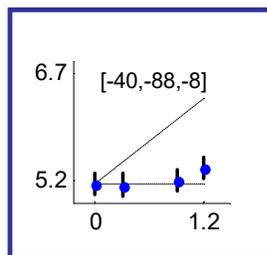
Could we obtain the attentional blink and the PRP within the same task ?
Audio-visual dual tasking can both delay and disrupt conscious access

Marti et al., NeuroImage 2012; Neuron 2015

The psychological refractory period

The Attentional Blink
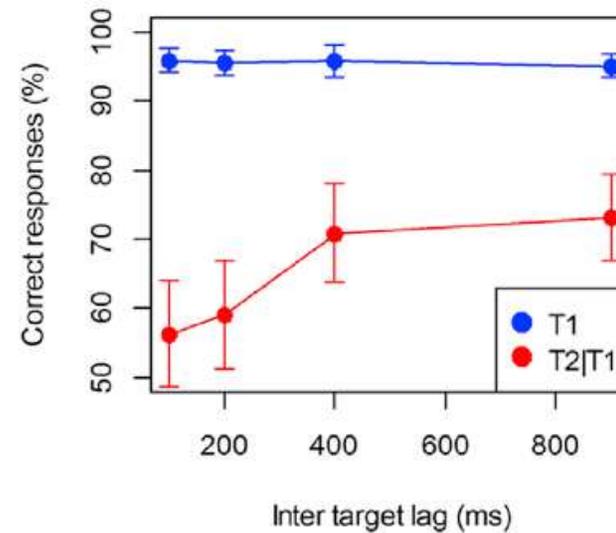
Temporal generalization reveals changes
in the time course of task 1 and task 2

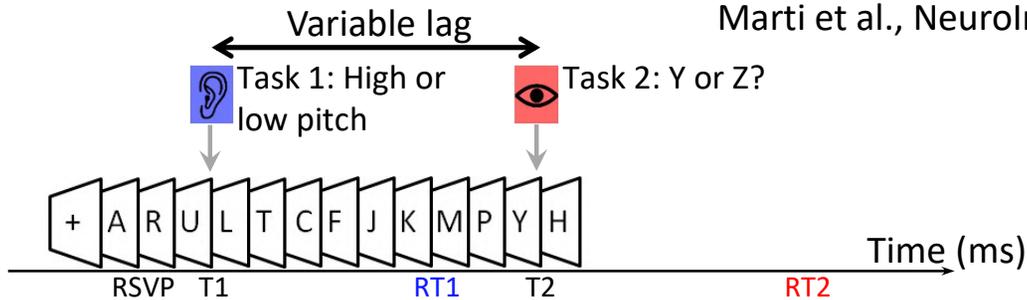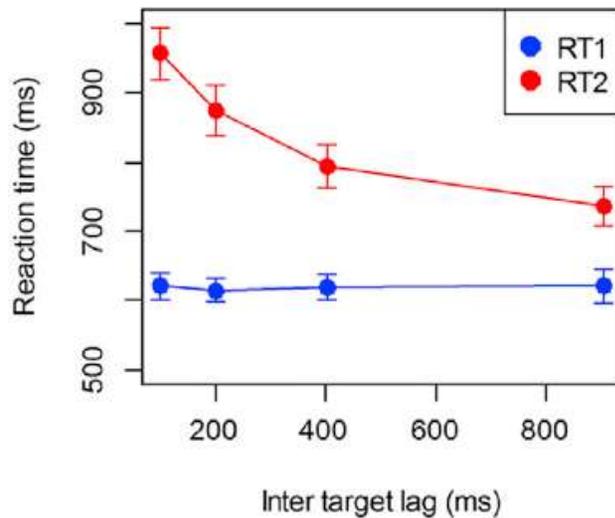Classifiers were trained at each time point, on lag 9 data (where the tasks do not interfere).
We then examined how the decoders generalized to the other lags.

Decoding Task 1

Output of decoder
=
Respond to the sound
versus
listen passively
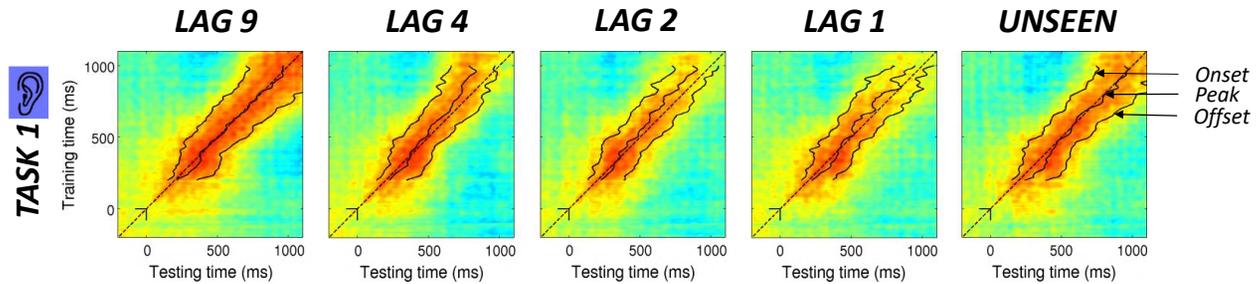
The decoding of task 1 stays on the diagonal or even accelerates.

Decoding Task 2

Output of decoder
=
Target letter
versus
distractor letter

The decoding of task 2 is reduced and leaves the diagonal after about 300-400 ms
→ Systematic dilution and delay of late stages

Task 1 is barely affected by dual-tasking, only slightly compressed

Temporal generalization of decoding

Sources   Sensors

time (ms)

Time-resolved pattern classification

Training: 600 ms

AUC
0.75
0.5

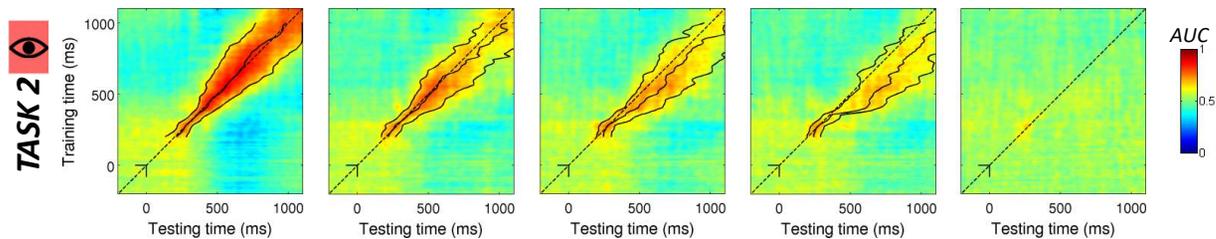**Training: 500 ms**

AUC
0.75
0.5

Training: 400 ms

AUC
0.75
0.5

Training: 300 ms

AUC
0.75
0.5

Training: 200 ms

AUC
0.75
0.5

0   500   1000
Testing time (ms)

Blinked trials behave like lag-9 trials – as if there was no task 2 at all!

Late stages are slightly compressed:

Onset is unaffected

Offset is shortened

Early stages are essentially unaffected

Lags 1 2 3 9
Unseen 1

Task 2 is massively affected: it is suppressed, diffused, and delayed,

Temporal generalization of decoding

Later stages are essentially delayed by dual-tasking.

On PRP trials, by 400 ms, processing is « diffused »: onset is similar, but amplitude decreases while duration increases.

By about 300 ms, on blinked trials, activation is reduced and late-stage ignition fails.

Early stages are essentially unaffected: A target is registered nonconsciously.
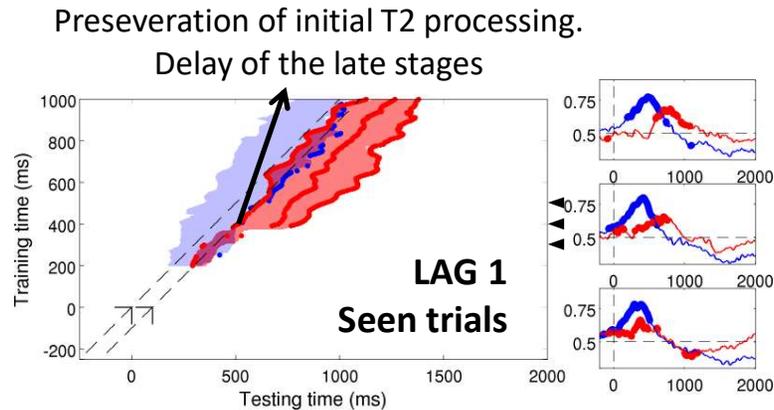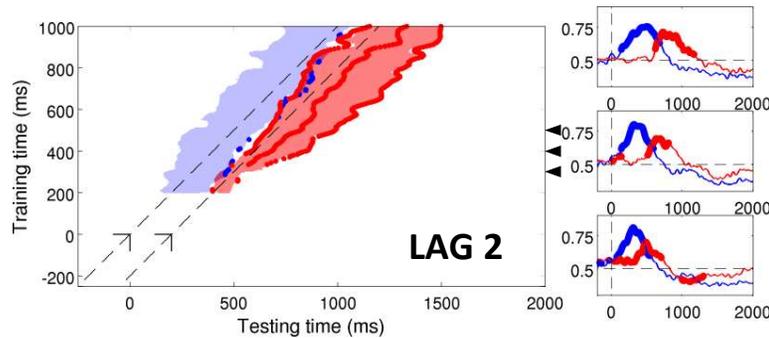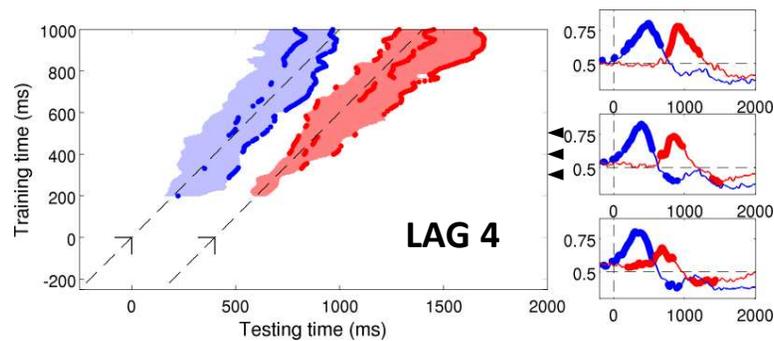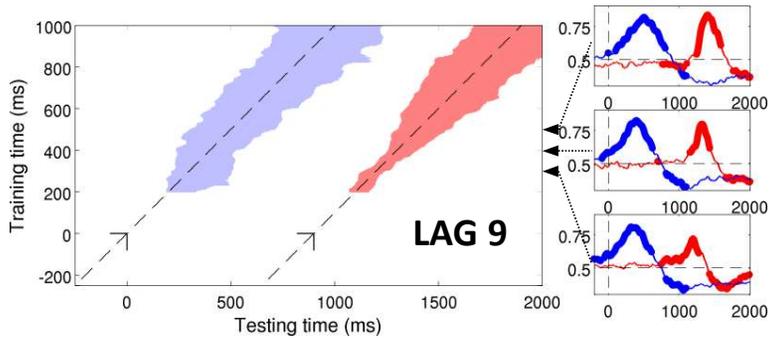
Lags 1 2 4 9
Unseen 1

Testing the mental collision hypothesis

Marti, King & Dehaene, Neuron 2015

Task 1   Task 2

Reference state: dual-tasking at long lag

LAG 9

LAG 4

Preseveration of initial T2 processing.
Delay of the late stages

LAG 2

LAG 1
Seen trials

Sébastien Marti

A prediction for consciousness : Subjective reports of the onset of T2 should also be delayed.

Subjects should only be aware of T2 once they are finished processing T1, and let T2 enter the global workspace.

They should not be aware that T2 is waiting is a nonconscious buffer.

Pushing the limits of heterophenomenology: Introspective response time

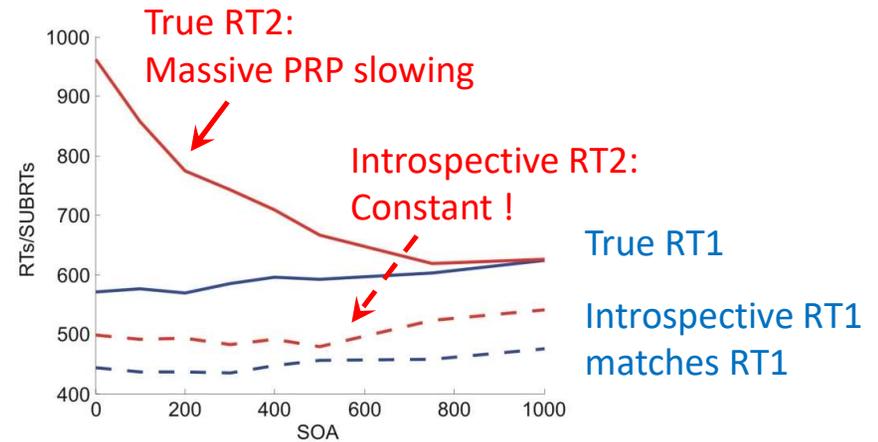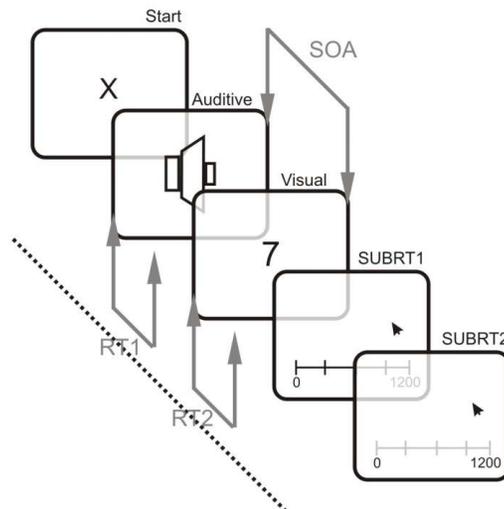Corallo, Sackur, Dehaene & Sigman, *Psychological Science*, 2008

« **Quantified introspection** » of task duration: after each trial of a standard cognitive task, ask subjects to estimate the time spent to complete the task (introspective RT)

In a **single-task context**, introspective RT is a reliable and sensitive measure.
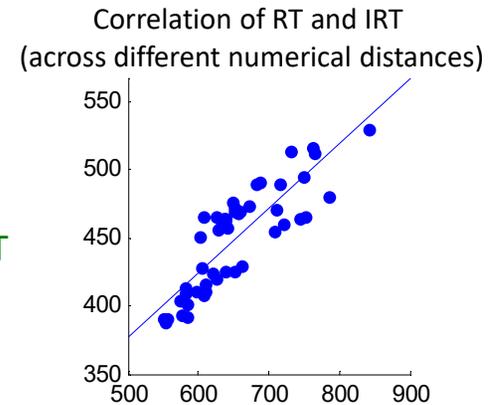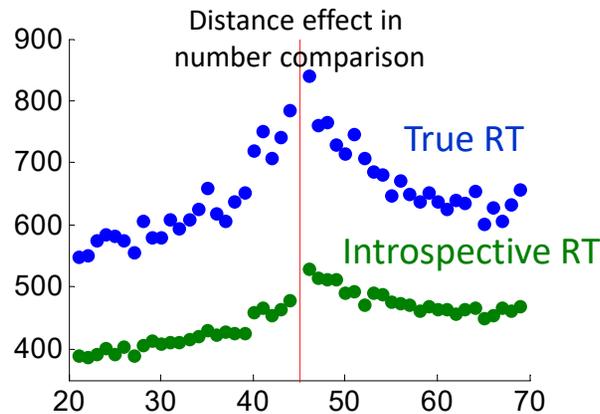
In a **dual task context**, introspective RT is totally insensitive to the PRP delay!

Pushing heterophenomenology to its limits:
Introspection of the PRP delay

Corallo, Sackur, Dehaene & Sigman, *Psychological Science*, 2008; Marti et al. *Cognition* 2010

According to the GNW model, both PRP and Attentional Blink involve a loss of consciousness:
During the PRP, subjects should be **blind** to the fact that T2 is waiting to be processed.

**PRP task: auditory T1
followed by a single visual T2**
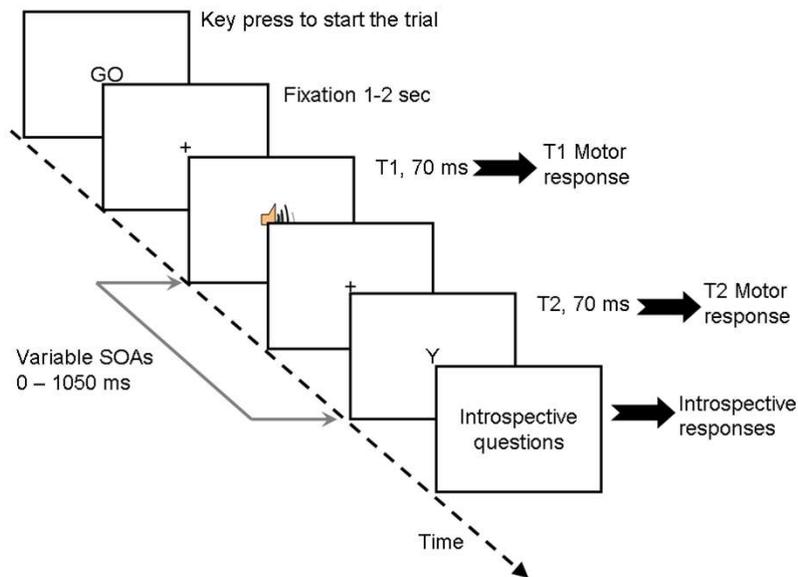
Each **trial is followed by 4 questions**
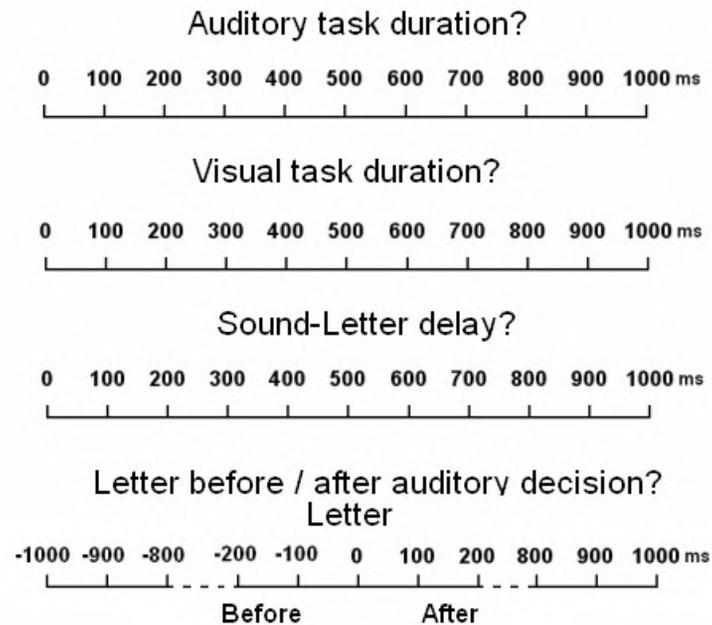
Slack time or free time: Did they have some free time after finishing the T1 task, and before the letter arrived? Or, on the contrary, did the letter arrive before they were finished with the auditory decision?

Reconstructing the subjective phenomenology of a dual-task trial

Marti, Sackur, Sigman & Dehaene, *Cognition*, 2010
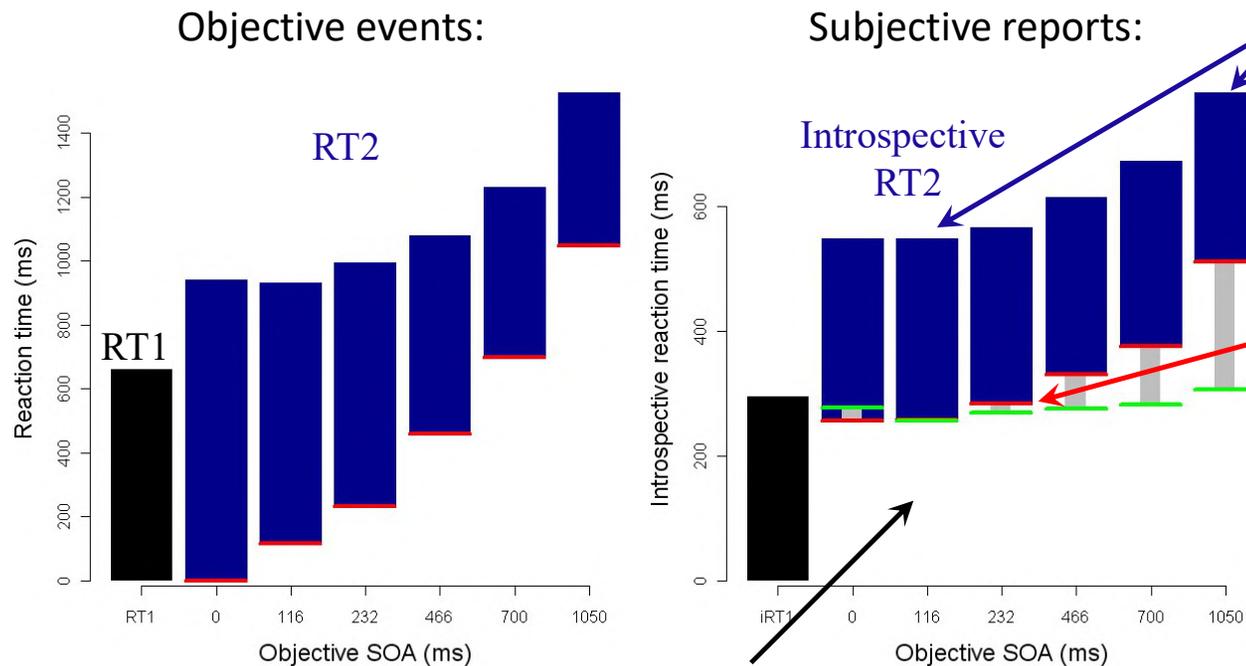

Objective events:

Subjective reports:

Subjectively, iRT2 does not vary with SOA : subjects are not aware of the PRP !

Subjects are wrong about the onset of the letter (T2) relative to the letter : They locate it at or after the end of the T1 task

The gray bar indicates their estimate of slack time or free time – they are only aware of free time.

By subtracting the grey bar from the red bar, we can reconstruct the subjective introspection of finishing the T1 task – and it is quite accurate
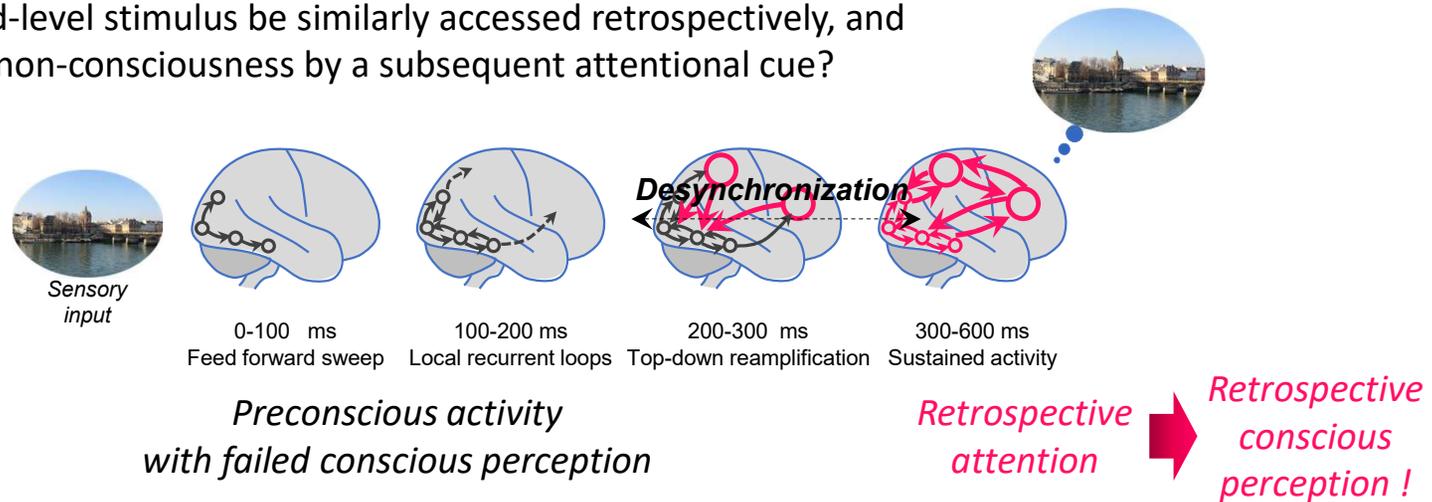
The blind spot of consciousness!
When our workspace is occupied by T1 processing, we have no introspection that T2 is waiting.
And yet T2 can be rescued ; Could this also occur in other circumstances?

A counter-intuitive prediction from late and global views : Conscious perception can be temporally dissociated from stimulus onset

In the Psychological Refractory Period (PRP), the T2 stimulus must be waiting in a nonconscious buffer, from which it is later accessed.
Could a threshold-level stimulus be similarly accessed retrospectively, and be "saved" from non-consciousness by a subsequent attentional cue?

Sensory input

0-100 ms	100-200 ms	200-300 ms	300-600 ms
Feed forward sweep	Local recurrent loops	Top-down reamplification	Sustained activity

Desynchronization

*Preconscious activity
with failed conscious perception*

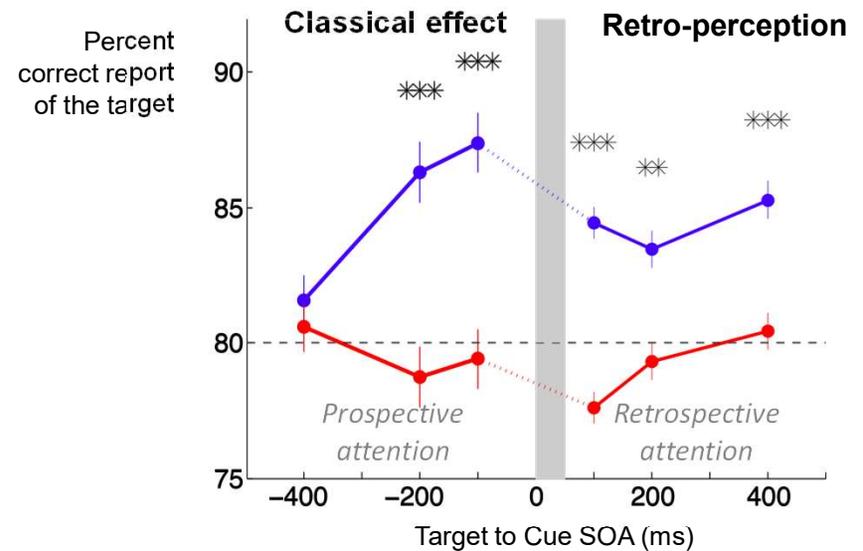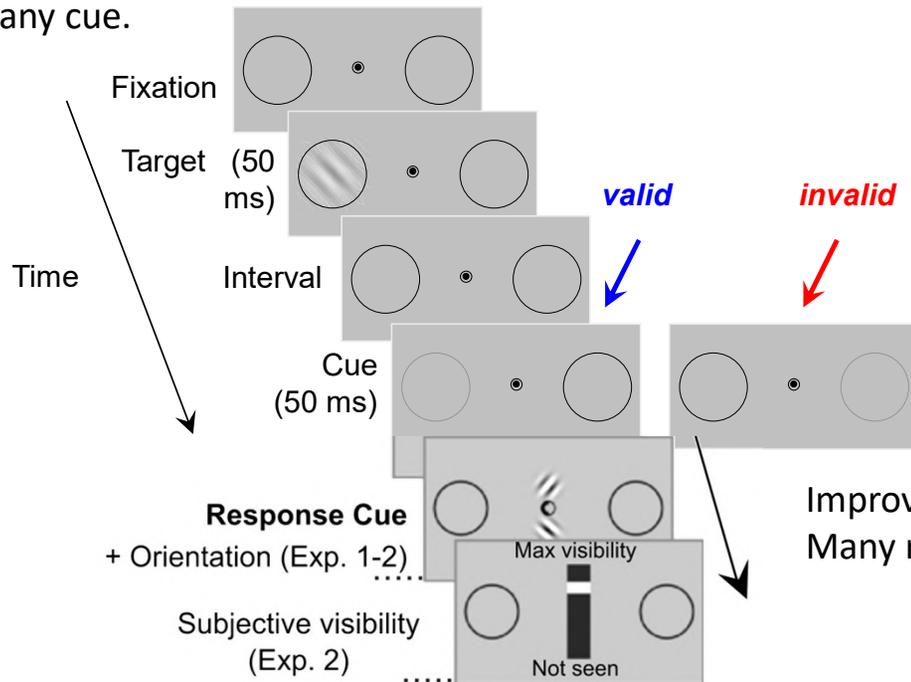*Retrospective attention* → *Retrospective conscious perception !*

Slides courtesy of
Claire Sergent

Triggering conscious access retrospectively: retro-perception

Sergent, C., Wyart, V., Babo-Rebelo, M., Cohen, L., Naccache, L., & Tallon-Baudry, C. (2013). Cueing attention after the stimulus is gone can retrospectively trigger conscious perception. *Current Biology: CB*, *23*(2), 150-155. https://doi.org/10.1016/j.cub.2012.11.047

A target grid is flashed at a low contrast, titrated so that its orientation is perceived only 80% of time in the absence of any cue.

Fixation

Target (50 ms)

Time

Interval

valid   invalid

Cue (50 ms)

Response Cue
+ Orientation (Exp. 1-2)

Subjective visibility (Exp. 2)

Max visibility

Not seen

Percent correct report of the target

Classical effect   **Retro-perception**

***   ***   ***   **   ***

90

85

80

75

Prospective attention   Retrospective attention

−400   −200   0   200   400
Target to Cue SOA (ms)

Improvement of orientation perception, detection d', subjective visibility
Many replications, including extensions to auditory stimuli :

Thibault al & Sergent, *PLoS ONE* 2015
Xia et al, *Journal of Vision* 2016 (replication by independent group)
Rimsky-Robert, Sackur & Sergent, *Sci.Rep.* 2019 (cross-modal)
Garnier-Allain, Pressnitzer & Sergent, *JEP-HPP 2023* (audition)
Rimsky-Robert, Lisi, Nguy, Jannin, Hardy, Béraud & Sergent, *In Revision* (visual masking)
Türker, Noorman, Keramidas, Pressnitzer & Sergent, *In Prep.*
Sergent et al. *In Prep.* (MEG)

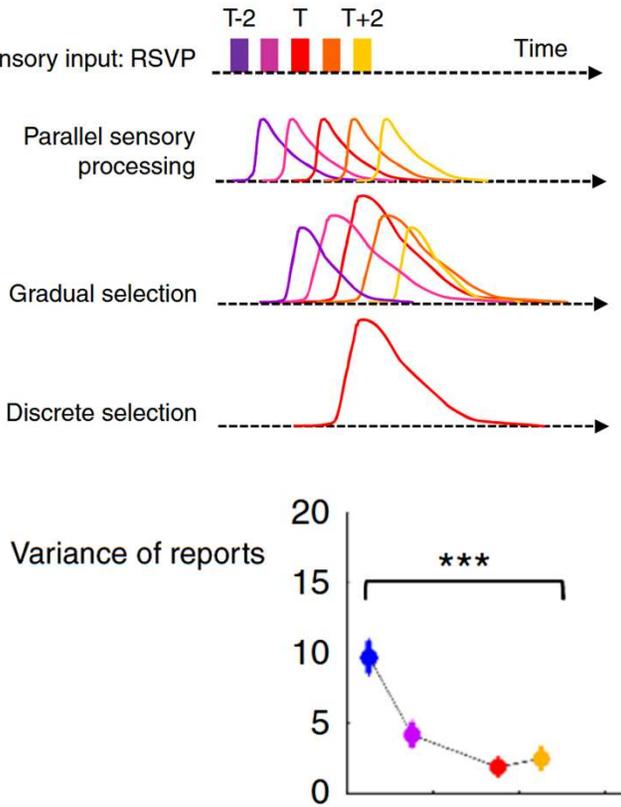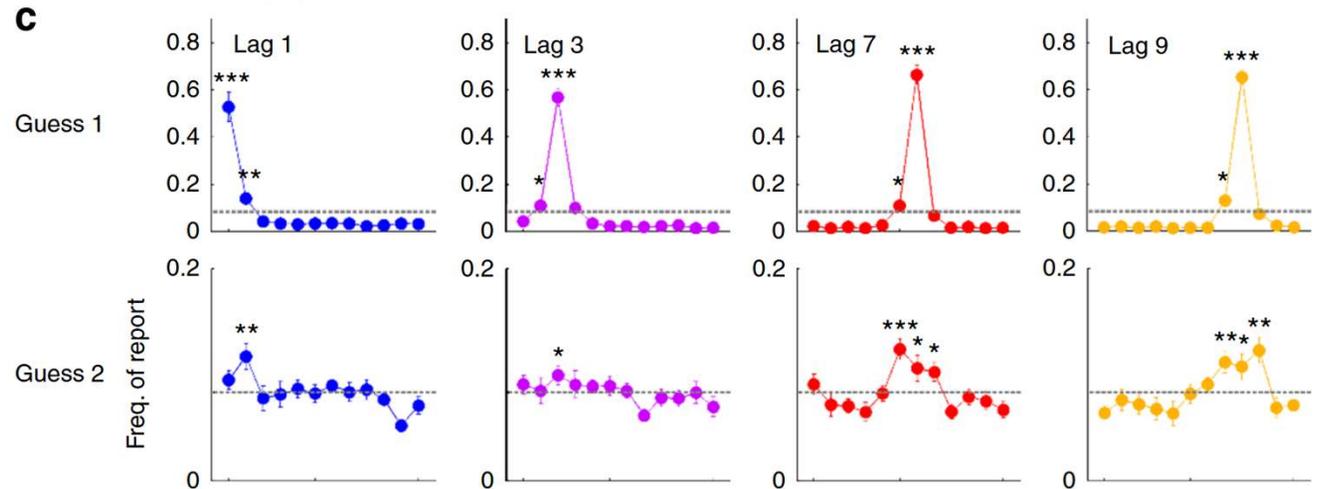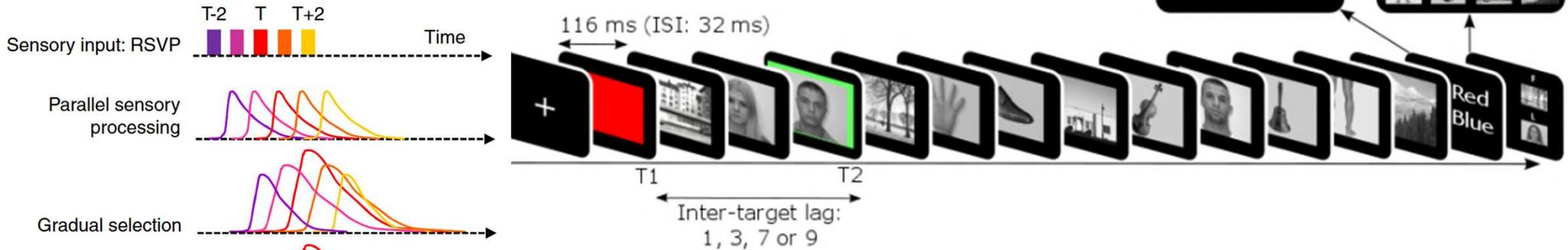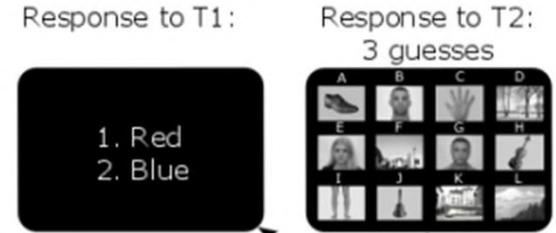# Discrete and continuous mechanisms of temporal selection

Marti & Dehaene, *Nature Communications*, 2017

Sébastien Marti

Subjects are bombarded with 12 images at a fast rhythm (9 images/s).
They must report the image within the green frame.
They are temporarily distracted by a second task (report the initial color)
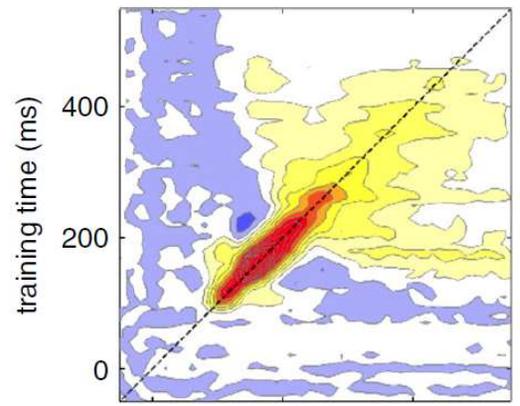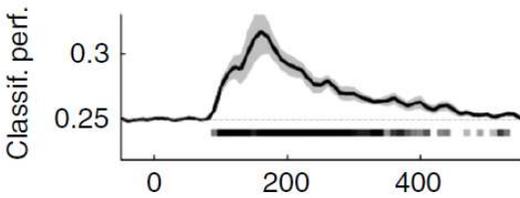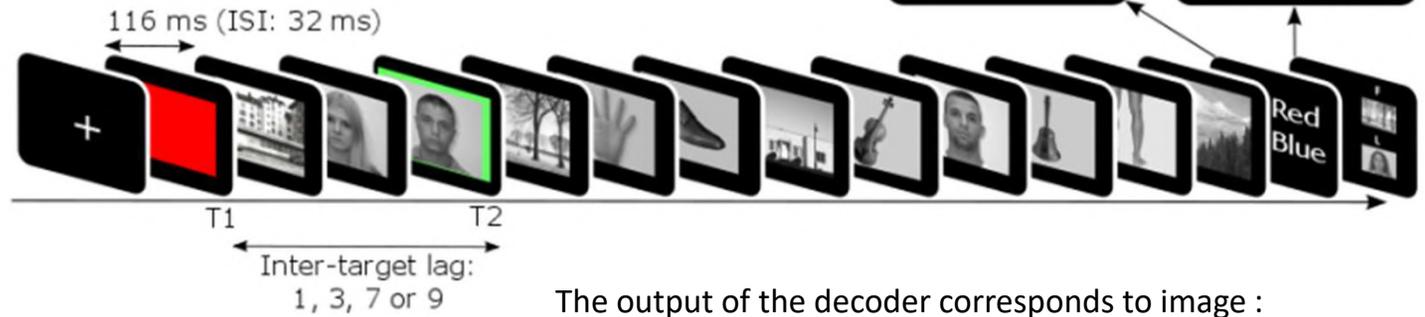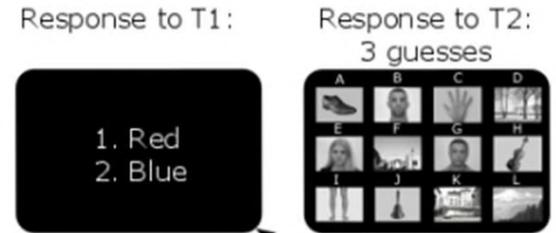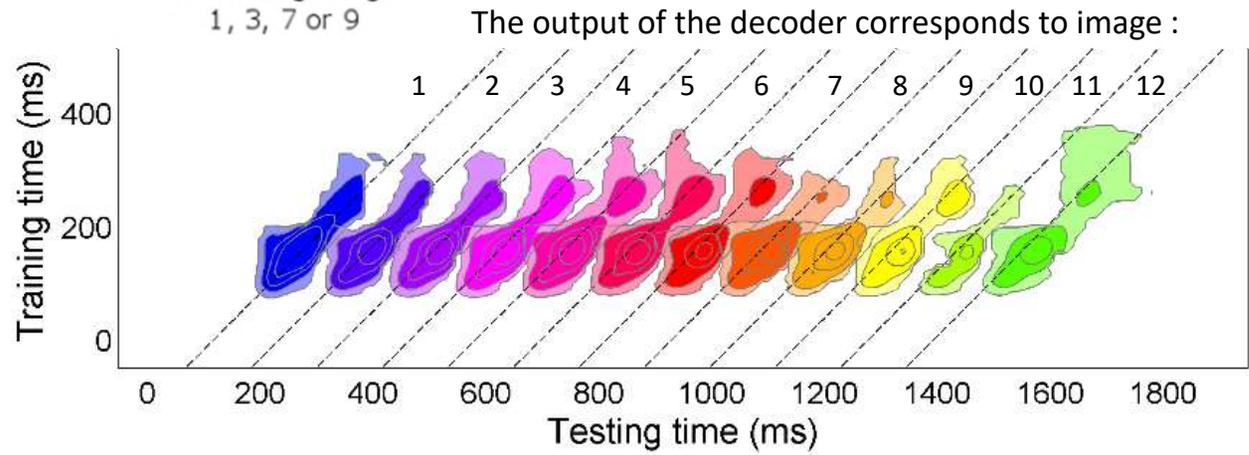Behavior suggests both gradual and discrete mechanisms of selection.

Discrete and continuous mechanisms of temporal selection

Marti & Dehaene, *Nature Communications*, 2017

Sébastien Marti

Subjects are bombarded with 12 images at a fast rhythm (9 images/s).
They must report the image within the green frame.
They are temporarily distracted by a second task (report the initial color)
A decoder can detect the identity of *every* image
→ nonconscious pipe-line

Response to T1:

1. Red
2. Blue

Response to T2:
3 guesses

116 ms (ISI: 32 ms)

T1   T2

Inter-target lag:
1, 3, 7 or 9

Red
Blue

The output of the decoder corresponds to image :

1   2   3   4   5   6   7   8   9   10   11   12

Discrete and continuous mechanisms of temporal selection

Marti & Dehaene, *Nature Communications*, 2017

What happens to the target image :
- Identical initial perceptual processing (nonconscious)
- Late perceptual amplification with two distinct components
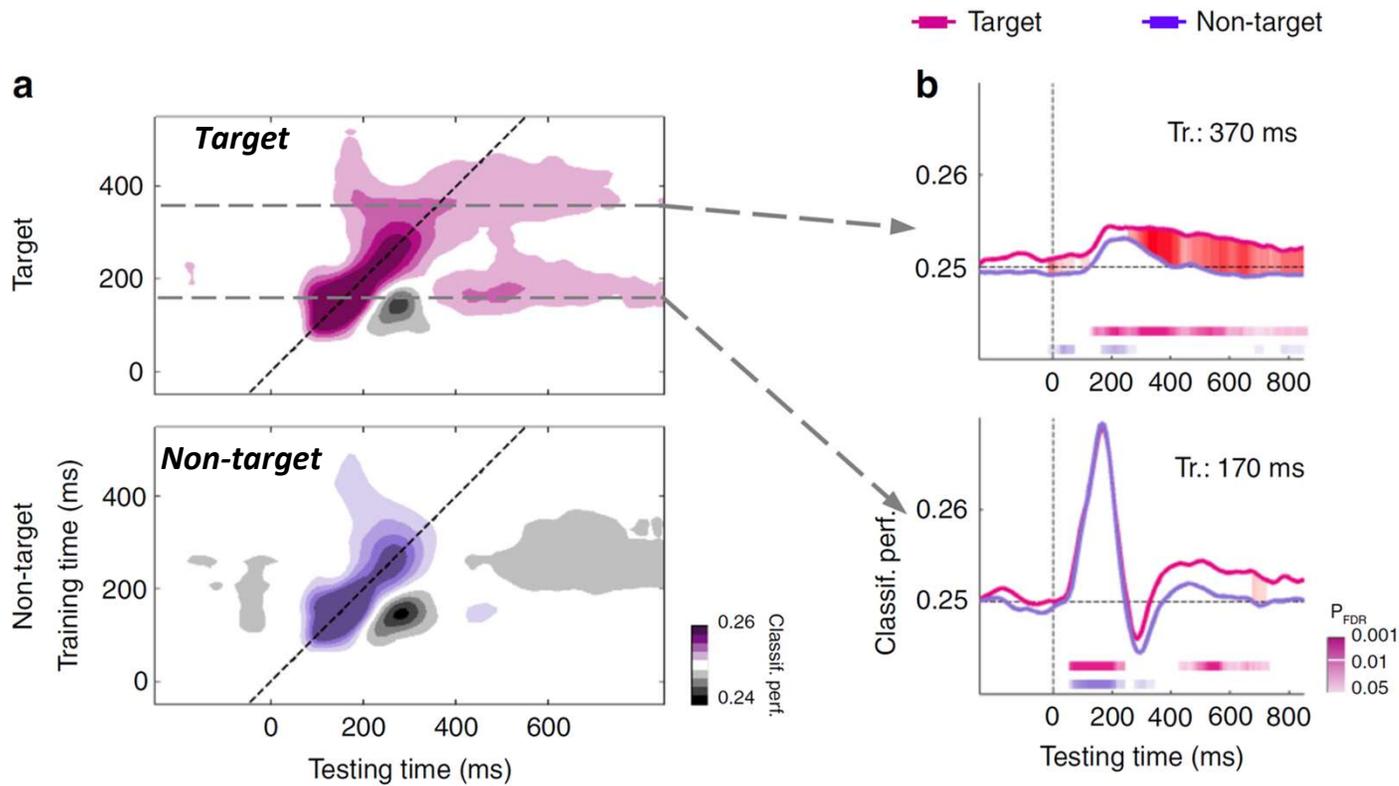
Discrete and continuous mechanisms of temporal selection

Marti & Dehaene, *Nature Communications*, 2017

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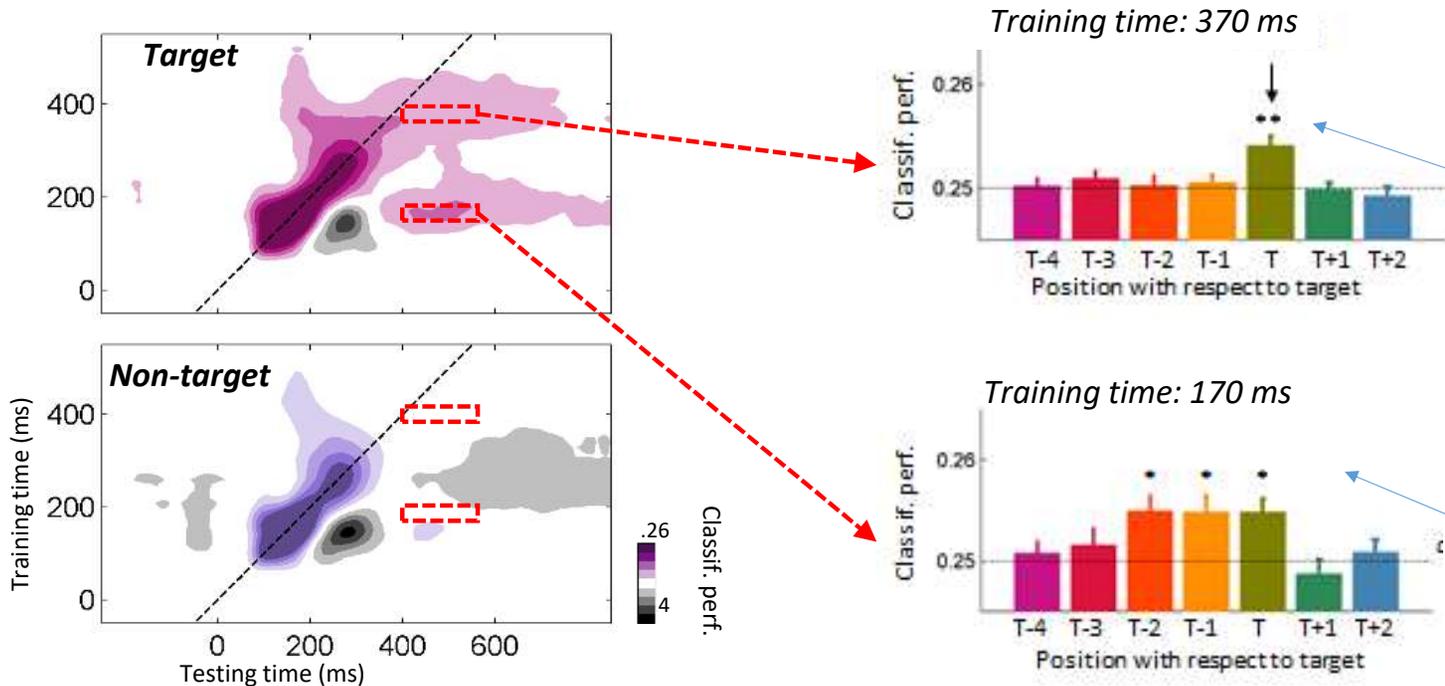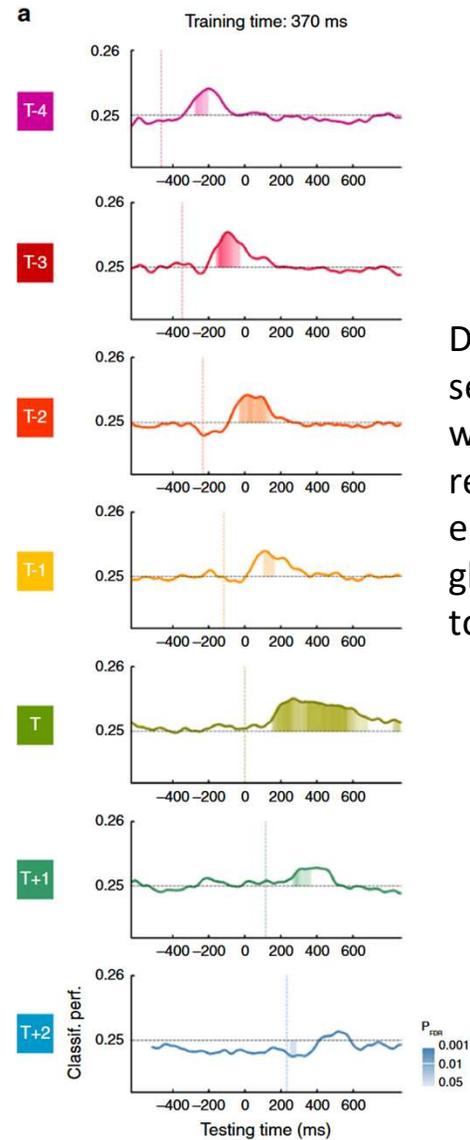

Discrete, all-or-none selection, correlated with subjective reports and with errors : access to the global workspace and to reportability.

Partial and gradual selection: attentional amplification of a few relevant candidates for attentional selection.
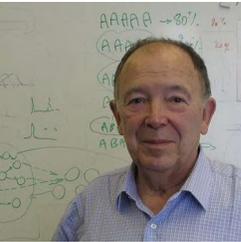
a

b Training time: 170 ms

Partial and gradual selection: attentional amplification of a few relevant candidates for attentional selection.

a Training time: 370 ms
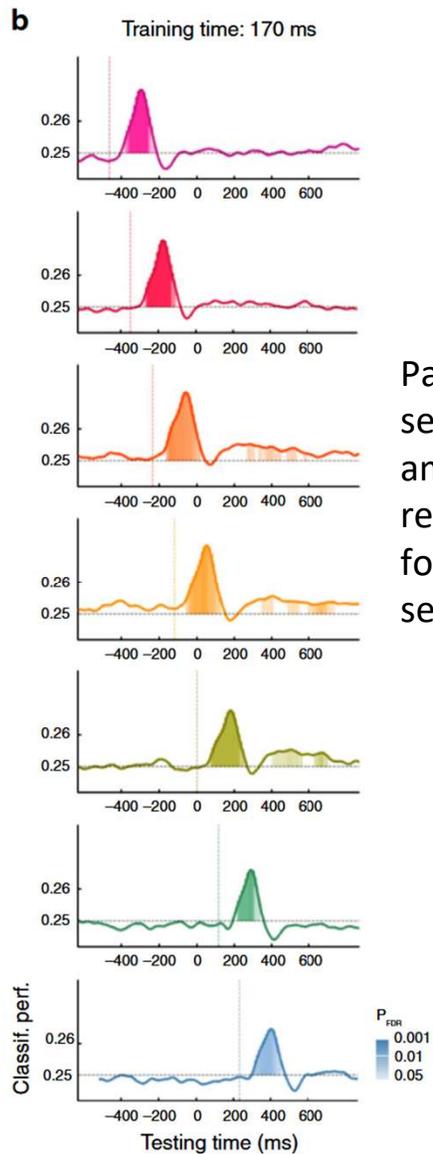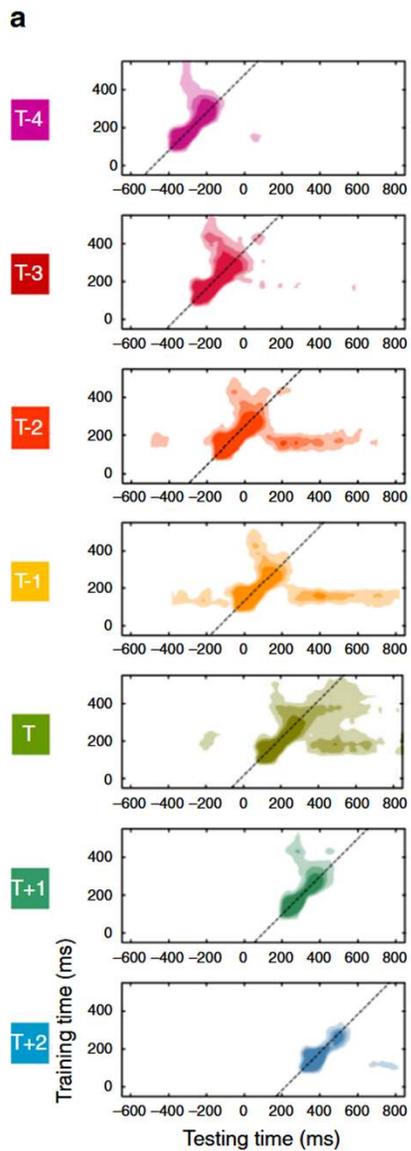
Discrete, all-or-none selection, correlated with subjective reports and with errors : access to the global workspace and to reportability.

Marietta Ren

The global neuronal workspace (GNW) hypothesis

Dehaene & Changeux, PNAS 1998 ; Dehaene & Naccache, Cognition 2001

Jean-Pierre Changeux

Lionel Naccache

Consciousness relates to the activity of a **global neuronal workspace** that evolved to **select** and **broadcast**, in a brain-wide manner, a piece of information relevant to its current goals.

The conscious workspace sits on top of a very large hierarchy of circuits that are constantly criss-crossed by multiple subliminal signals, all activating in parallel.

It can occasionally "seize" one of those fleeting representations and hold on to it for an arbitrary duration.

→ A massively parallel architecture with a central bottleneck.

→ Is it already present in infancy ?
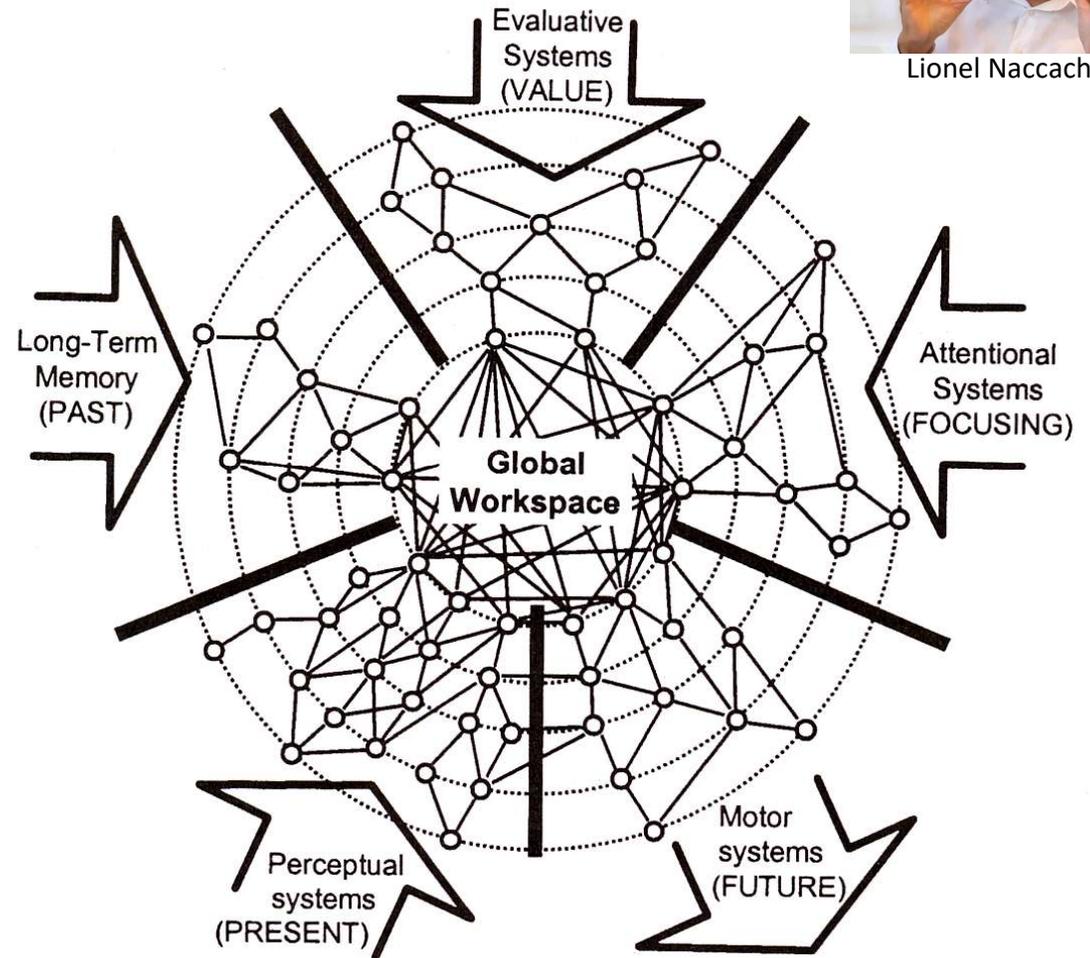
Does the attentional blink exist in infants?

Two consecutive faces are presented, one at the center (F1), and after a variable delay, another in the periphery (F2).
Eye tracking is used to evaluate whether infants orient to the side of F2.

The results are somewhat variable, but suggest that
- The attentional blink already exists
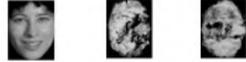- Its duration is massively longer in infancy.

Consecutive presentations

F1-F2 delay: 300 ms or 200 ms

F1

F2

early delays

F1-F2 delay: 900 ms or 600 ms
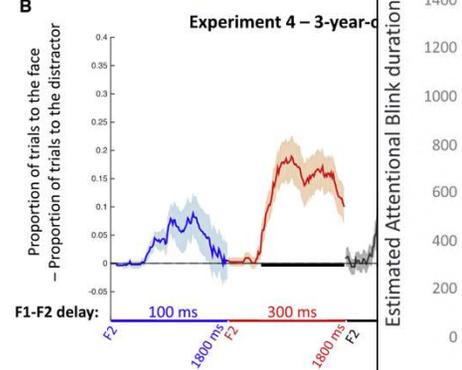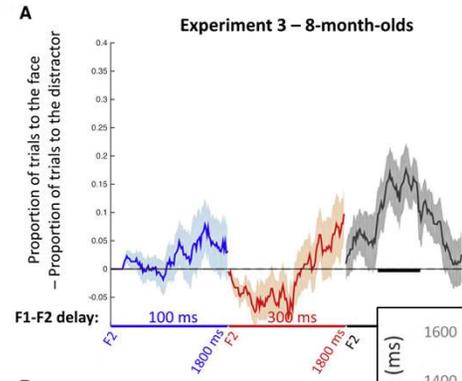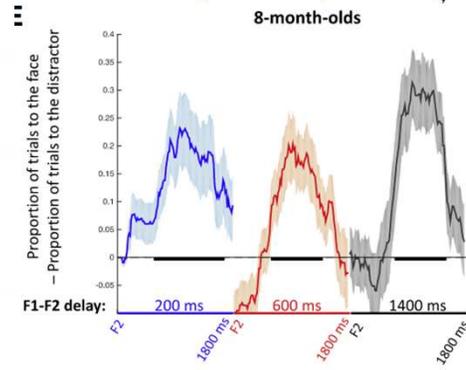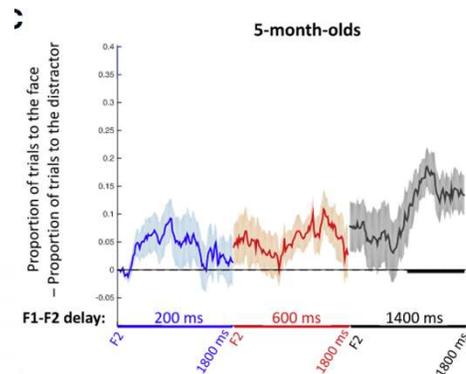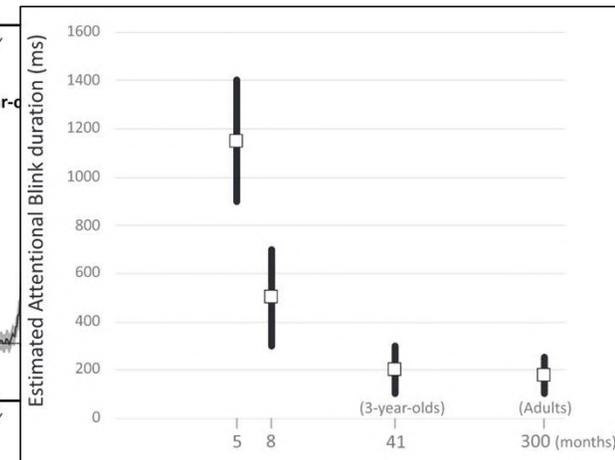
F1

2x

F2

late delays

F1-F2 delay: 2100 ms or 1400 ms

F1

6x

F2

Electrophysiological correlates of the attentional blink in infants

Leroy, ... & Dehaene-Lambertz, PNAS 2026, in press

A central teddy bear (T1) attracts attention, then after a variable delay a peripheral face (T2) sometimes appears, cueing the location of a subsequent visible face (T3).
Only at long delays do the infants use the cue to orient to the side of the face
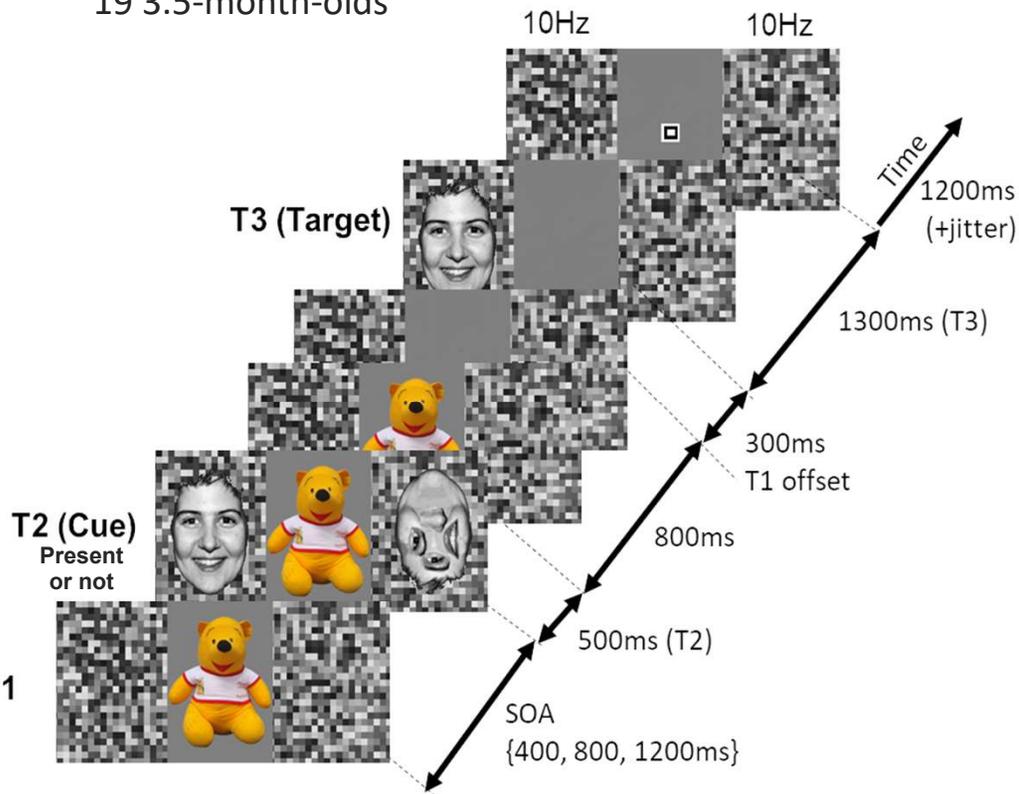
19 3.5-month-olds

On trials when infants make a saccade

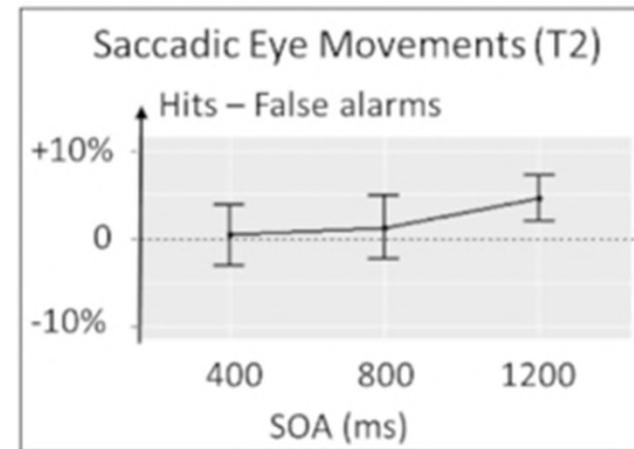# Electrophysiological correlates of the attentional blink in infants

Leroy, … & Dehaene-Lambertz, PNAS 2026, in press

A central teddy bear (T1) attracts attention, then after a variable delay a peripheral face (T2) sometimes appears, cueing the location of a subsequent visible face (T3).
On trials without saccades, pupil size to T2 again changes only at long delays (1200 ms).

19 3.5-month-olds

Only at long delays, EEG recordings show a suppression of the tagged frequency, indicating they attend to the picture and suppress the background.

Many other subtleties of the blink are present in infants

Leroy, … & Dehaene-Lambertz, PNAS 2026, in press

1. At the intermediate delay (800 ms), face visibility is improved when the face is presented in the left hemifield, i.e. to the right hemisphere (lateralization of face perception).
2. ERPs can be used to sort trials into those where the teddy bear (T1) strongly engaged the infant, and those in which T1 induced a much smaller engagement.

The strong N290 is taken as a measure of a strong engagement in T1.

Trials sorted depending on their Fly-bys to the T1 P400
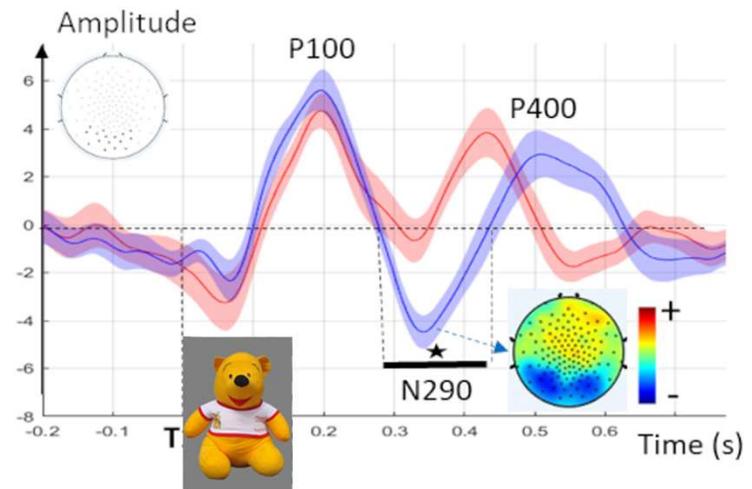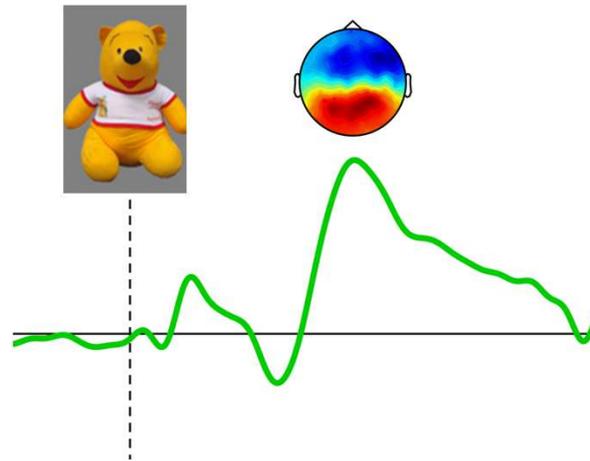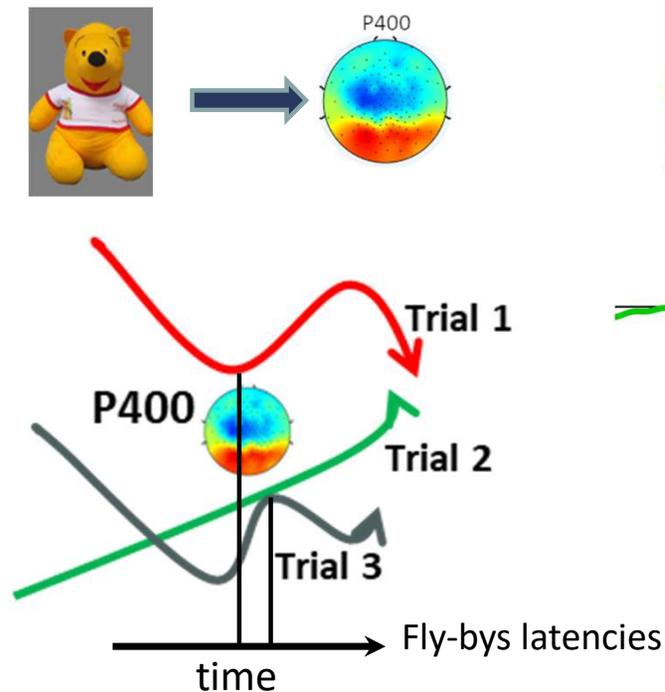
Many other subtleties of the blink are present in infants

Leroy, ... & Dehaene-Lambertz, PNAS 2026, in press

We then examine the effect of those fluctuations on T2 at long SOA (which should be visible)
When infants were strongly engaged by T1 (large N290, delayed P400), multiple cues
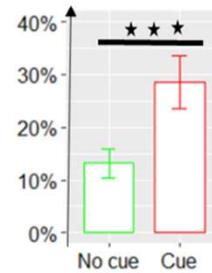converge to suggest that they did not see T2.

Trials sorted depending on
their Fly-bys to the T1 P400
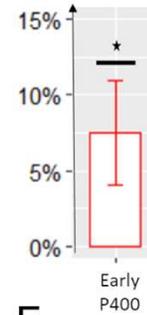
shallow
attention to T1

Deeper
attention to T1
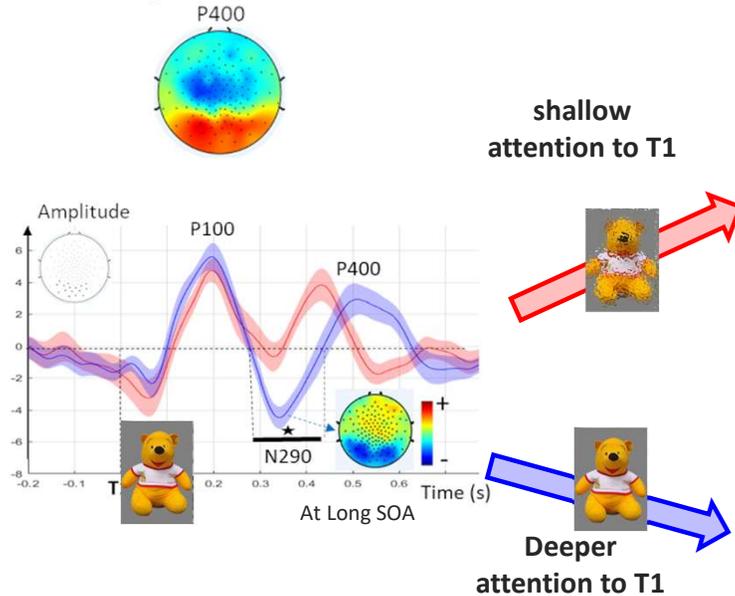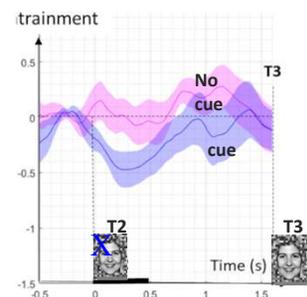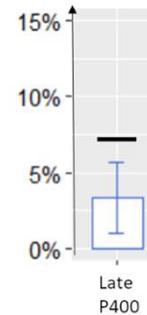
fewer saccades

% Saccades to T2

no influence of cue on
saccade direction

Correct orientation
to the face

Early
P400

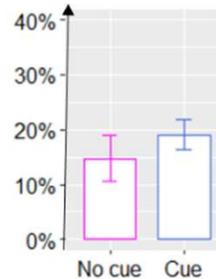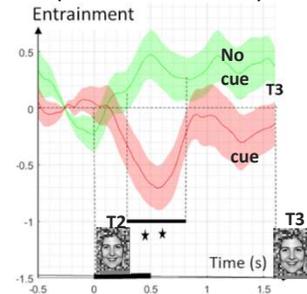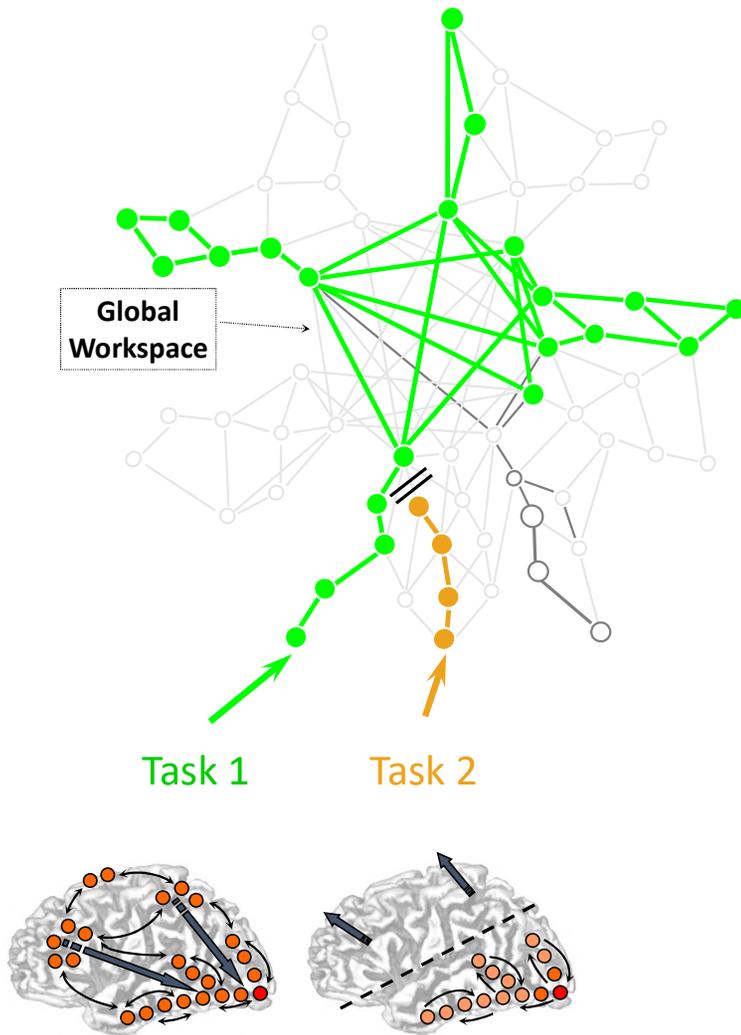Late
P400

nor frequency tagging

Neural Entrainment
(lateral attention)

Conclusions : The timing of consciousness differs from objective time

Global Workspace

Task 1   Task 2

The moment when we become aware of a mental representation may differ dramatically from the moment when the event actually occurred.
- It can be dramatically delayed – in babies, but also in adults, when we are distracted (PRP) or when we turn our attention to a past event (retro-cueing).
- And yet we are usually not aware of this delay !
All these effects are explained by the hypothesis that the Global Workspace acts as a dual-task bottleneck.

Prefrontal areas

Sensory areas

Metastable representation ~300 post-stimulus

target T1

delayed ignition (PRP)

target T2

or collapse (attentional blink)