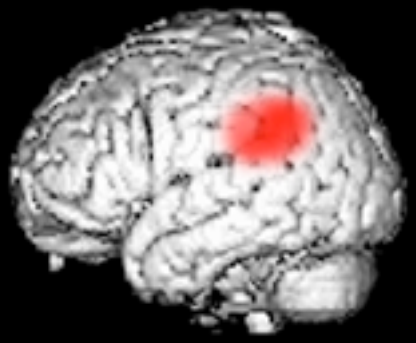
Outline

- What is Working Memory (WM)?
- Why is WM important?
- Capacity limits of WM
- Contrasting WM and LTM
  - Evidence for separate WM & LTM systems?
- Forms of WM
- Systems vs. Emergent Accounts of WM

Evidence that WM & LTM are Distinct: Neuropsychological Data

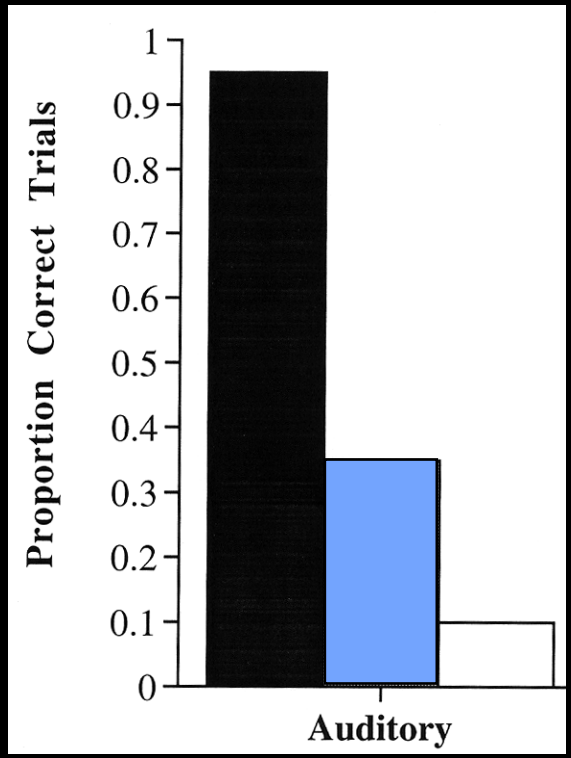
- H.M. & other AMNs → intact WM, but impaired LTM
- K.F. → impaired WM, but relatively intact LTM



left temporal/parietal lesion

limited span for auditory material (letters)

span 1: 19/20 trials correct
span 2: 7/20 trials correct
span 3: 2/20 trials correct



Evidence that WM & LTM are Distinct: Neuropsychological Data

- K.F. demonstrates intact LTM despite impaired WM

Table 3.3. *Performance of STM patients on tests of LTM*

	KF[a]	JB[b]	WH[b]	PV[c]	Control
Wechsler paired-associate learning (success score)	14	18	11	19	14.8
Ten-word learning (no. trials)	7	10	9	4	9

[a] Warrington and Shallice (1969)
[b] Warrington, Logue, and Pratt (1971)
[c] Basso, Spinnler, Vallar, and Zanobia (1982)

From Shallice, 1988

Double Dissociation:
WM and LTM depend on different systems or processes

Outline

- What is Working Memory (WM)?
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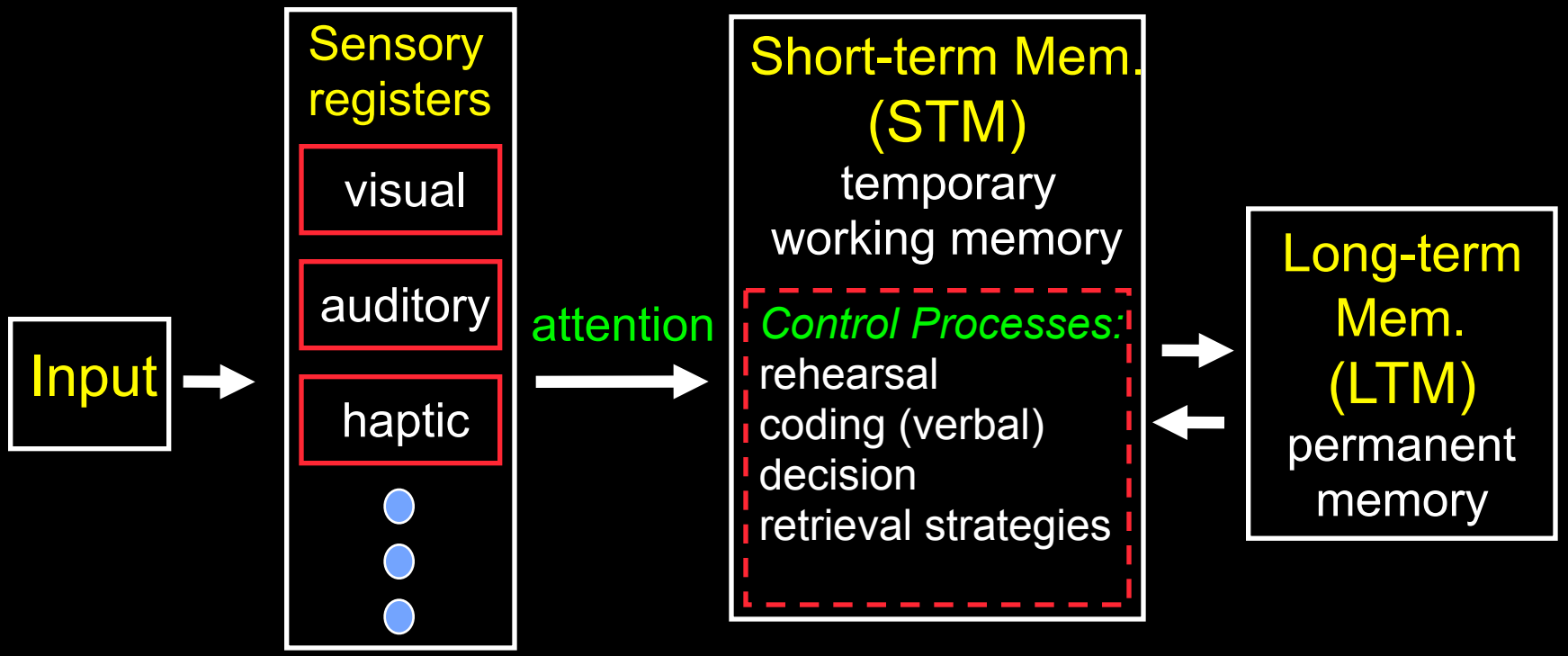
“Modal Model” of Memory



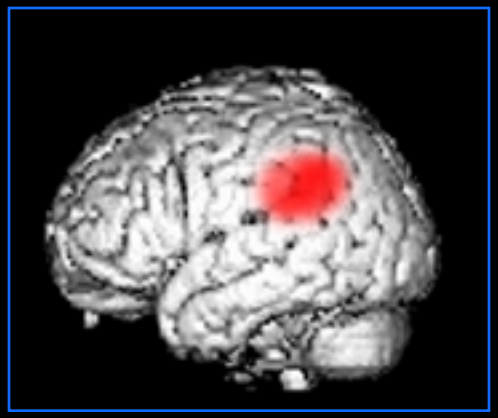
Atkinson & Shiffrin (1968)

Is WM Unitary?

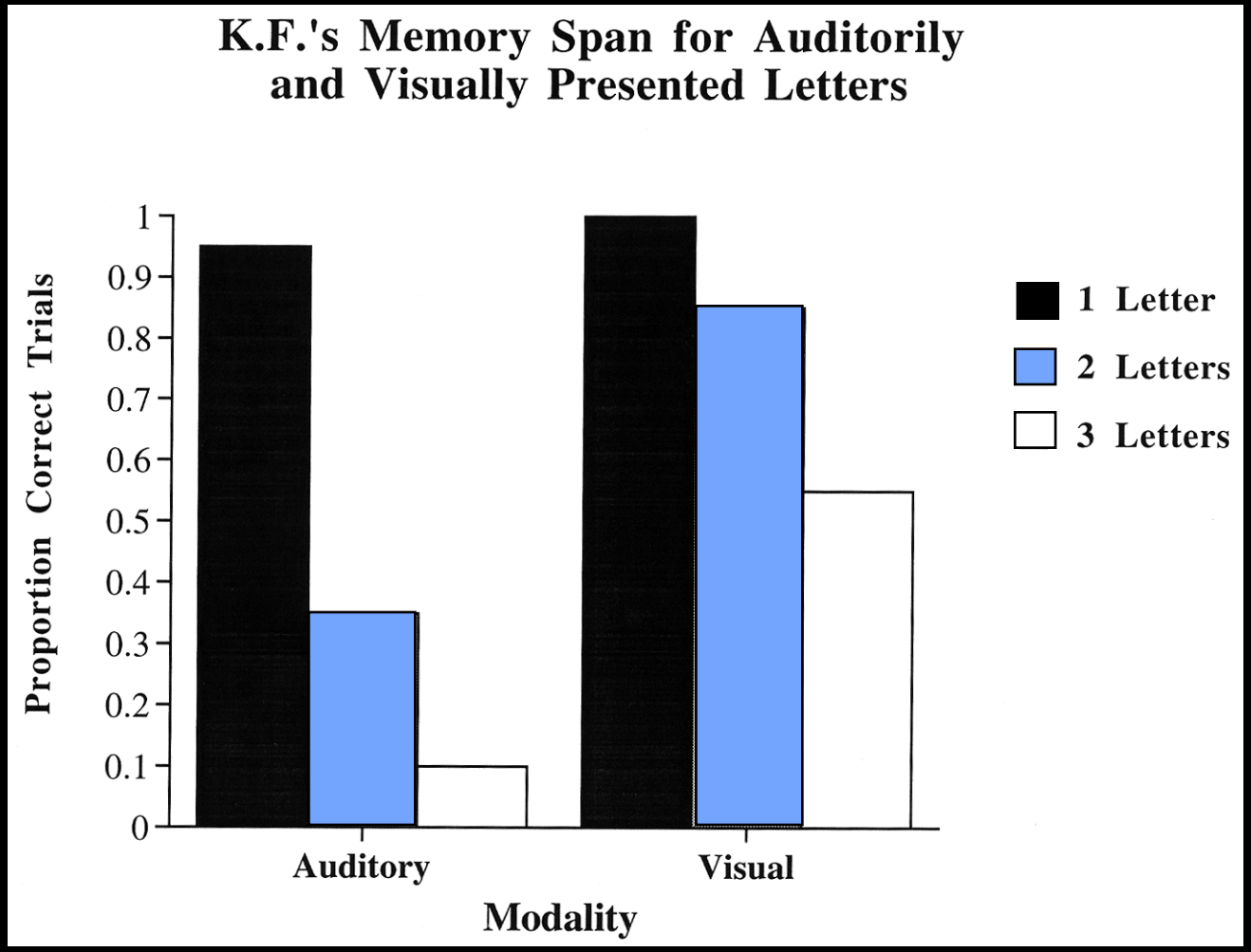
- In the modal model, all sensory modalities and types of information pass through a common STM store
- Neuropsychological and behavioral studies suggest WM can be fractionated

Auditory vs. Visual Letter Span: Neuropsychological Data

Patient K.F.



- Left hemisphere temporal/parietal lesion
- Impaired auditory span relative to visual span

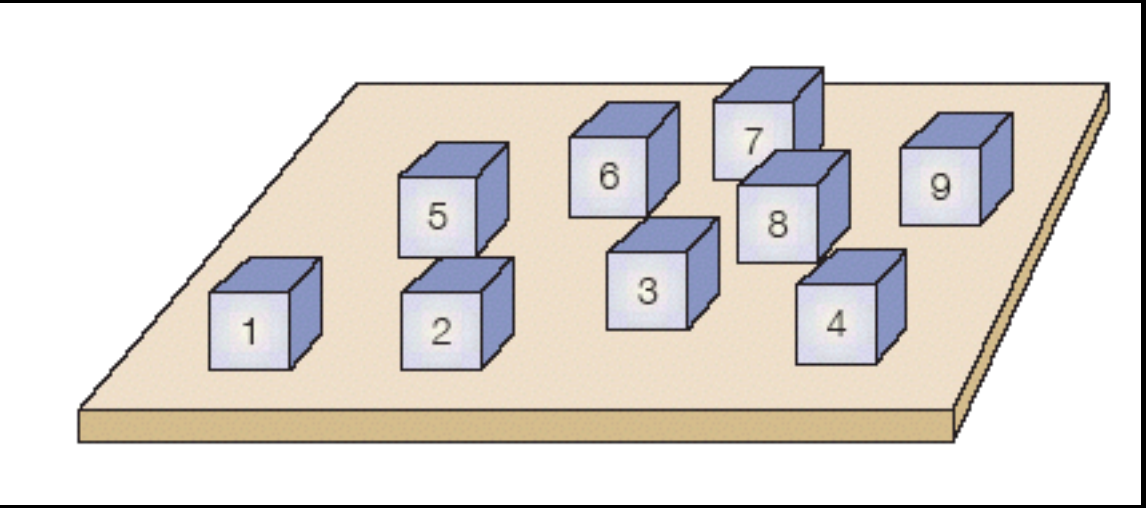


Visuospatial Working Memory: Neuropsychological Data

Patient E.L.D.

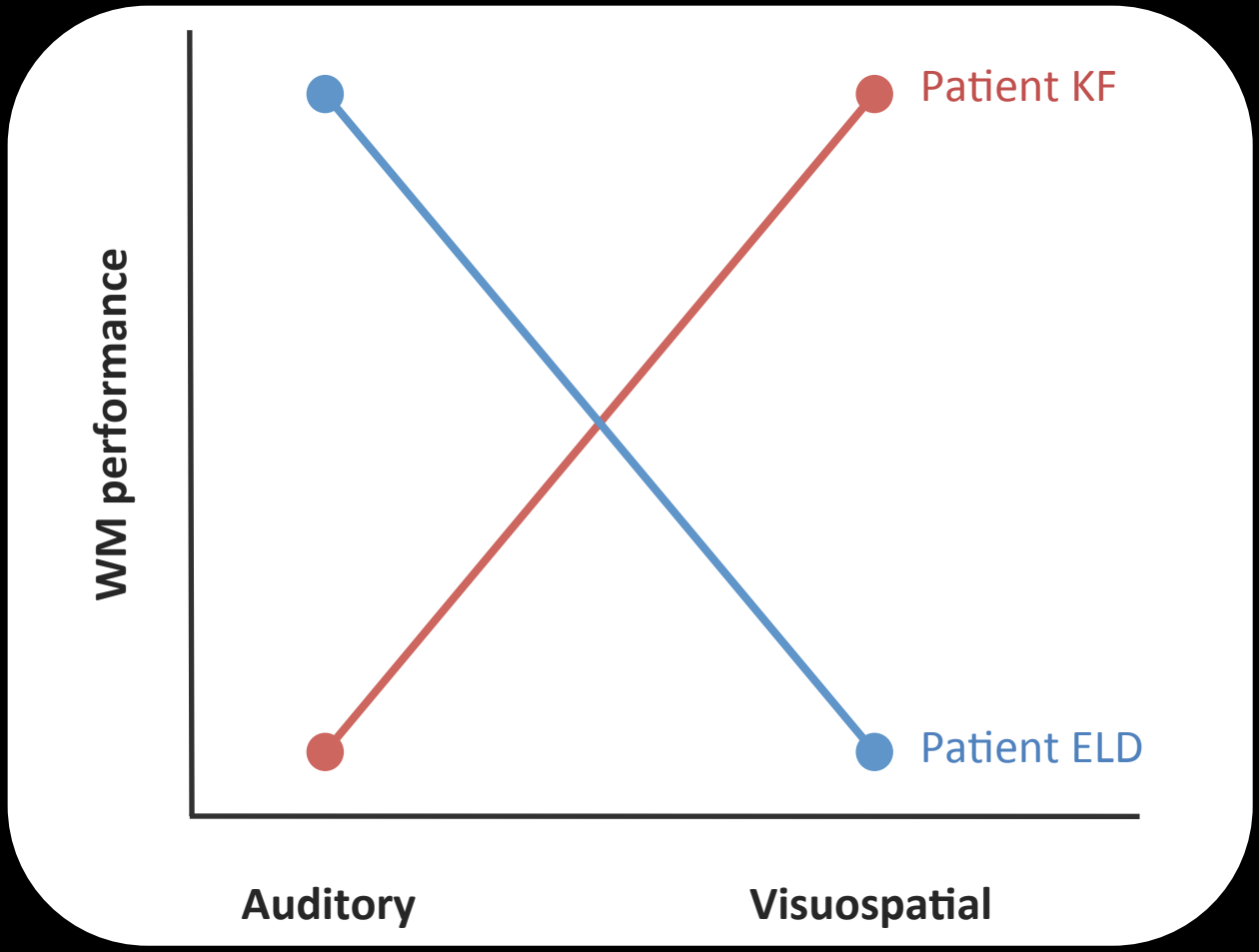
- Right hemisphere frontal/temporal lesion
- Impaired visuospatial WM, normal auditory verbal WM

Corsi Block-Tapping Test



(Hanley et al., 1991)

Double Dissociation within WM



- suggests that WM is not a unitary function
- similar double dissociations seen in healthy Ss using dual-task distraction paradigms

Brain Imaging Evidence on WM: Reminder about Neuroimaging "Subtractive" Logic

Brain is always "active"

– "baseline" firing rates

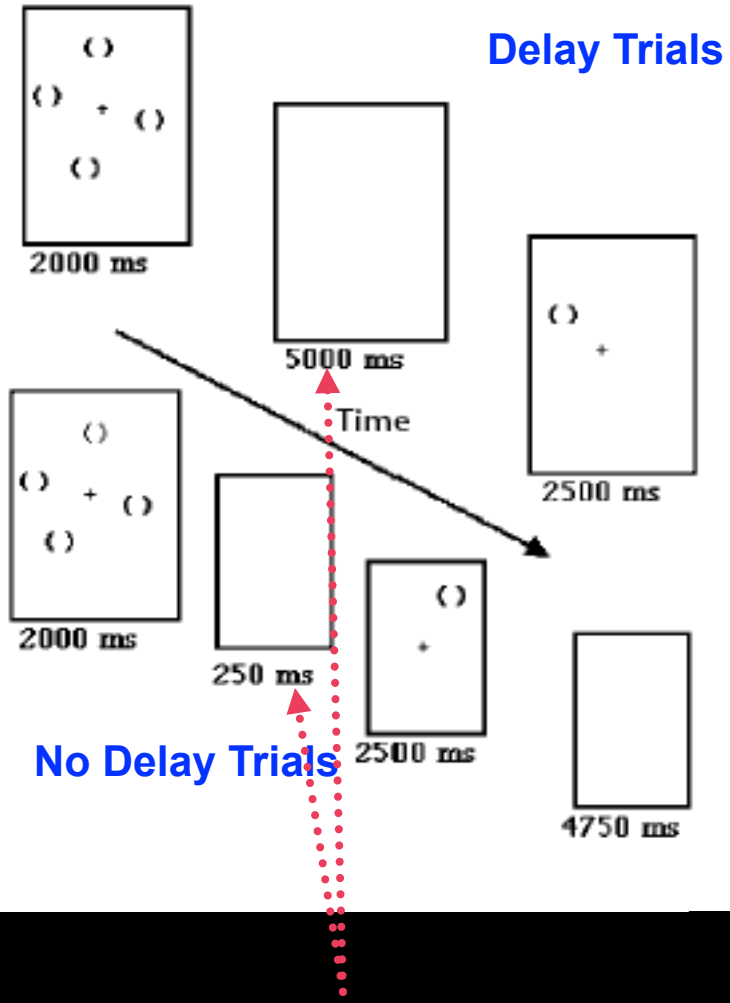
– "baseline" blood flow/blood oxygenation levels

To measure a response, need to **COMPARE** at least two conditions

Condition 2 – Condition 1 ("difference image")

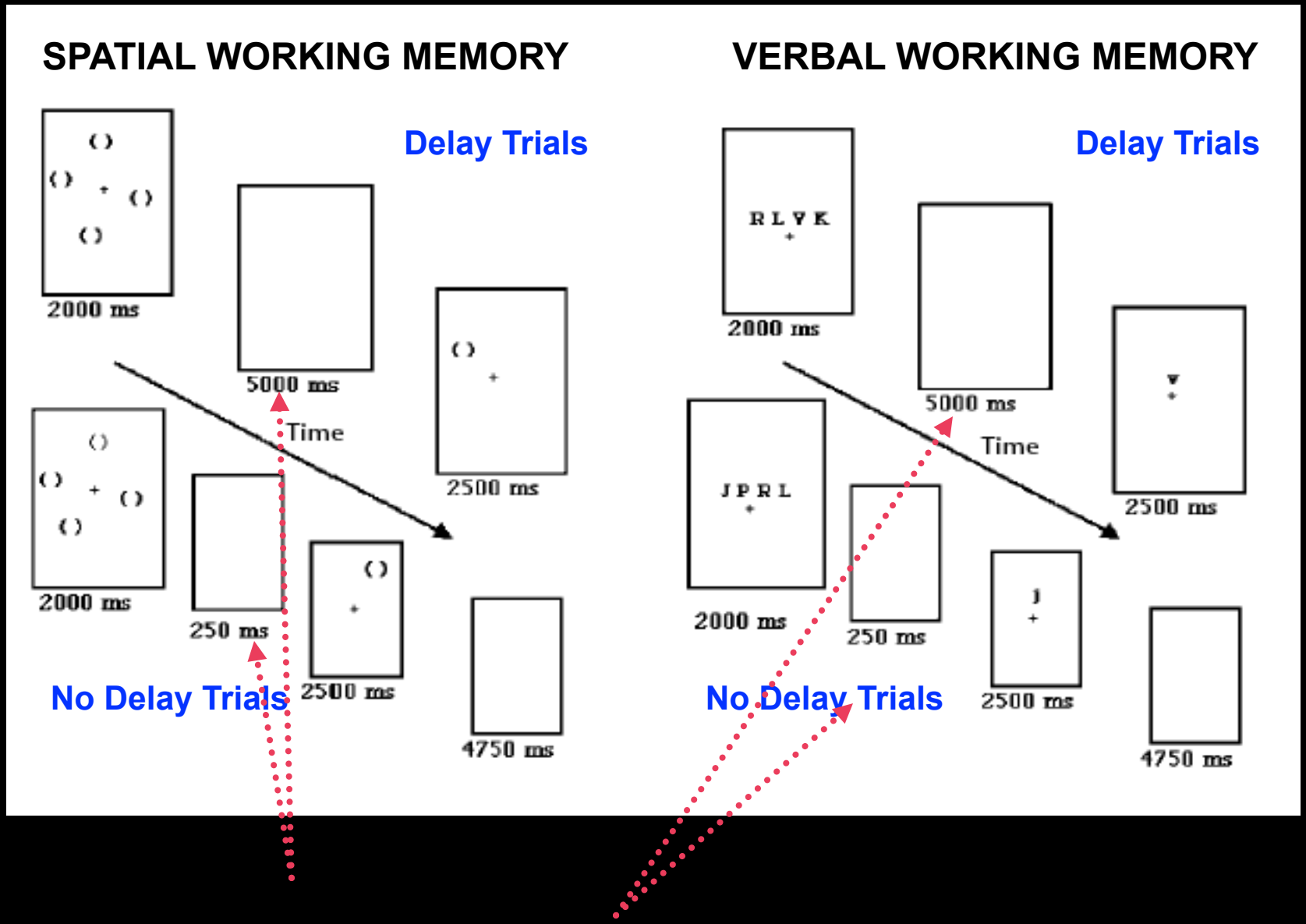
(Prabhakaran et al., 2000)

SPATIAL WORKING MEMORY



Assumption: differences in brain response are due to the different cognitive demands of having to maintain information across a 5000 vs 250 ms delay

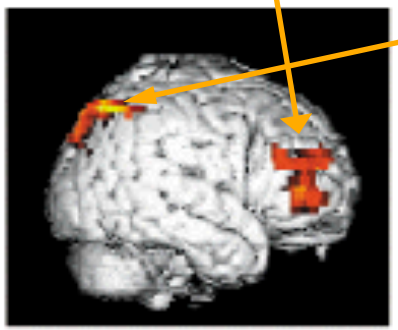
(Prabhakaran et al., 2000)

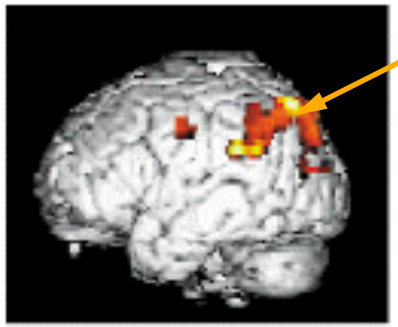


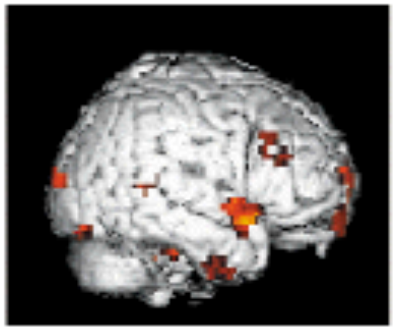
Assumption: differences in brain response are due to the different cognitive demands of having to maintain information across a 5000 vs 250 ms delay

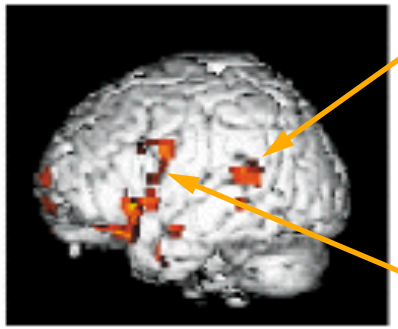
Spatial and Verbal WM Maintenance

(Delay Trials – No Delay Trials)









Right Frontal

Bilateral Superior Parietal

SPATIAL

Left Inferior Parietal & Temporal

VERBAL

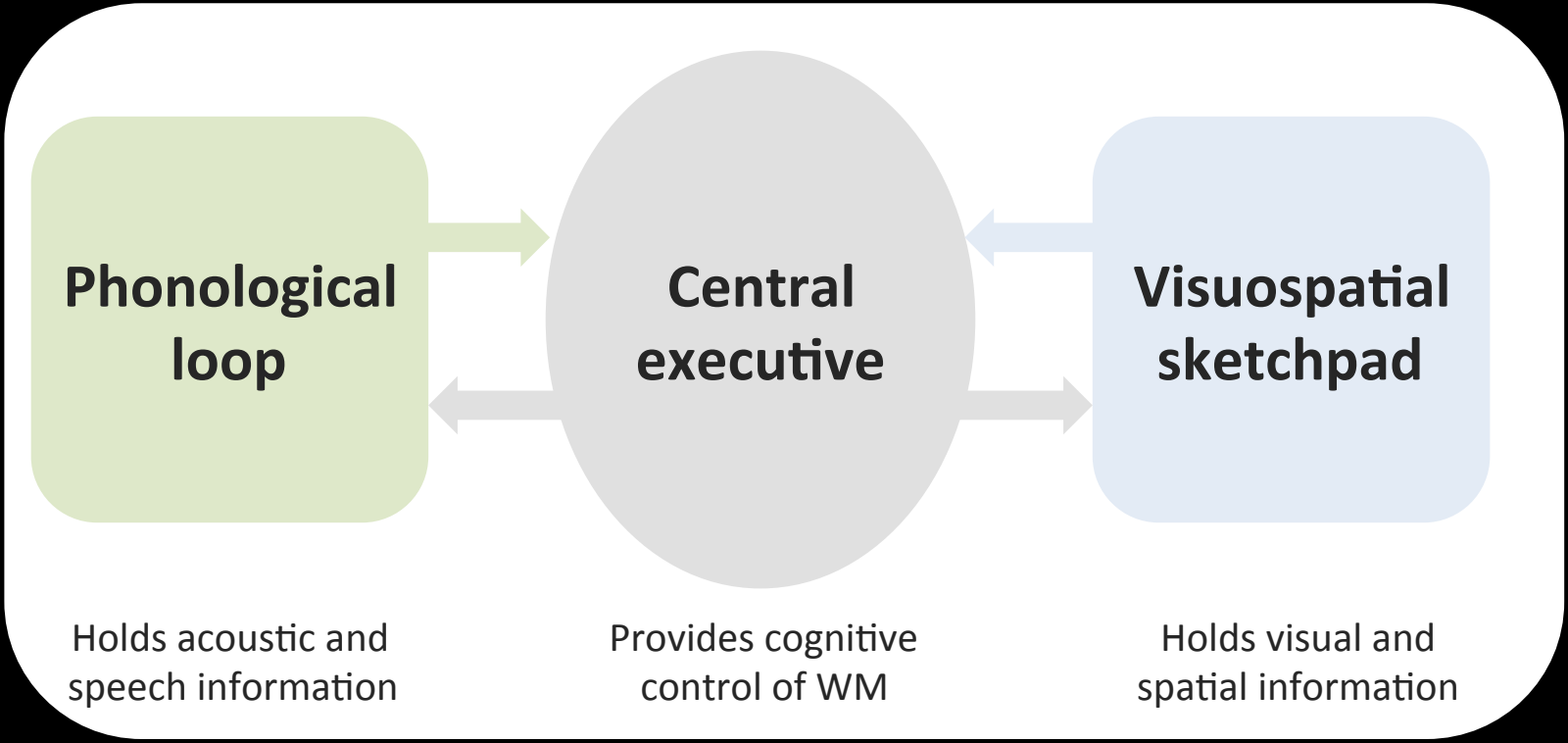
Left Inferior Frontal (Broca's) & Premotor

Right

Left

Tripartite Model of WM

(Baddeley & Hitch, 1974)



- Highly influential multi-component model of WM
- Combined processing & storage model

The Phonological Loop

Phonological store

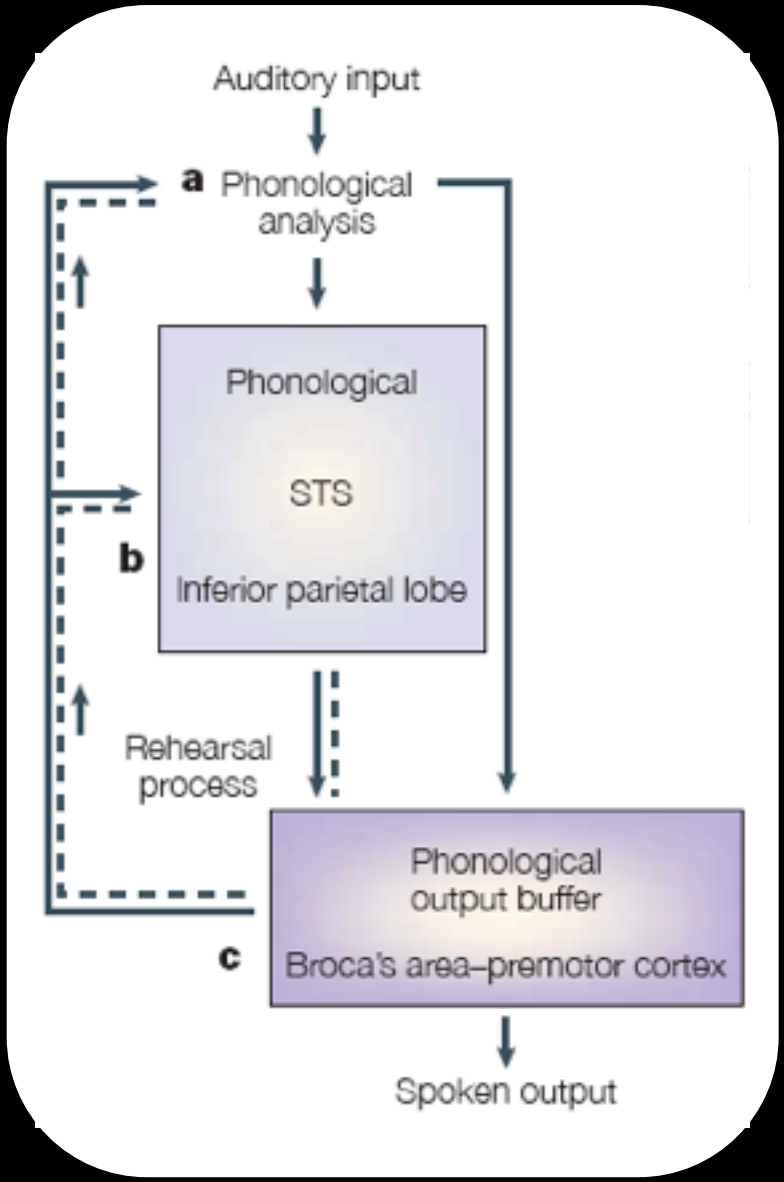
- stores active phonological representations

Phonological rehearsal/control

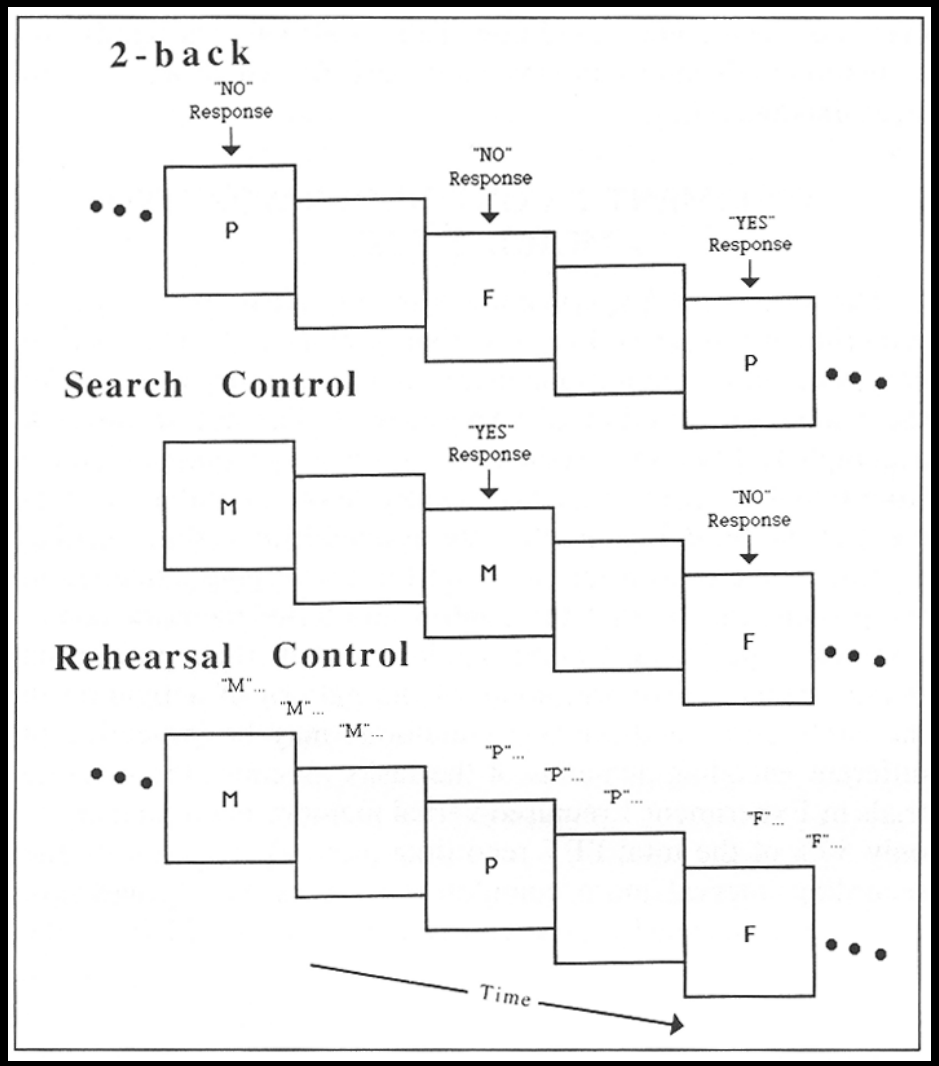
- subvocal rehearsal maintains phonological representations

Behavioral Evidence

- Impairments with longer words, phonologically similar words, and with articulatory suppression
- Visuospatial information doesn't cause much interference



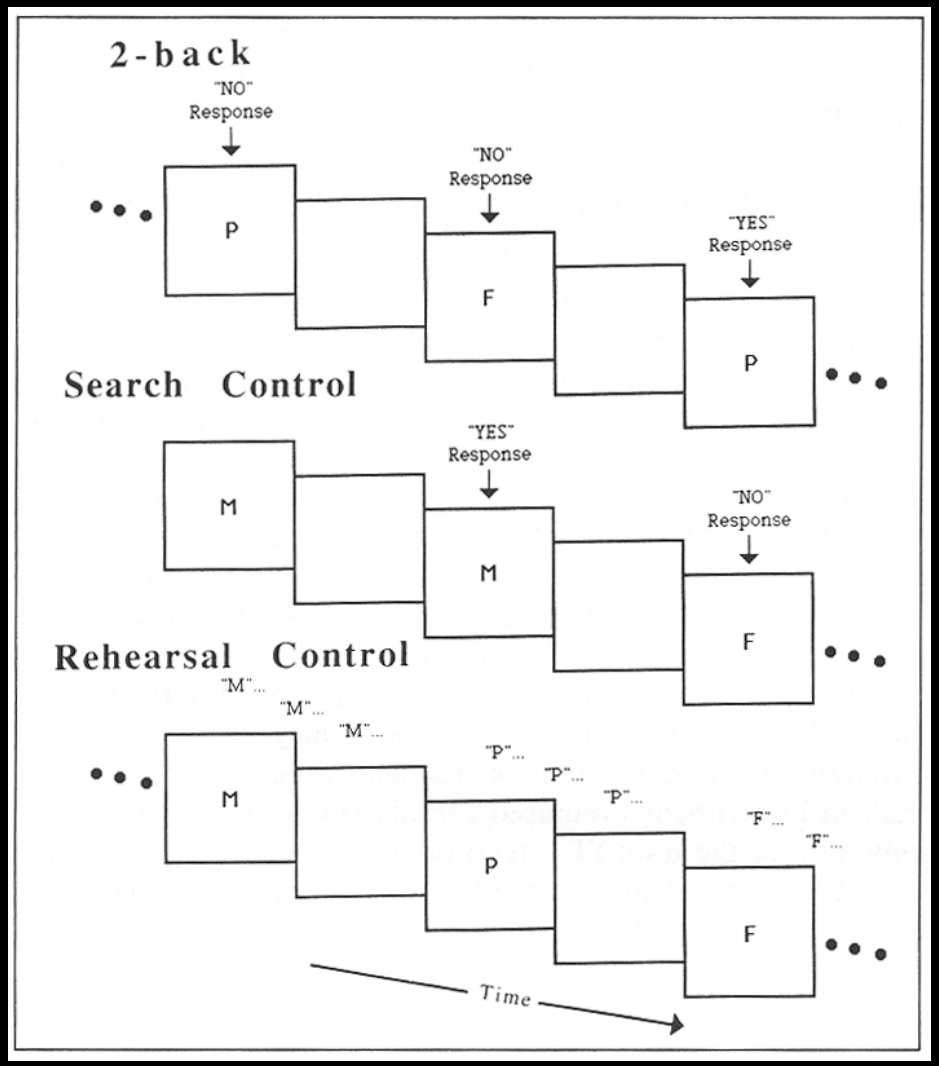
PET: Separating Phonological Rehearsal from Storage



2-Back > Search Control

- left frontal (Broca's area)
- left inferior parietal lobe

PET: Separating Phonological Rehearsal from Storage



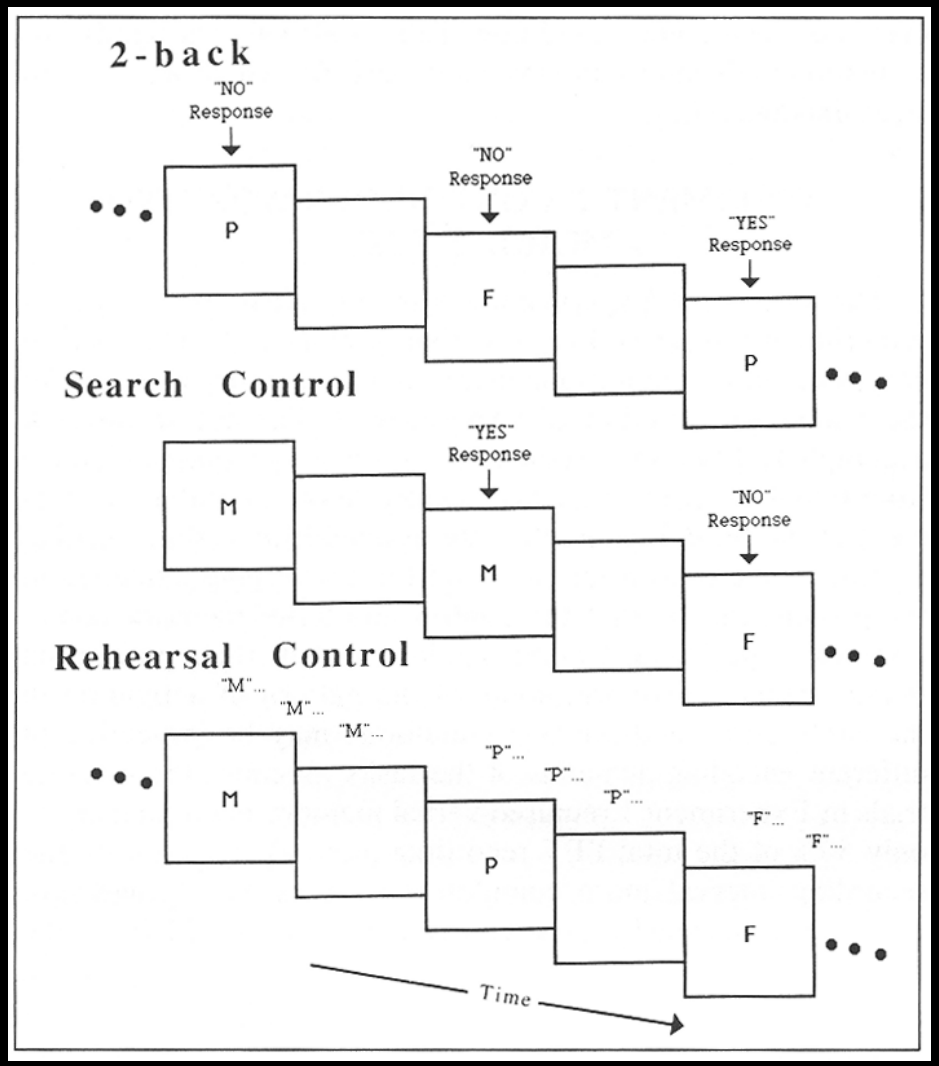
2-Back > Search Control

- left frontal (Broca's area)
- left inferior parietal lobe

2-Back > Rehearsal Control

- left inferior parietal lobe

PET: Separating Phonological Rehearsal from Storage

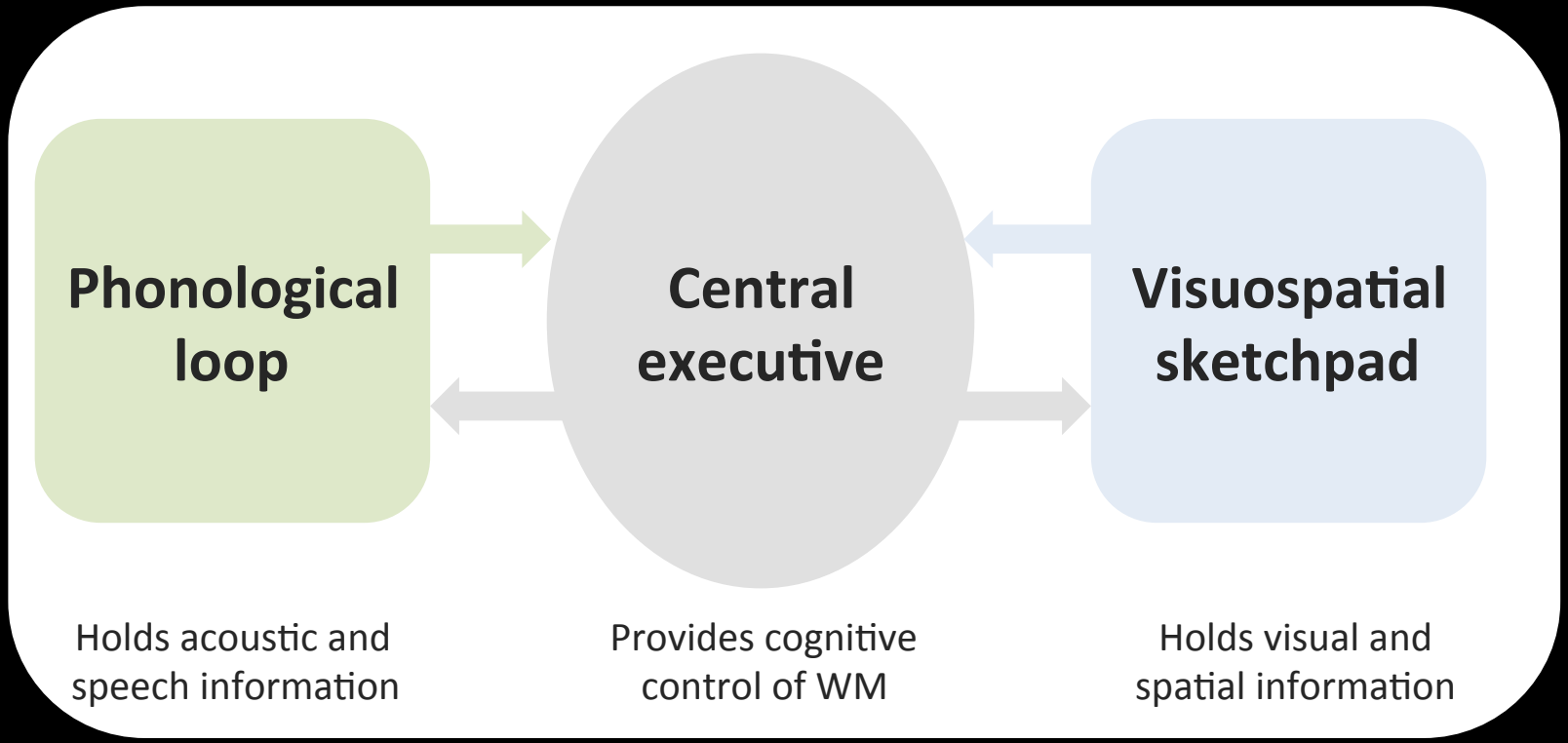


2-Back > Search Control
- left frontal (Broca's area)
- left inferior parietal lobe

2-Back > Rehearsal Control
- left inferior parietal lobe

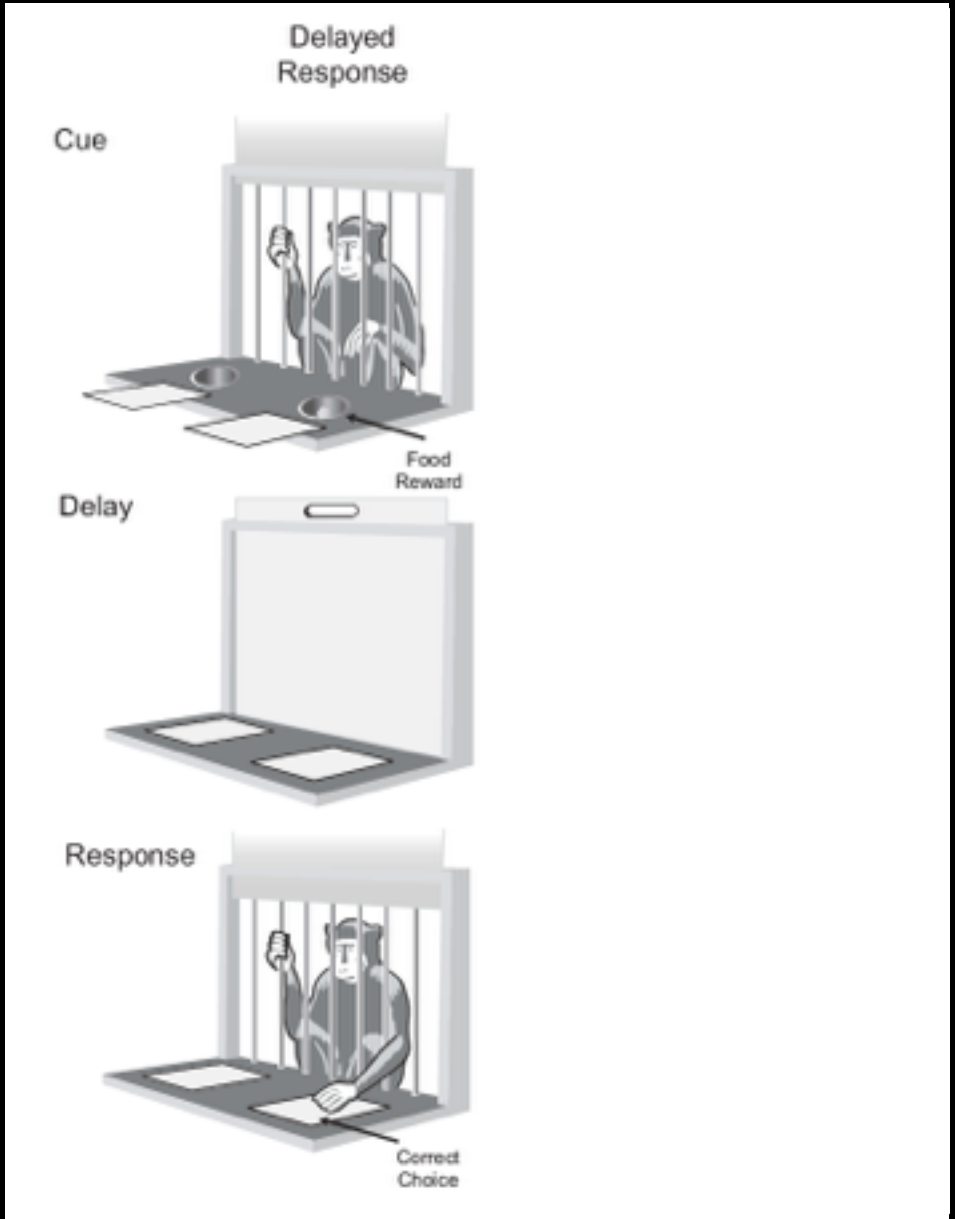
inference: left frontal = rehearsal control mechanism
left inferior parietal = storage

Tripartite Model of WM
(Baddeley & Hitch, 1974)



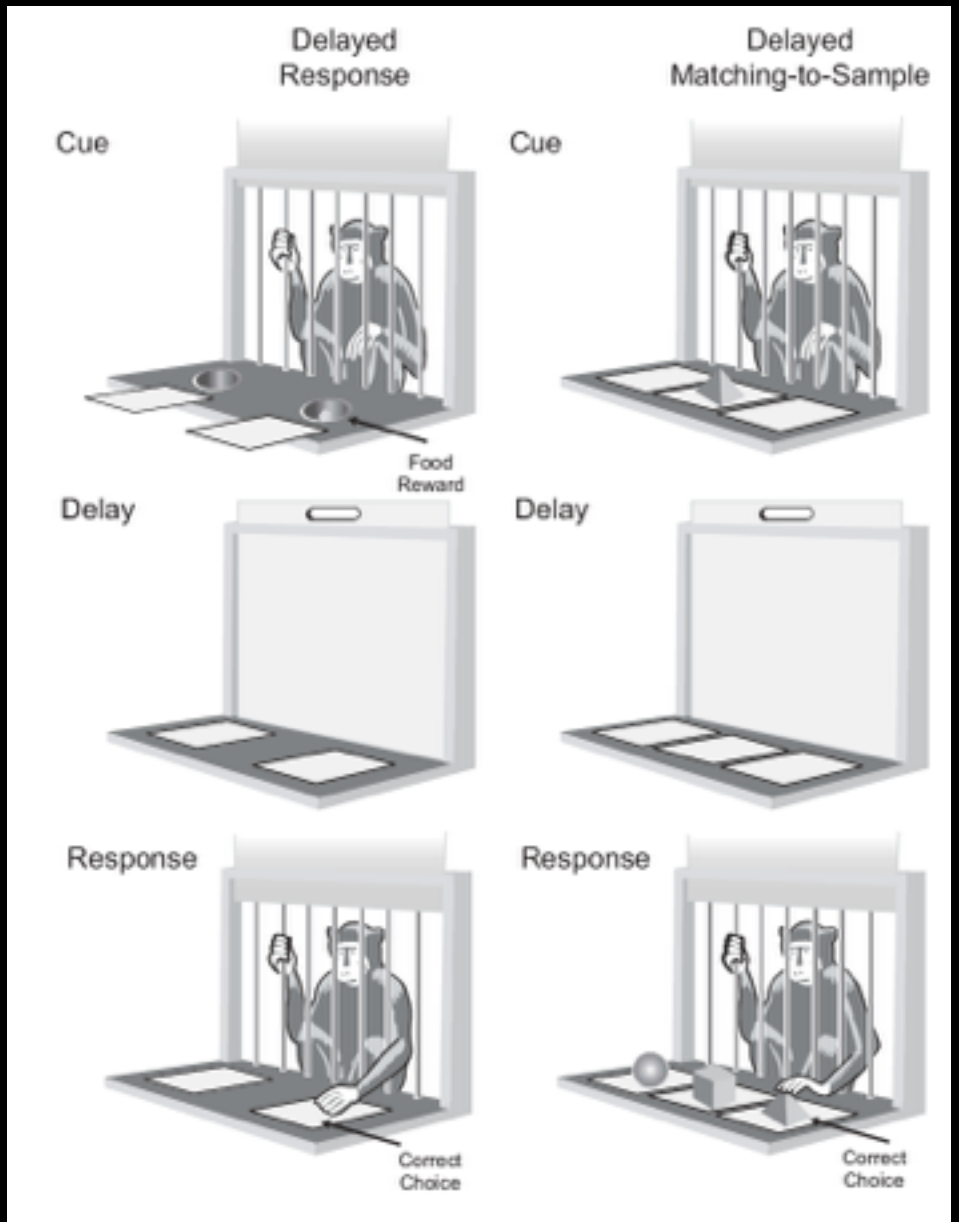
Visual WM for "What" (object) and "Where" (spatial)

Prefrontal Cortex is Necessary for Object and Spatial WM



Jacobson et al. 1935

Prefrontal Cortex is Necessary for Object and Spatial WM



Jacobson et al. 1935

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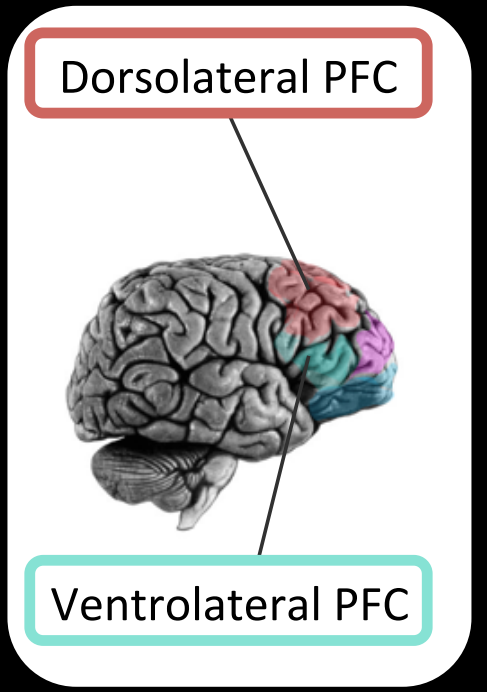
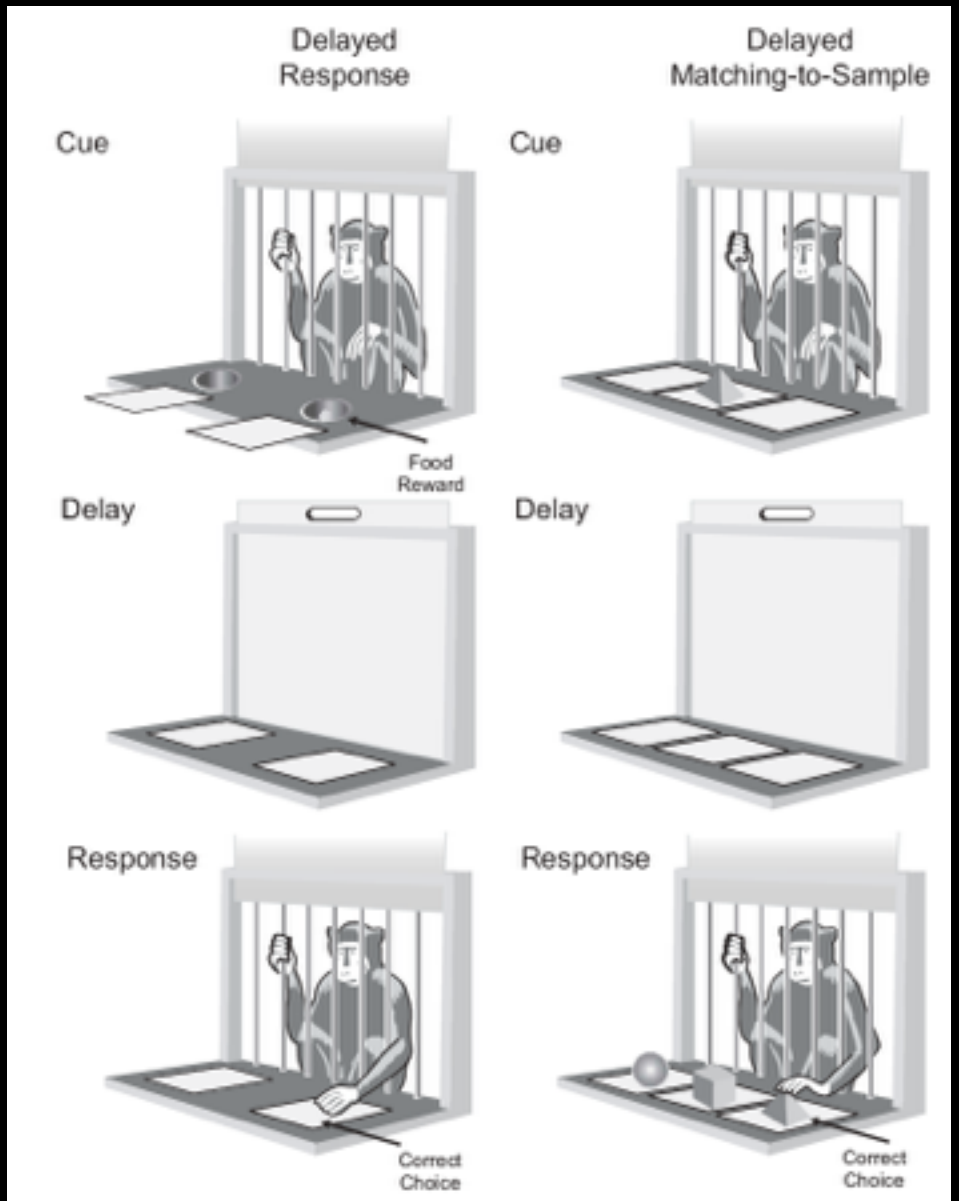




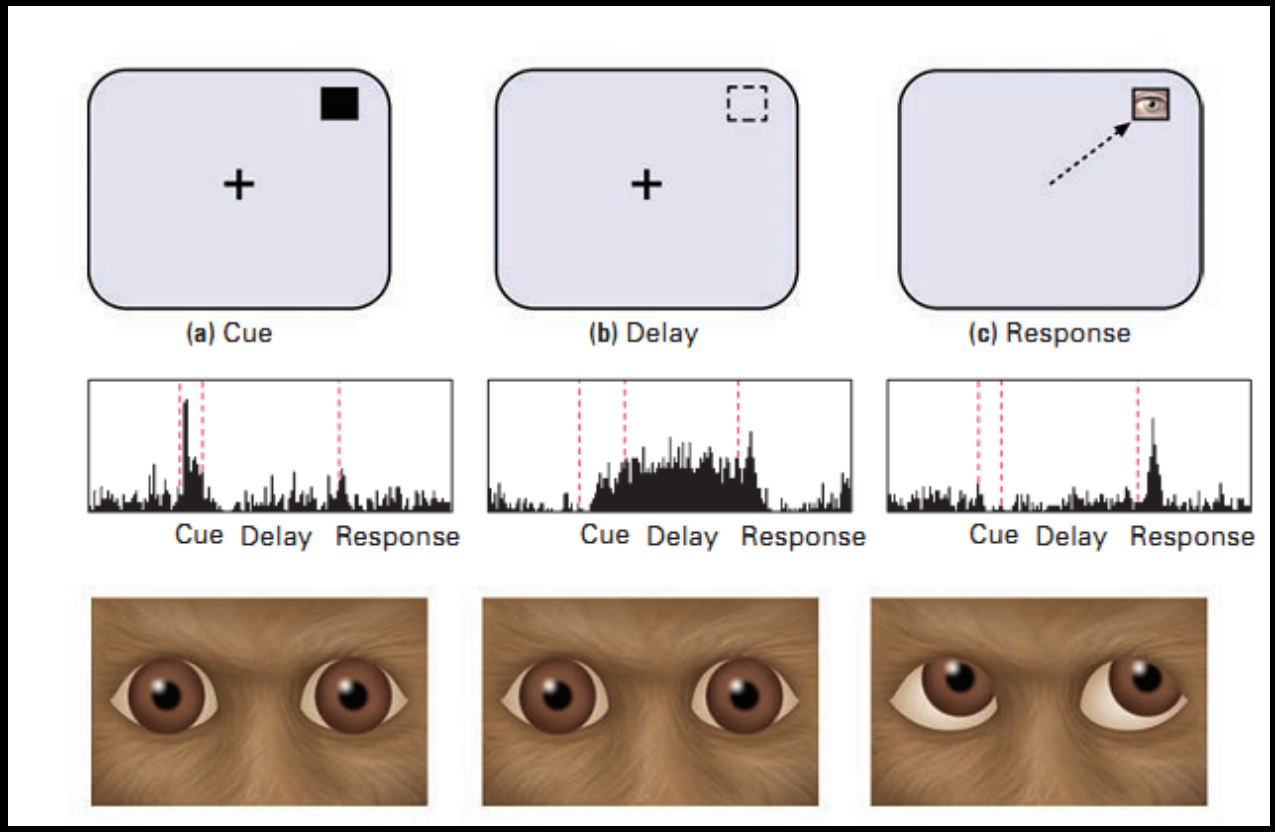
- monkeys with PFC lesions show impaired performance

- however, turn out the lights during the delay period and performance improves (though may not be normal)

Jacobson et al. 1935

Prefrontal Cortex and Spatial WM: Neurophysiological Data

Recordings in primates during a delayed-response eye gaze task



(Funahashi et al., 1989)

Prefrontal Cortex and Spatial WM: Neurophysiological Data

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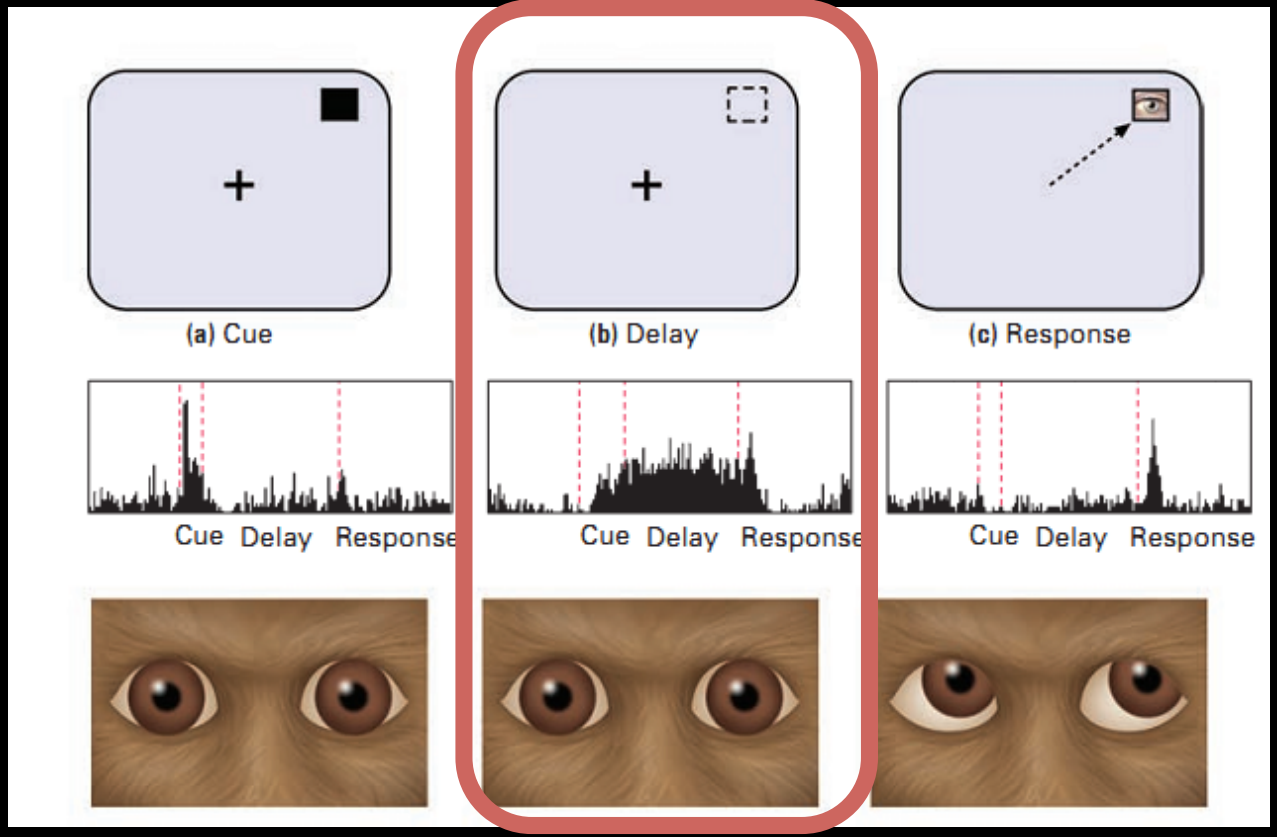
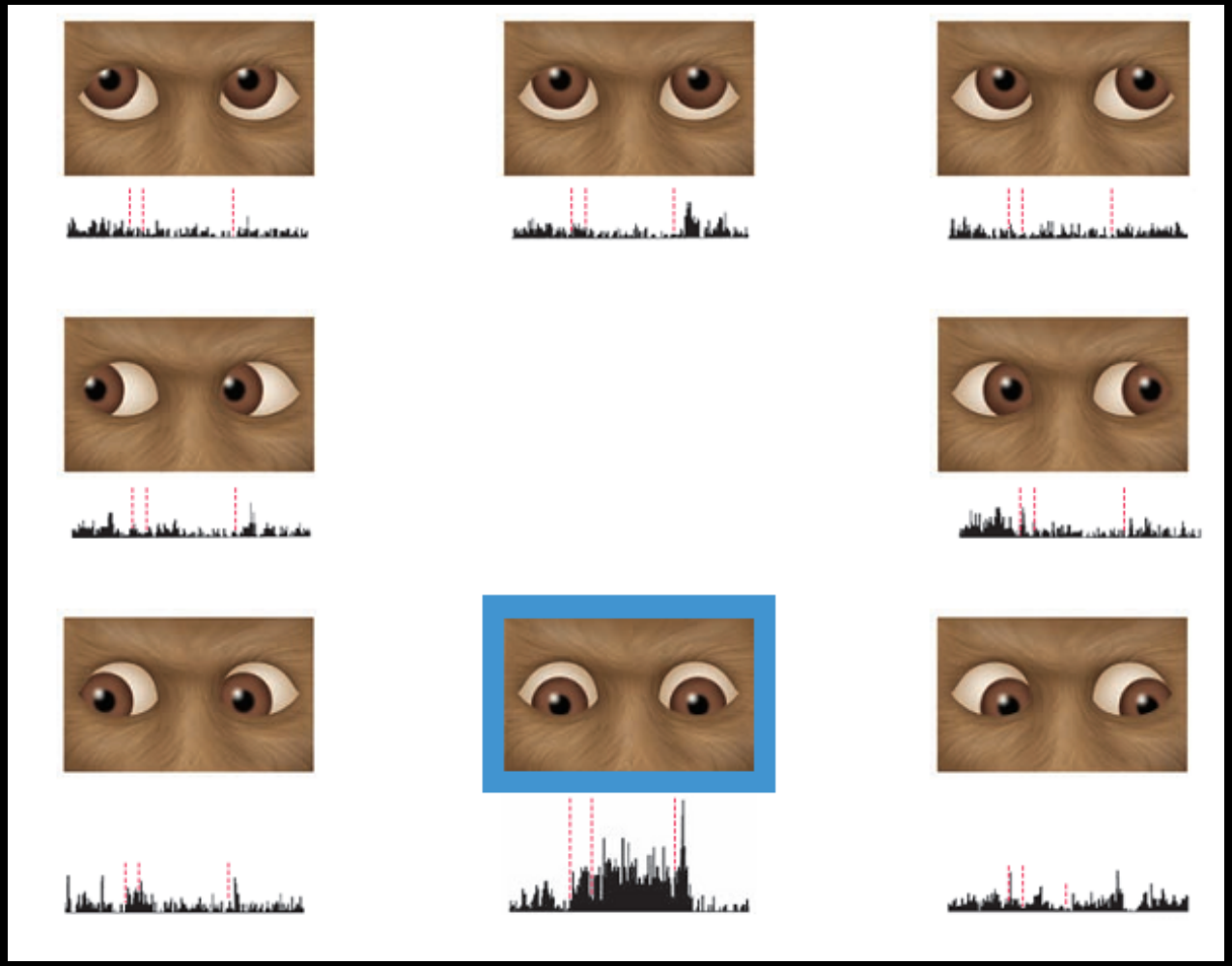


(Funahashi et al., 1989)

Prefrontal Cortex and Spatial WM: Neurophysiological Data

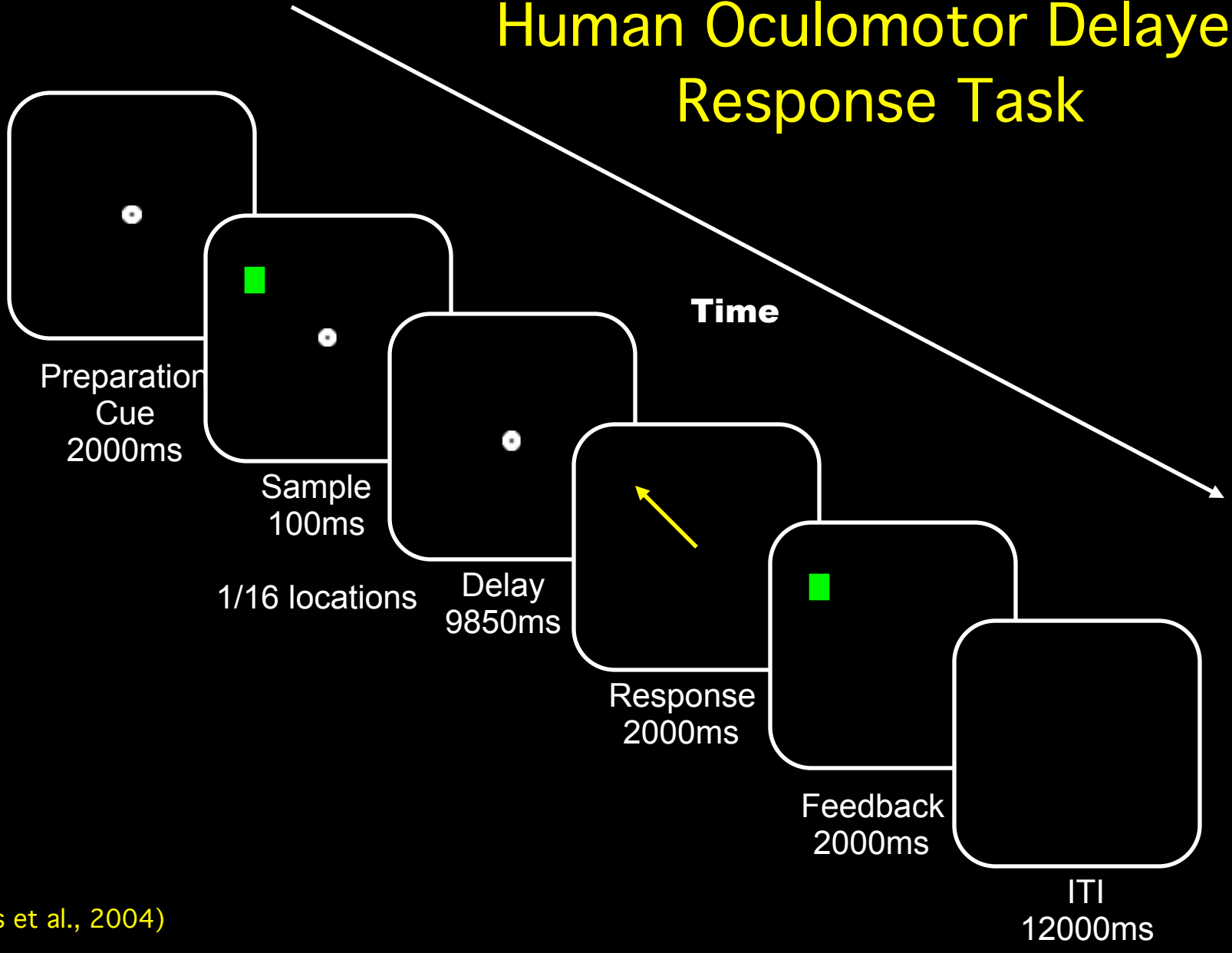
Recordings from the **SAME** neuron



- "Delay" neurons code for different spatial locations
- e.g., this neuron only fires when the monkey is remembering the bottom-center location during the delay period

(Funahashi et al., 1989)

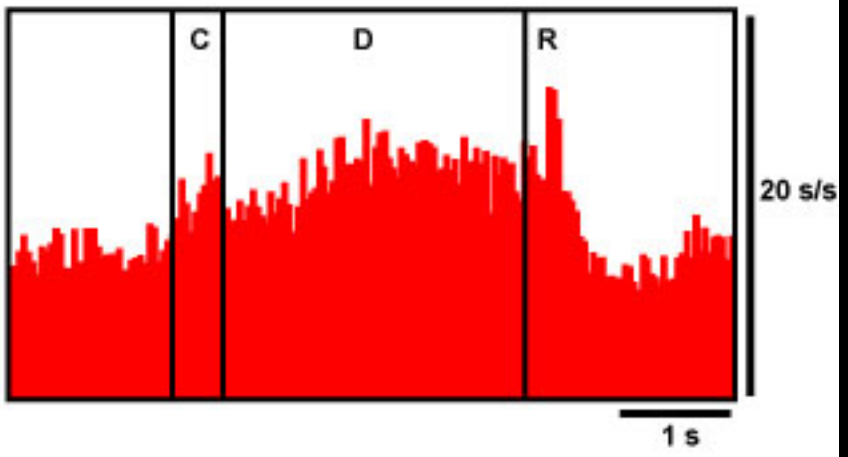
Human Oculomotor Delayed Response Task



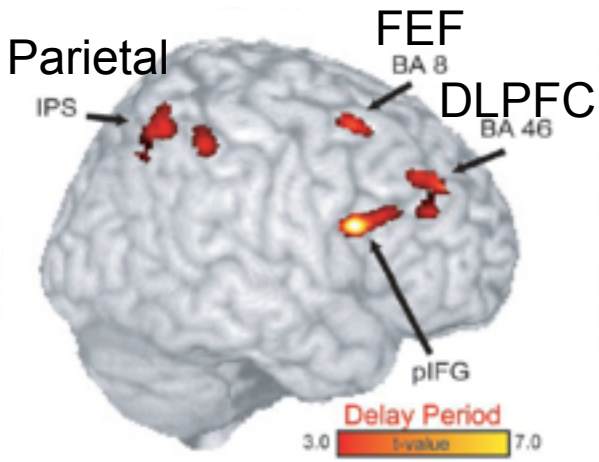
(Curtis et al., 2004)

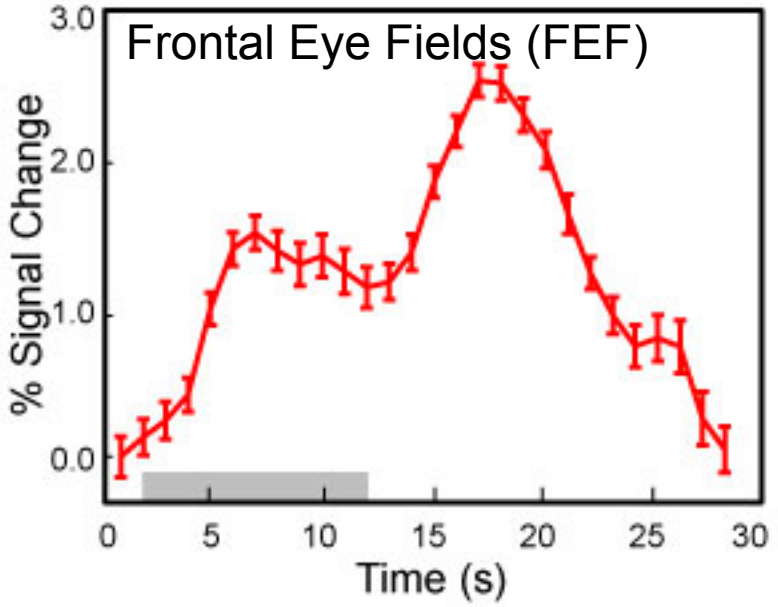
Prefrontal and Parietal Cortices: Oculomotor Delayed Response Task

MONKEY - Single Unit Recordings



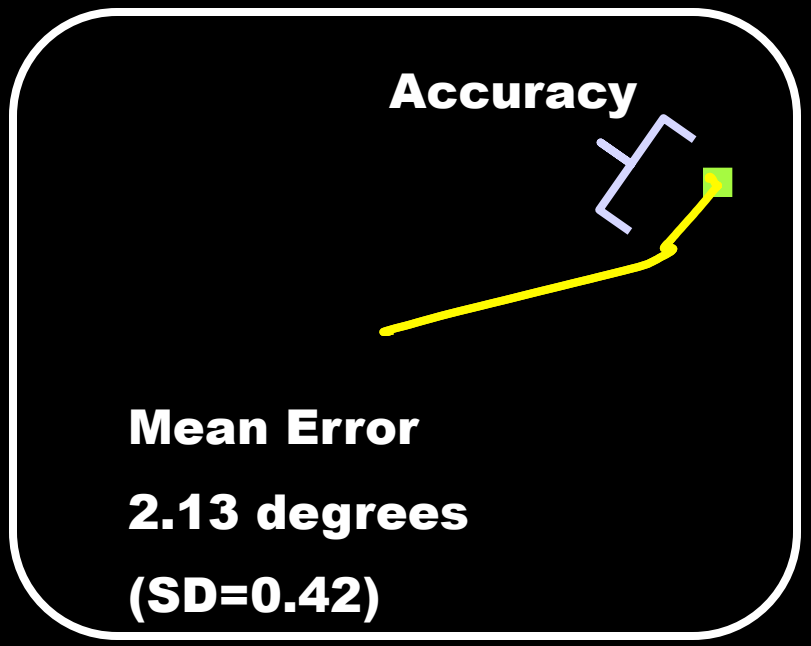
HUMAN - Functional MRI Activity





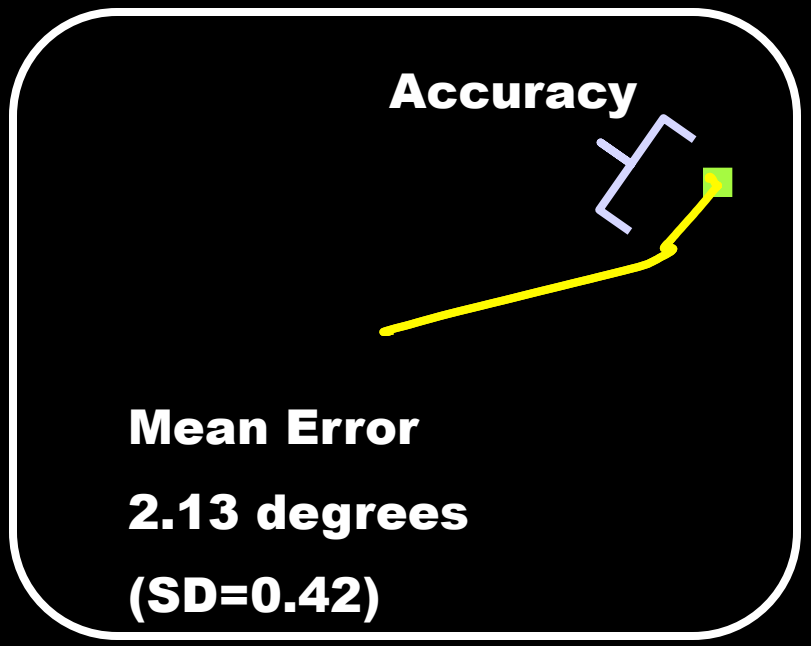
Curtis et al., 2004

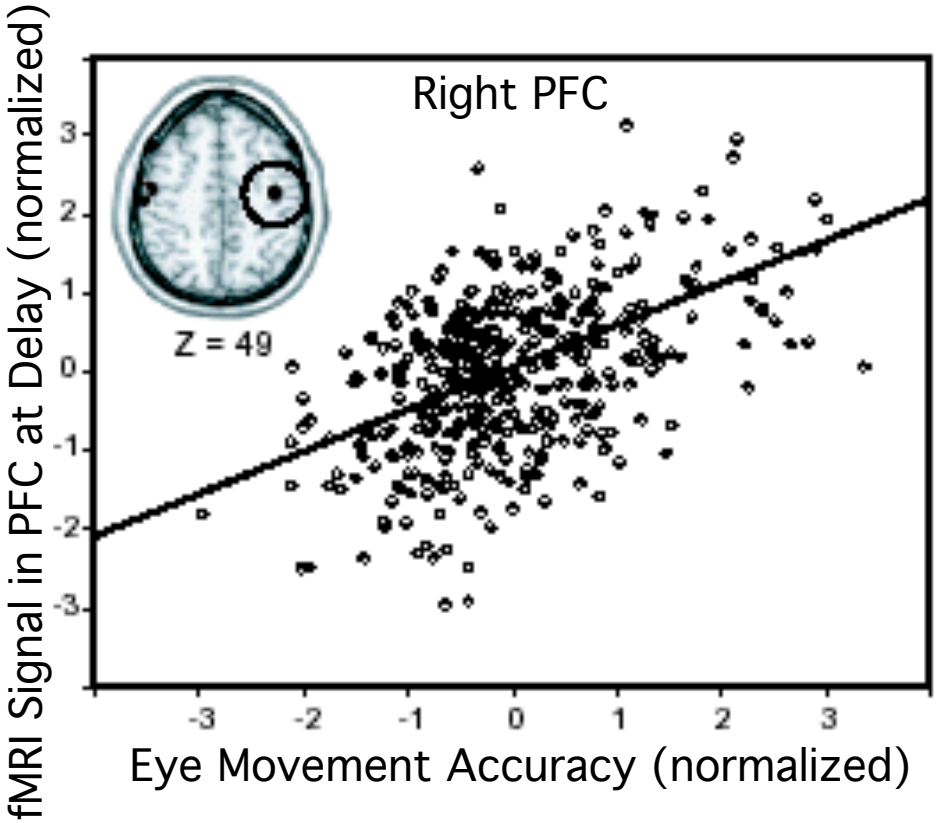
Prefrontal and Parietal Cortices: Oculomotor Delayed Response Task



(Curtis et al., 2004)

Prefrontal and Parietal Cortices: Oculomotor Delayed Response Task

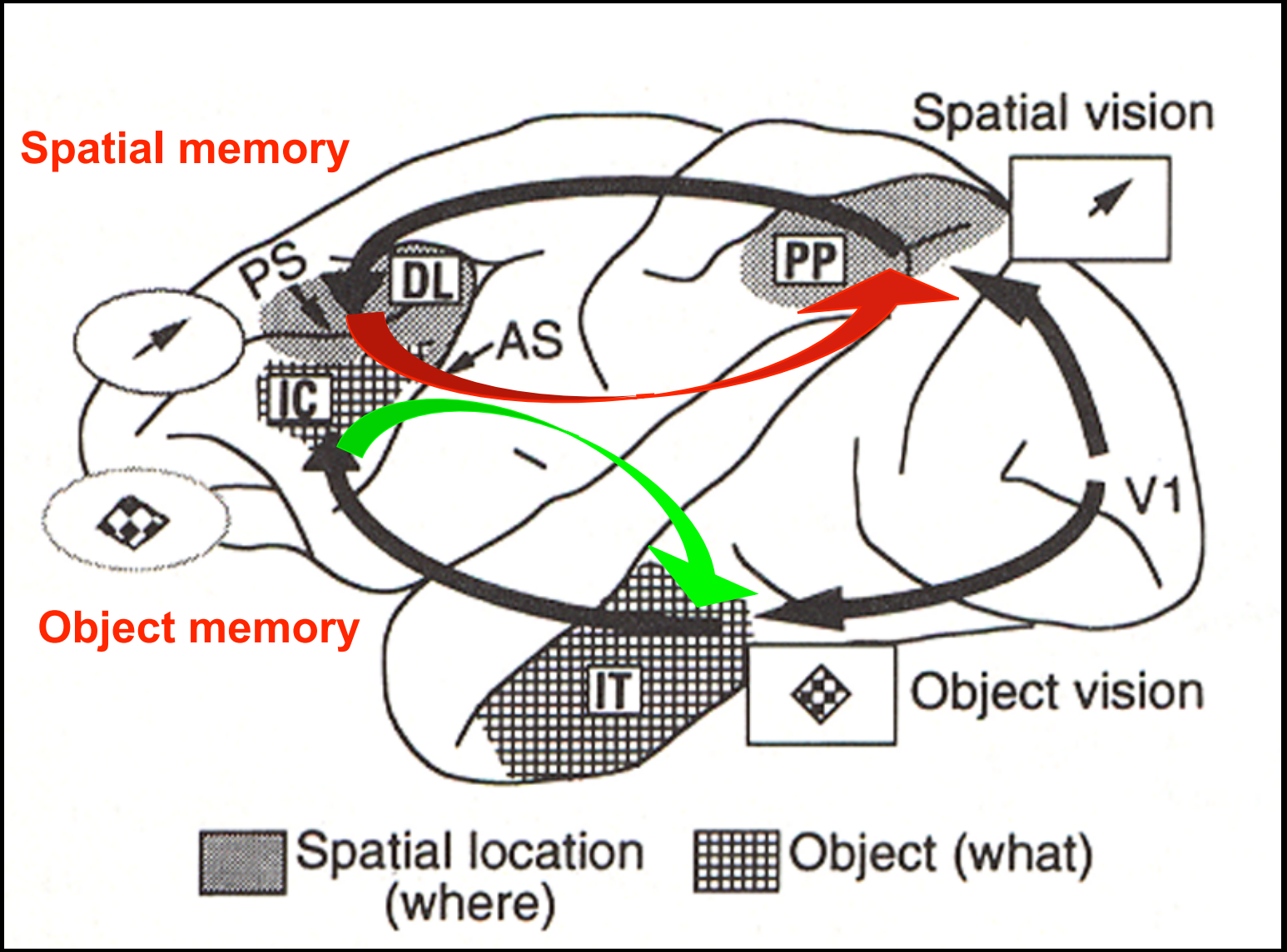




(Curtis et al., 2004)

WM delay periods
– prefrontal cortex neural firing rates increase
– disrupt delay period activity and performance declines (causation)
– firing rates in posterior cortical regions also increase

WM and Cortical Circuits: Reverberating Activity



maintenance in WM:

persistent top-down interactions between frontal cortex and posterior representations

PFC also able to self-maintain content

(Wilson et al., 1993)

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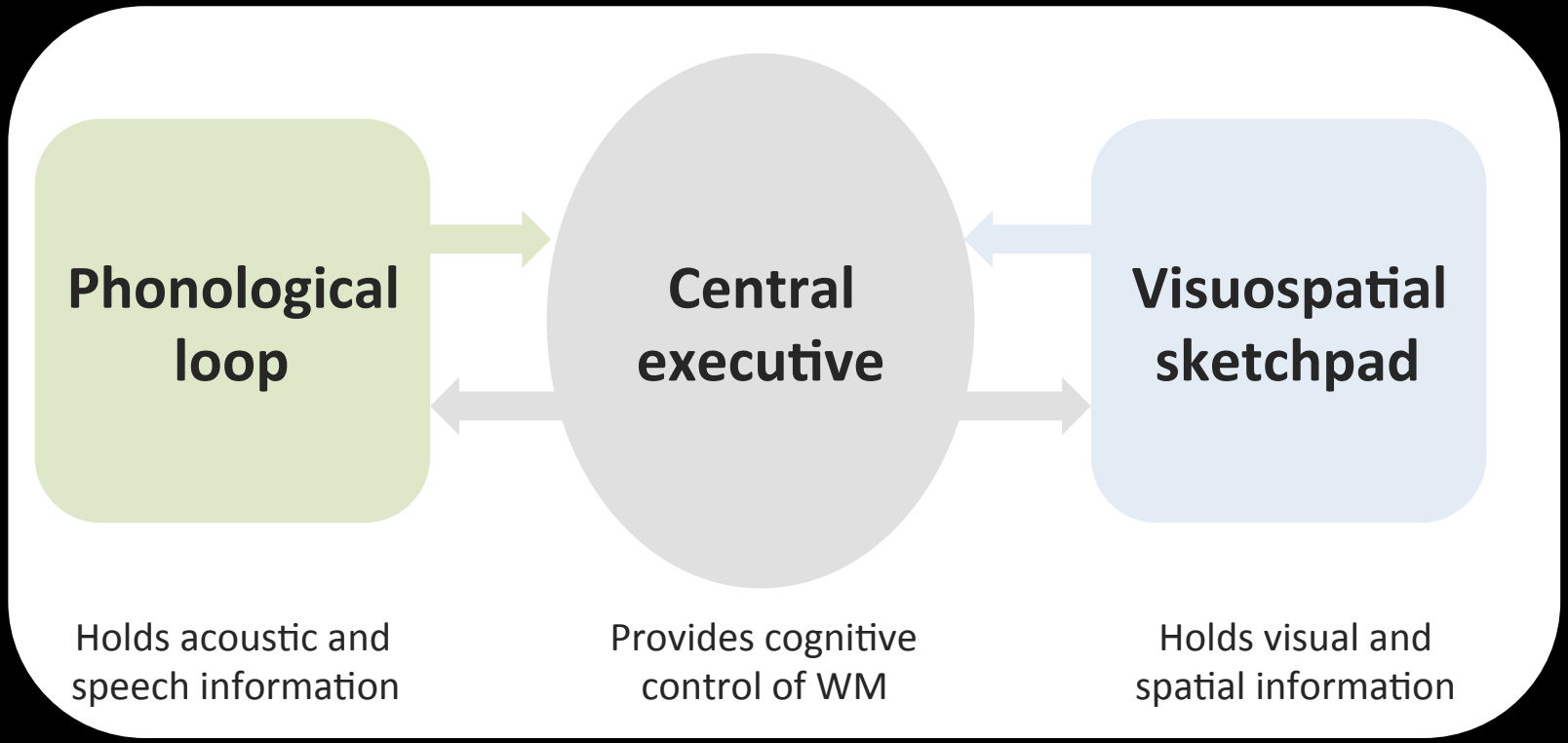
Tripartite Model of WM?

(Baddeley & Hitch, 1974)



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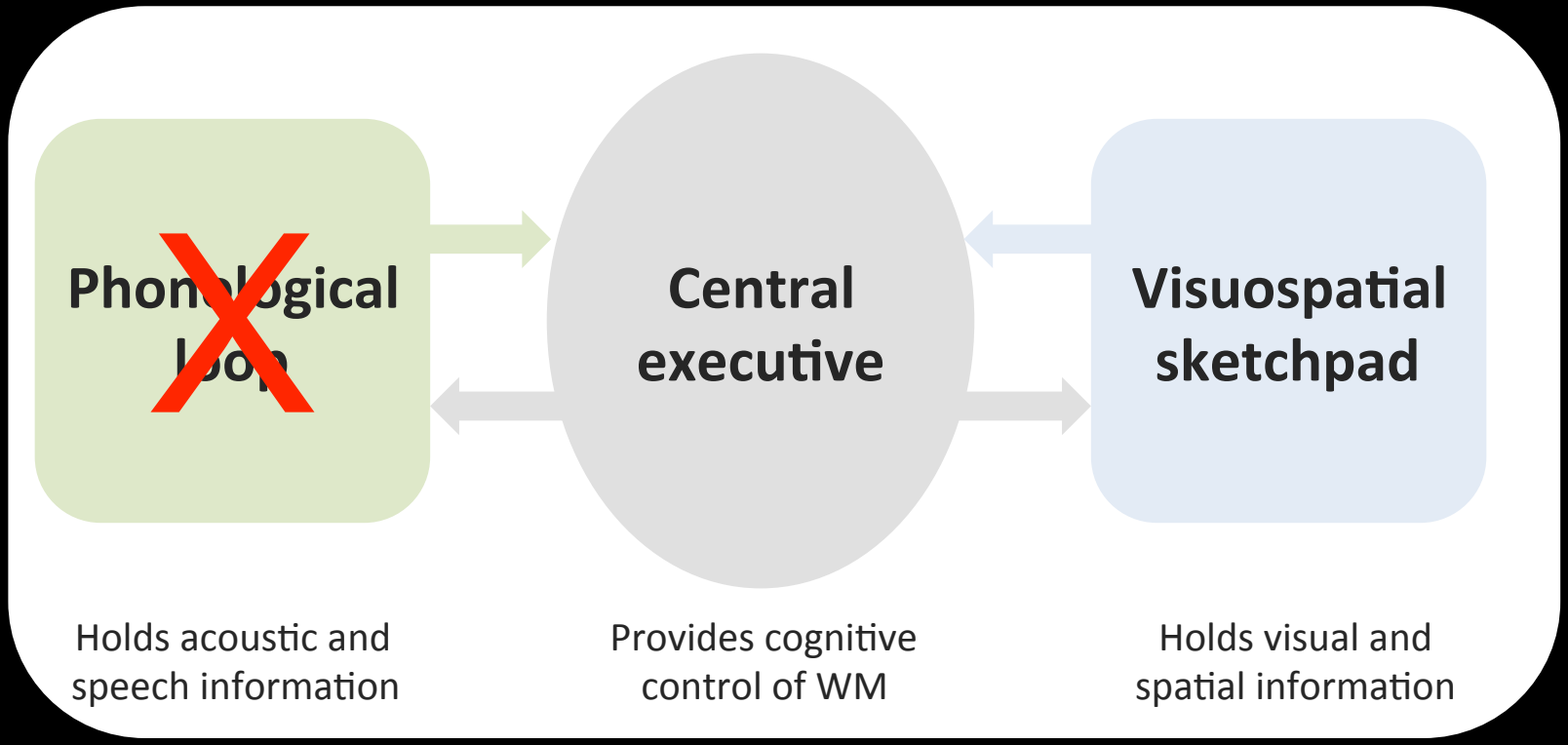
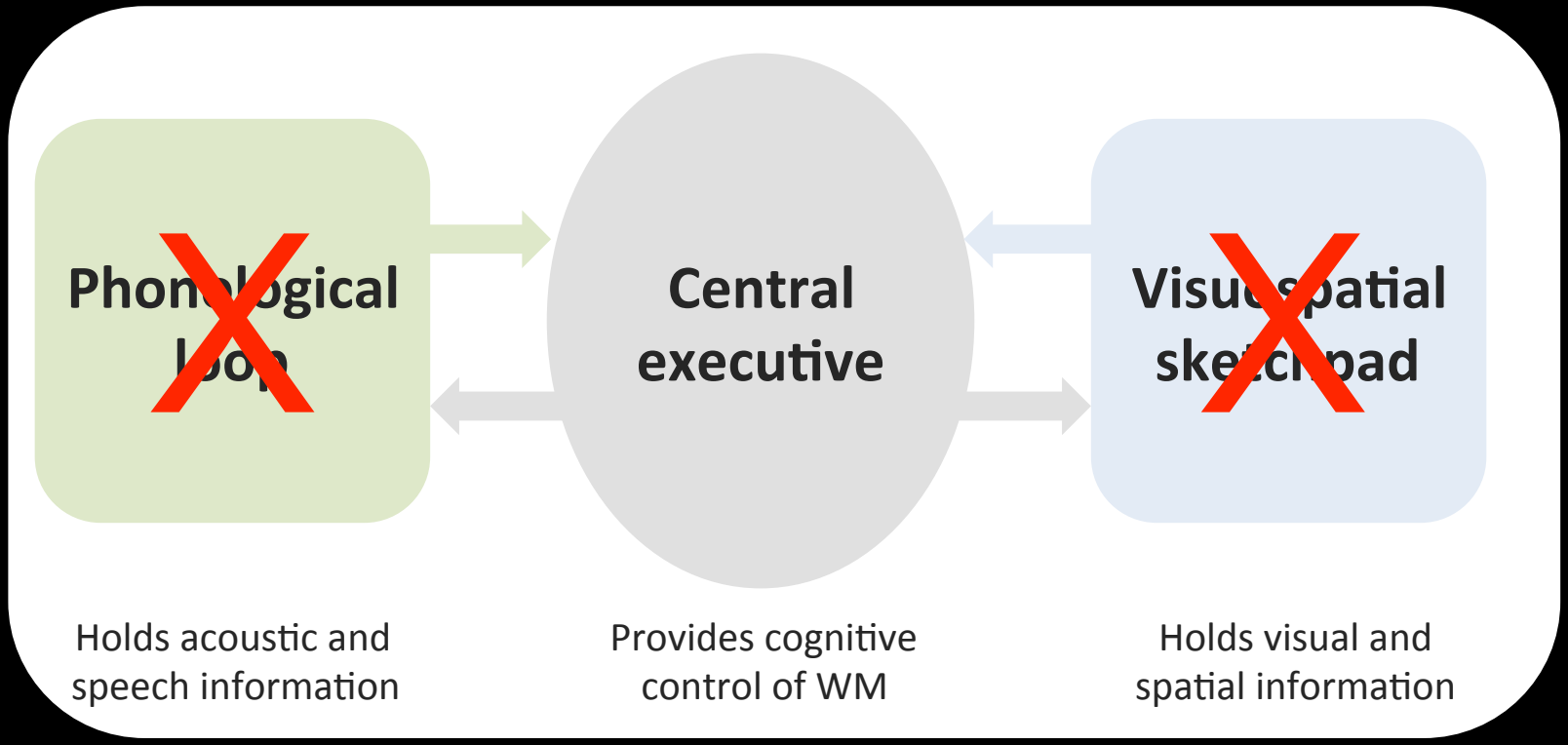


Phonological loop

Semantic

Tripartite Model of WM?

(Baddeley & Hitch, 1974)



Phonological loop

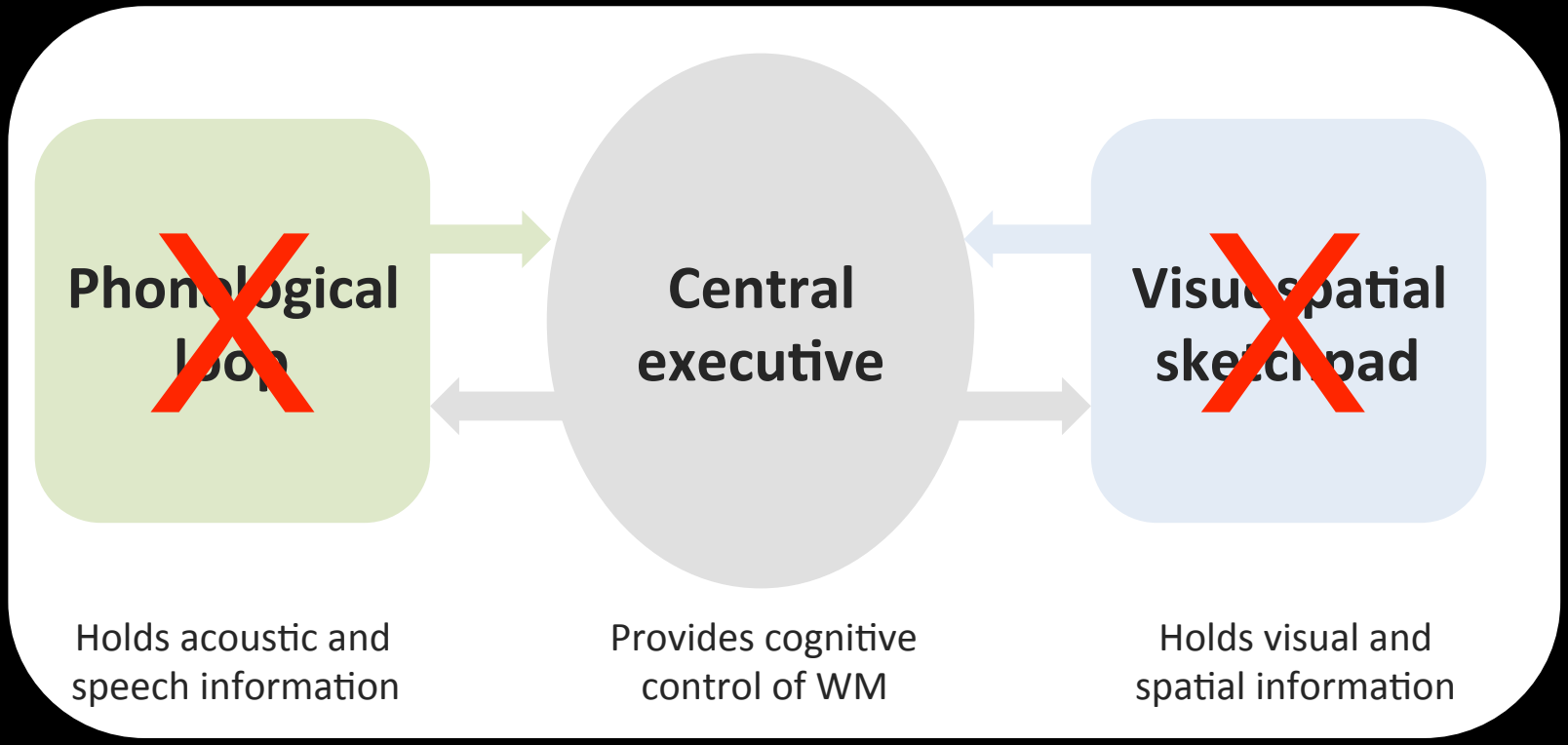
Semantic

Visuo-Object

Spatial

Tripartite Model of WM?

(Baddeley & Hitch, 1974)



Phonological loop

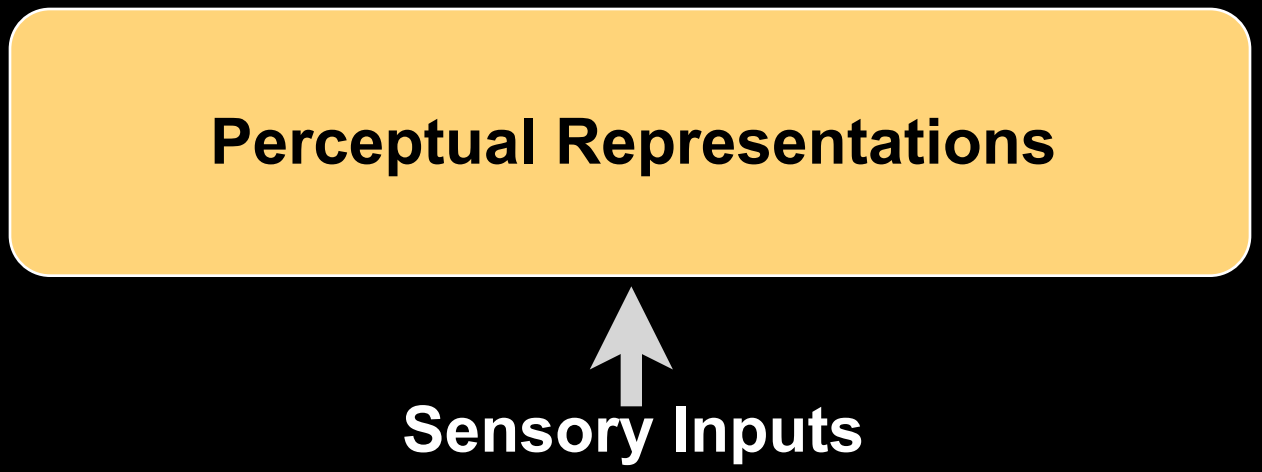
Visuo-Object

Semantic

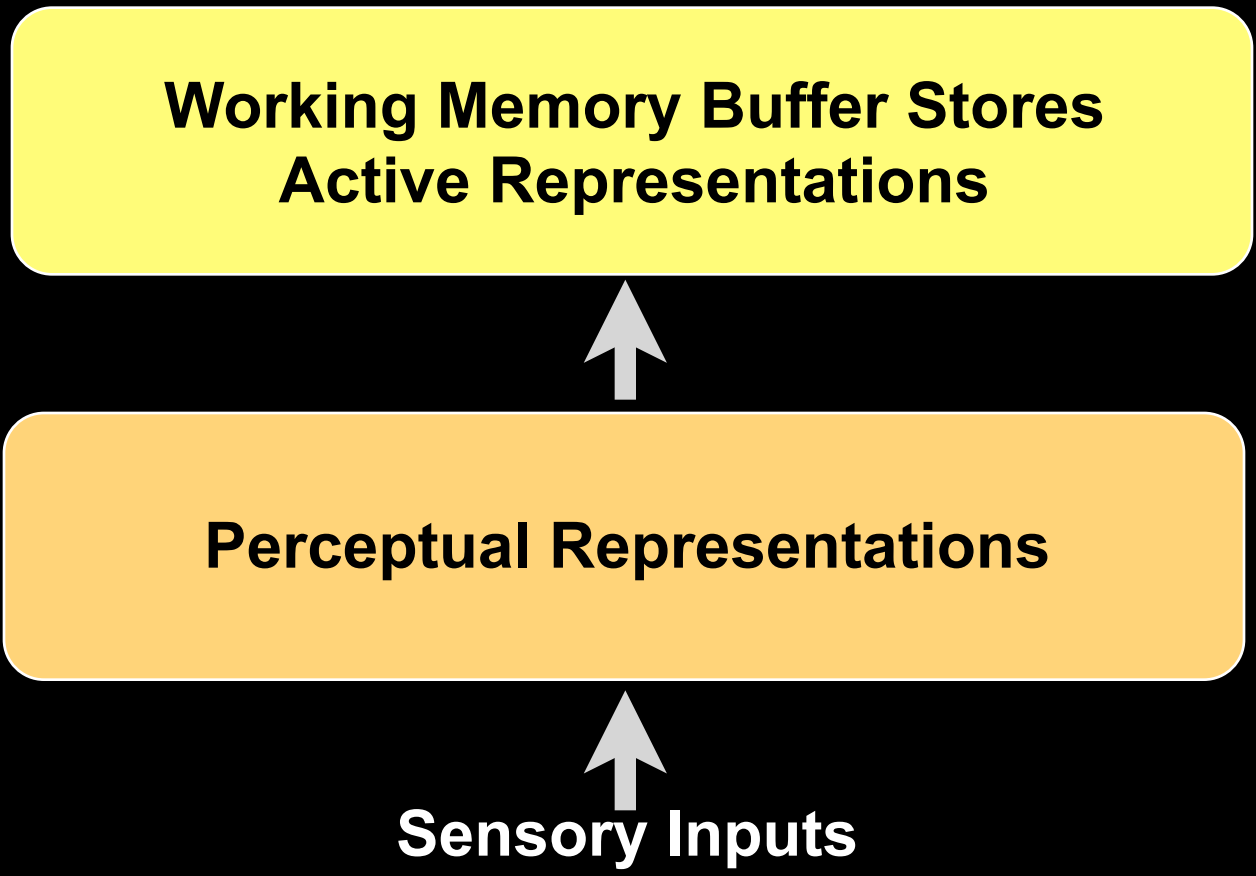
Spatial

Is WM a System or an Emergent Property?

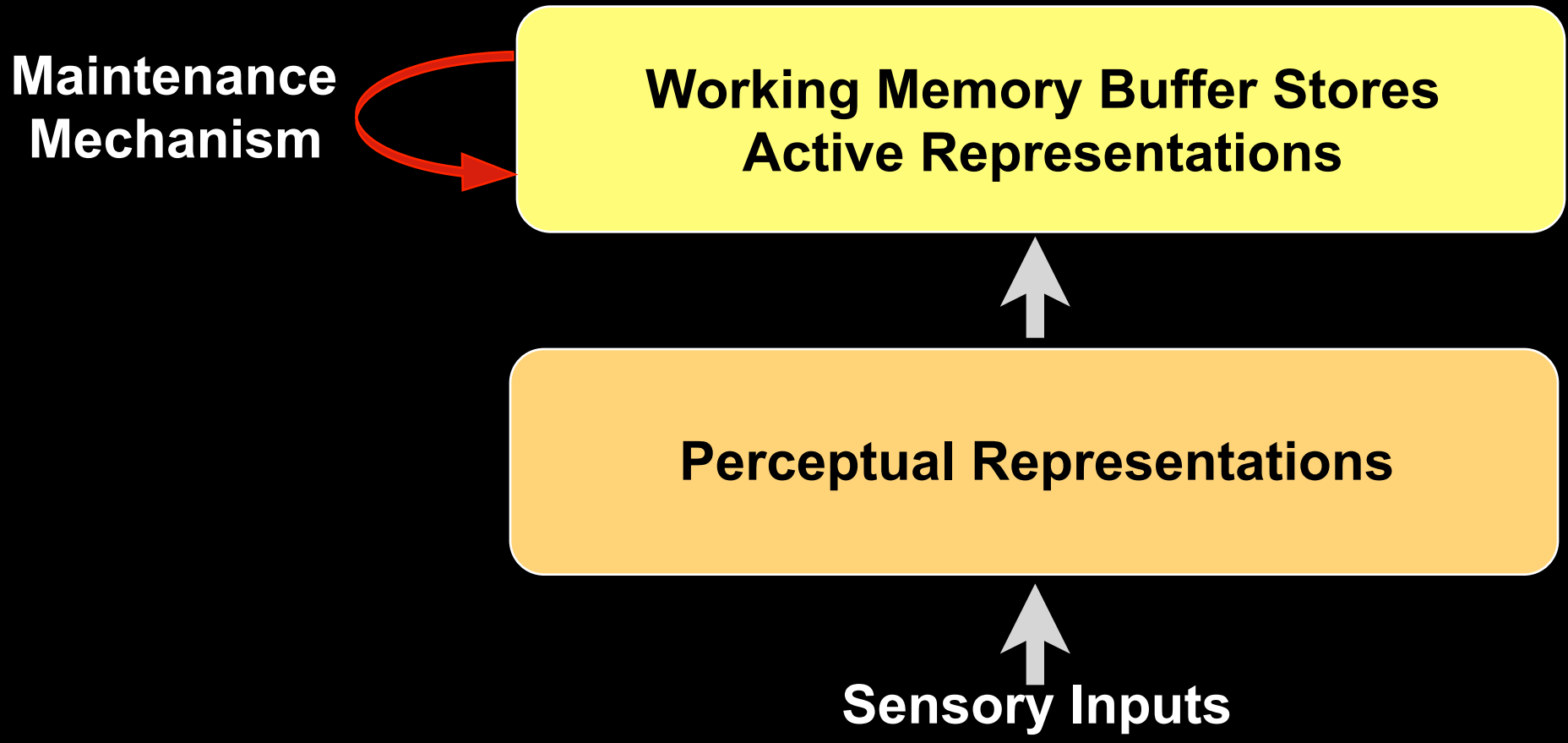
Systems Hypothesis of WM



Systems Hypothesis of WM



Systems Hypothesis of WM



Perceptual representations and working memory representations are distinct

Emergent Hypothesis of WM

Hypothesis

WM emerges when attention is directed towards perceptual representations

- WM storage buffers do not exist (cf. phonological store)
- Information in WM resides in the perceptual/semantic systems that represent that class of information

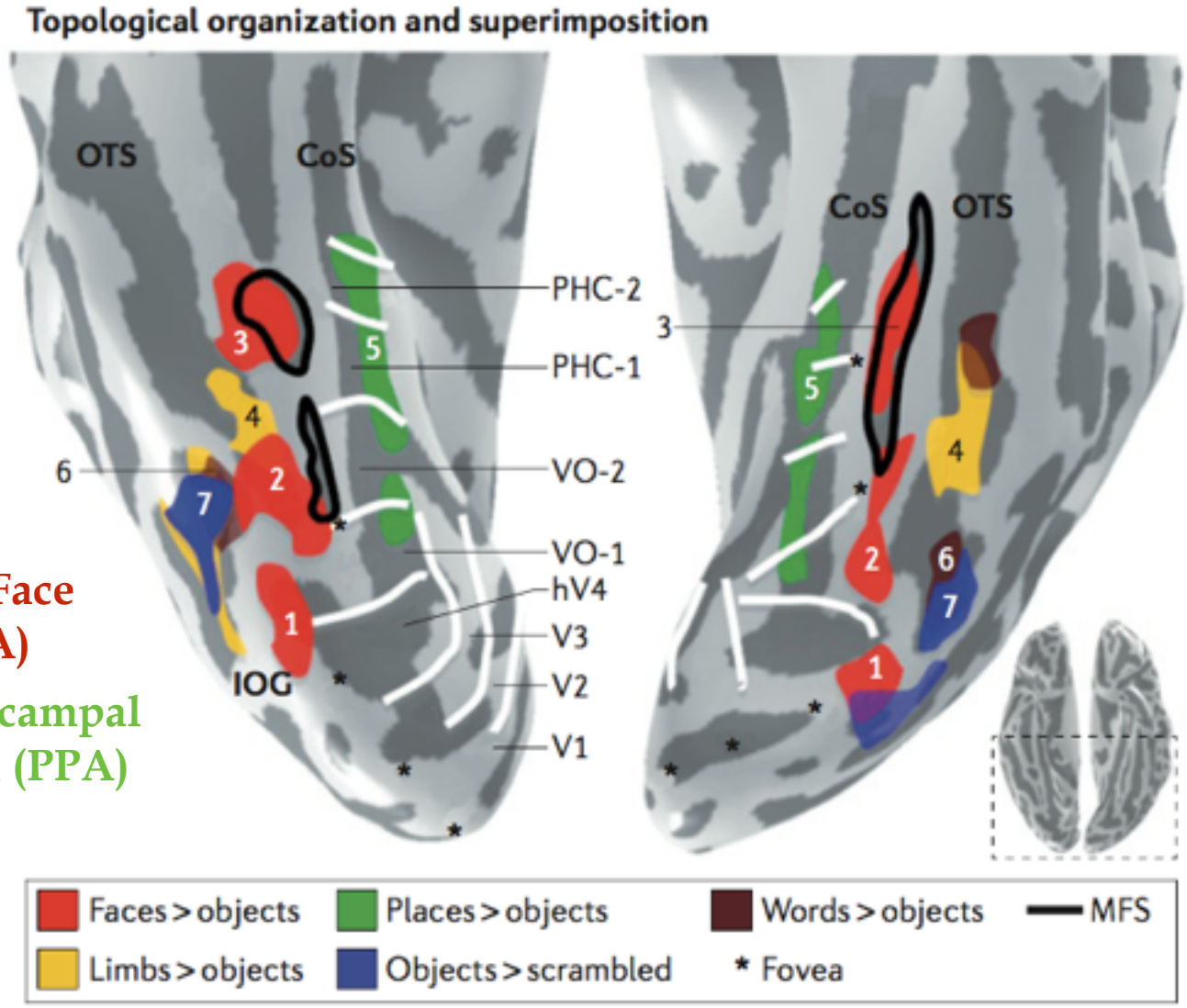
Prediction

The contents of visual WM reside in visual/perceptual cortex

- Should be able to measure the contents of WM from visual cortex

Emergent Hypothesis of WM

Perceptual Responses in Visual Cortex: Human fMRI Data



Fusiform Face Areas (FFA)

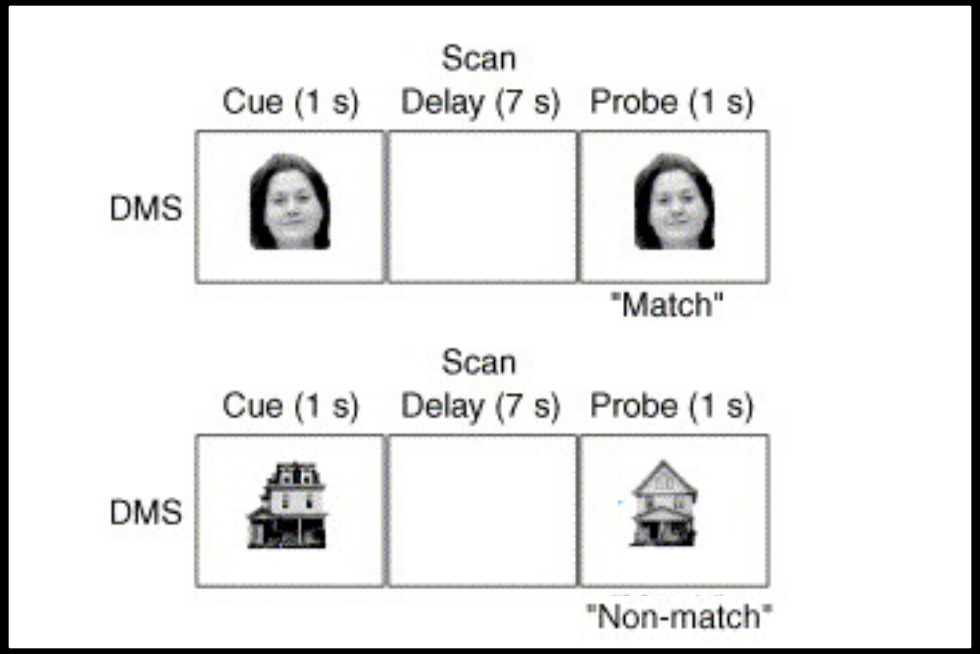
Parahippocampal Place Area (PPA)

(Grill-Spector & Weiner, 2014)

Testing the Emergent Hypothesis of WM: Category-Specific Delay Period fMRI Activity in High-Level Visual Cortex

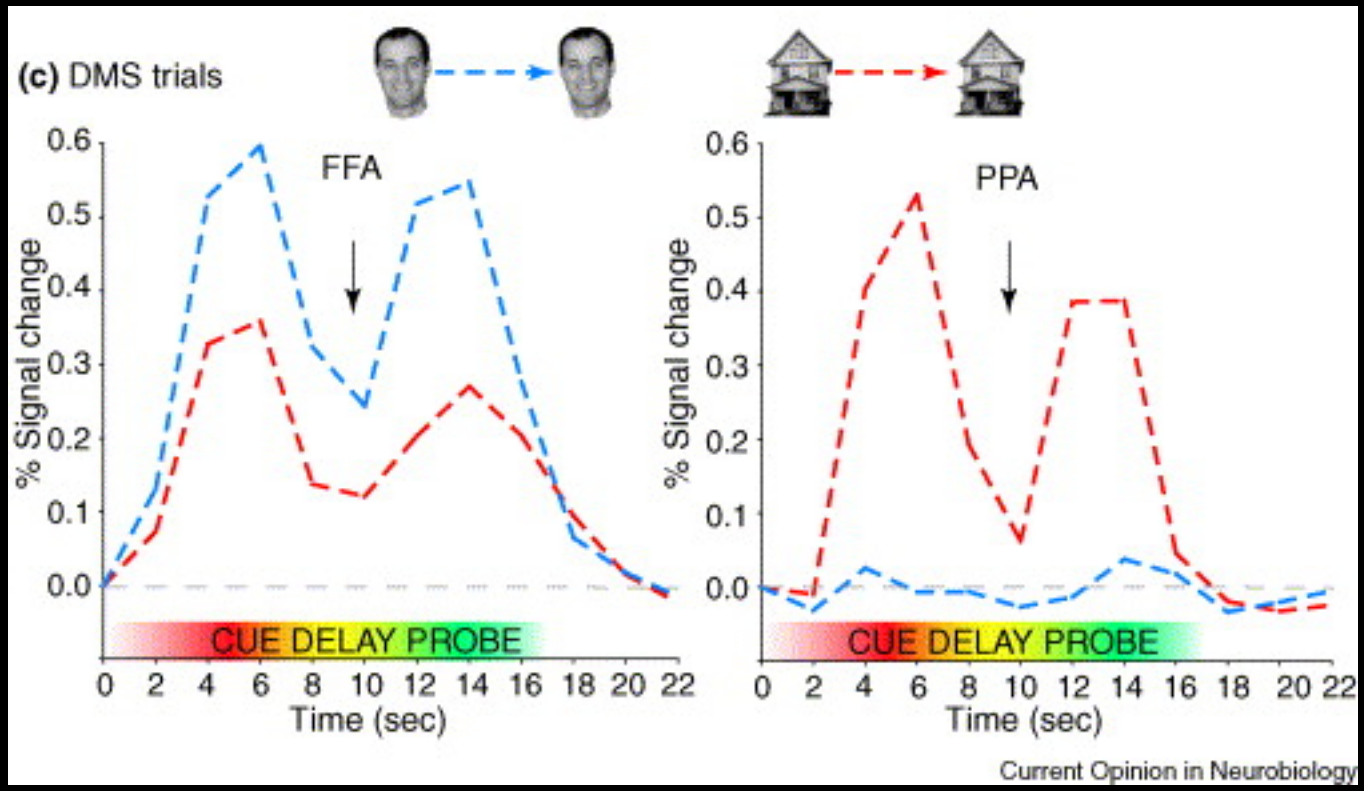
Faces

Houses



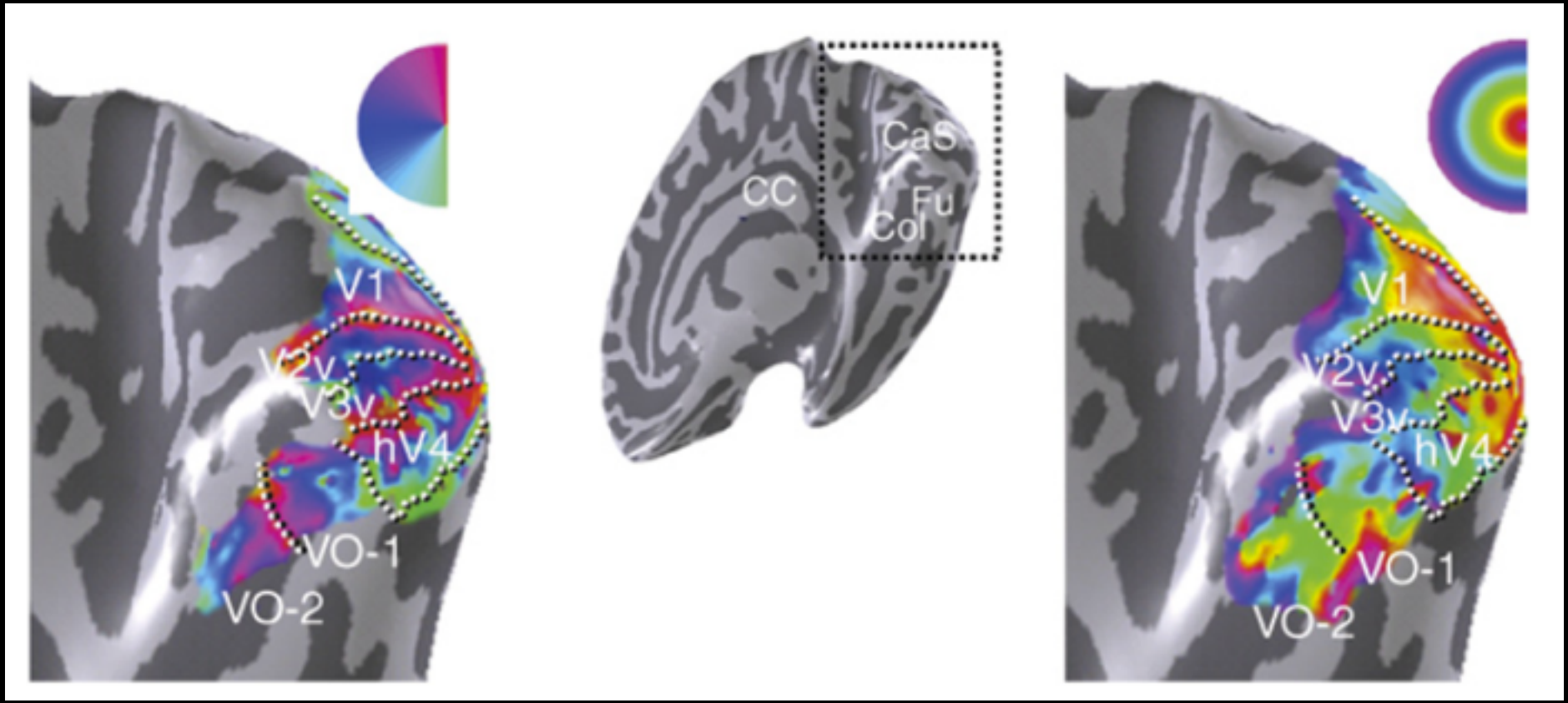
(Ranganath et al., 2004)

Testing the Emergent Hypothesis of WM: Category-Specific Delay Period fMRI Activity in High-Level Visual Cortex



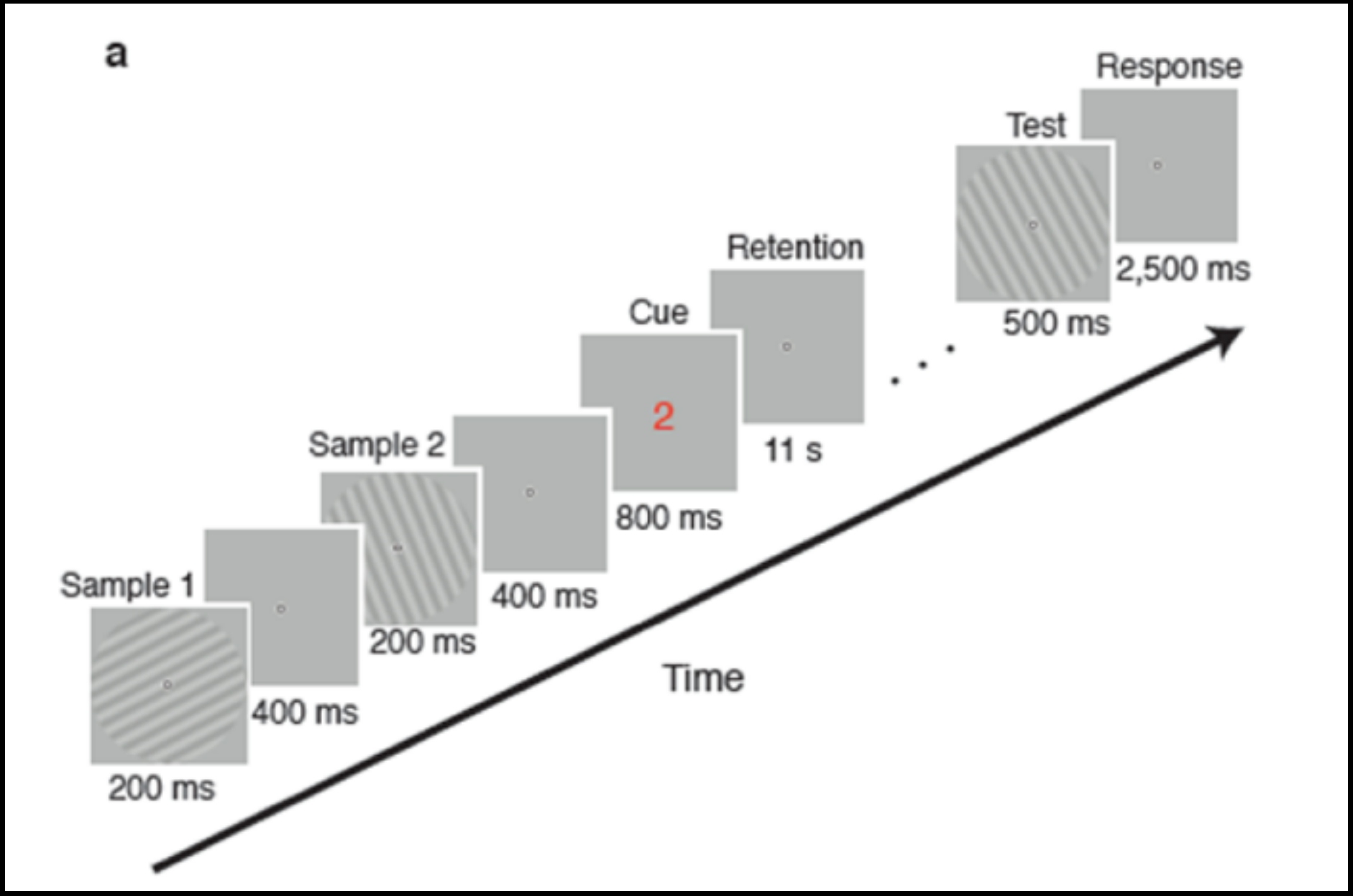
(Ranganath et al., 2004)

Testing the Emergent Hypothesis of WM: Delay Period fMRI Activity in Early Visual Cortex



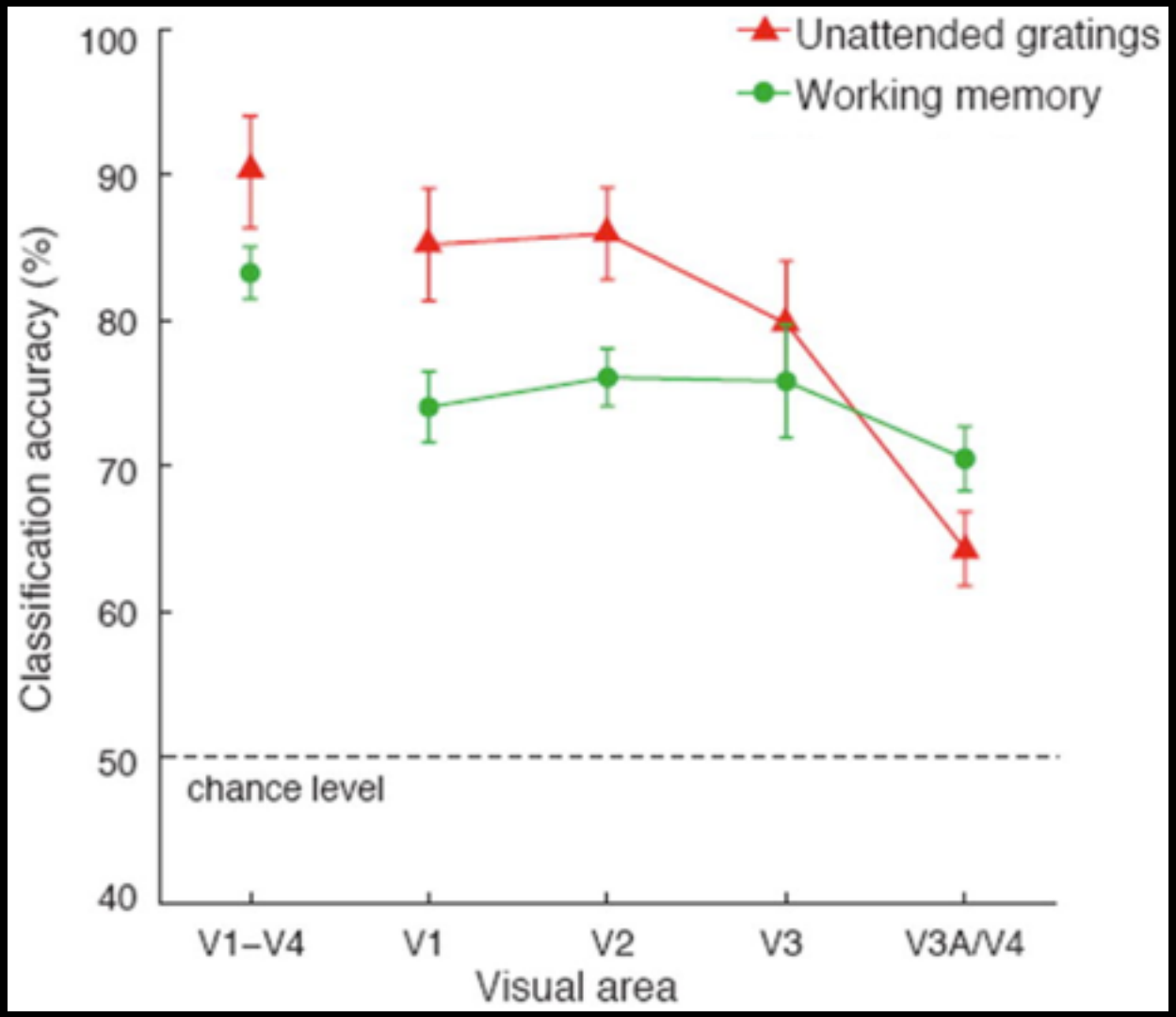
(Wandell et al., 2007)

Testing the Emergent Hypothesis of WM



(Harrison & Tong, 2009)

Testing the Emergent Hypothesis of WM



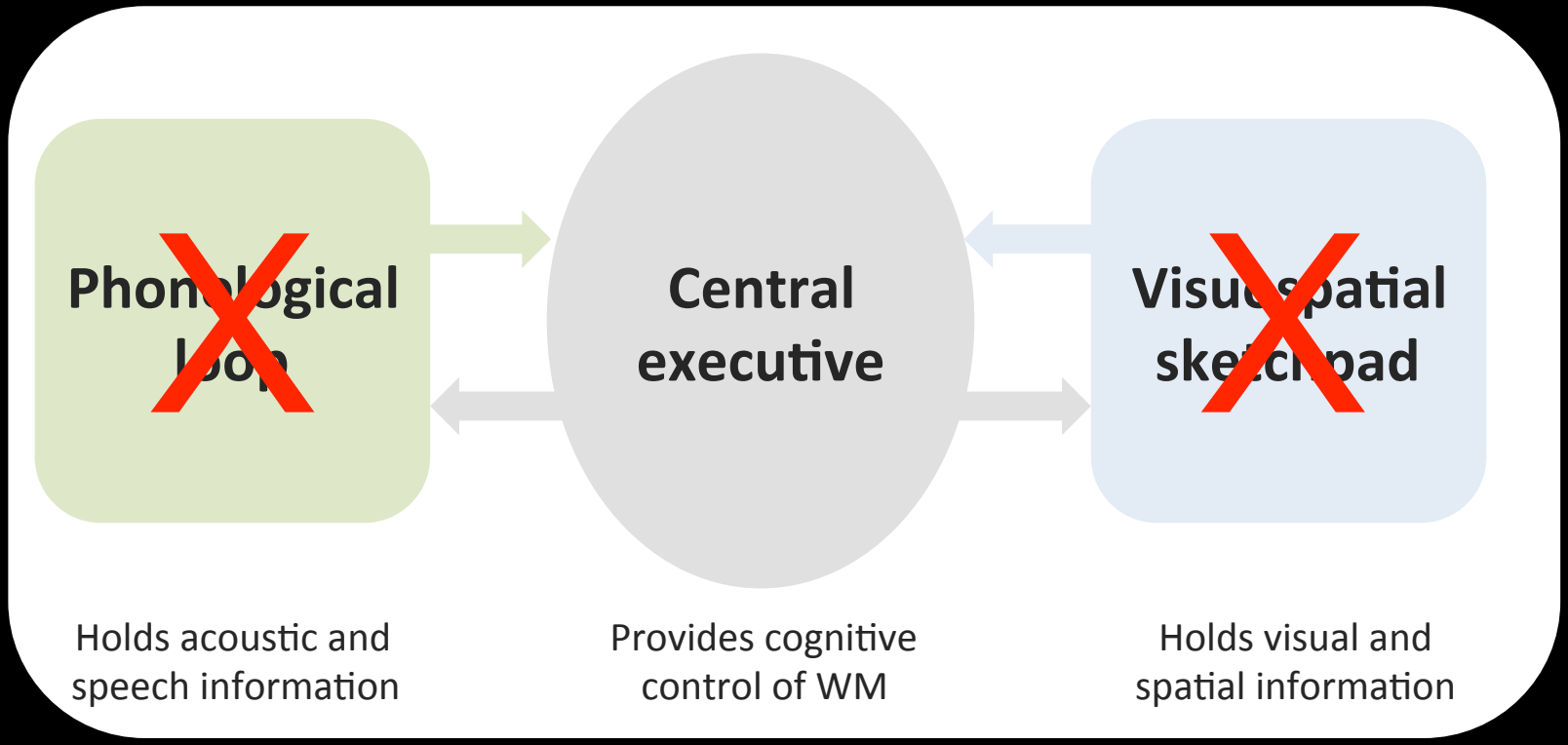
Unattended viewing (central letter detection task, while gratings flashed in background)

Patterns of activity even in the very earliest sensory cortical regions (V1) carry information about what (the item) is maintained in WM

(Harrison & Tong, 2009)

Tripartite Model of WM?

(Baddeley & Hitch, 1974)



Phonological loop

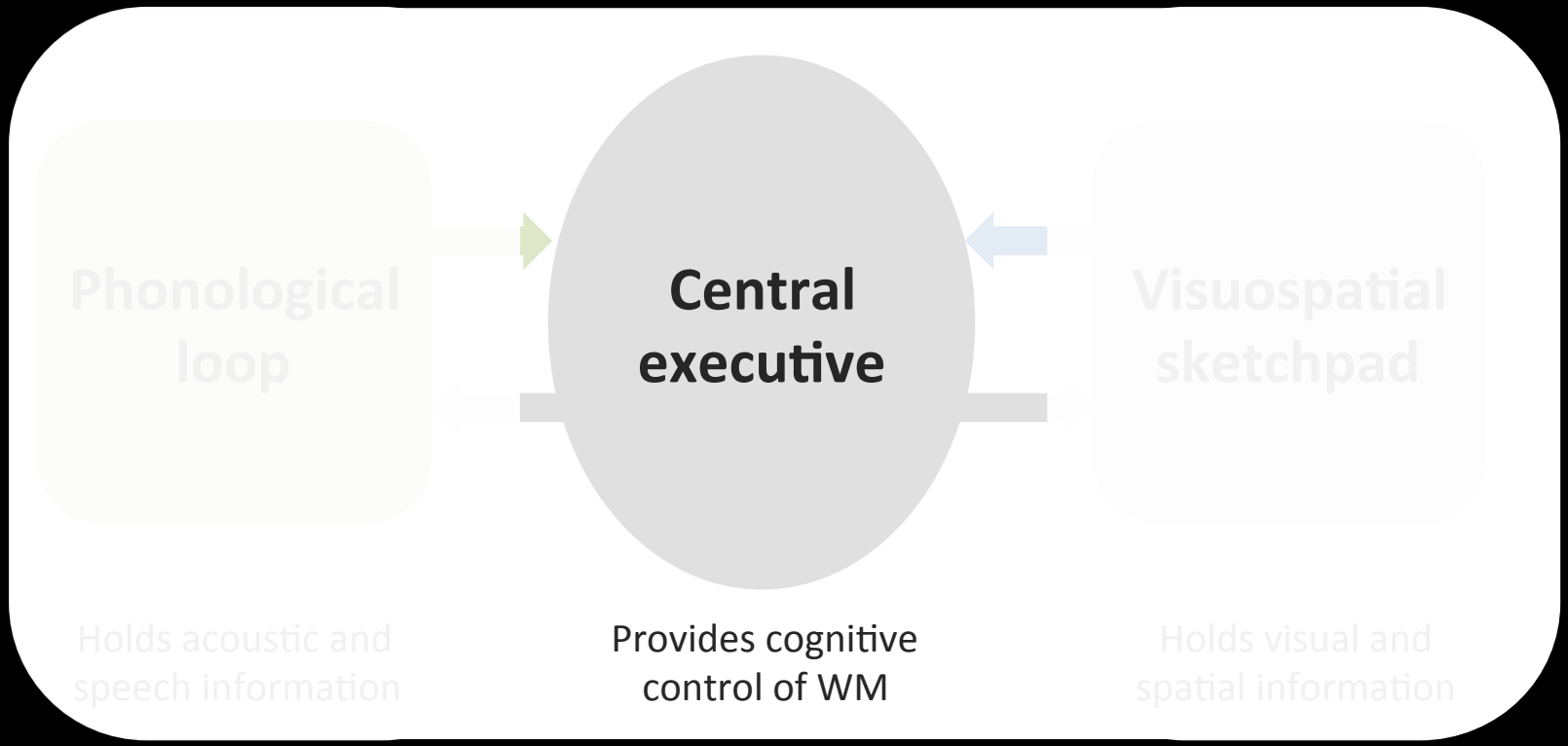
Visuo-Object

Semantic

Spatial

WM is an Emergent Property / NOT a system

Next time…Cognitive Control



Announcements

- Memory at the Movies tonight 7pm
  - Location 420-419
- Midterm 1 - Next Tuesday, April 19th
  - Time of Review Session TBD via Piazza poll

T F Sperling's *partial report* procedure demonstrated that although attentional capacity, or information-processing capacity, is limited, visual sensory memory seems to contain all presented visual input.

As discussed in the textbook, in the Wisconsin Card sorting task, individuals with frontal lobe damage:

a. Are unable to learn any rules by which to sort the cards.
b. Are unable to shift to a new rule once an old rule becomes irrelevant.
c. Are unable to keep track of how they sorted the cards on previous trials.
d. A and C

Define the *primacy effect*

Describe the *Systems Hypothesis* and the *Emergent Hypothesis* of working memory, and state the main difference between these two accounts. In your answer, please discuss how each account conceives of the role of neural representations of perceptual information in working memory.