Models of memory

Sander Bosch

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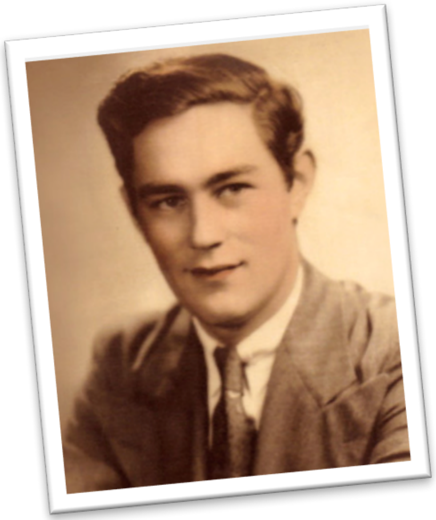
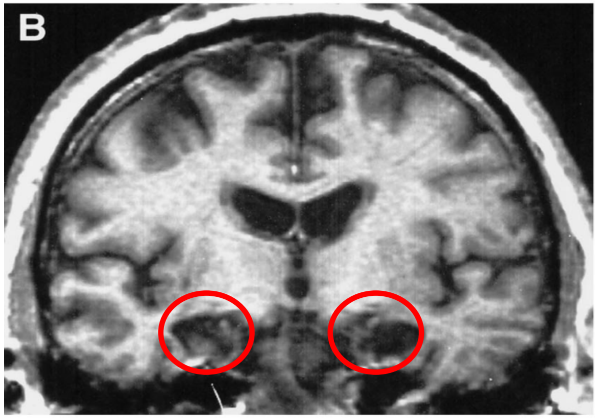
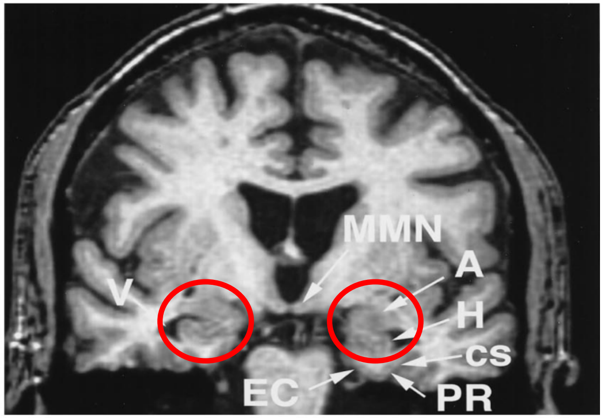
Henry Molaison (HM)





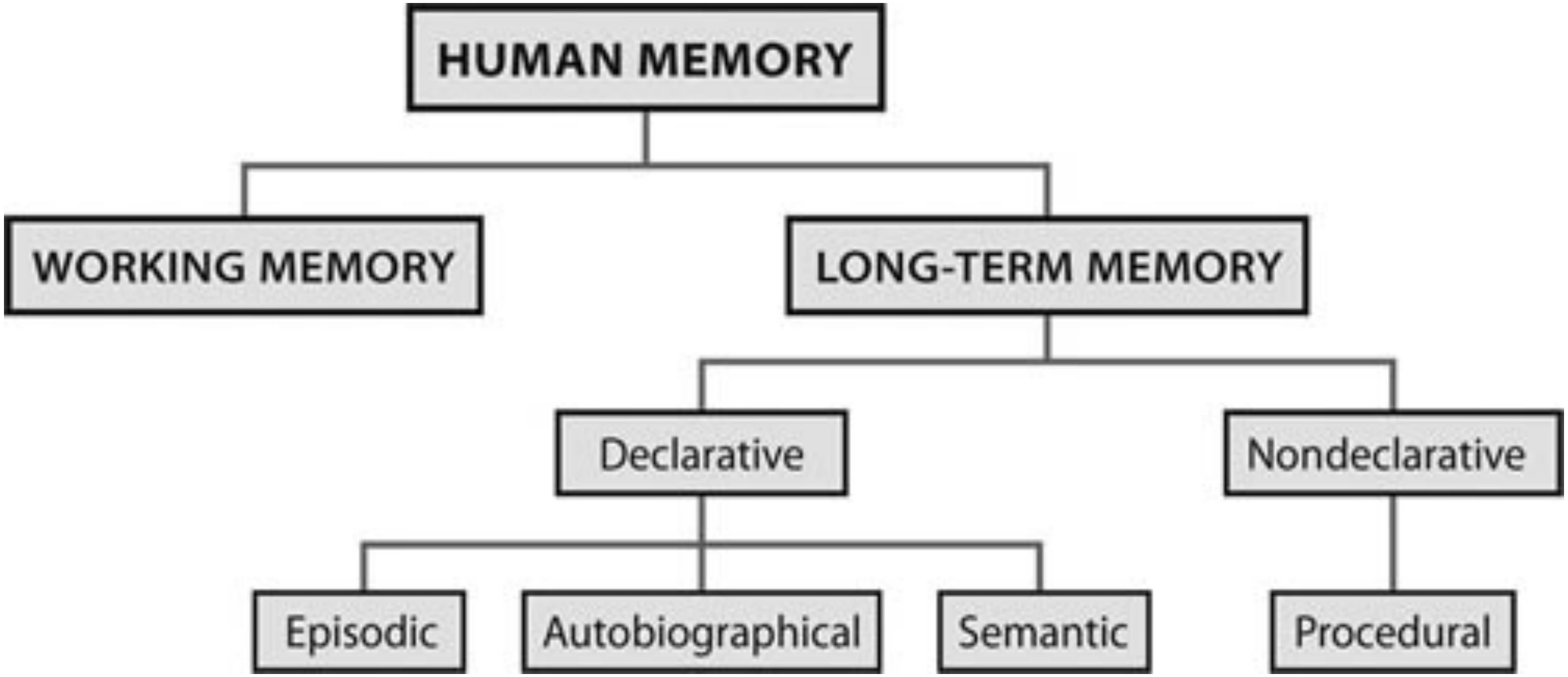


Scoville & Milner, J.Neurol.Neurosurg.Psychiat.1957

CW

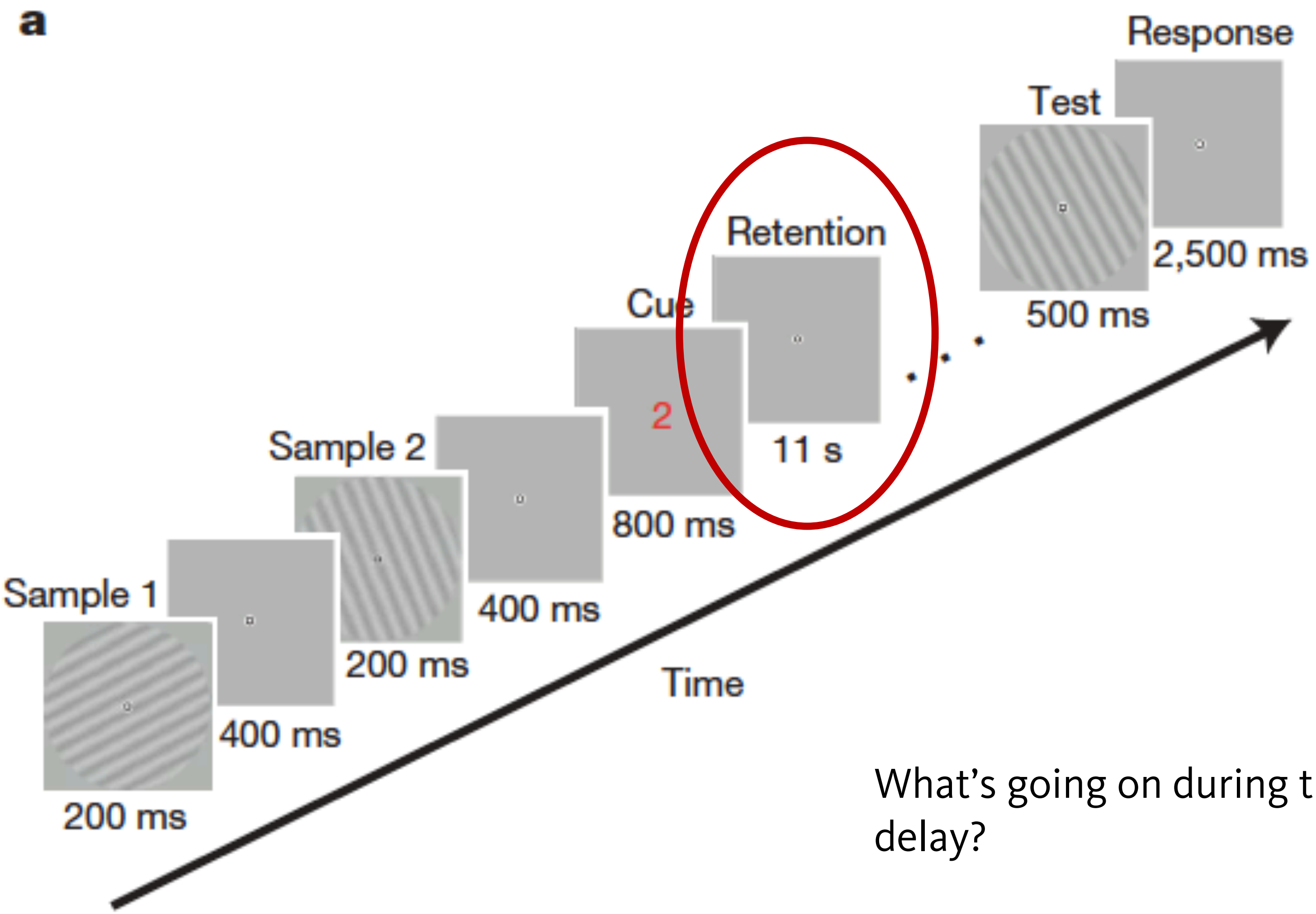
https://www.youtube.com/watch?v=Vwigmktix2Y

Taxonomy of memory



Working memory

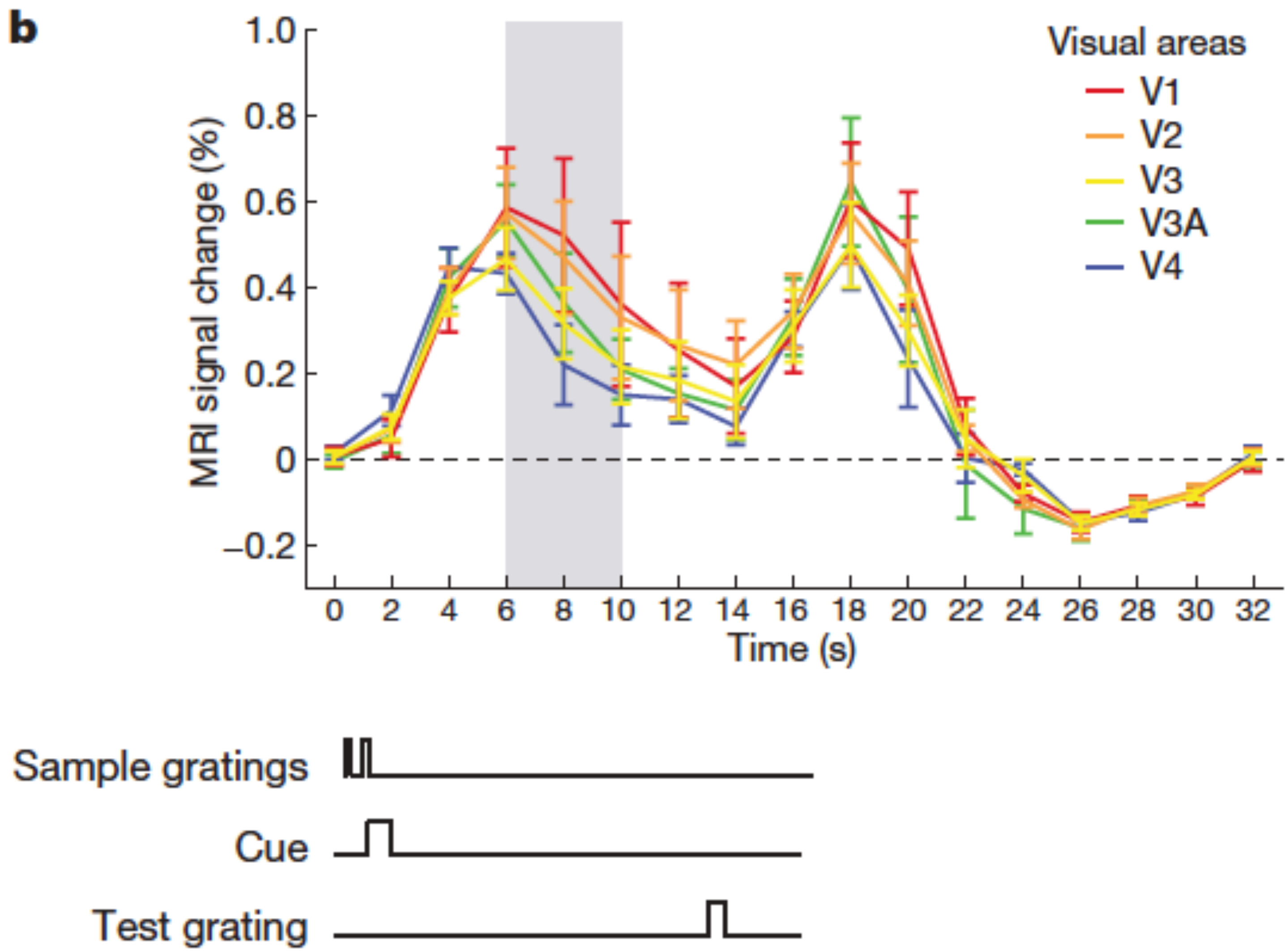
Working memory paradigm



What’s going on during the delay?

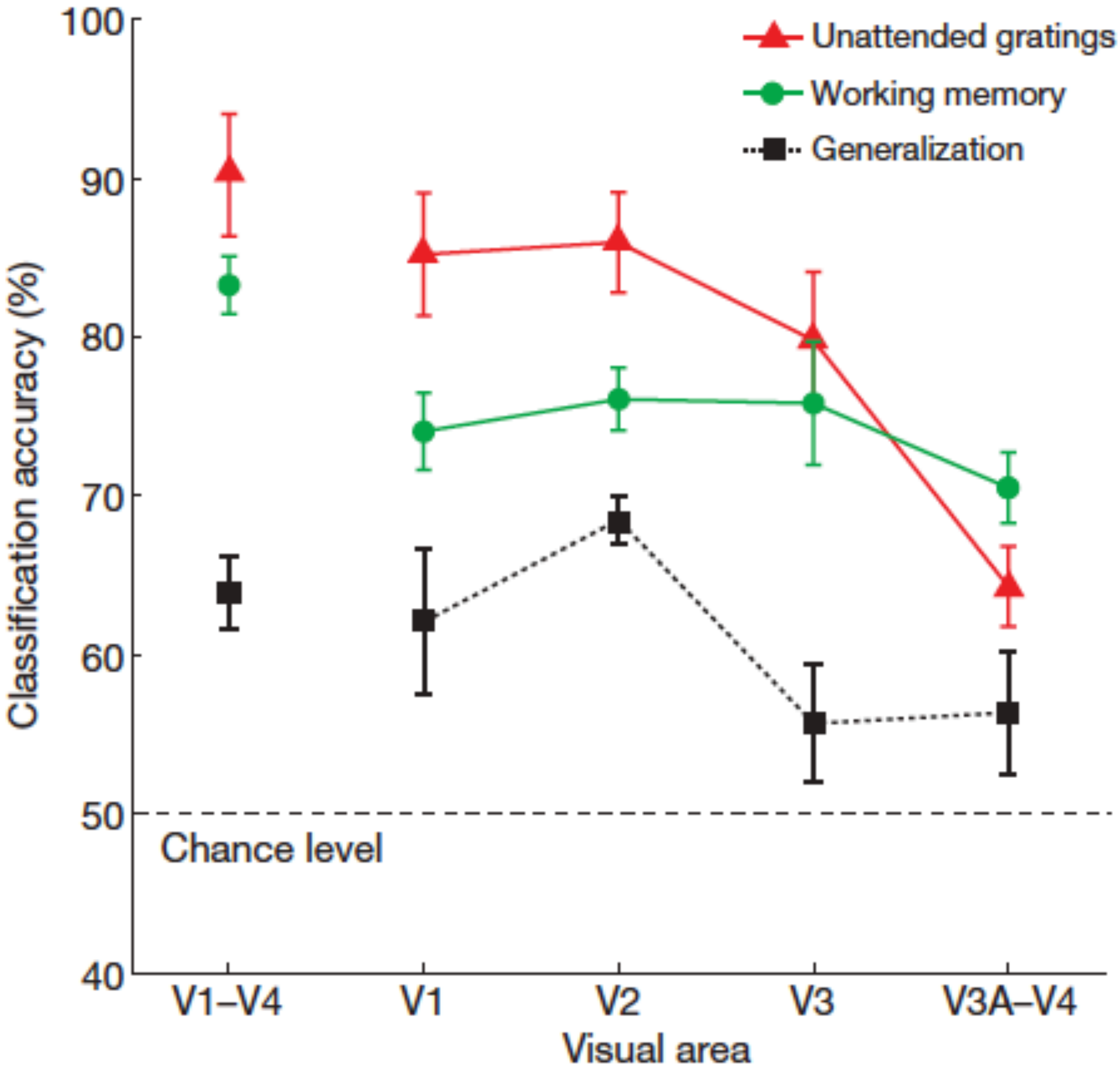
Harrison & Tong, Nature 2009

Working memory in early sensory cortex



Harrison & Tong, Nature 2009

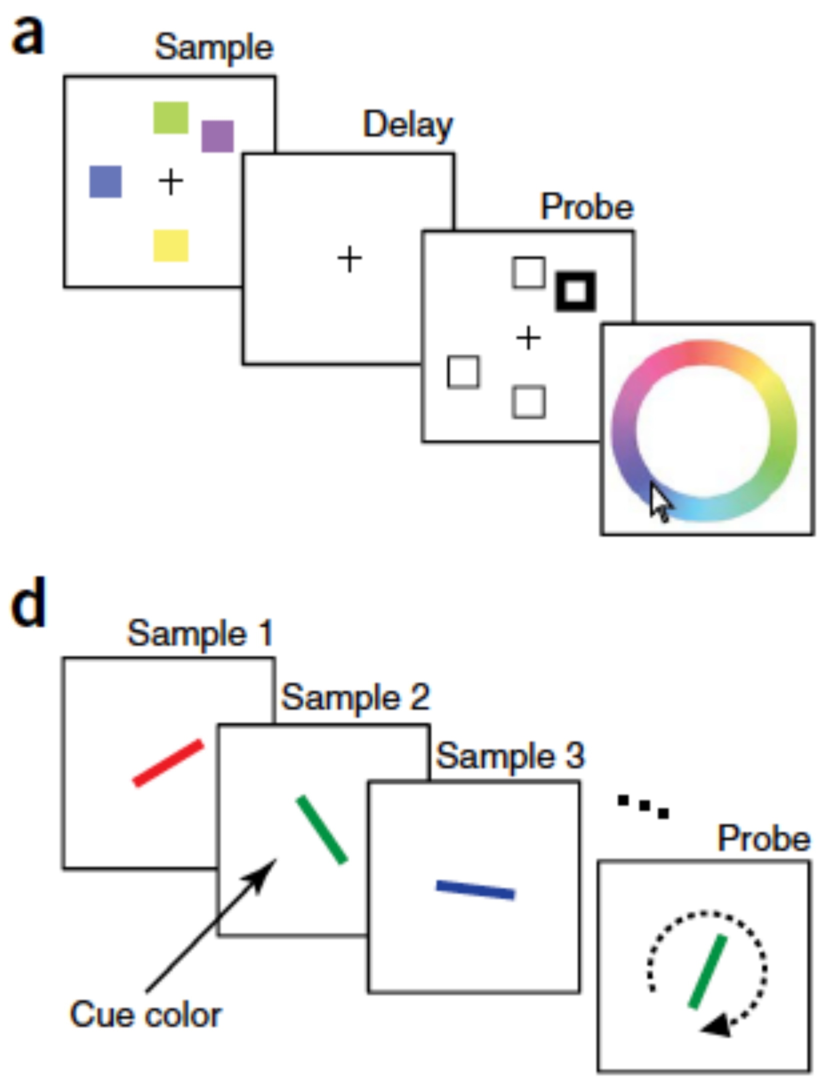
Classification of working memory



Harrison & Tong, Nature 2009

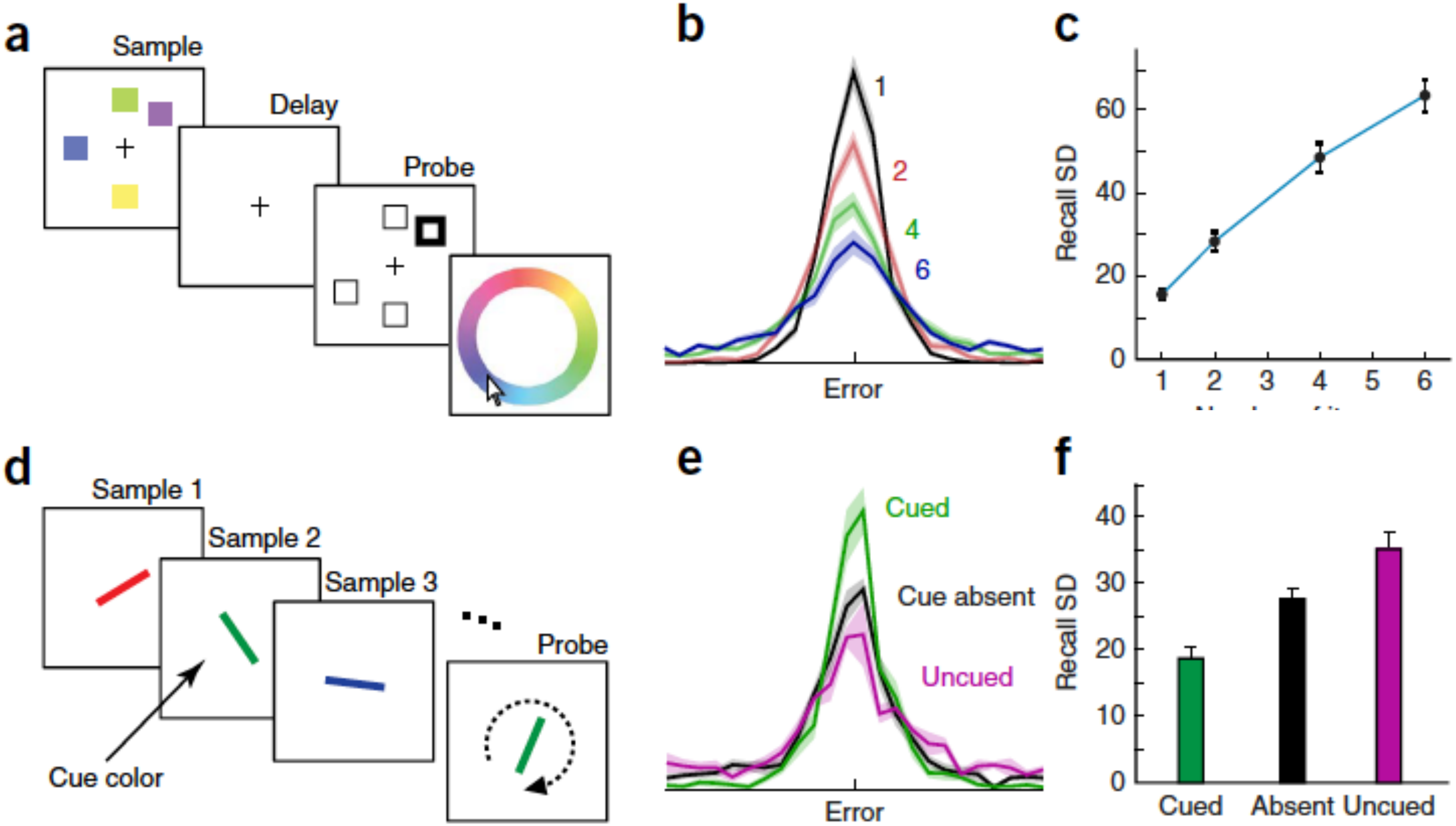
Limits of working memory

Limits of working memory



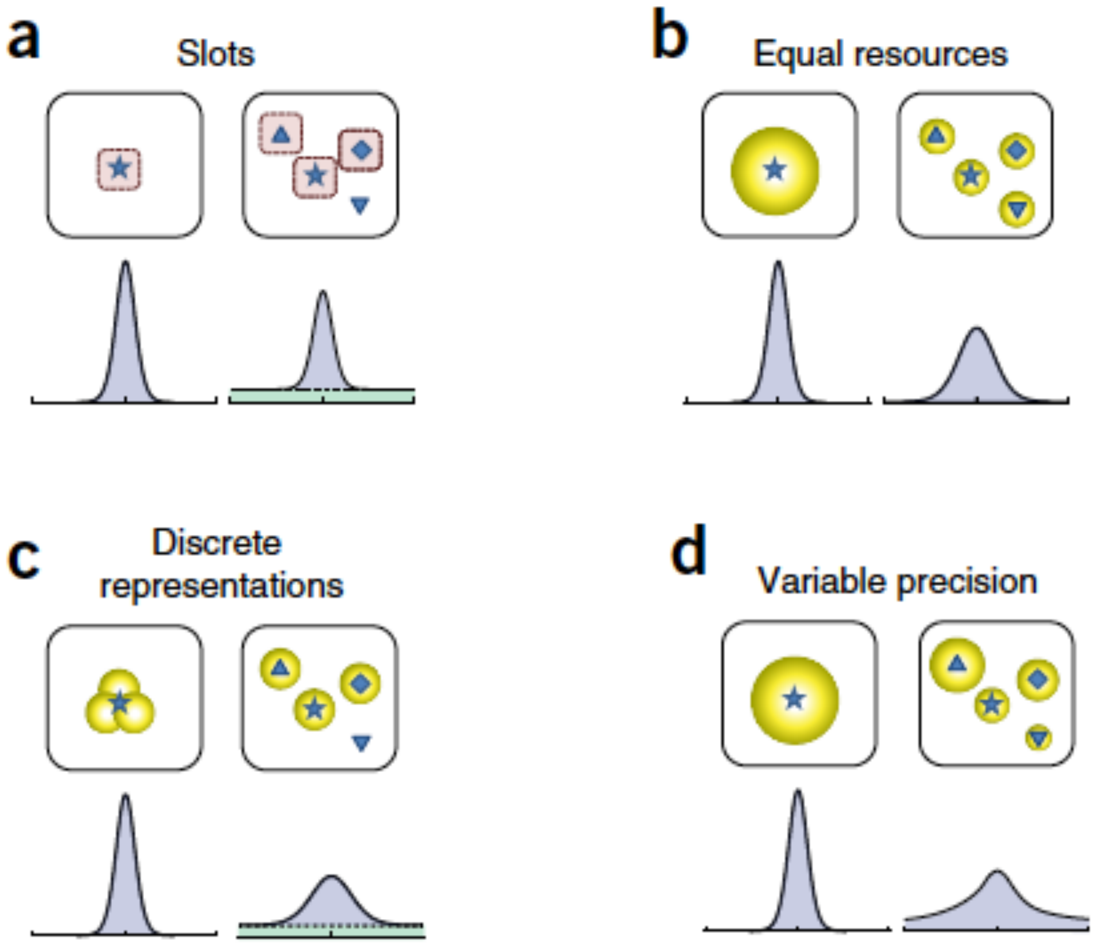
Ma, Husain & Bays, Nature Neuroscience 2014

Limits of working memory



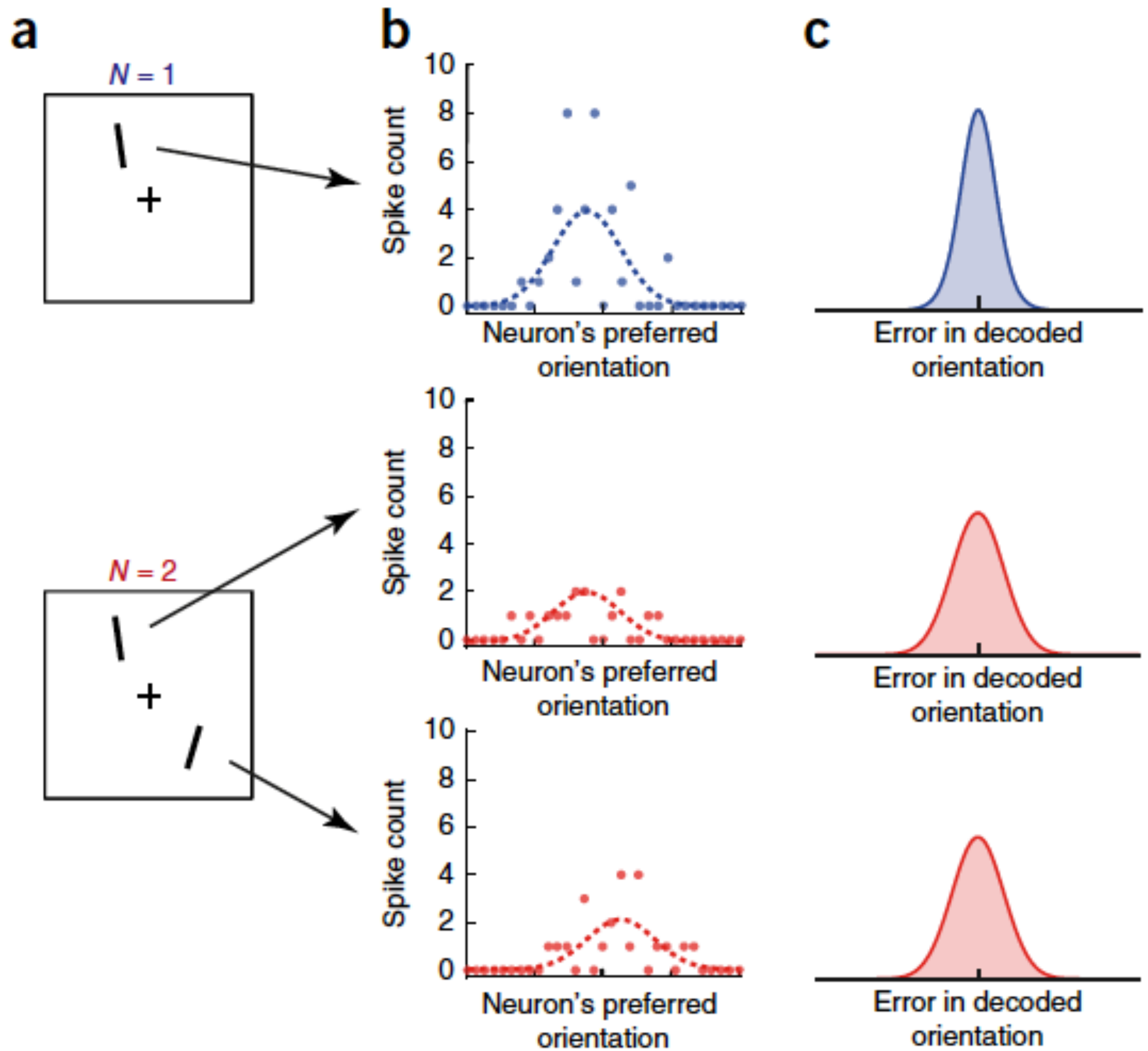
Ma, Husain & Bays, Nature Neuroscience 2014

Models of working memory



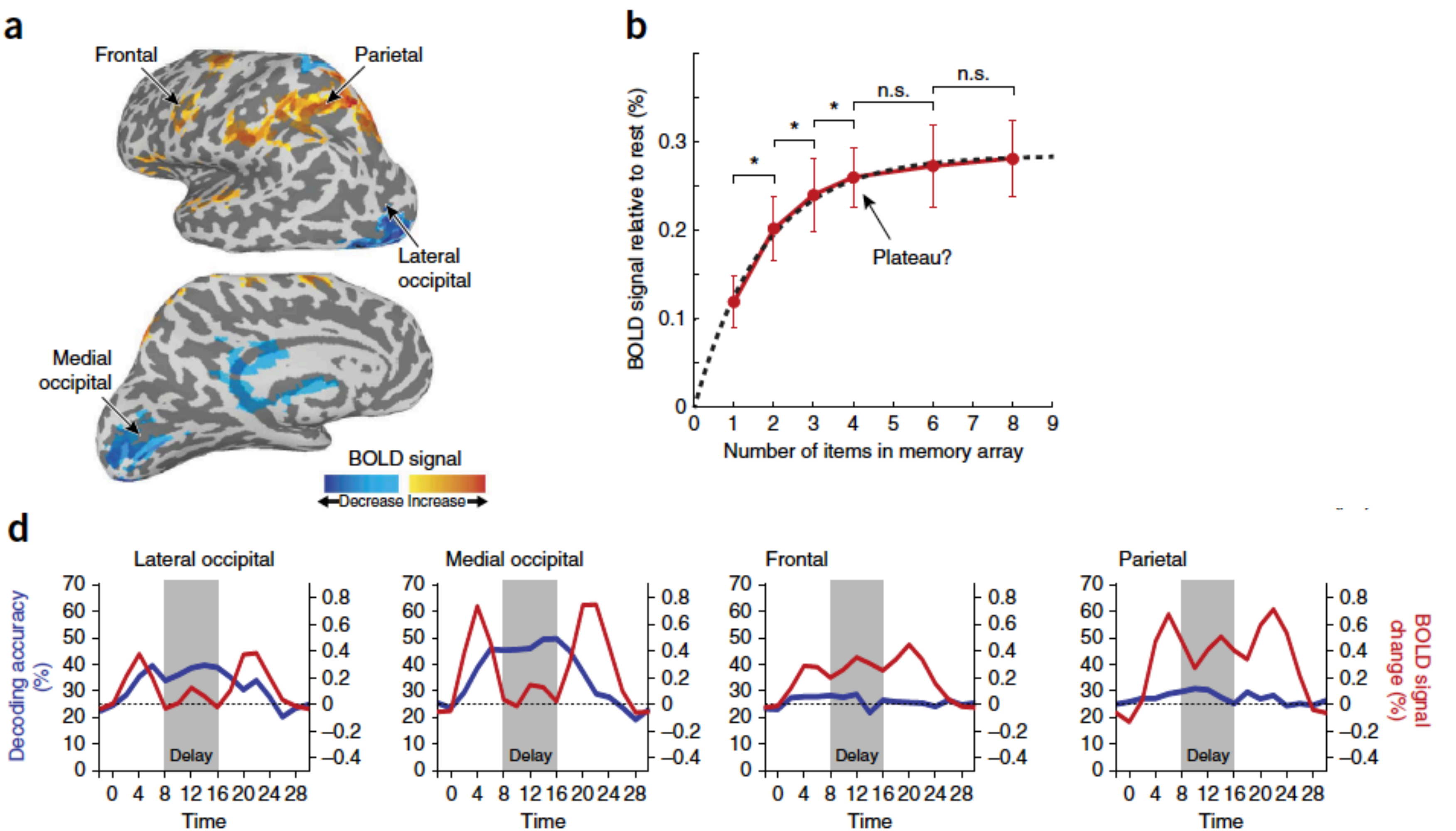
Ma, Husain & Bays, Nature Neuroscience 2014

Neuronal basis of working memory



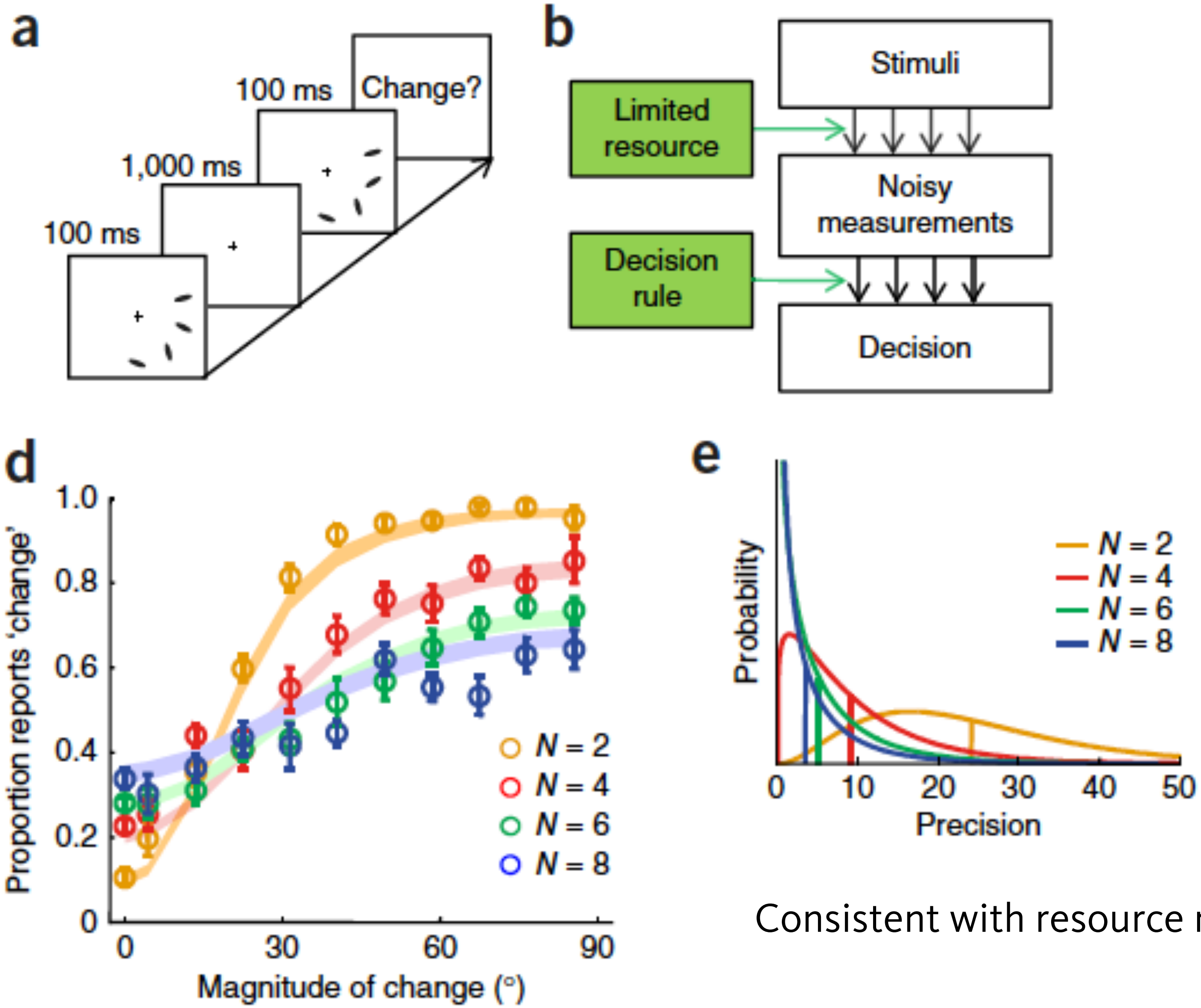
Ma, Husain & Bays, Nature Neuroscience 2014

Neural correlates of working memory



Ma, Husain & Bays, Nature Neuroscience 2014

Change detection



Consistent with resource models

Ma, Husain & Bays, Nature Neuroscience 2014

Working memory summary

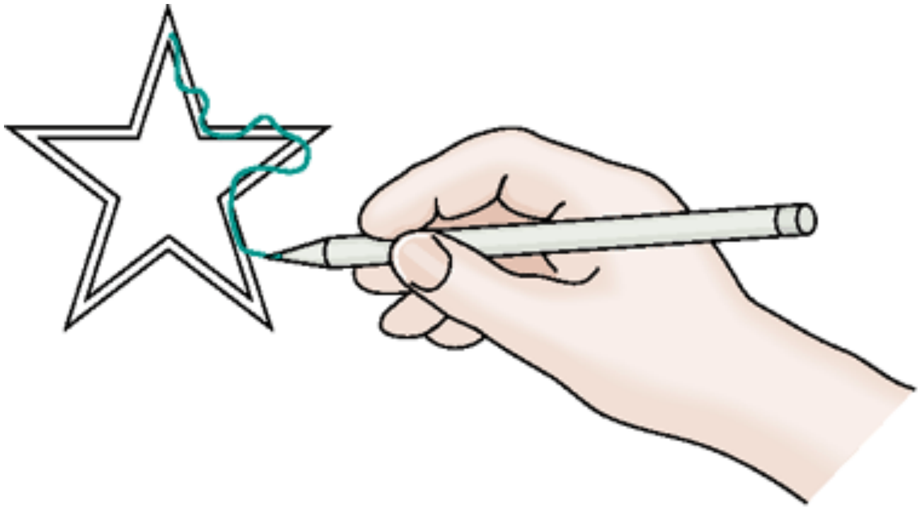
Slot vs resource models

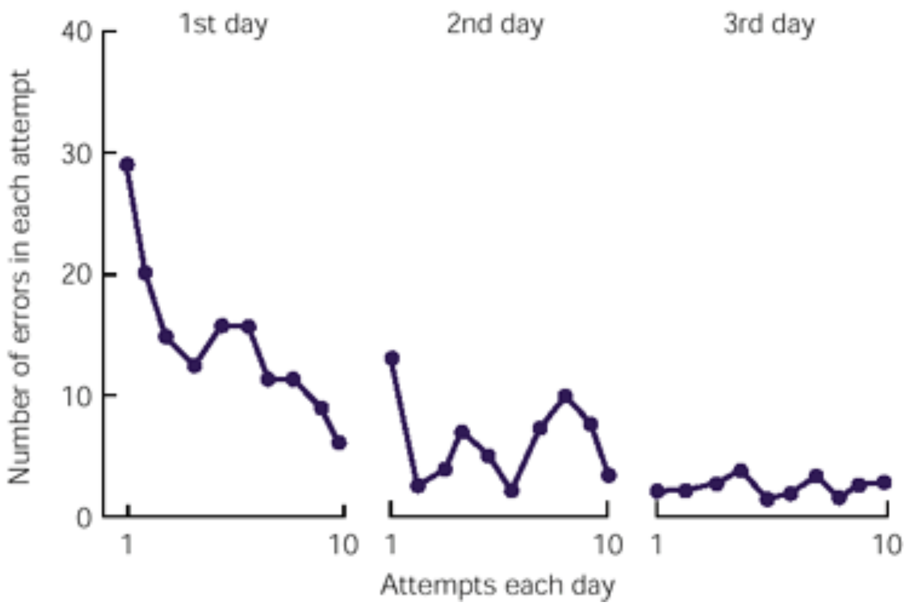
Sensory, parietal and frontal cortices involved

But: items aren’t processed independently?
Is there a gist representation?

Procedural memory

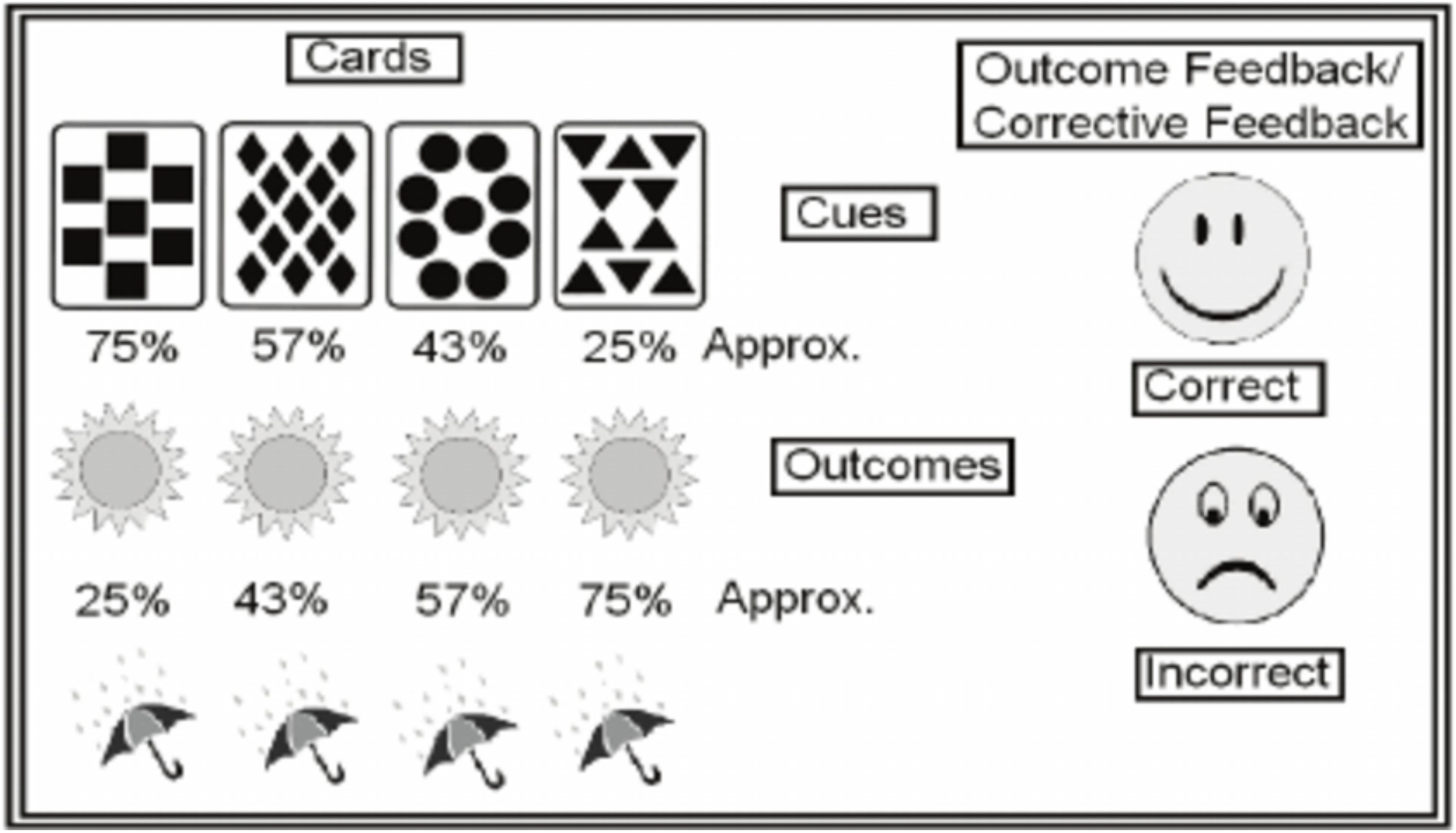
Procedural memory





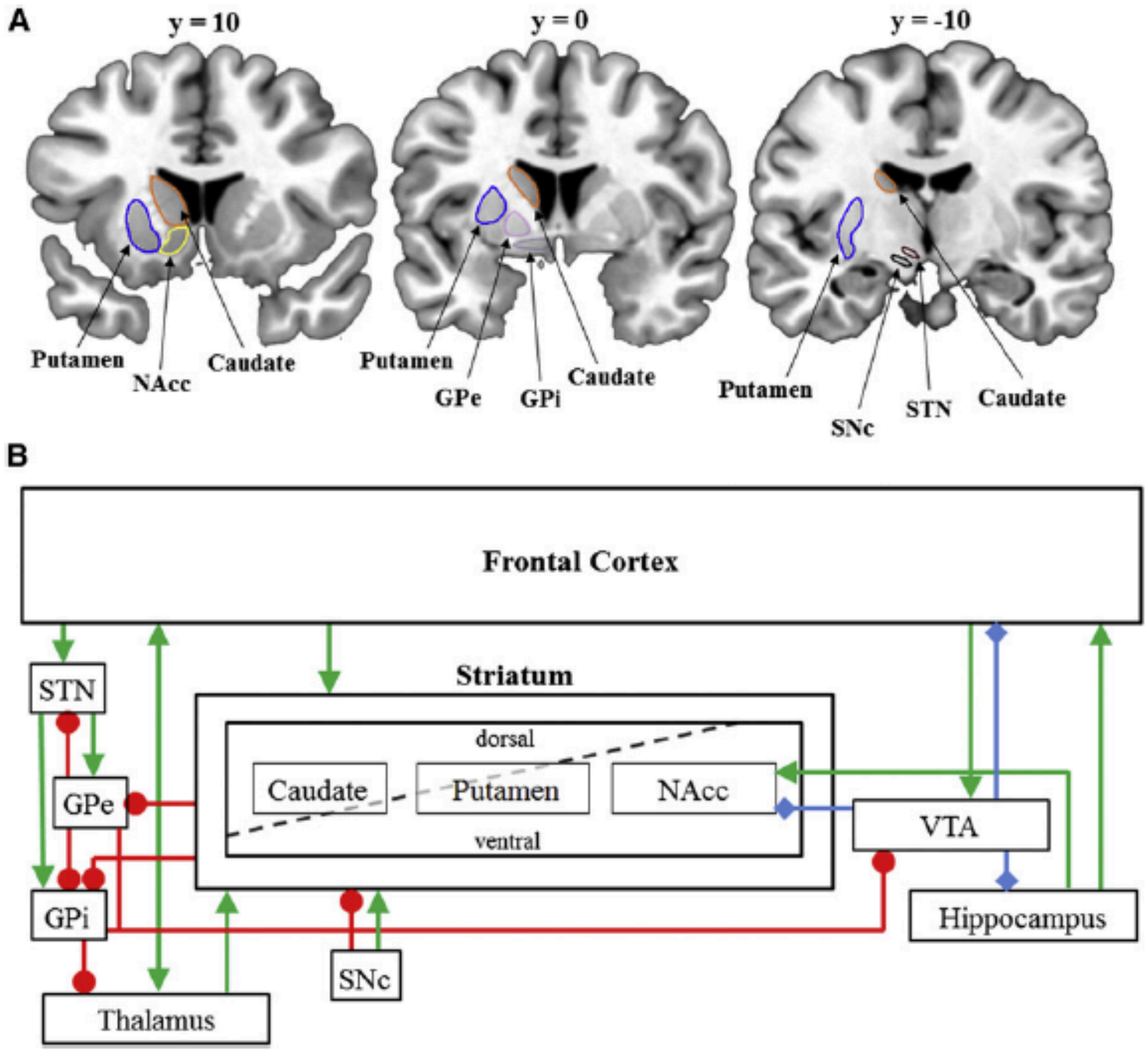
Cohen & Squire, Science 1980

Weather prediction task



Knowlton et al., Learning & Memory 1994

Basal ganglia



Scimeca & Badre, Neuron 2012

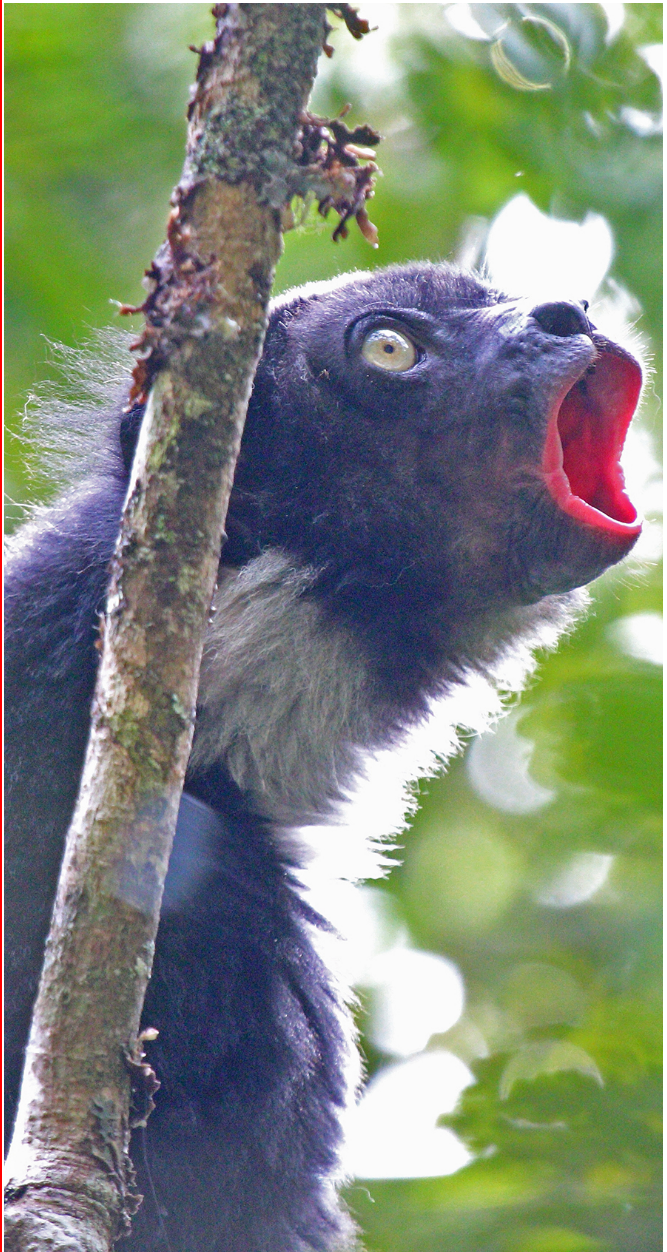
Declarative long-term memory

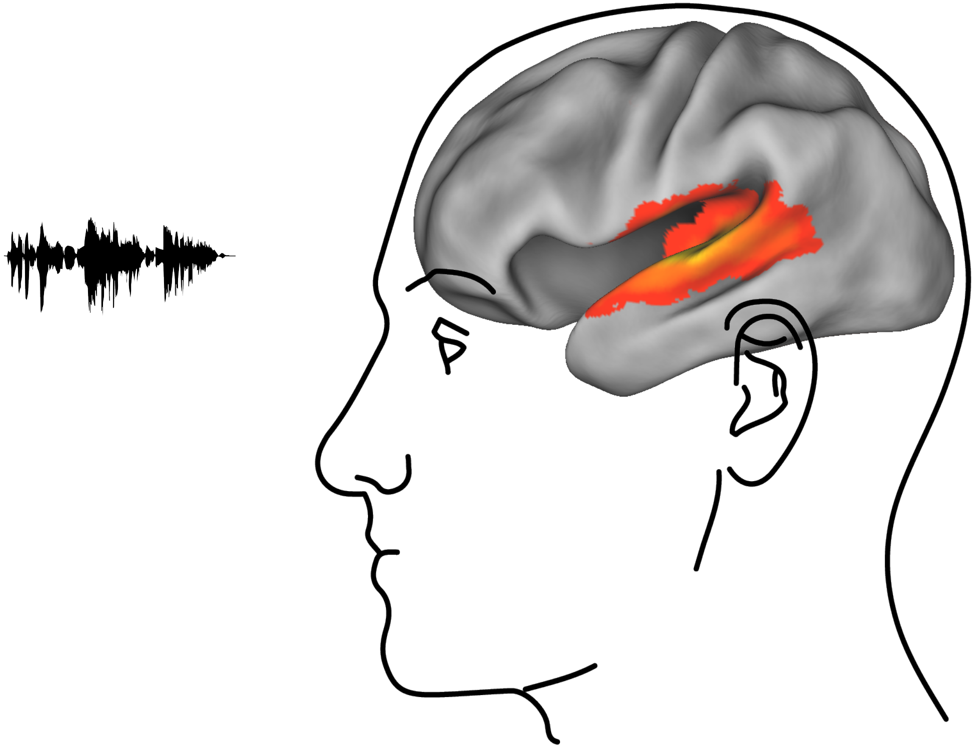
Stages of long-term memory

Active behavioural states ENCODING/RETRIEVAL

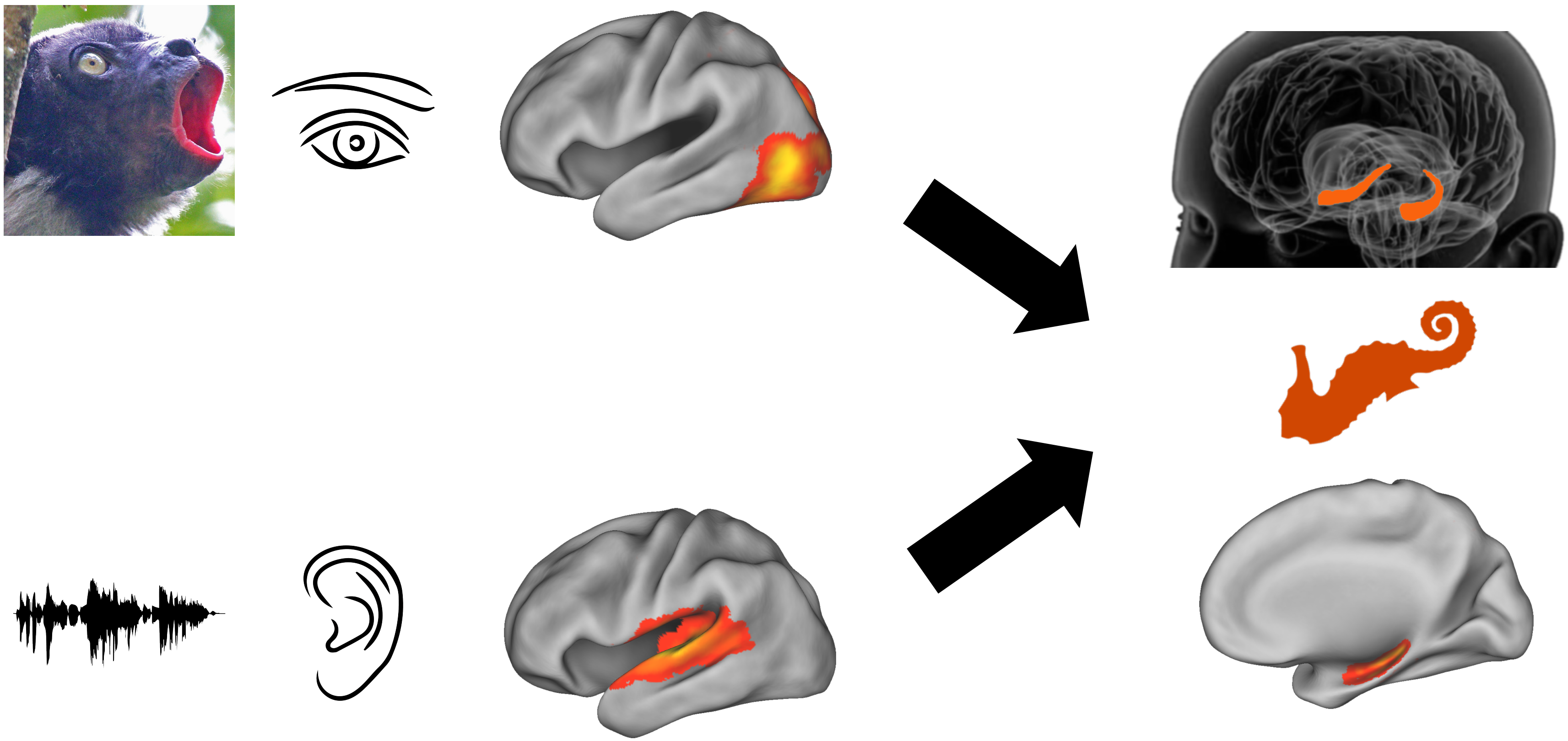
Inactive behavioural states CONSOLIDATION

Indri Indri

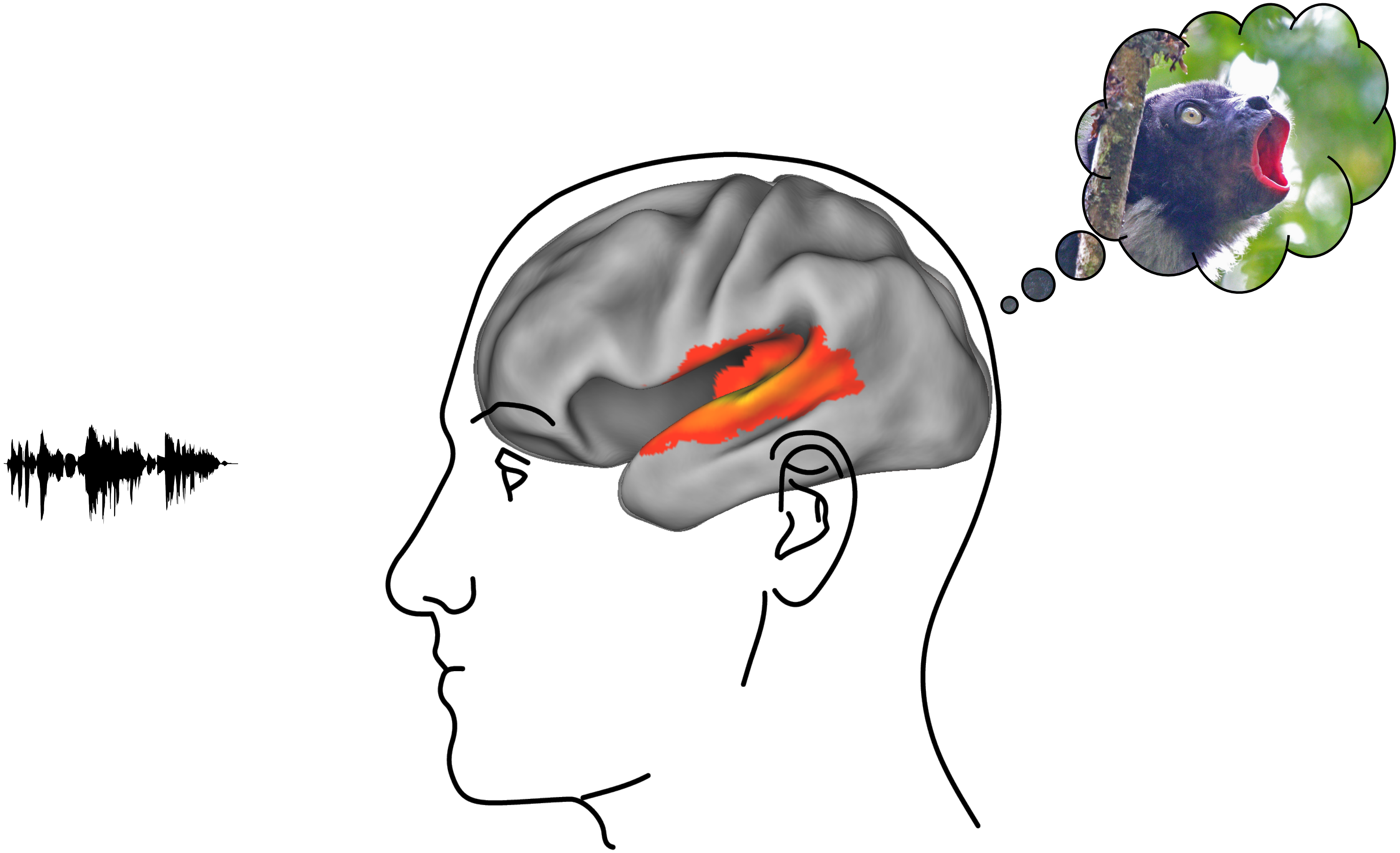




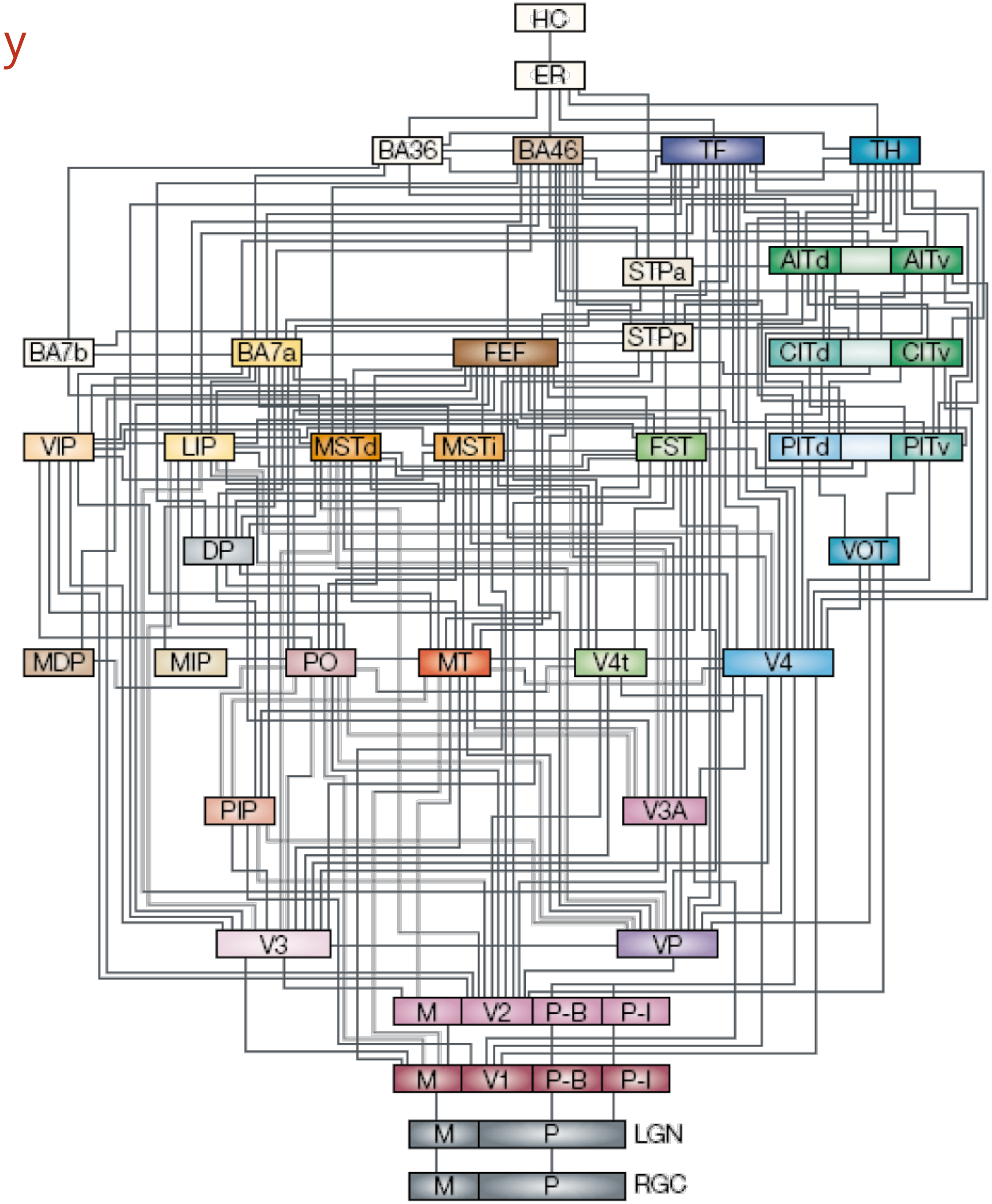
Encoding



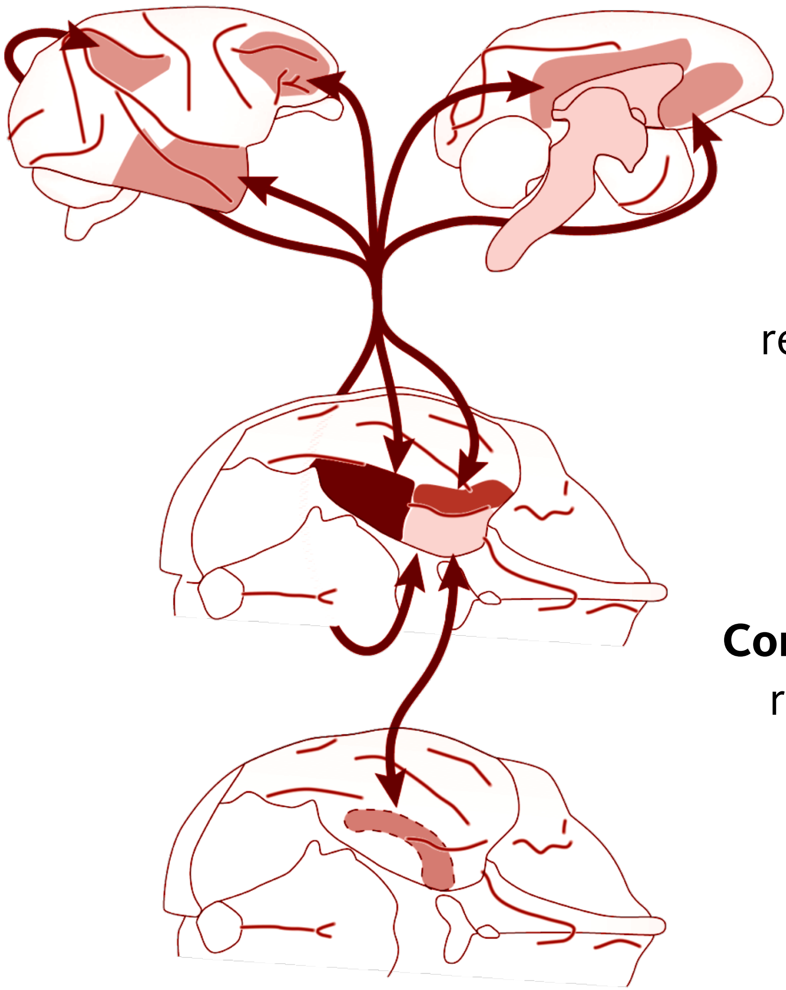
Retrieval



Apex of a hierarchy

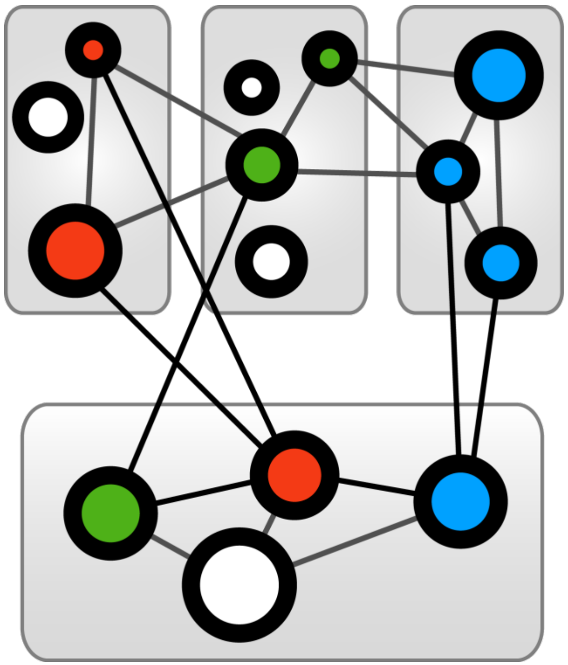


Convergence



"Feature" representations

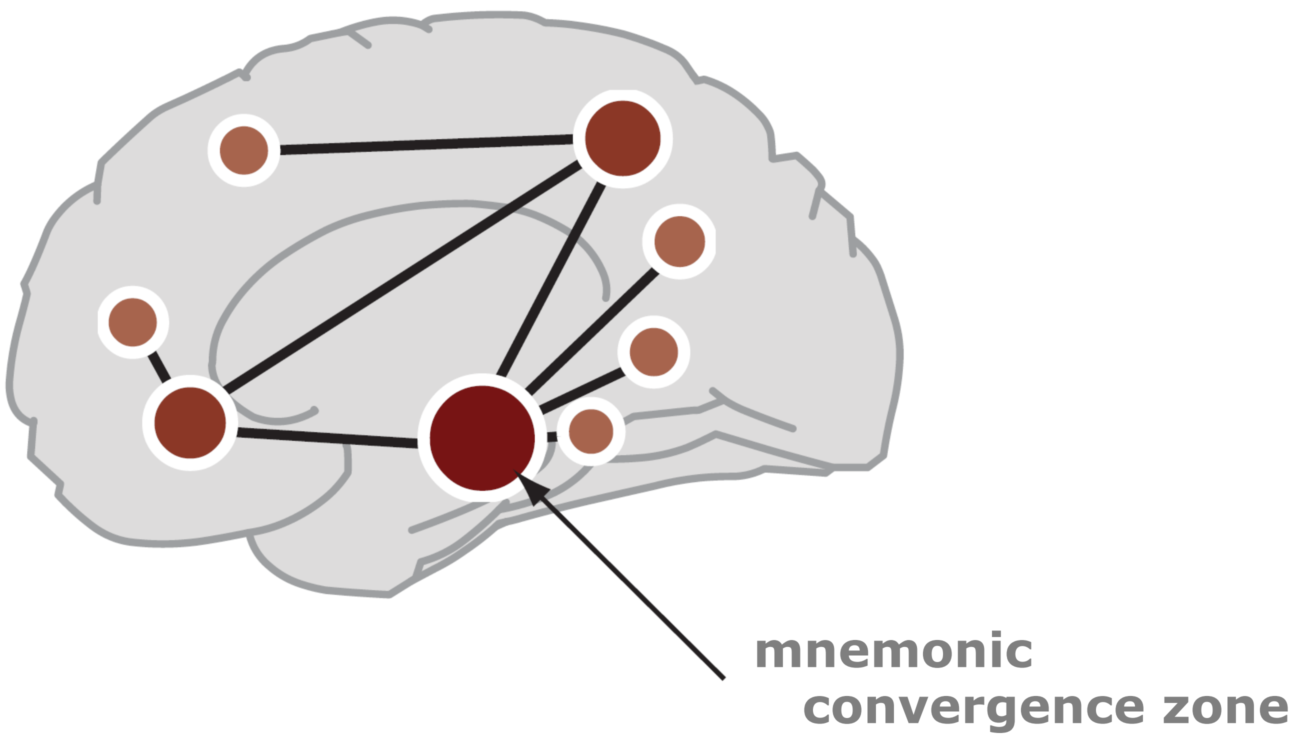
Conjunctive "index" representations



Marr, PTRSL-B 1971; Teyler & DiScenna, Behav Neurosci 1986

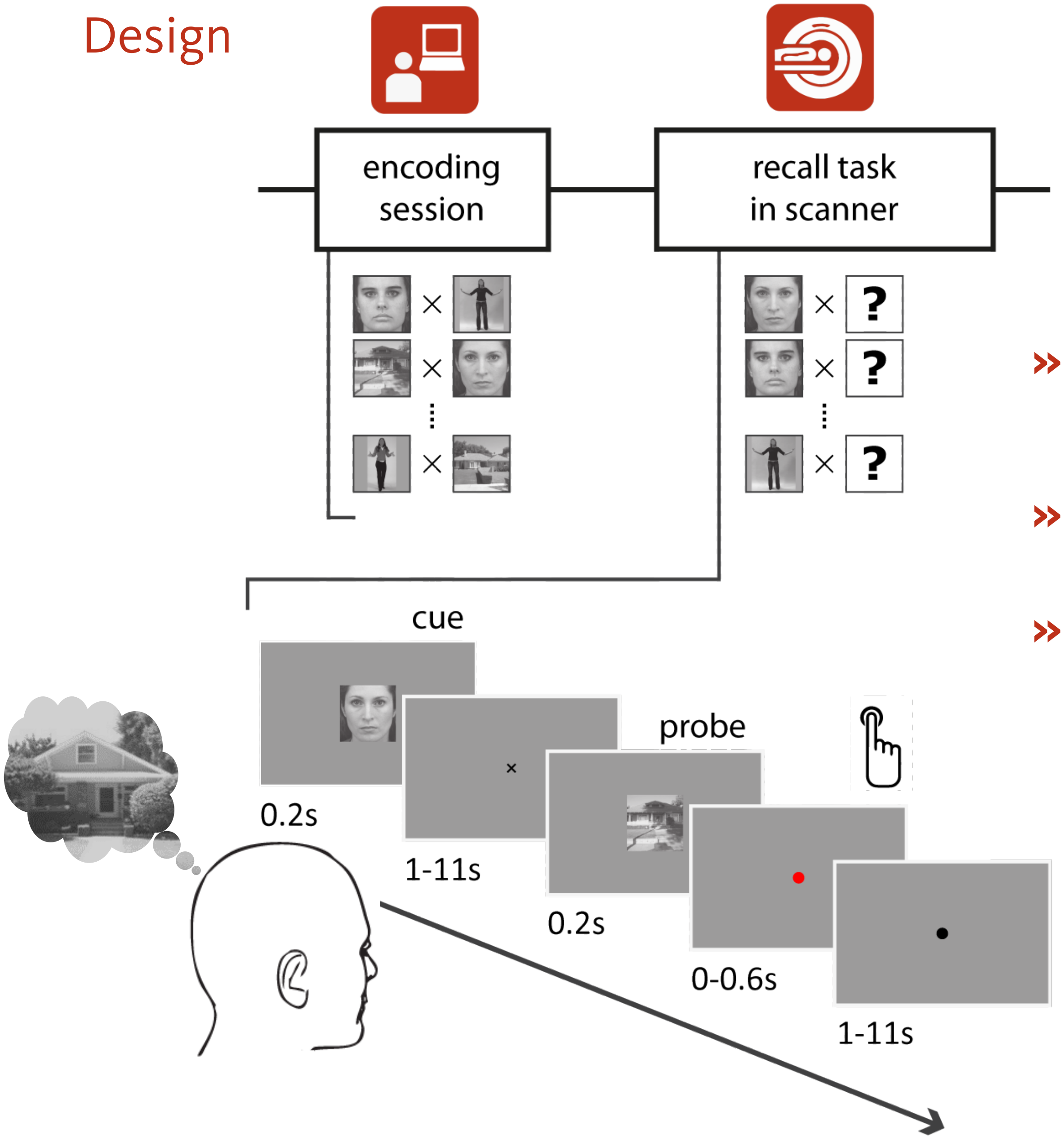
Aim

1 **REPRESENTATION** ⟷ 2 **CONNECTIVITY**



Backus, Bosch et al., Nature Communications 2016

Design

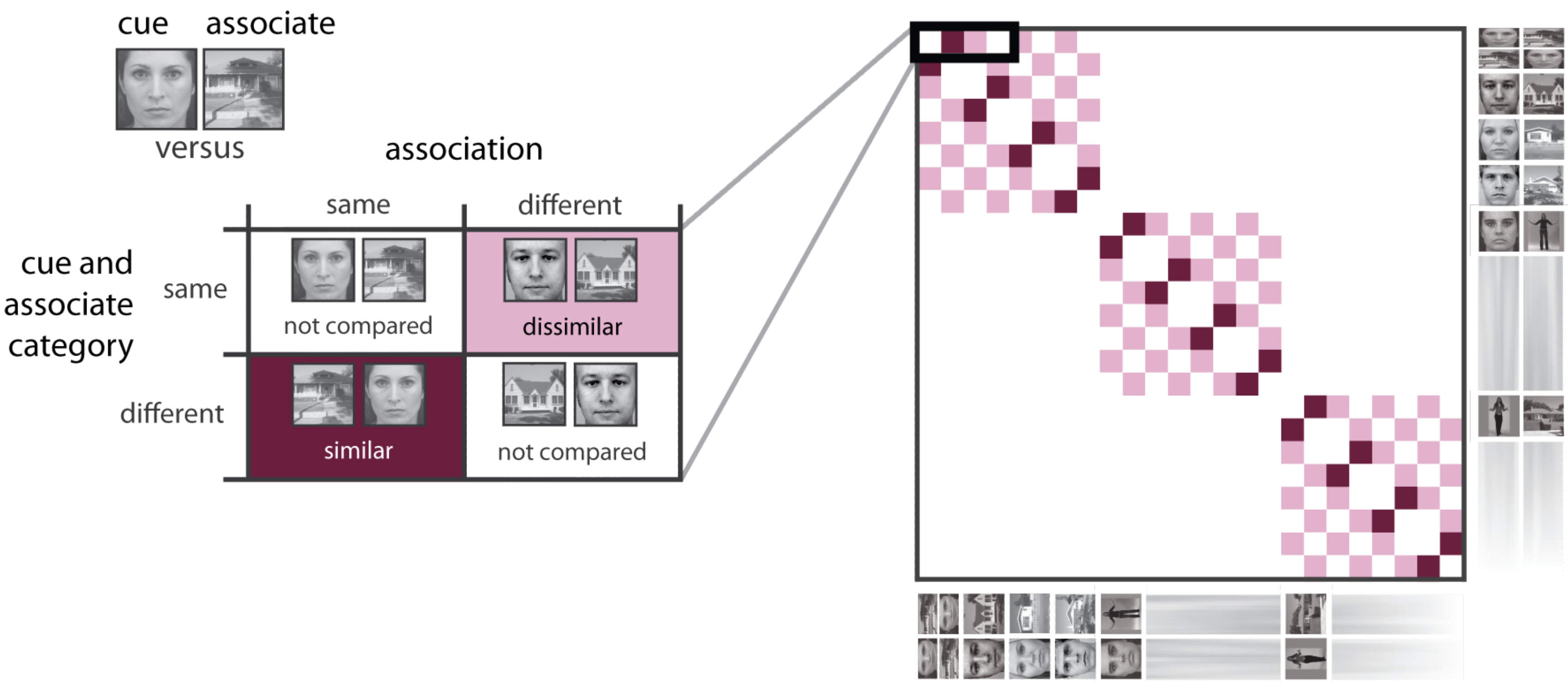


» **PAIRED-ASSOCIATE** LEARNING

» **12** ASSOCIATIONS

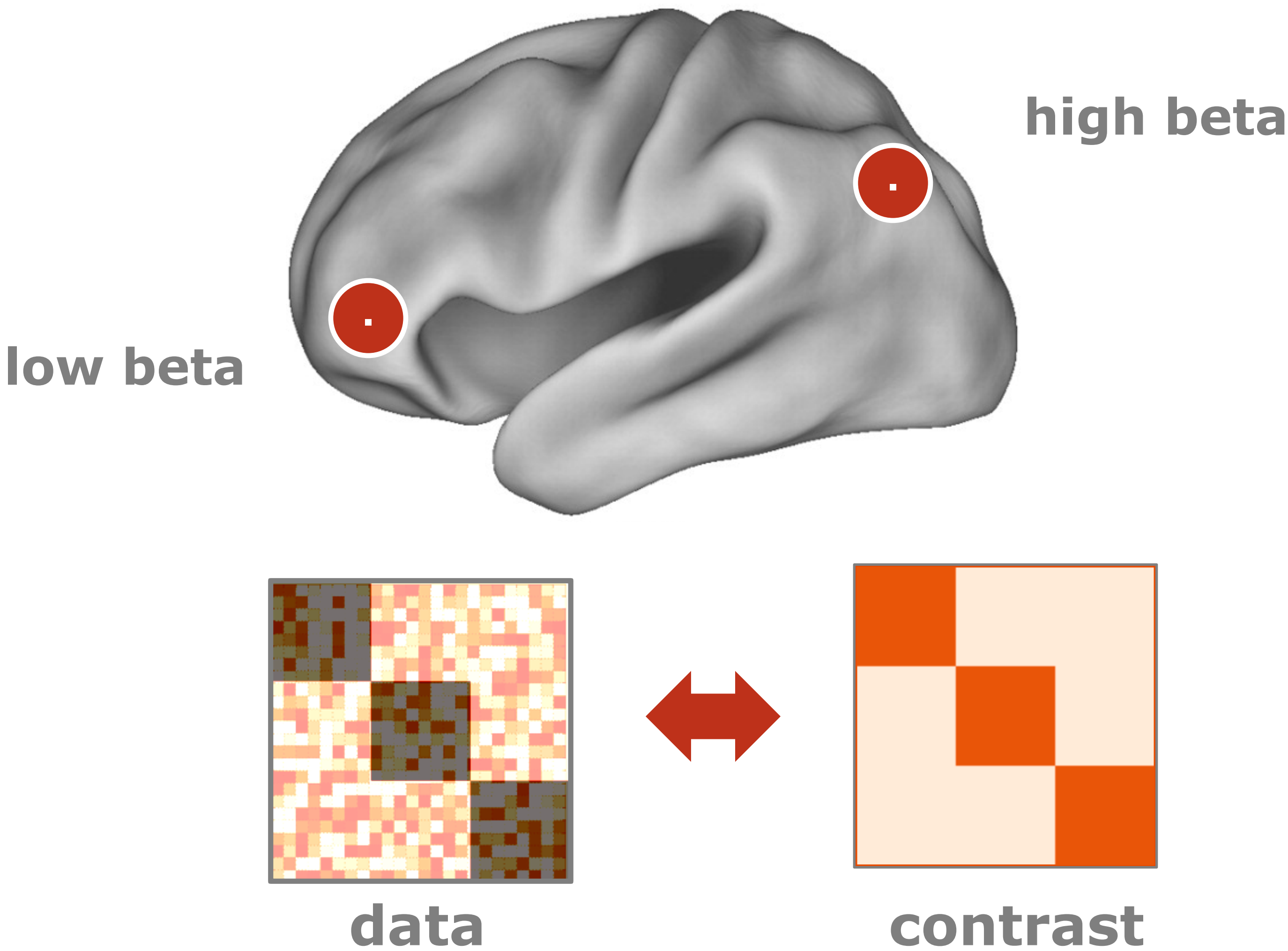
» CUED **RECALL**

Representational similarity analysis



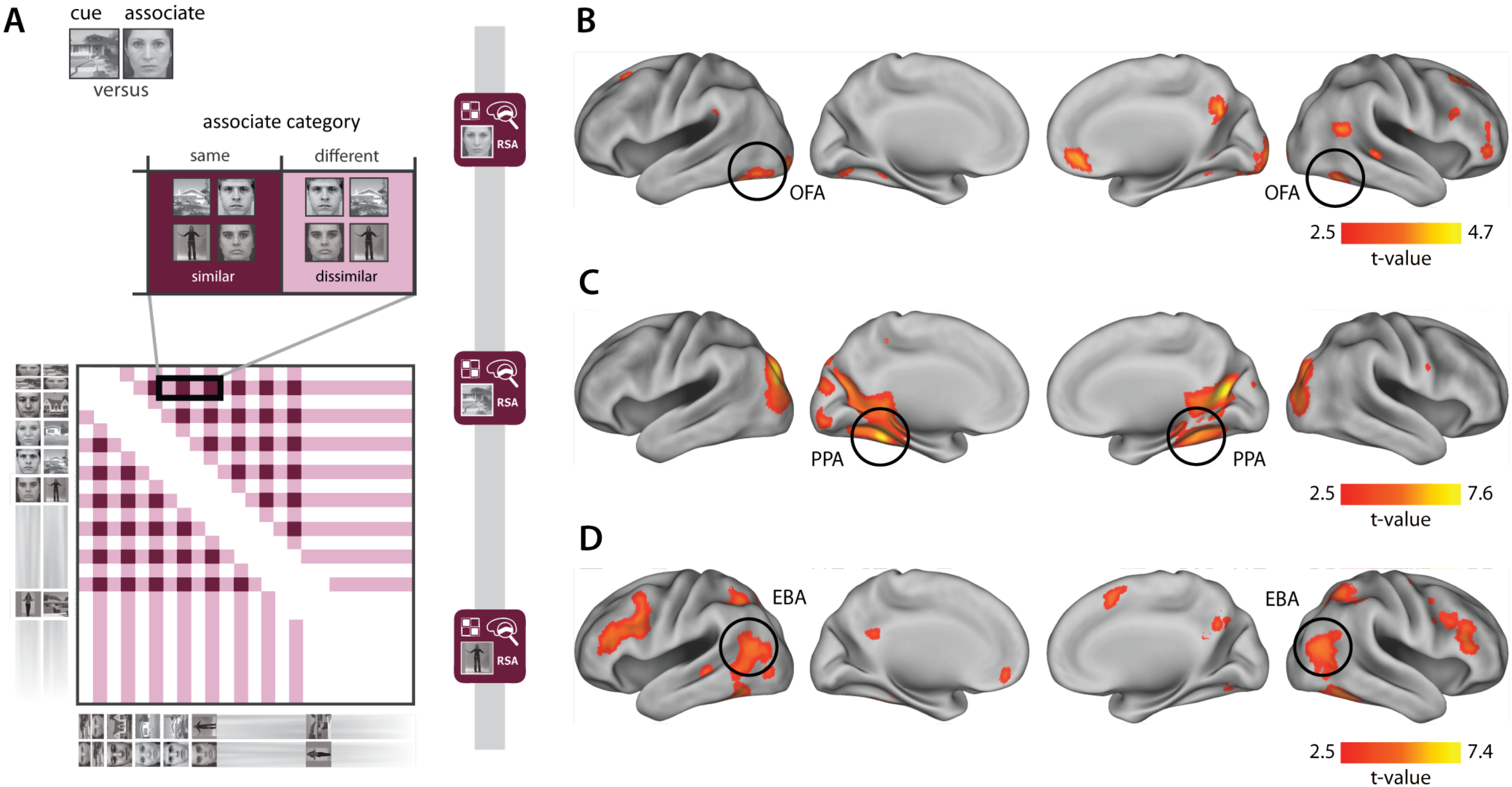
Backus, Bosch et al., Nature Communications 2016

Searchlight

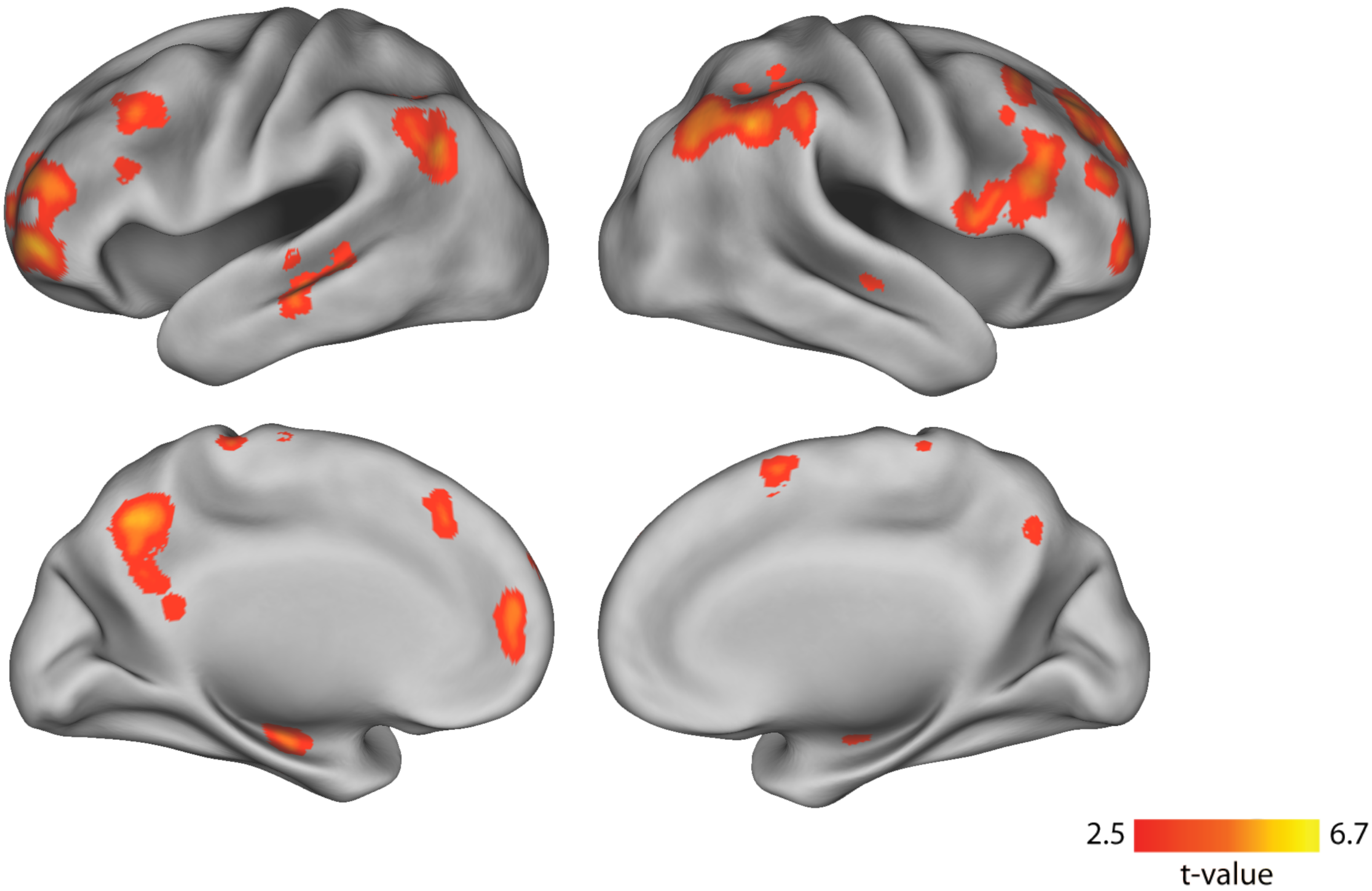


Kriegeskorte, FISN 2008

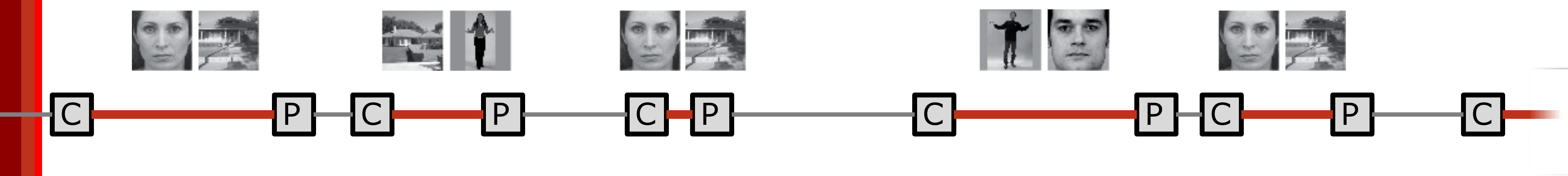
Category-specific information during retrieval

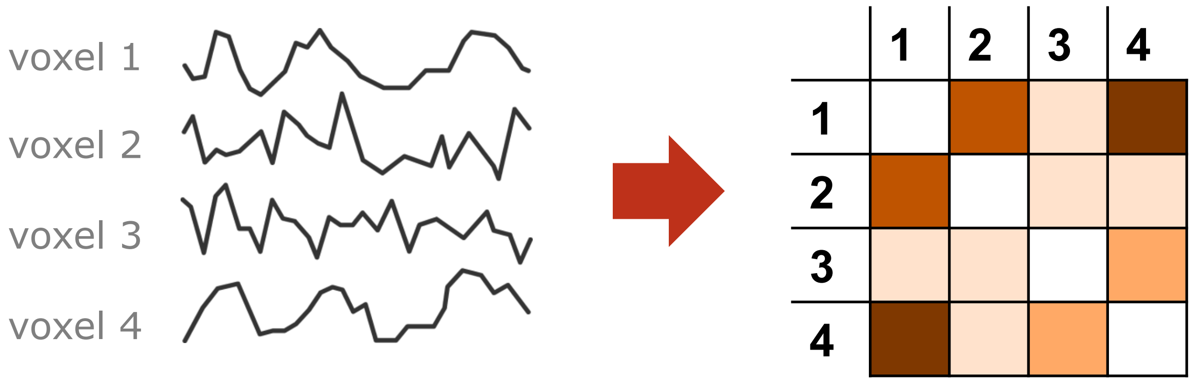


Conjunctive representations



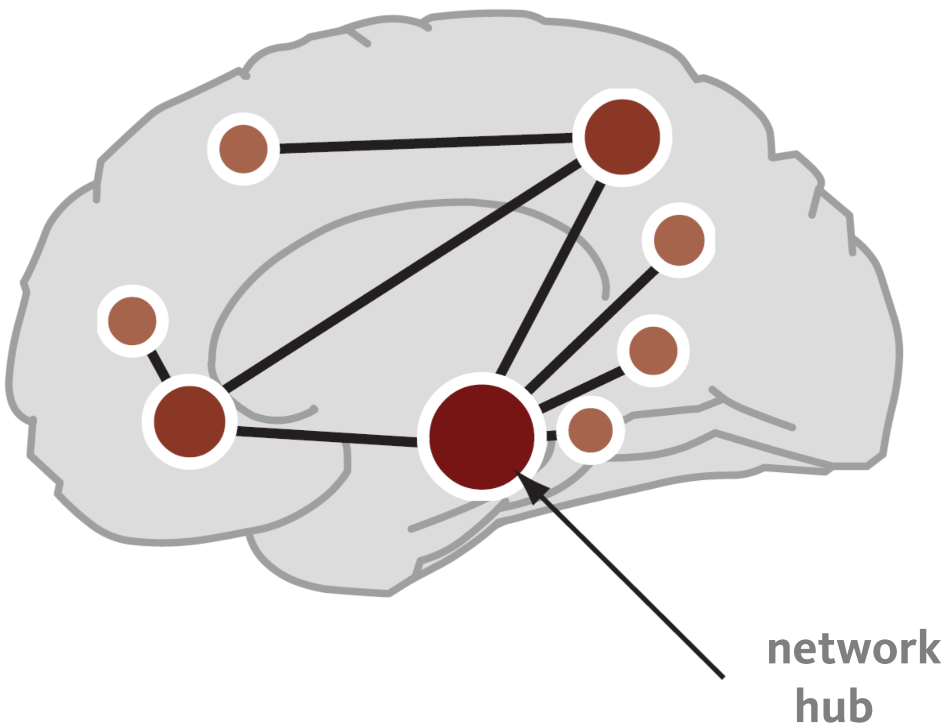
Voxel-wise time course correlation

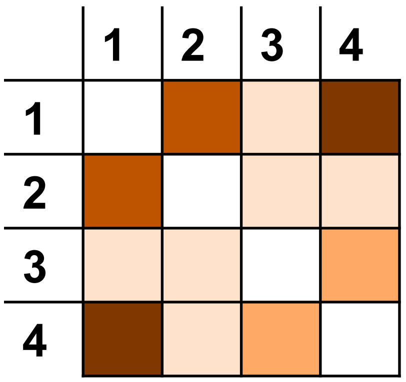




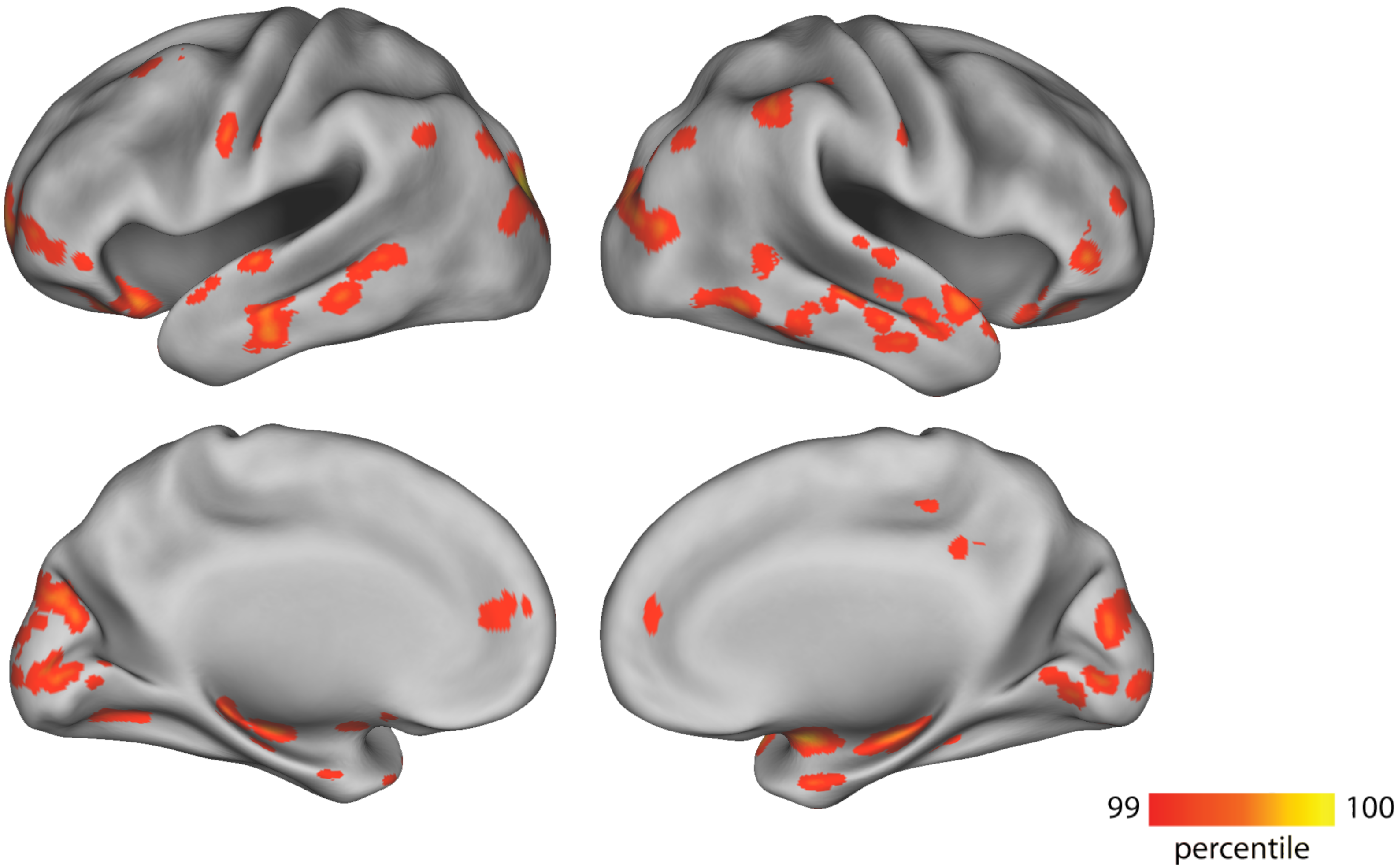
Graph-theoretical analysis

eigenvector centrality

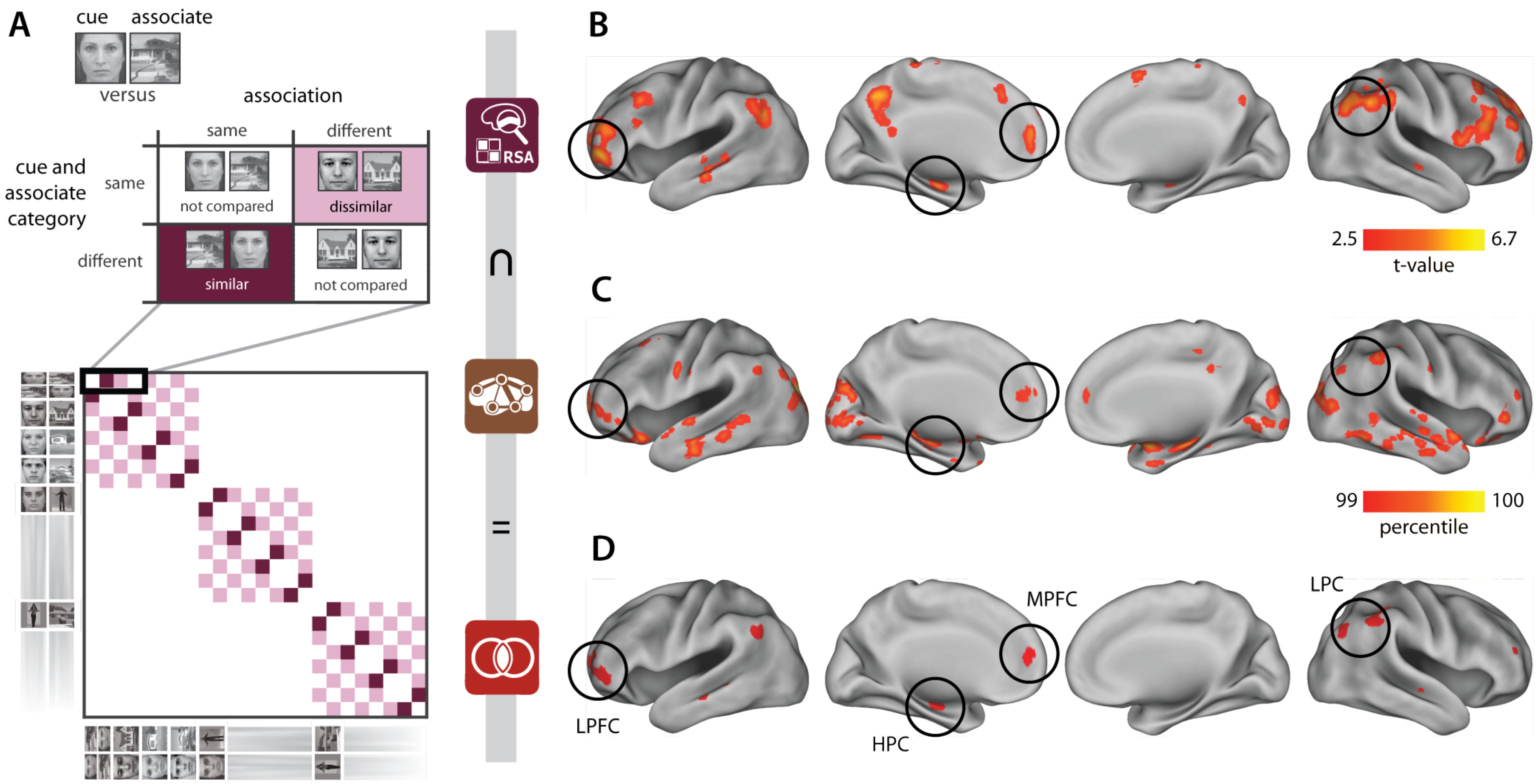




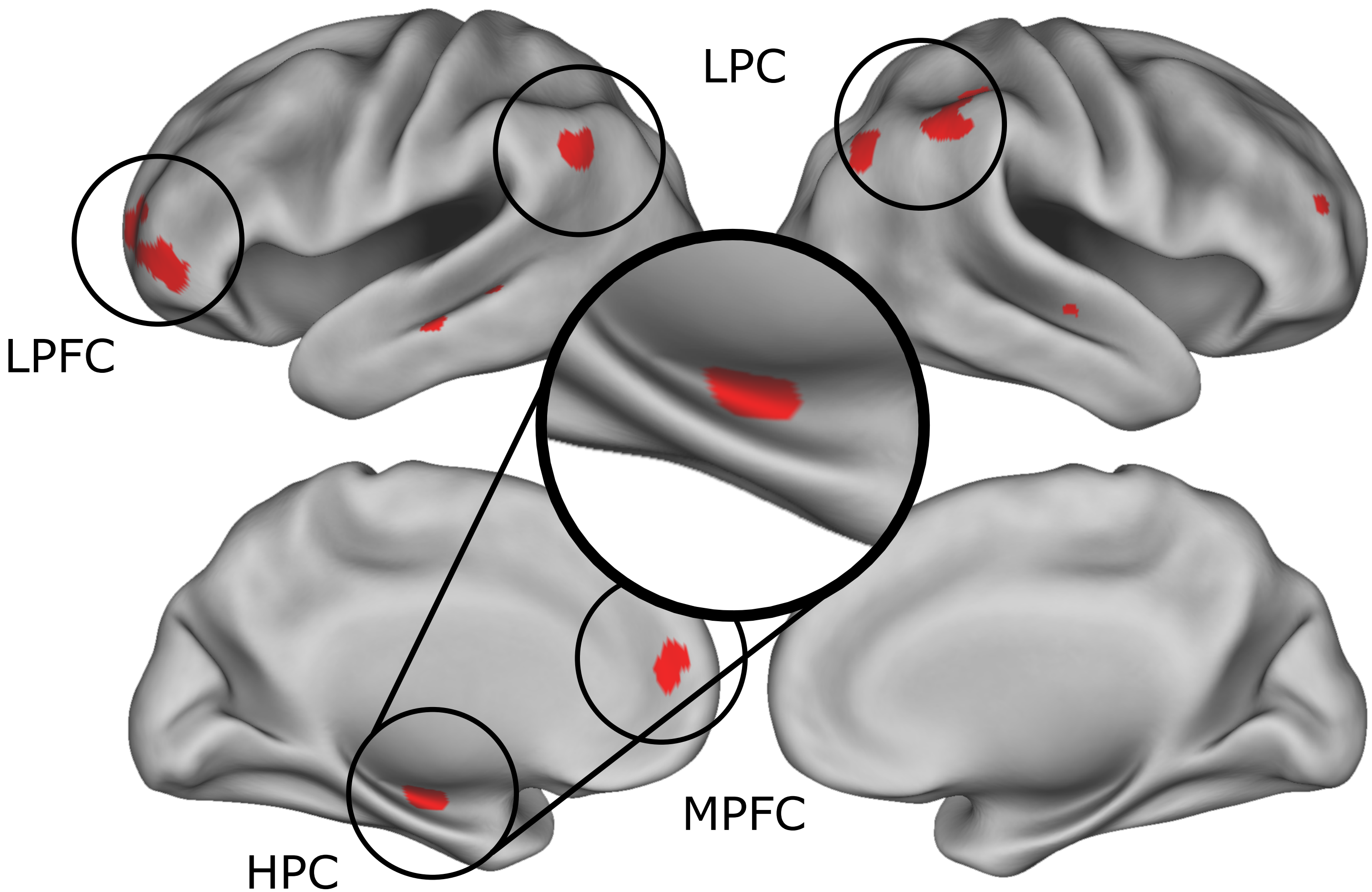
Network hubs during retrieval



Network of connected convergence zones



Mnemonic convergence zones



Convergence summary

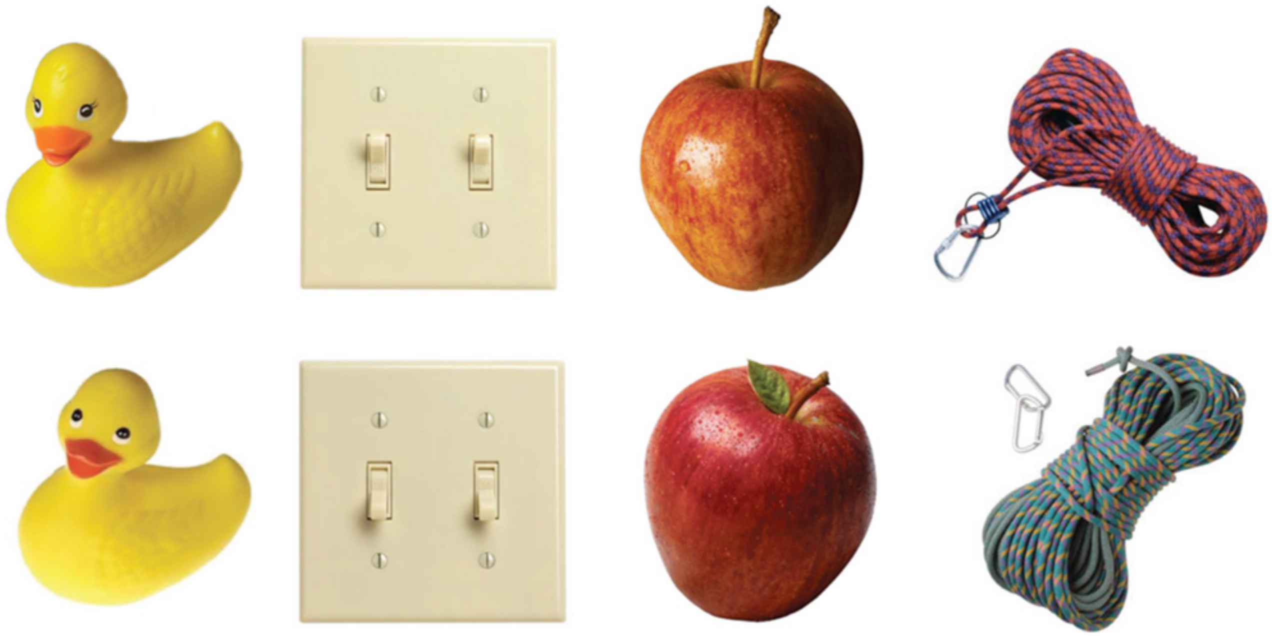
Hippocampus as a convergence zone for information

Apex of the sensory stream

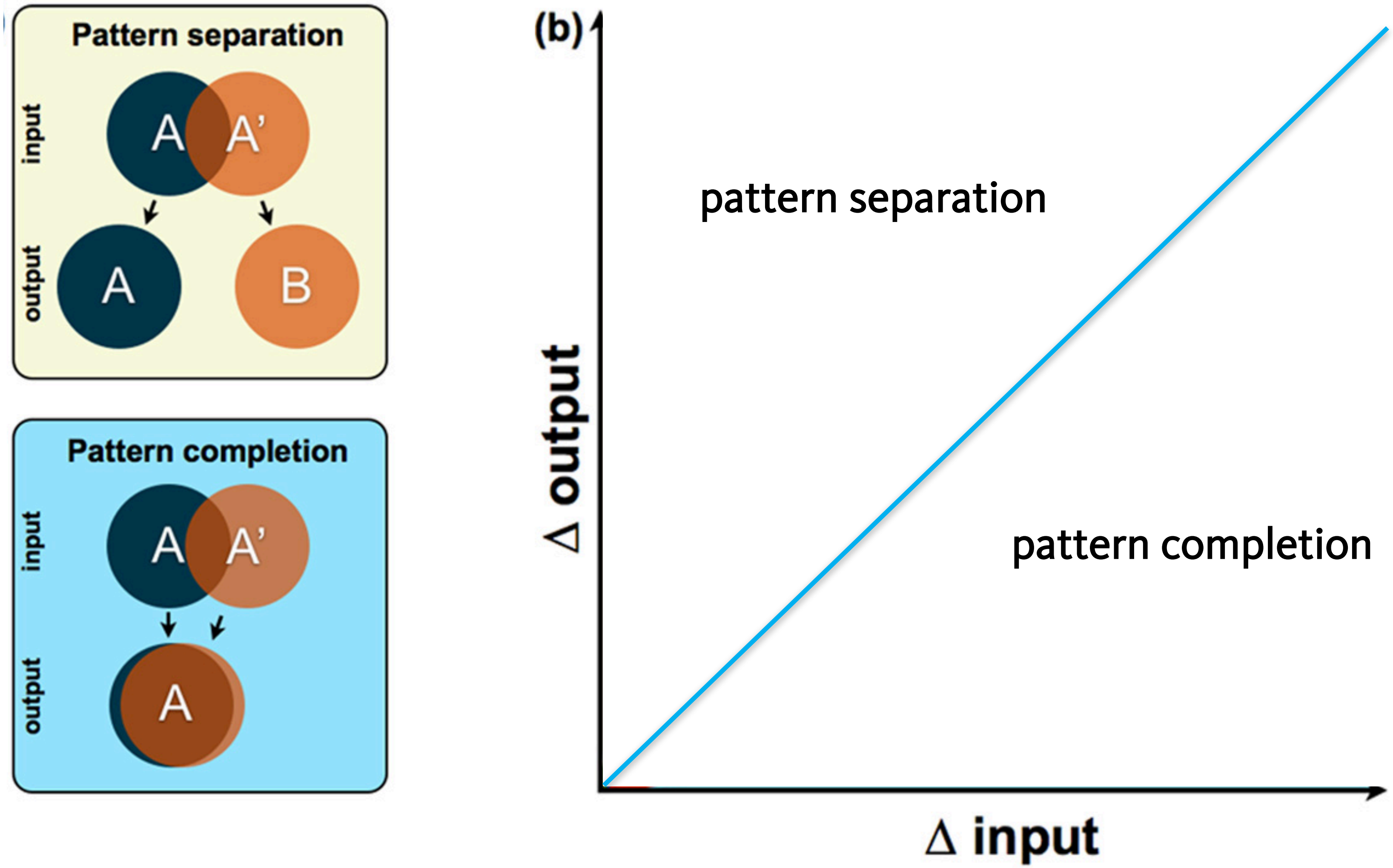
Hippocampus contains conjunctive information ...

... and is highly connected to other brain regions

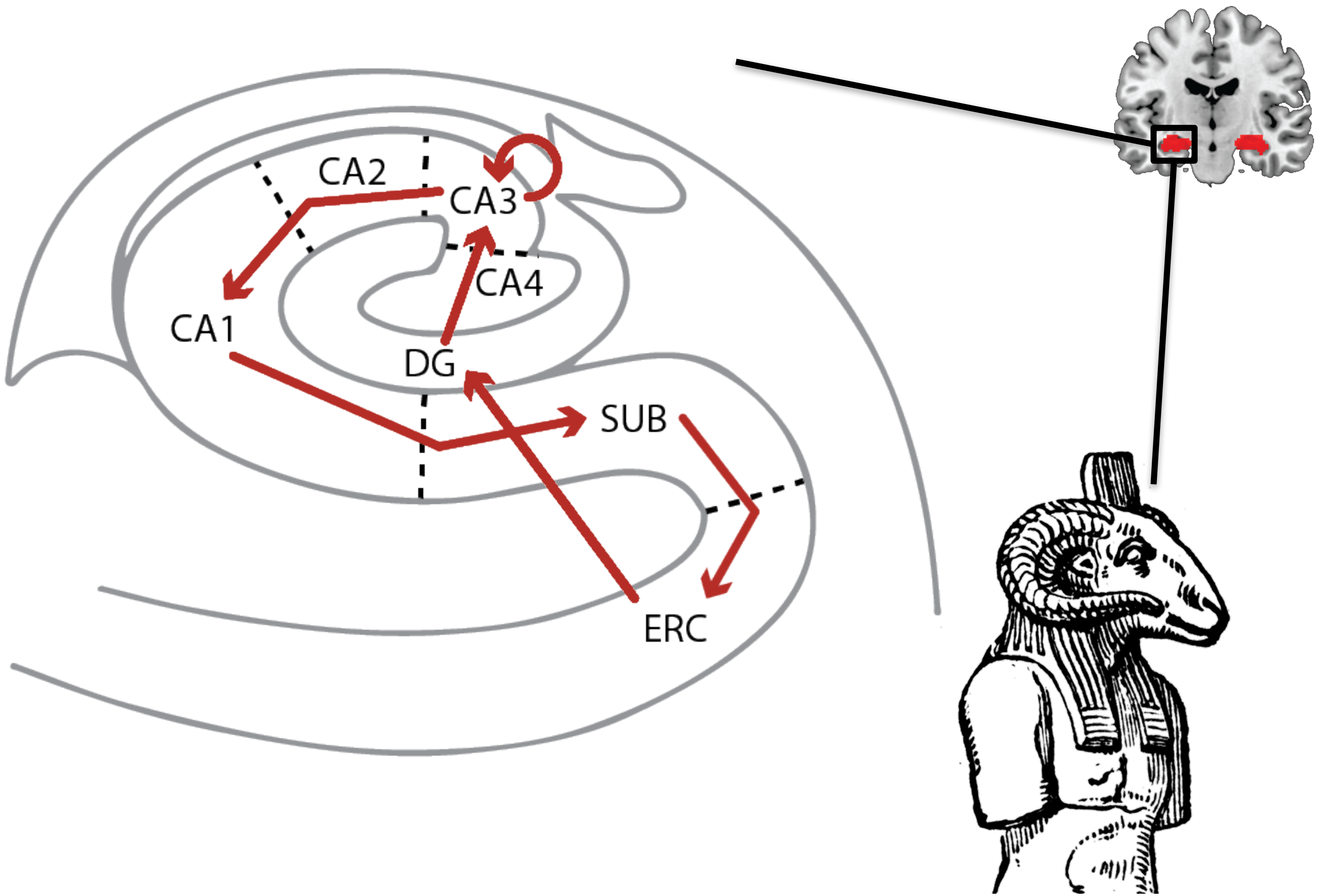
Pattern separation and completion



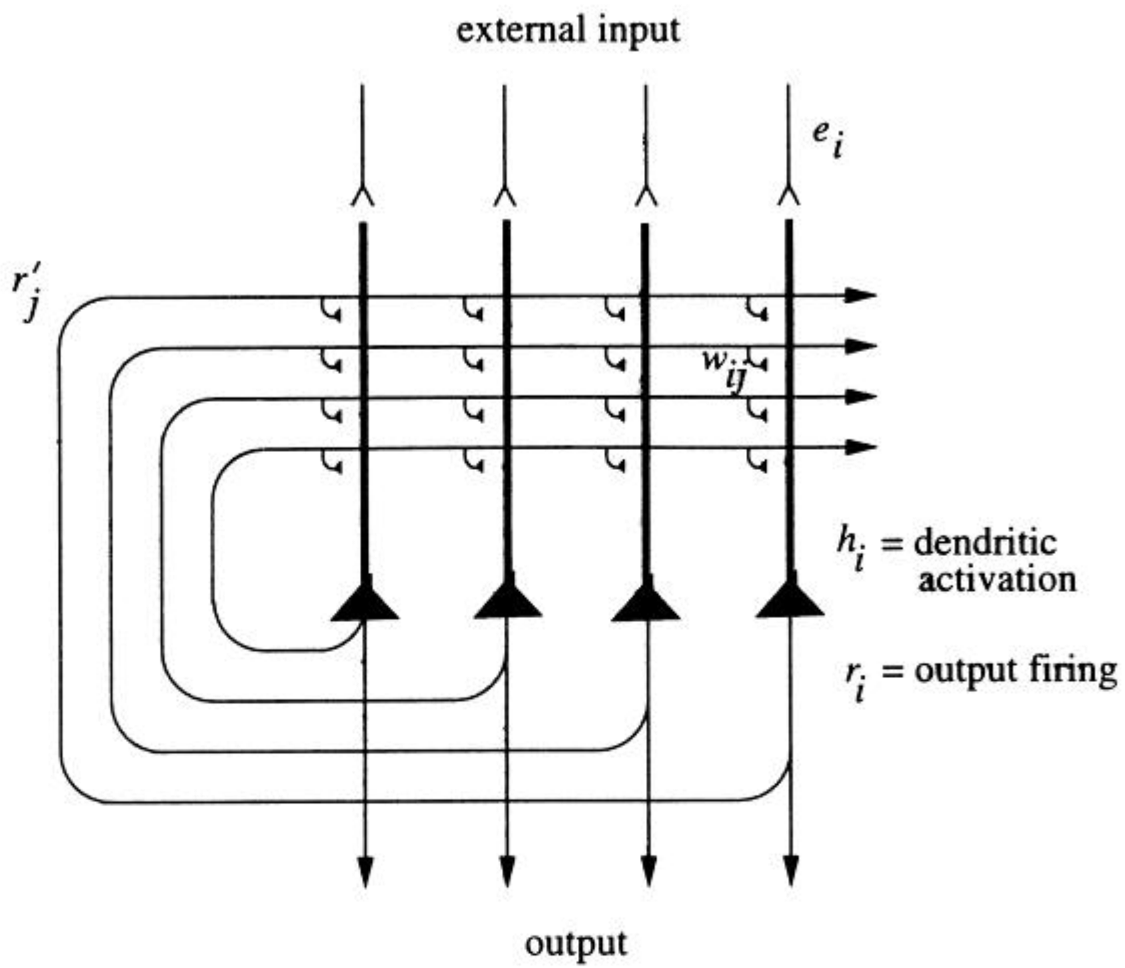
Mechanisms in the hippocampus



Hippocampal specialization

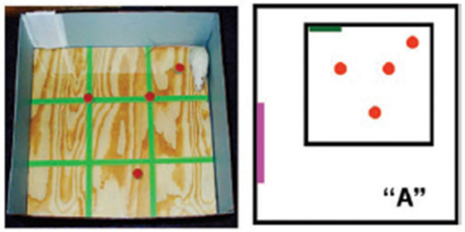


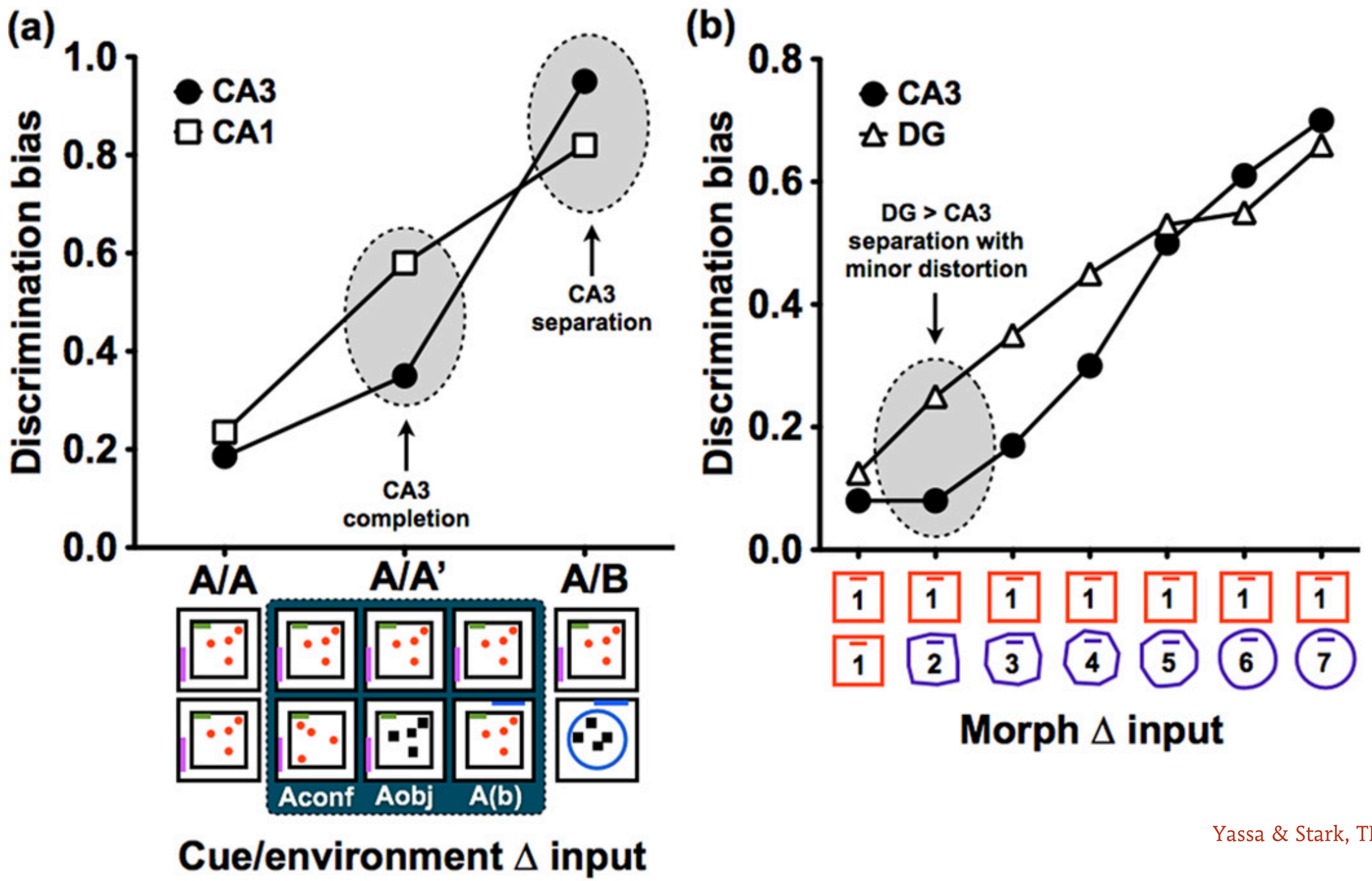
CA3



Rolls & Treves, 1998. Neural networks and brain function.

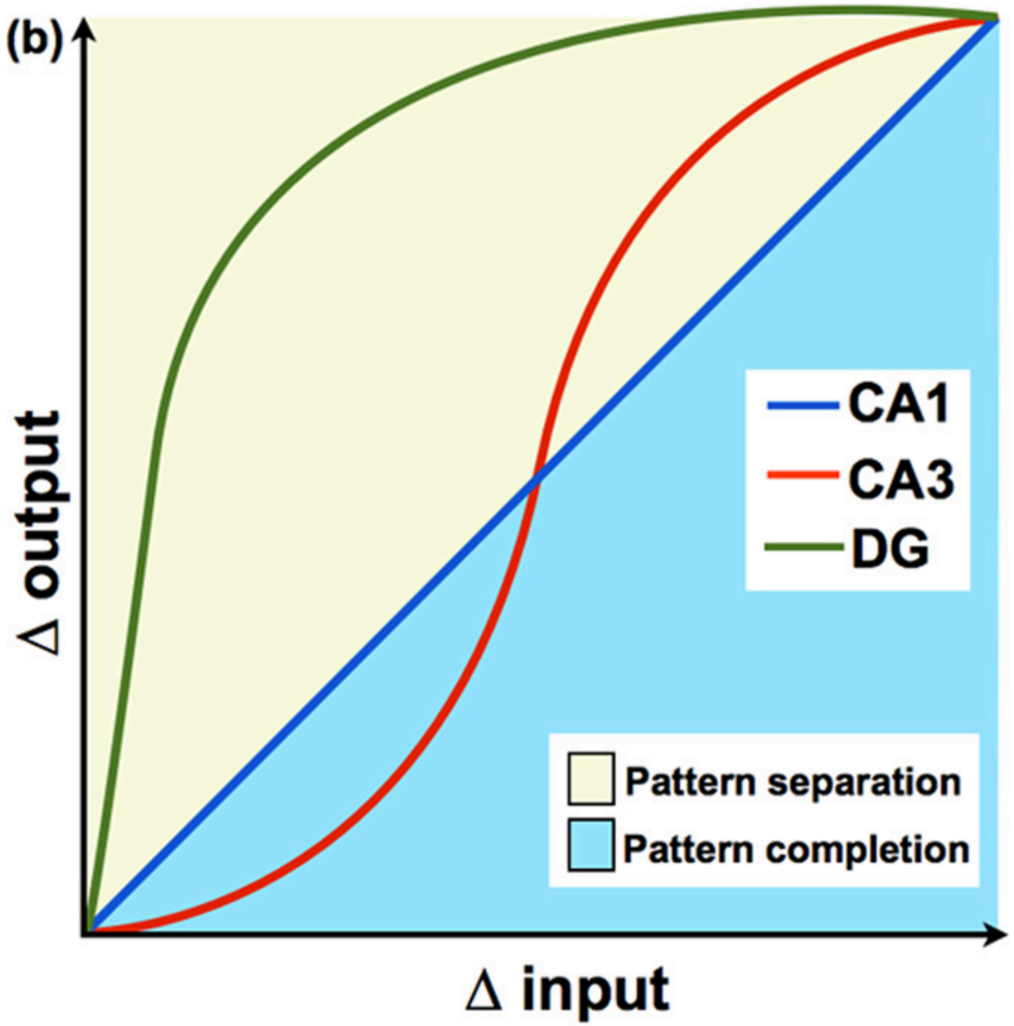
Differences in subfields





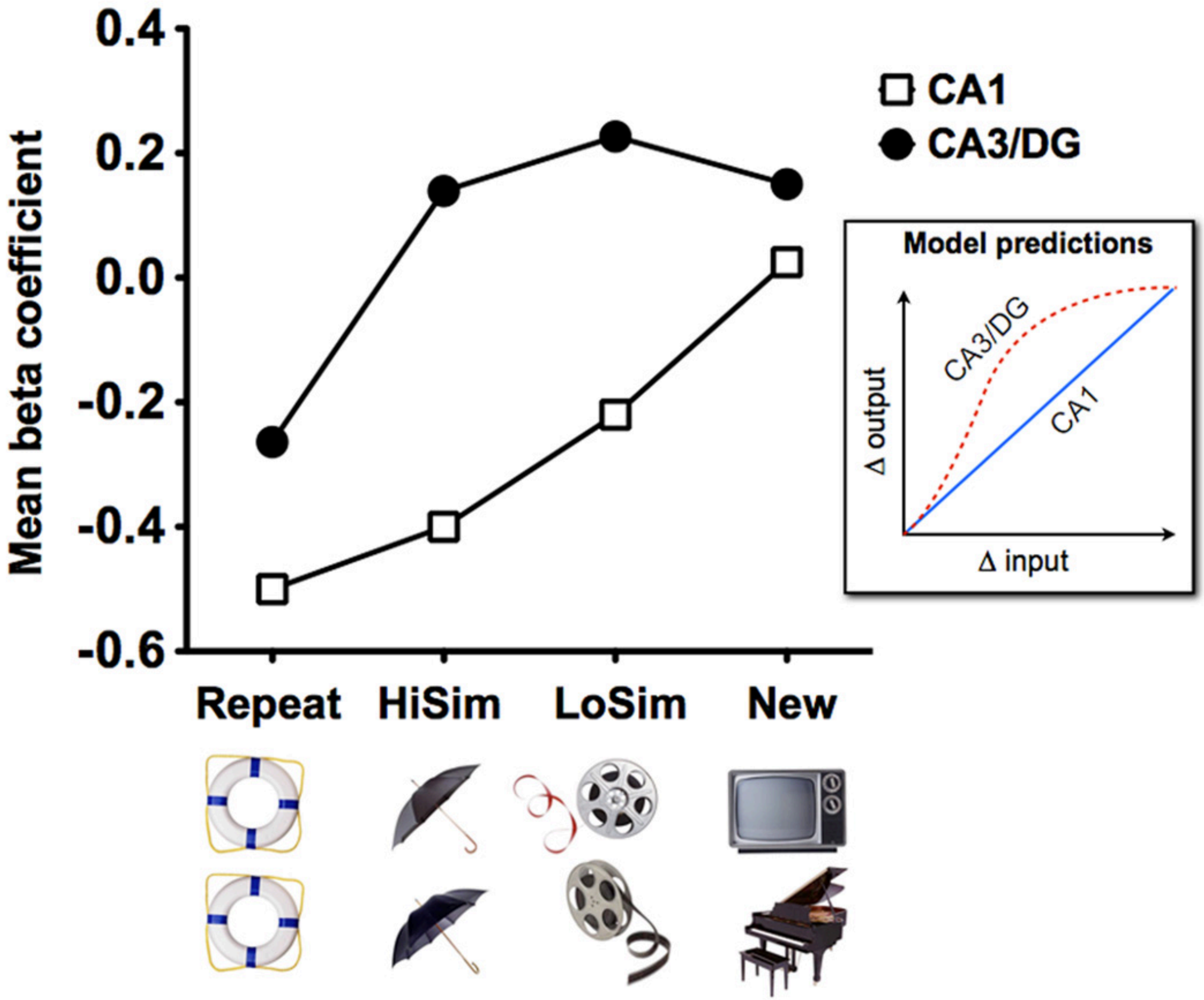
Yassa & Stark, TINS 2011

Model



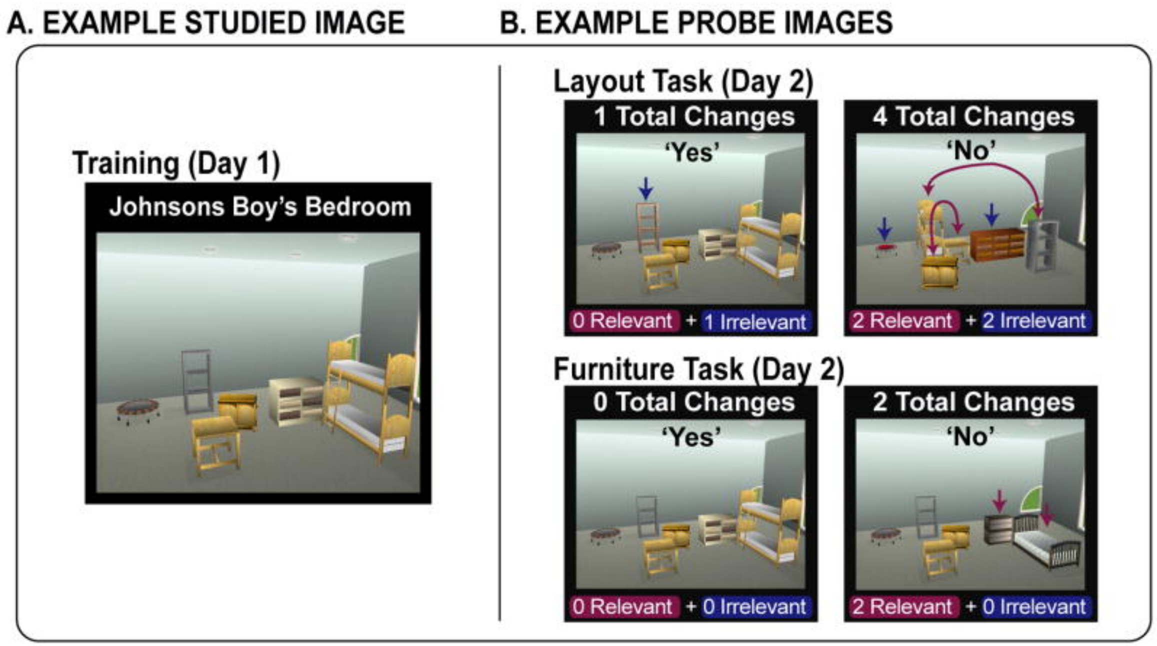
(b)
Δ output
Δ input
CA1
CA3
DG
Pattern separation
Pattern completion

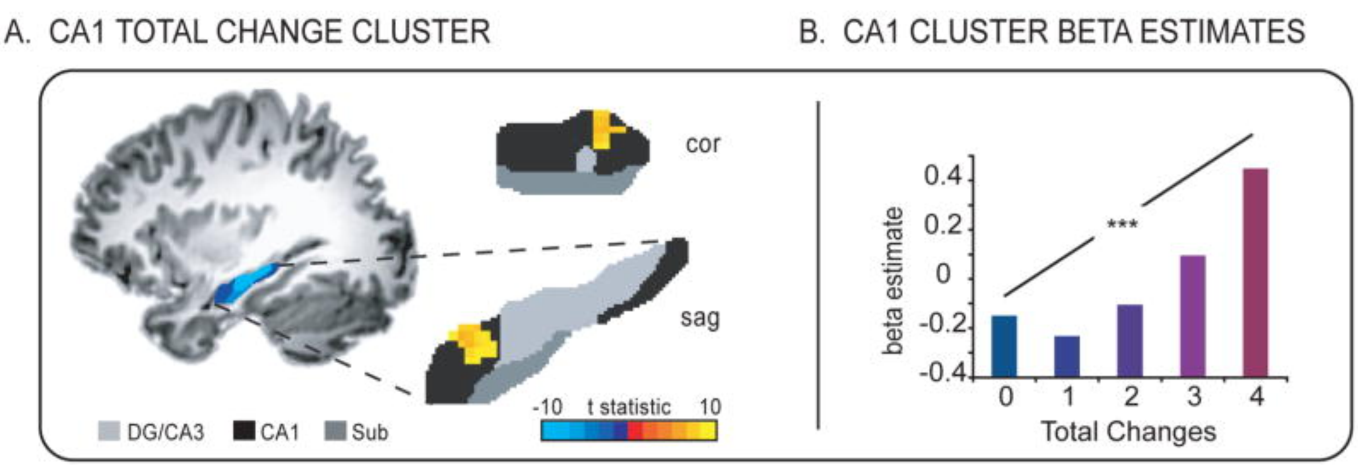
CA1 vs CA3



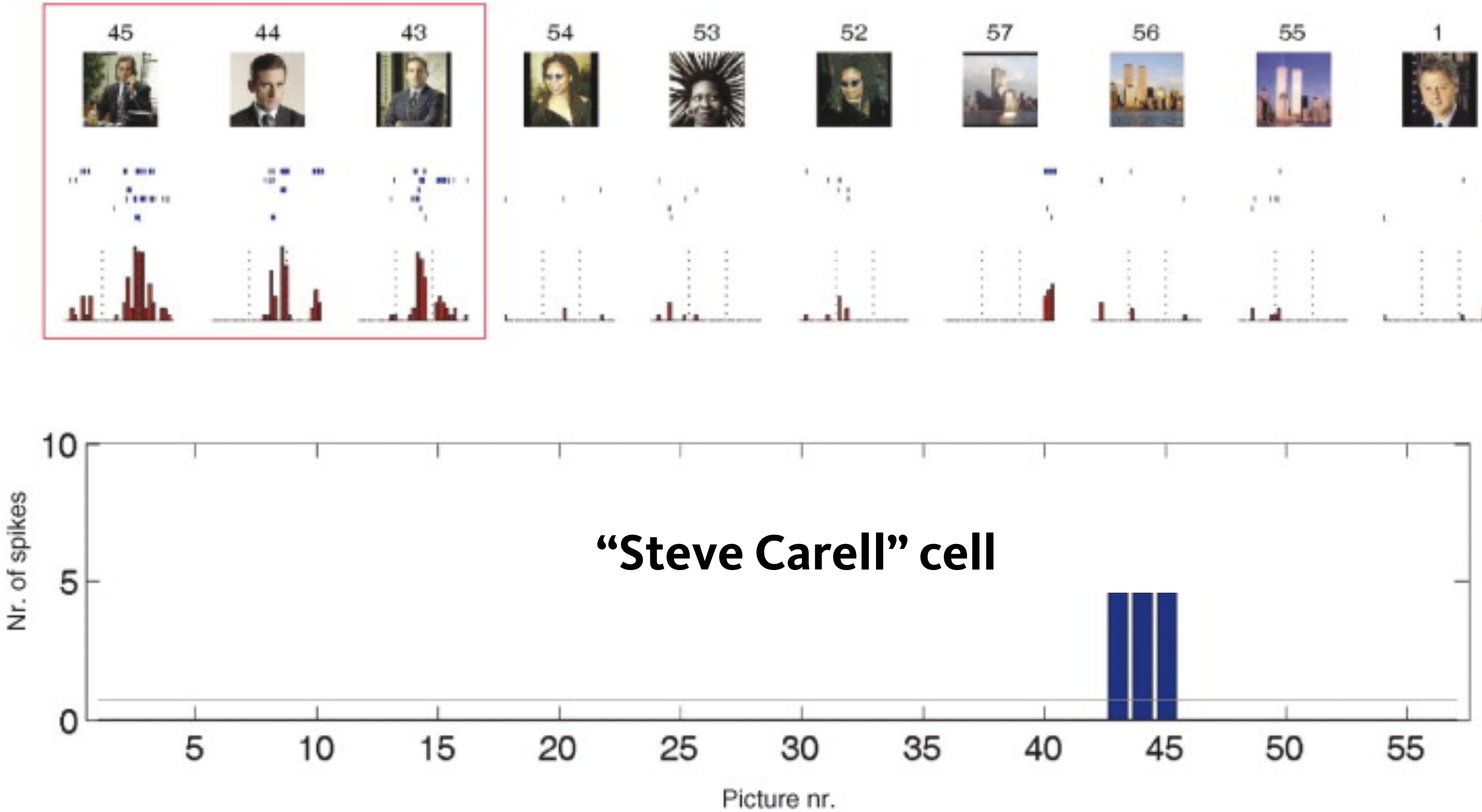
Yassa & Stark, TINS 2011

CA1 linearly increases with changes to spatial layout





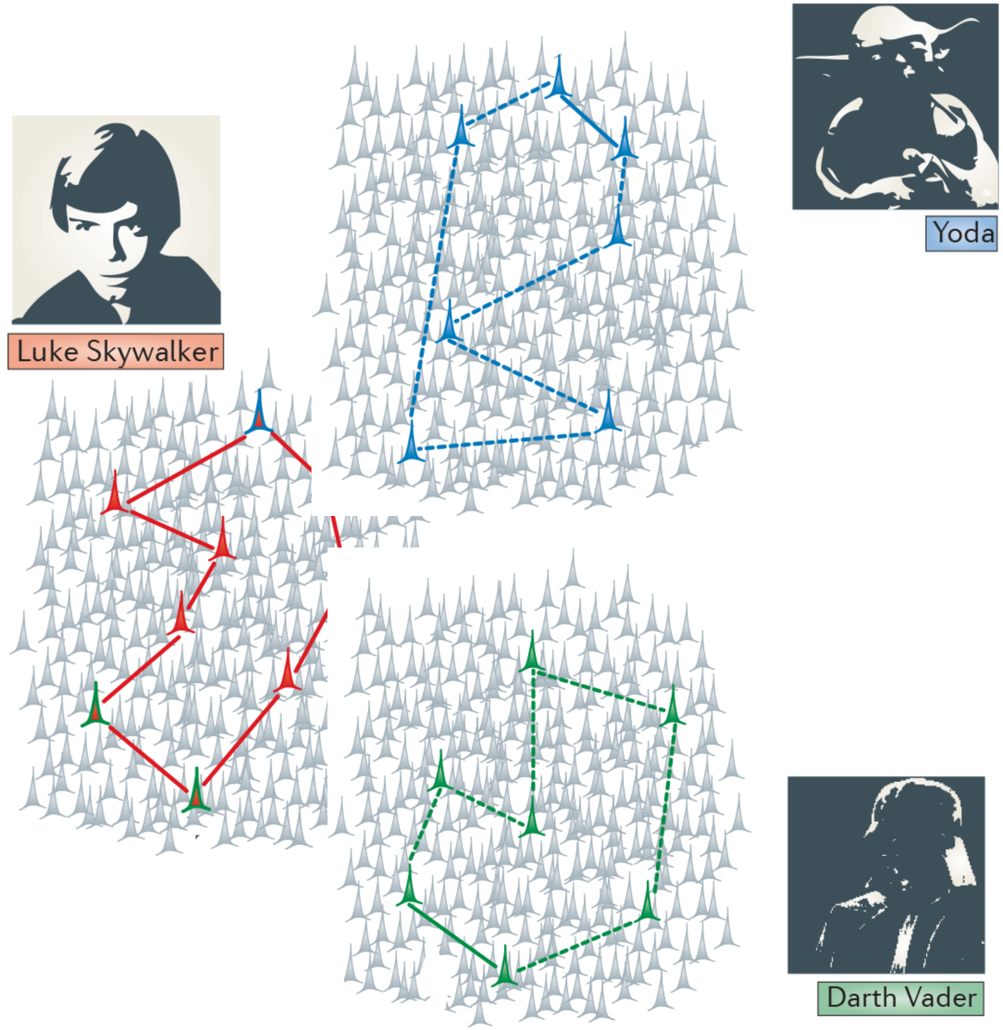
Sparse coding in medial temporal lobe – pattern completion?



Modality-invariant!

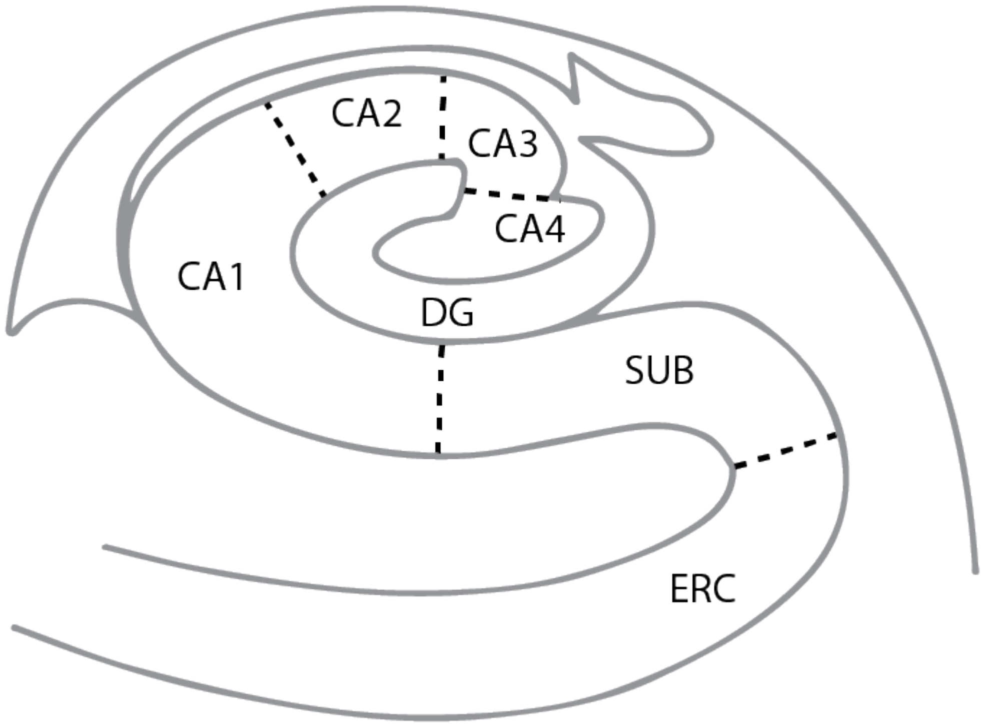
Quiroga, TiCS 2008

Sparse concept networks in MTL?



Quiroga, TiCS 2008

Pattern separation/ completion summary



DG: pattern separation

CA3: pattern separation/completion

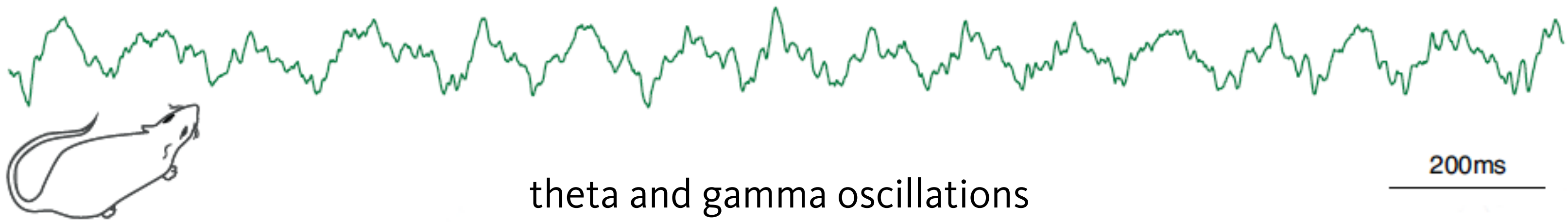
→ autoassociative network

CA1: mismatch detector between CA3 and ERC inputs

Sparse concept networks in the human MTL

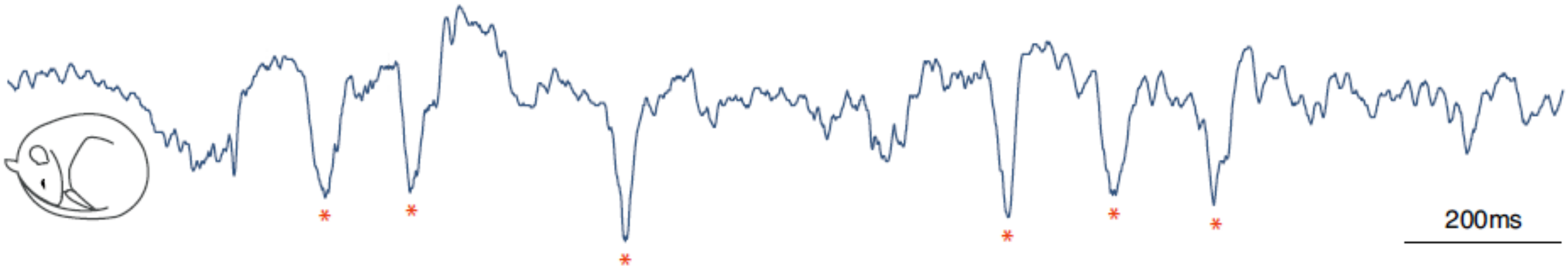
Oscillatory mechanisms?

Active behavioural states **ENCODING/RETRIEVAL**



theta and gamma oscillations

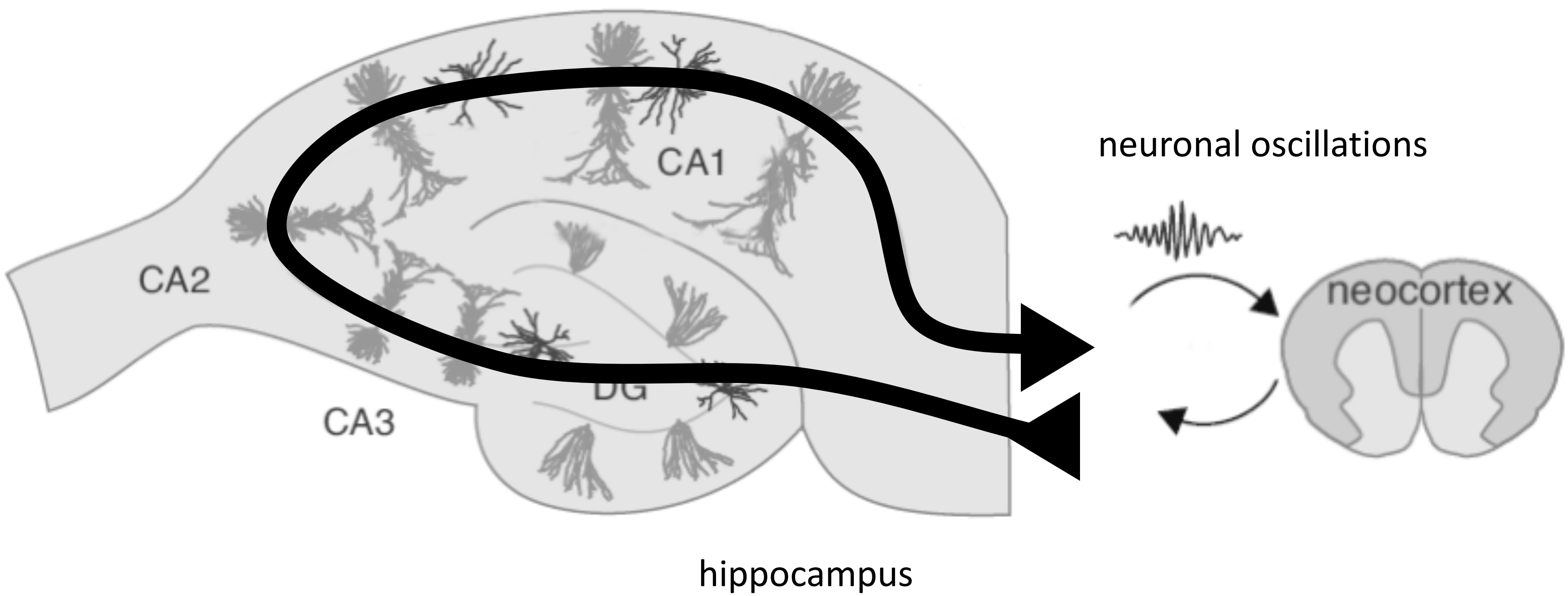
Inactive behavioural states **CONSOLIDATION**



sharp-wave ripple events, slow oscillations, spindles

Buzsáki, Cereb Cortex 1996; Girardeau & Zugaro, Curr Opin Neurobiol 2011

Hippocampal-neocortical dialogue



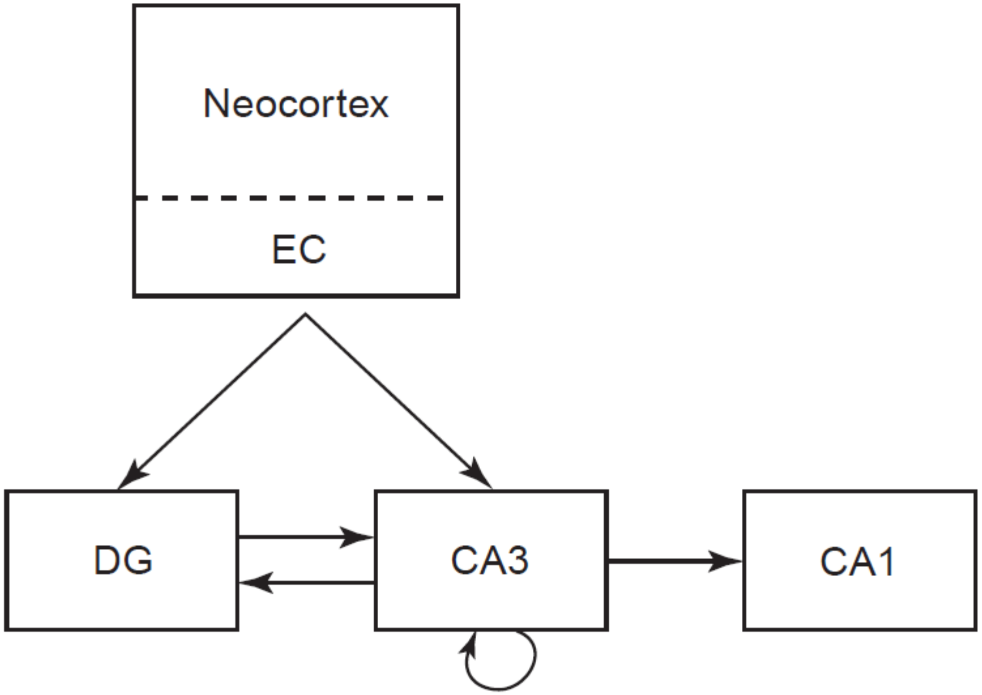
Buzsáki, Cereb Cortex 1996; Girardeau & Zugaro, Curr Opin Neurobiol 2011

Hippocampal-neocortical dialogue

Learn sequence of items: **A B C D E F G**
(separated in time)

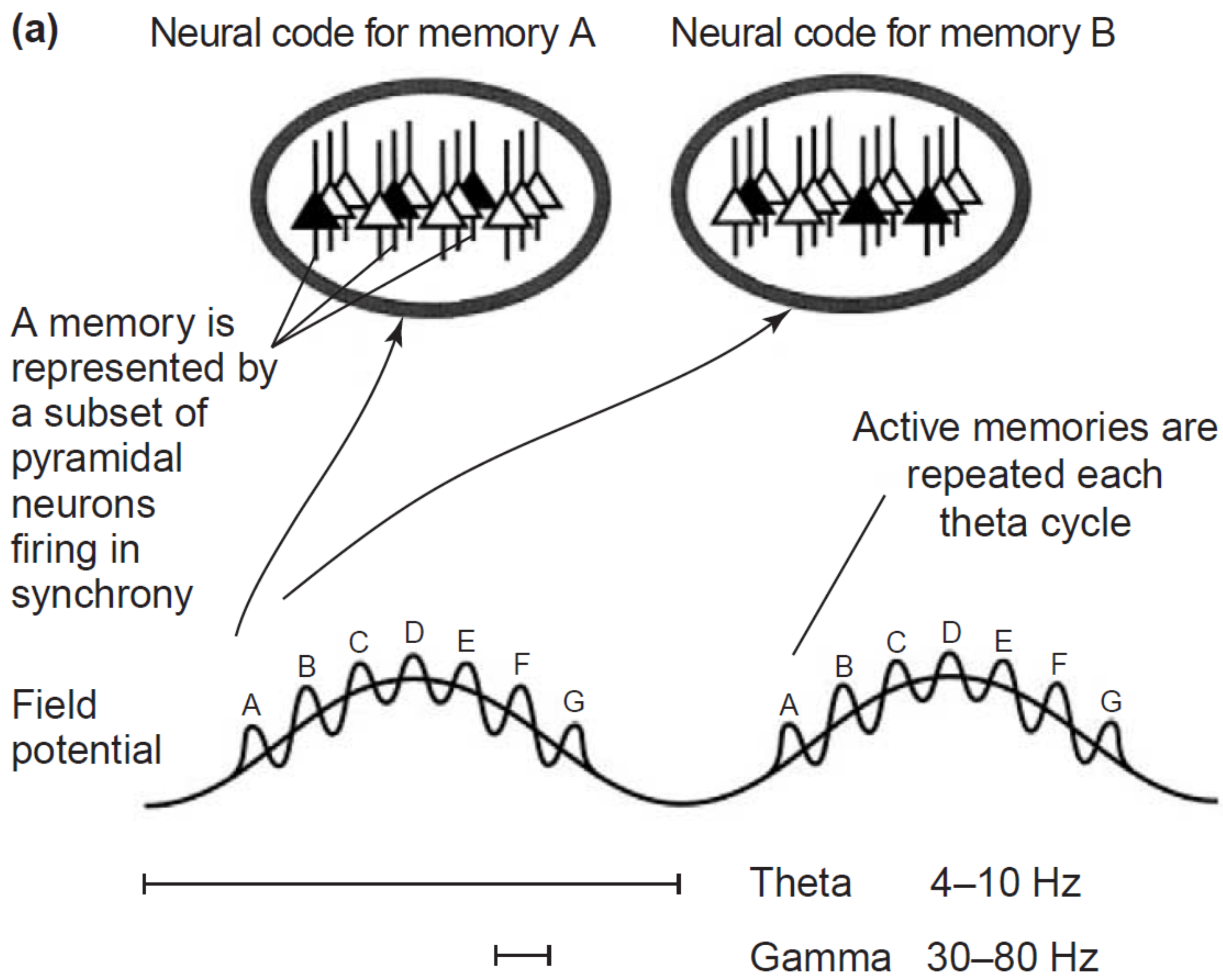
Neocortex
Working memory buffer

Hippocampus
Sequence encoding and recall



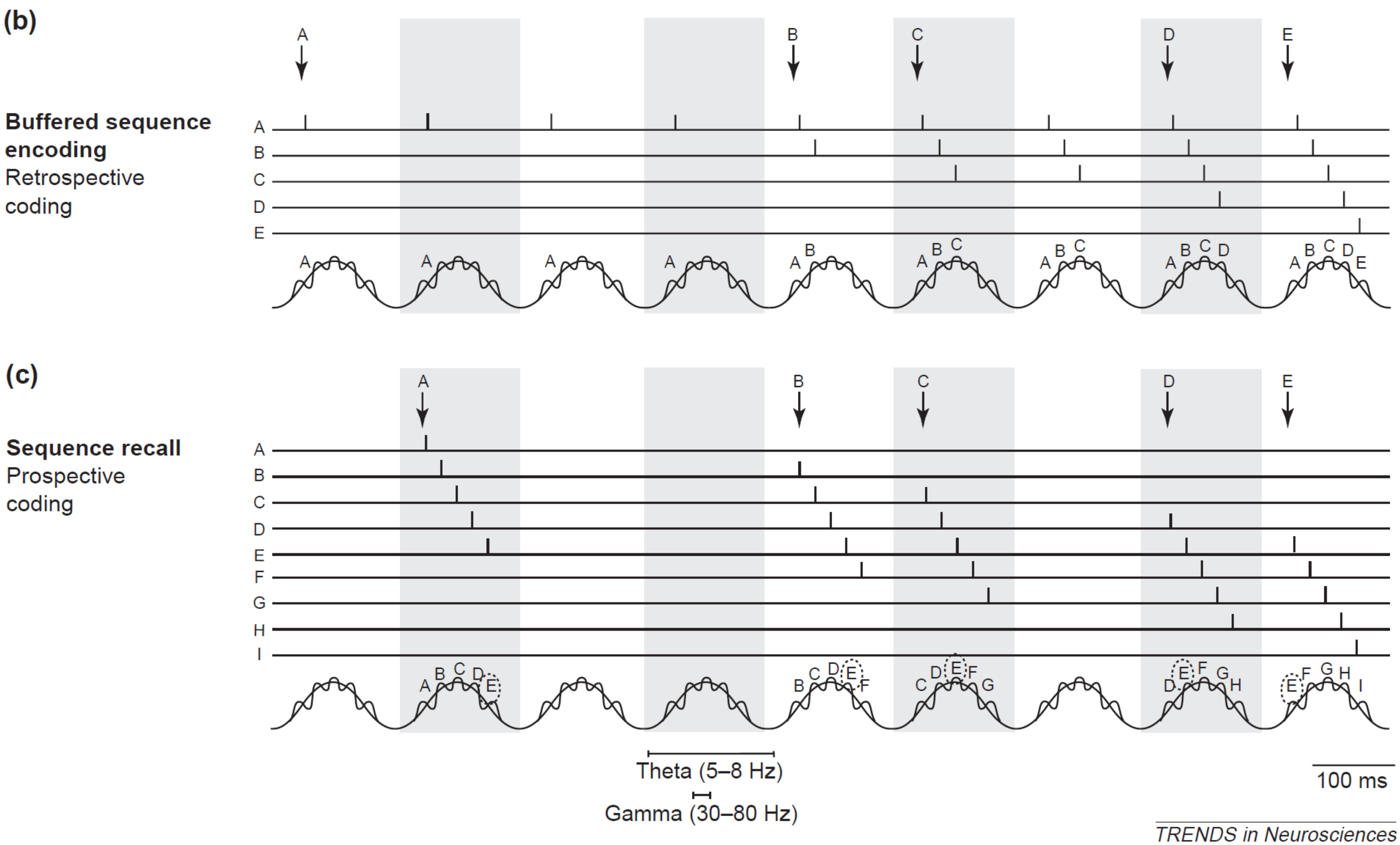
Jensen & Lisman, TiNS 2005

Hippocampal-neocortical dialogue



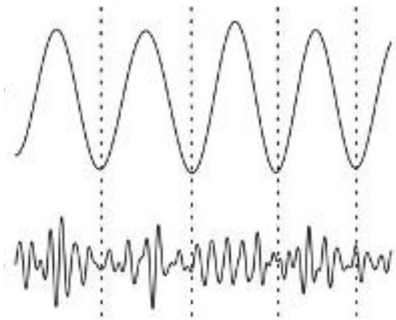
Jensen & Lisman, TiNS 2005

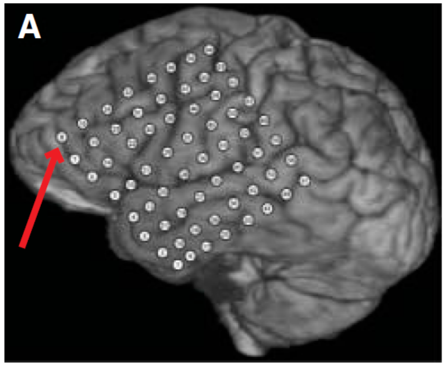
Hippocampal-neocortical dialogue



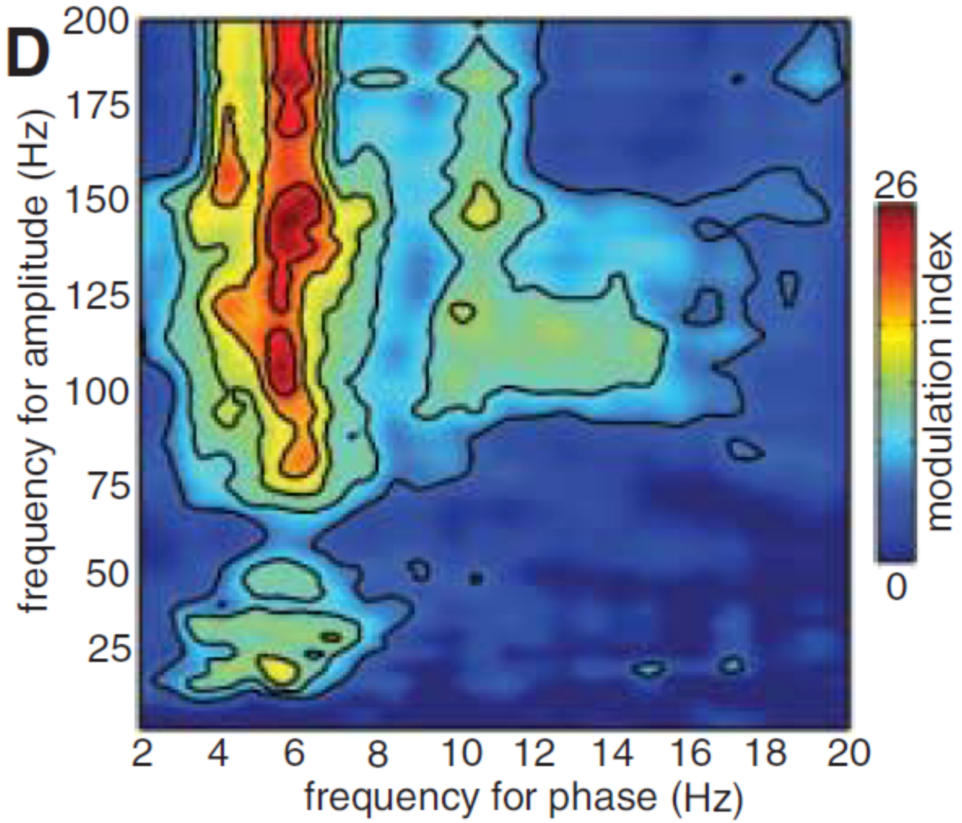
Jensen & Lisman, TiNS 2005

Neocortical gamma is phase-locked to theta





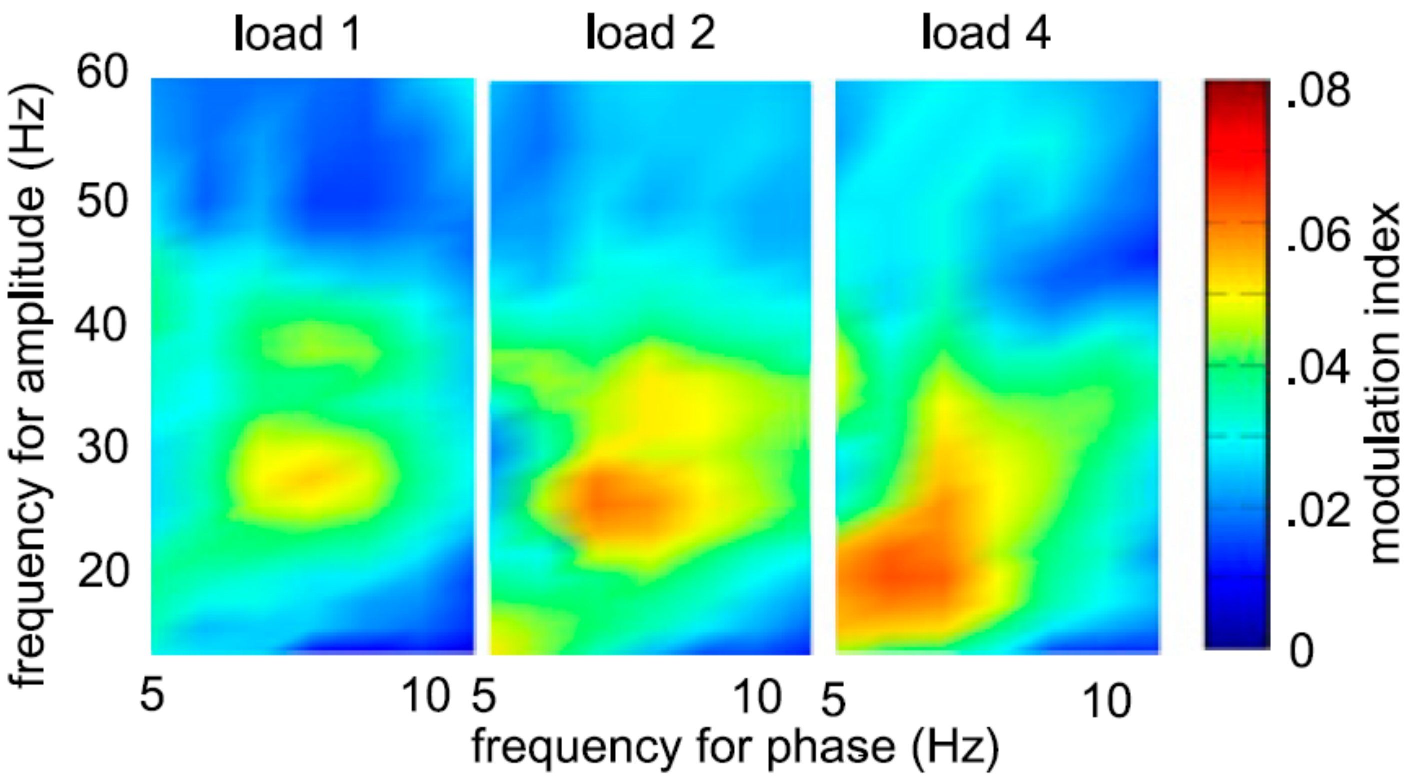
Electrocorticography
(ECoG)



Canolty, Science 2006

Cross-frequency coupling increases with memory load

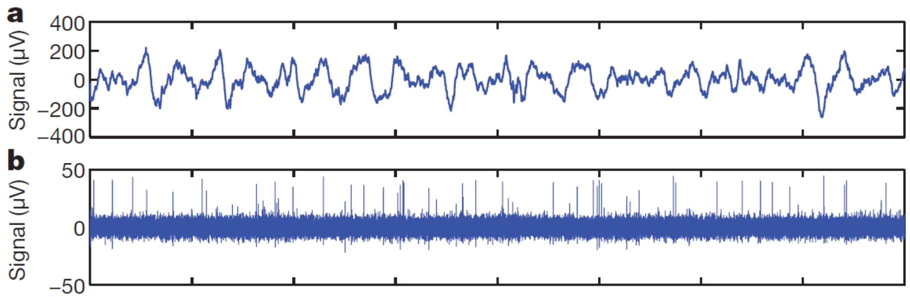
Hippocampus is also involved in working memory!



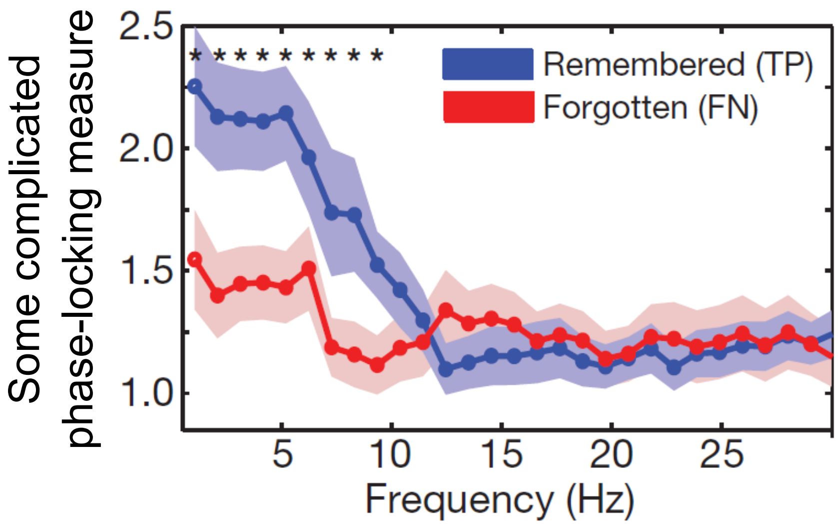
Intracranial hippocampal EEG (iEEG)

Axmacher, PNAS 2010

Theta-frequency phase-locking of single neurons



Intracranial hippocampal EEG (iEEG)

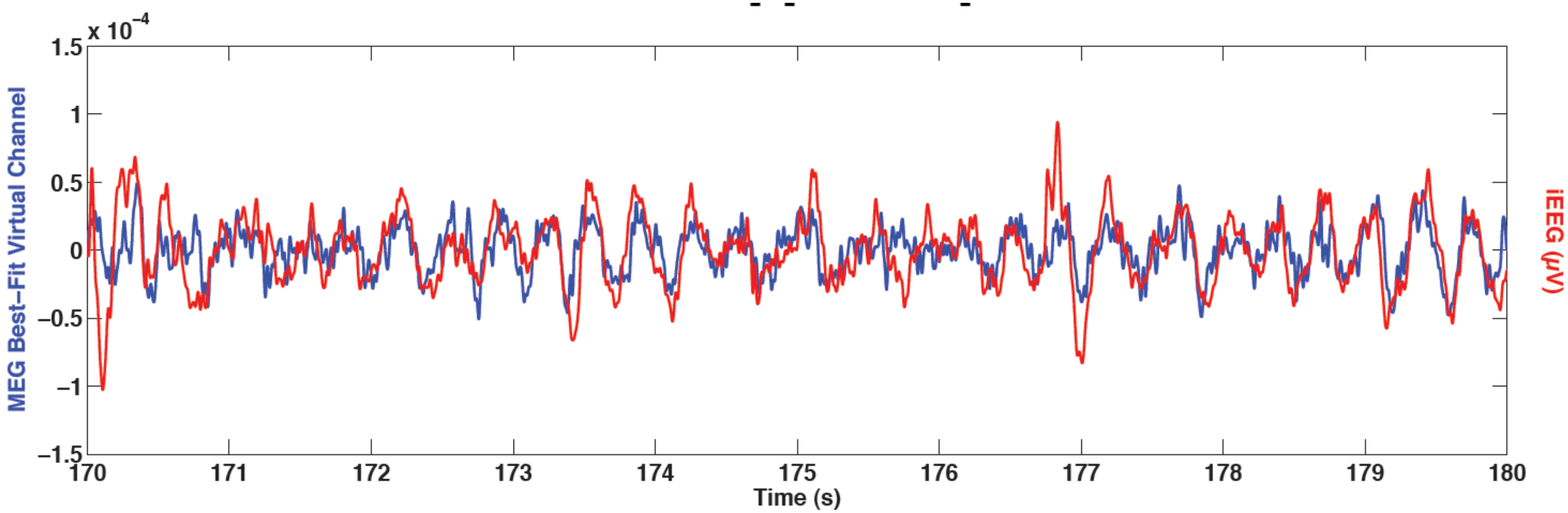


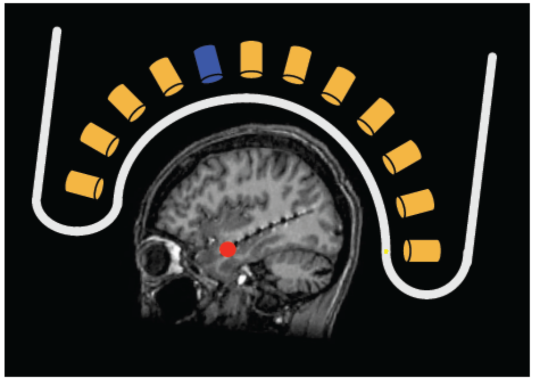
...predicts **memory strength**

Rutishauser, Nature 2010

MEG signals from medial temporal lobe?

Simultaneous MEG and intracranial hippocampus EEG



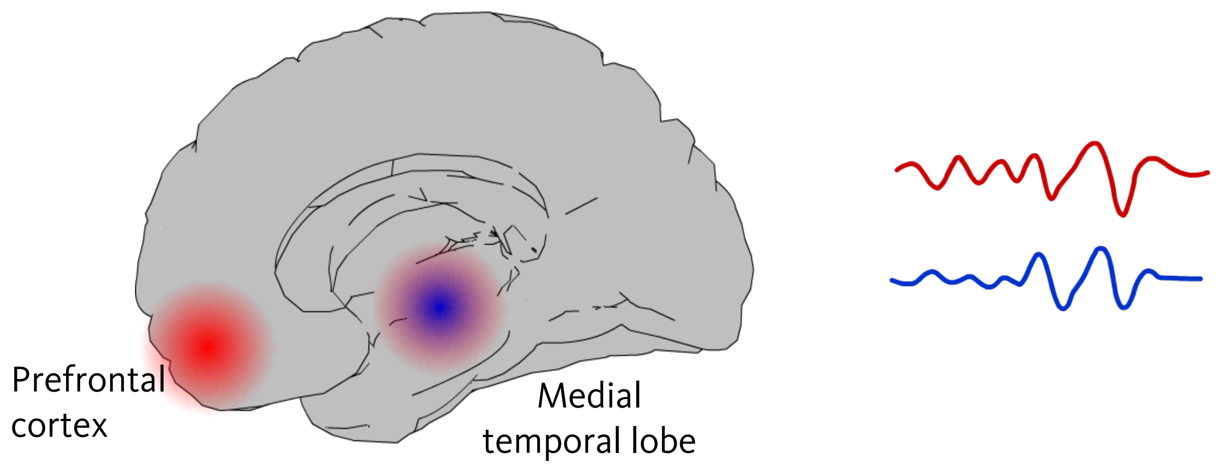


hippocampus iEEG electrode

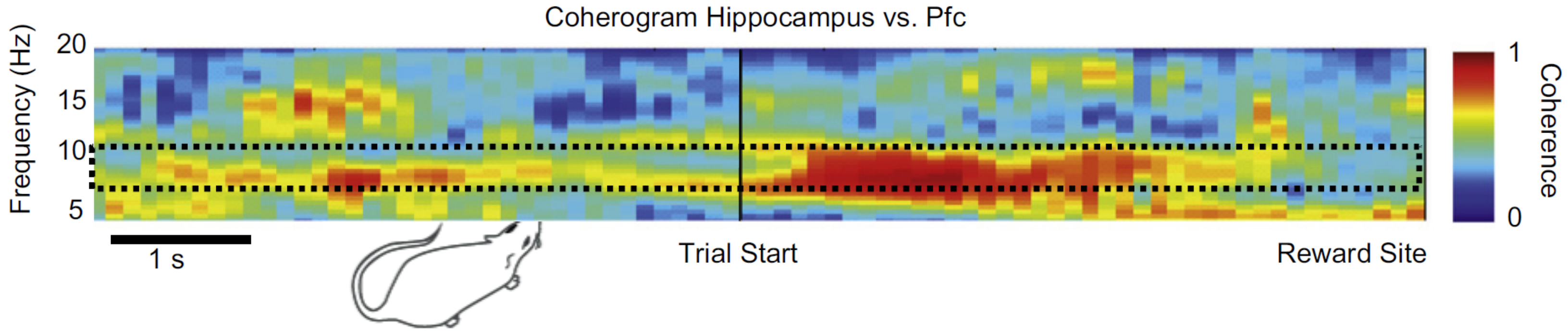
most correlated MEG sensor (r=0.3)

Dalal, HAL 2013 (http://hal.upmc.fr/file/index/docid/823750/filename/DalalEBM.pdf)

Prefrontal cortex plays important role during memory formation

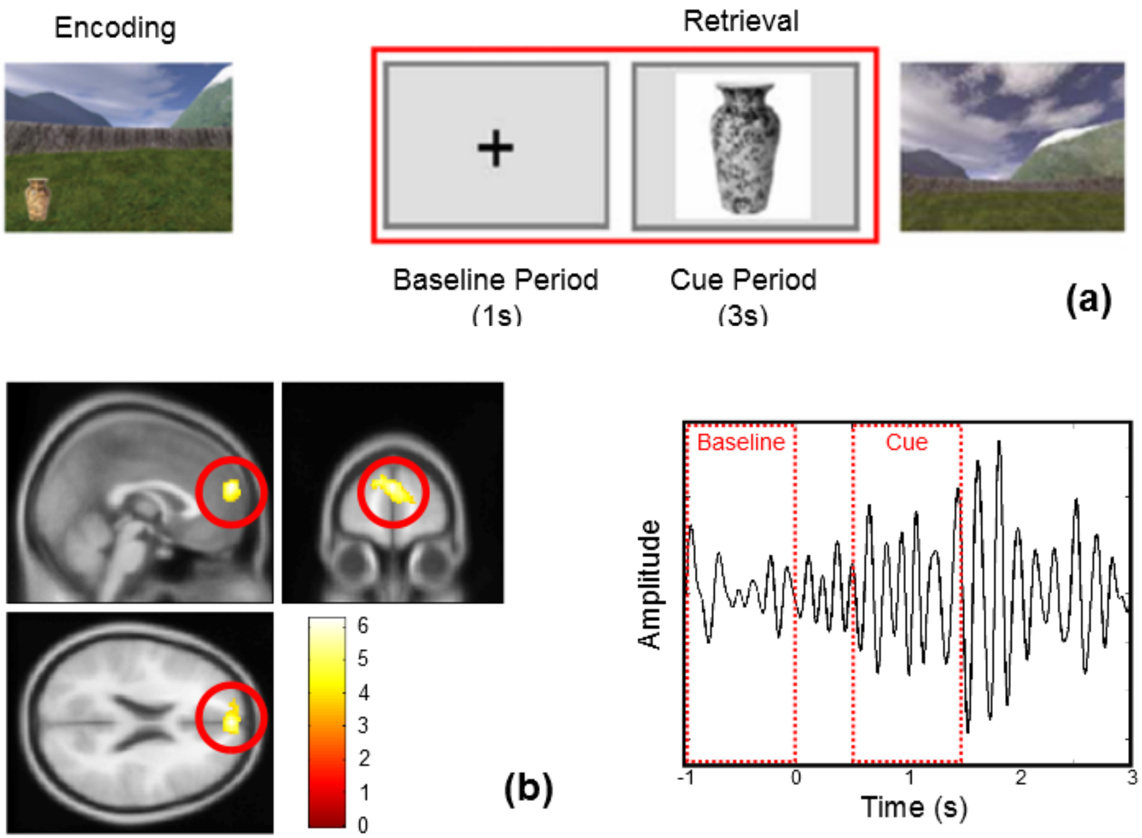


PFC communicates directly with **hippocampus**



Benchenane, Neuron 2010

Theta power increase in PFC during spatial memory retrieval



Kaplan et al., PLOS Biology 2012

Encoding/ retrieval summary

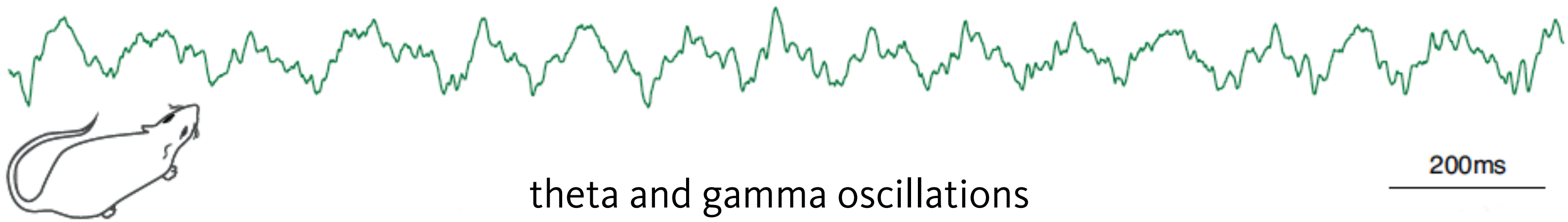
Hippocampal-neocortical dialogue during active behavioural states via theta and gamma oscillations

Theta oscillations likely code spatiotemporal context and provide windows of communication

Prefrontal cortex interfaces with hippocampus

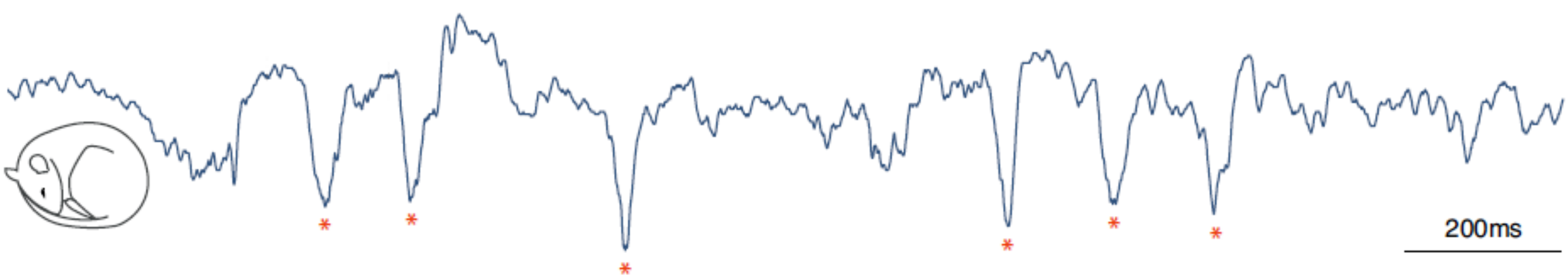
Inactive behavioural states

Active behavioural states **ENCODING/RETRIEVAL**



theta and gamma oscillations

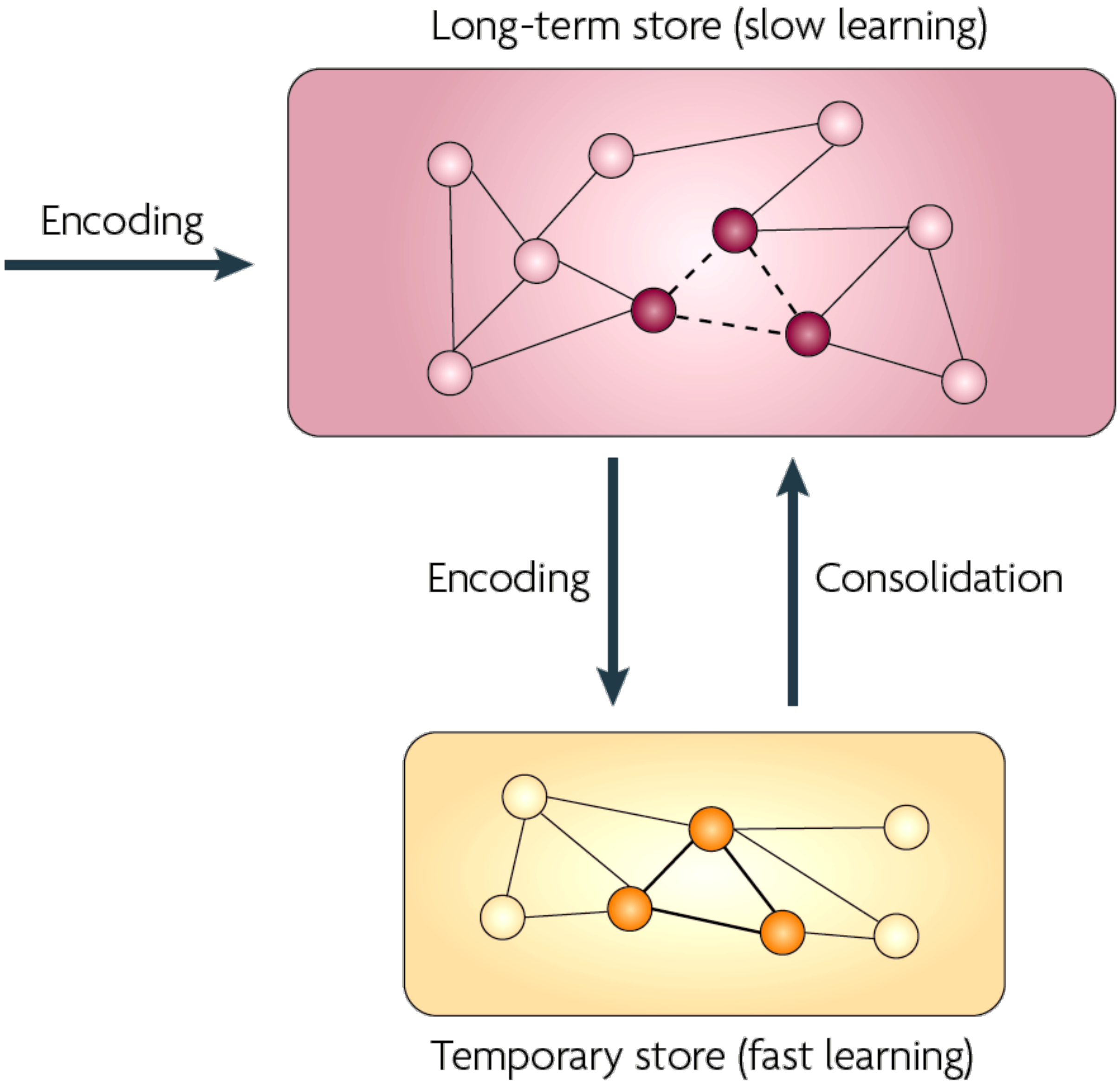
Inactive behavioural states **CONSOLIDATION**



sharp-wave ripple events, slow oscillations, spindles

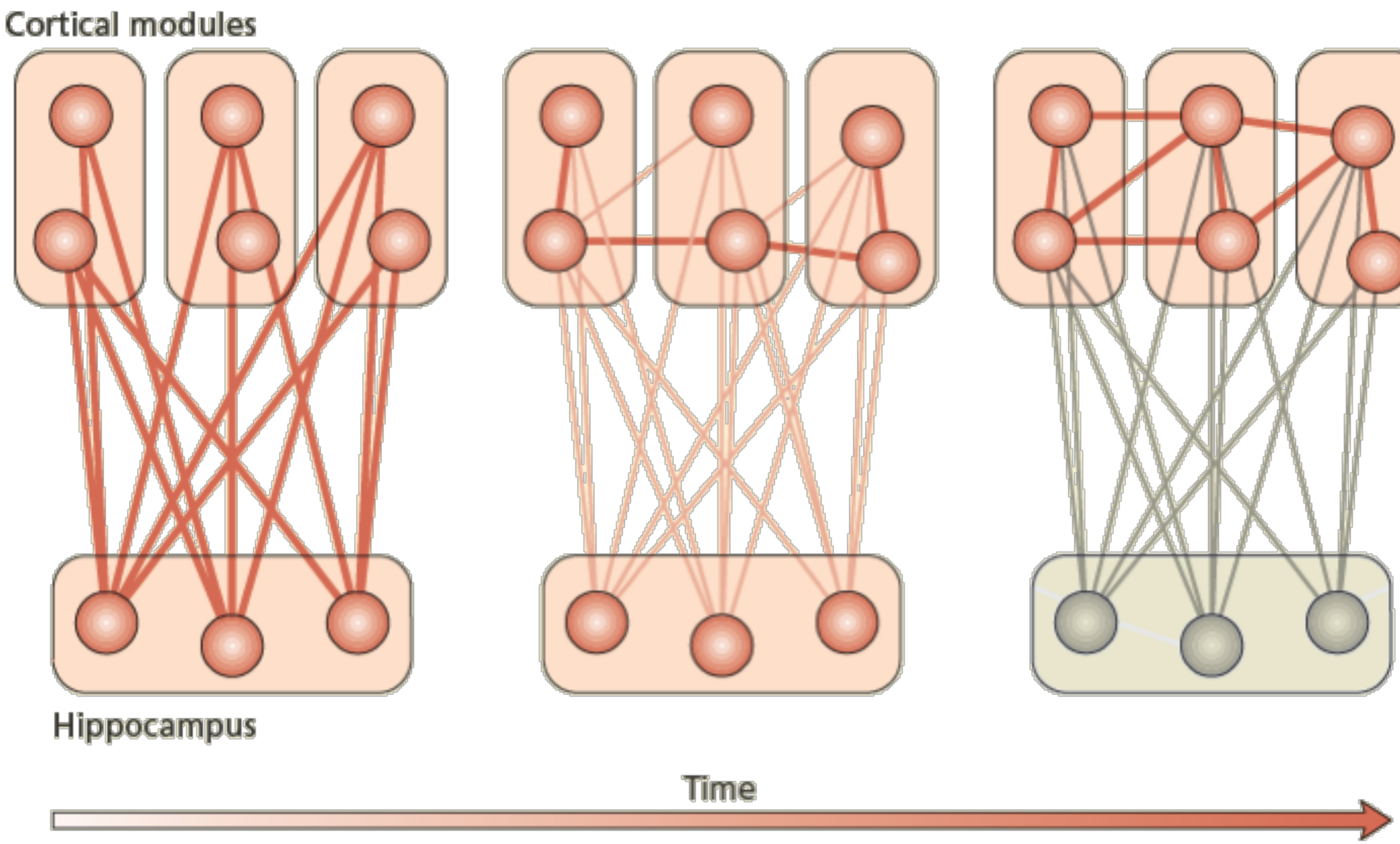
Buzsáki, Cereb Cortex 1996; Girardeau & Zugaro, Curr Opin Neurobiol 2011

Consolidation



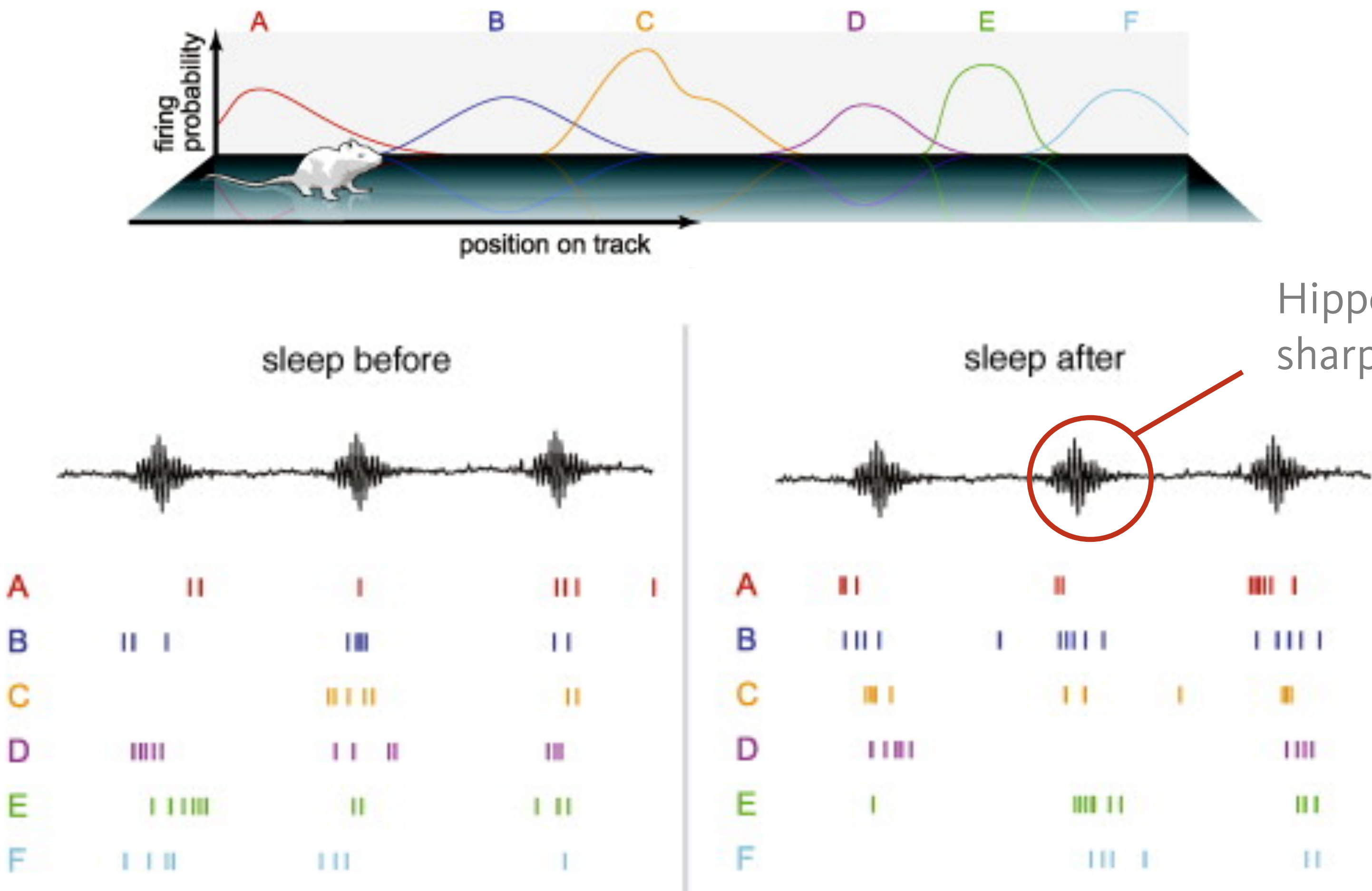
Diekelmann & Born, NRN 2010

Systems consolidation



Frankland & Bontempi, Nature Reviews Neuroscience 2005

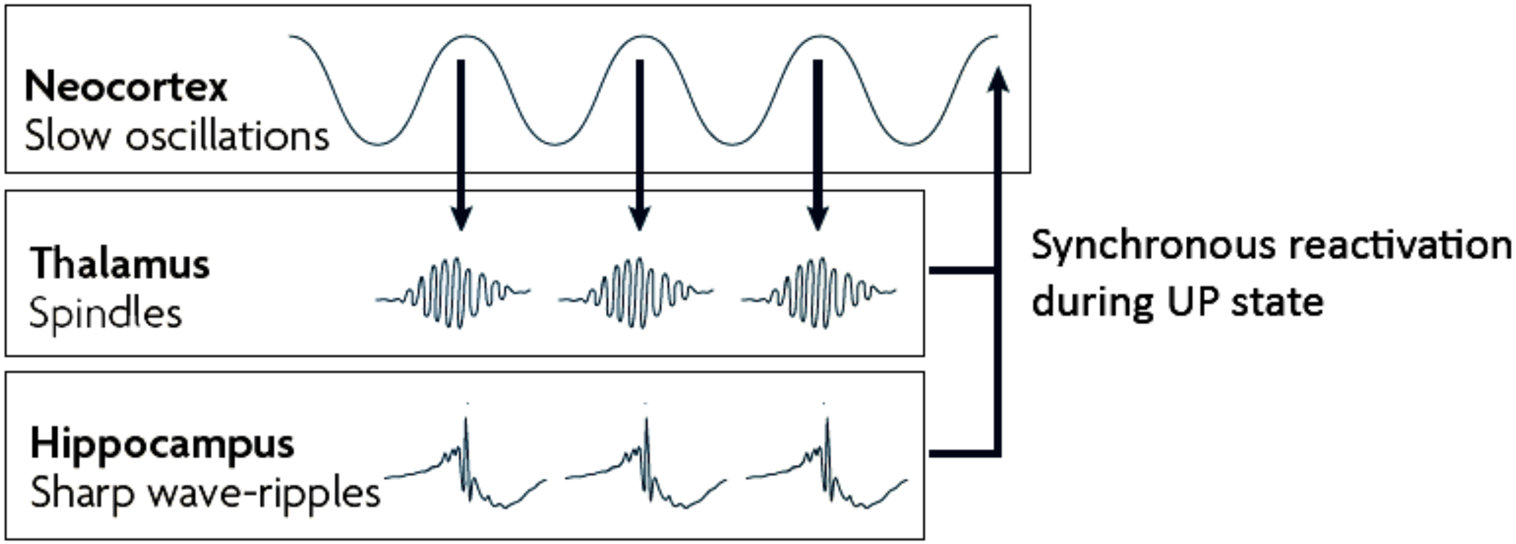
Memory replay as consolidation mechanism



Hippocampal sharp-wave ripples

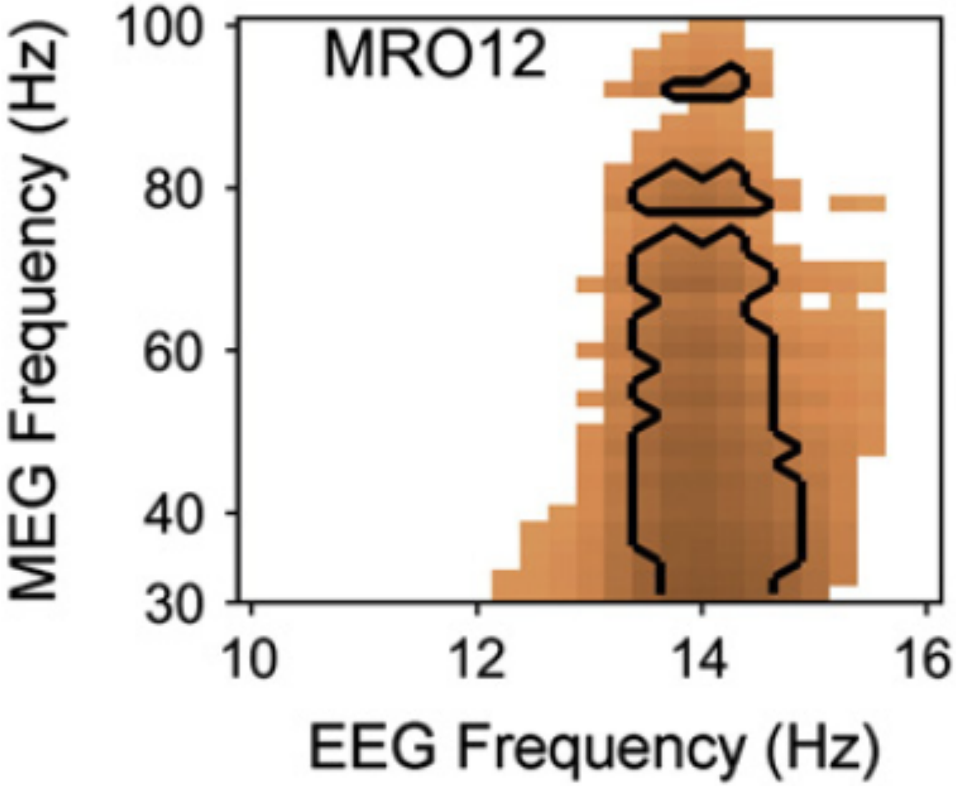
O'Neill et al., TiNS 2010

Replay is orchestrated by neuronal oscillations



Diekelmann & Born, NRN 2010

Neocortical bursts of activity measured with MEG are grouped by EEG sleep spindles

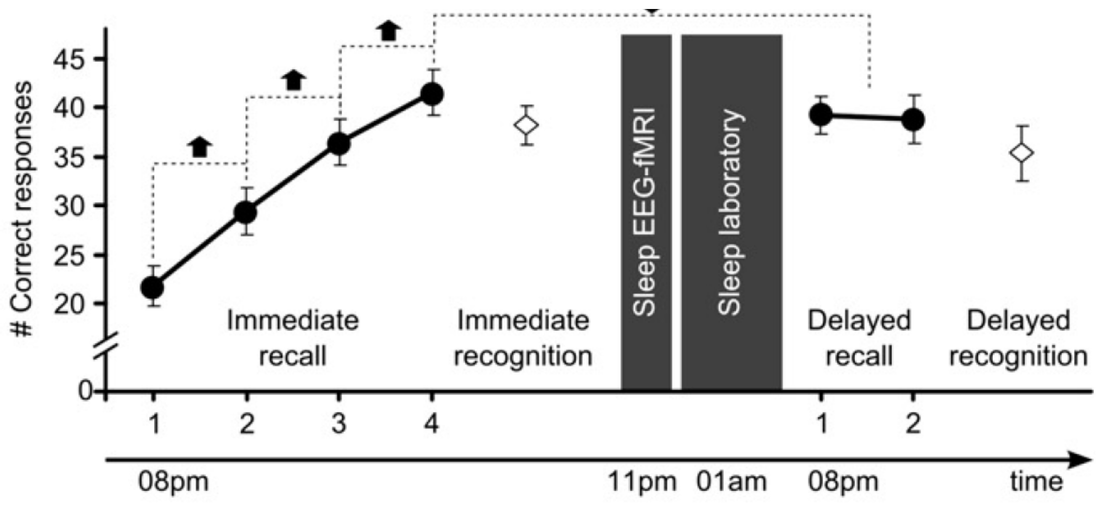


Ayoub, NeuroImage 2012

Combined EEG-fMRI to study consolidation

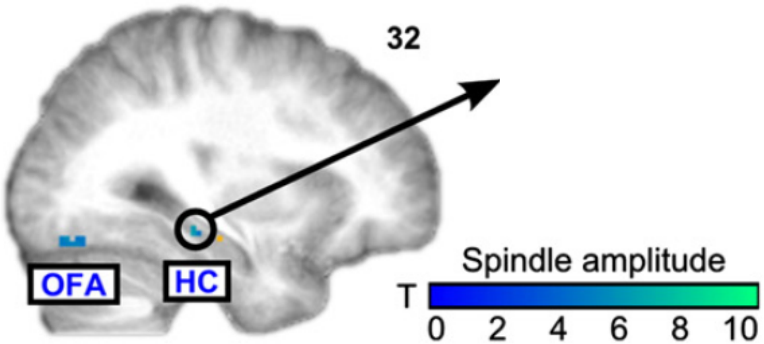
Subjects were required to...

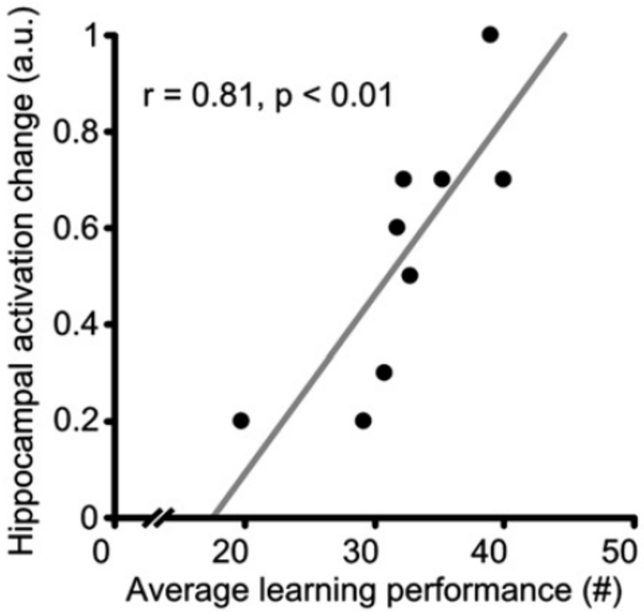
1) ...learn associations between pairs of stimuli
2) ...sleep in fMRI scanner with EEG cap
3) ...perform memory tests



Bergmann, NeuroImage 2012

Learning performance correlates with spindle-related hippocampal activity during subsequent sleep

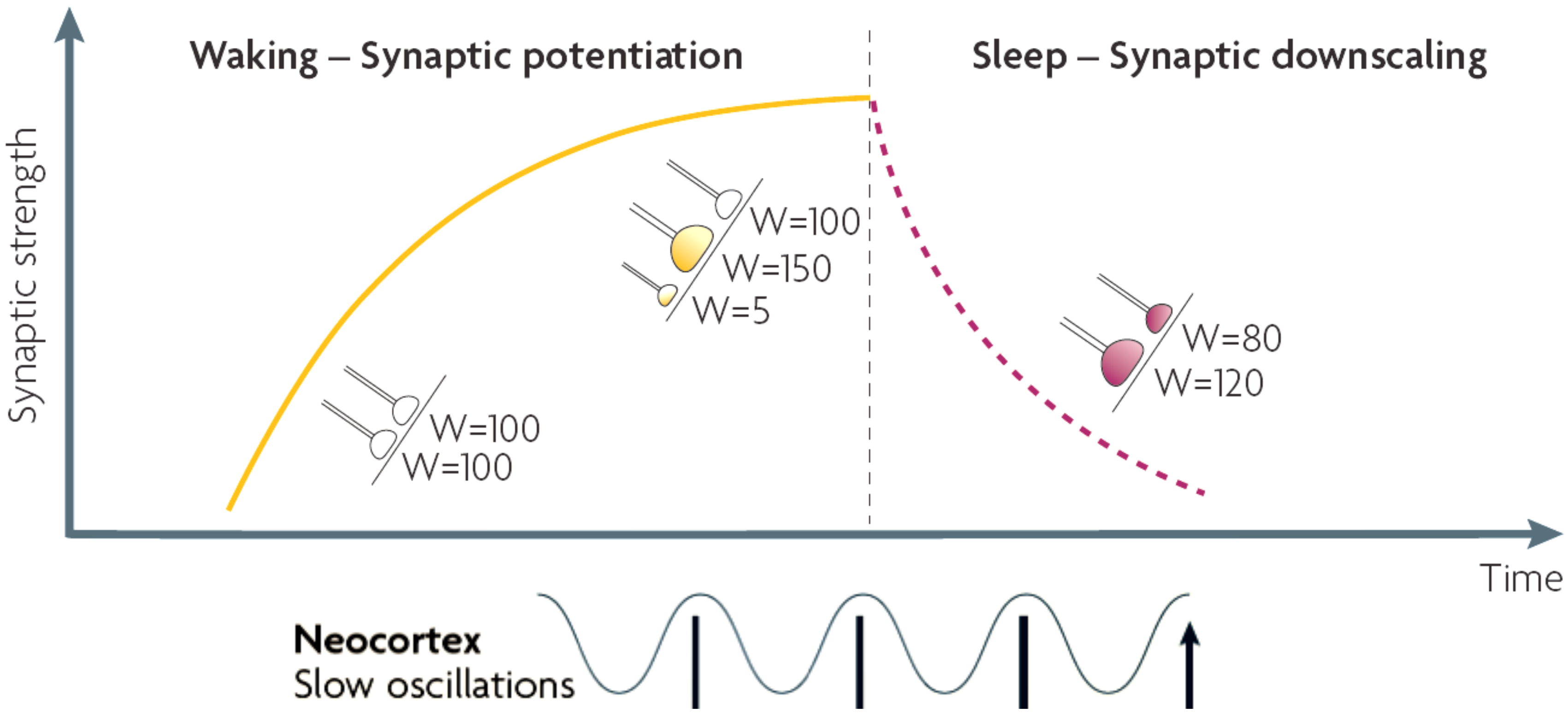




EEG **spindle amplitude** used as fMRI **regressor**!

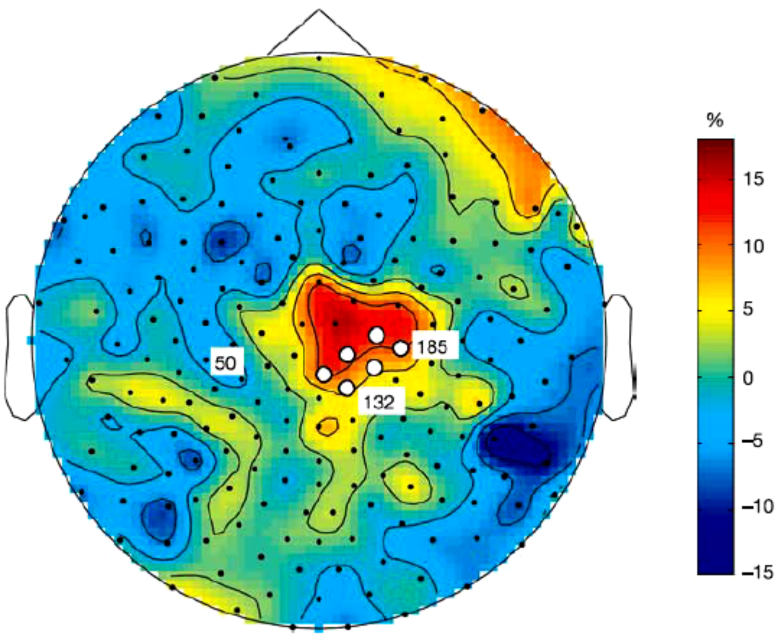
Bergmann, NeuroImage 2012

Another role of sleep: synaptic downscaling

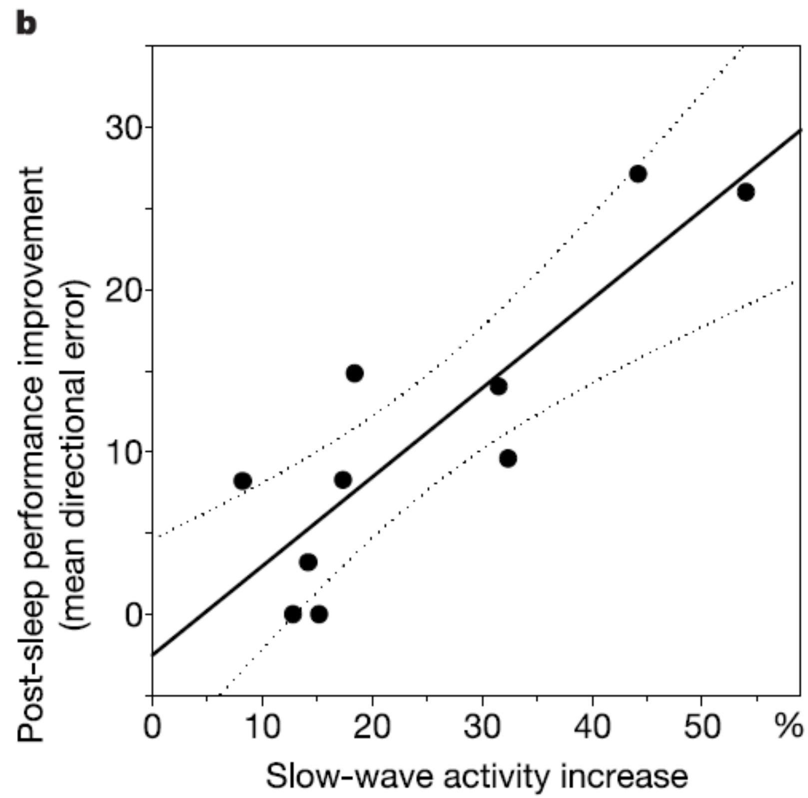


Diekelmann & Born, NRN 2010

Local increase in slow-wave activity after learning



Human **EEG**



Huber, Nature 2004

Consolidation summary

Consolidation of neocortical memory representations may be guided by hippocampal index representations

Memory replay during inactive behavioural states as a consolidation mechanism

Consolidation is orchestrated by various neuronal oscillations

Synaptic downscaling and replay might lead to sharpening of memory representations