Working Memory: Critical Constructs and Some Current Issues

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Outline

- Background
- Maintenance: Modality specificity and buffers
- Interference resolution: Distraction and proactive interference
- Manipulation: Some basics, and some different kinds of manipulation
- Relevance for schizophrenia

Starting Points

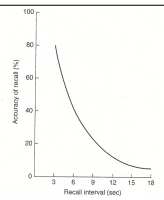
- Definition of Working memory (WM)
  The system responsible for the active maintenance and manipulation of information

Starting Points

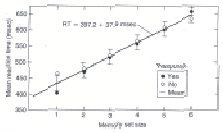
- The approach: Componential analysis of WM
  - WM tasks vary widely, and so do results
  - Distinguish tasks by their computational components, and explain variation in terms of these components
  - More specific components are more likely to be localized in brain

Basic Facts about WM

- Limited capacity: 7+/-2 items (Miller, 1956); 4+/-1 (Cowan, 2001)
- Brief duration: Information that is not rehearsed is lost in seconds (Peterson & Peterson, 1959)
- Rapidly accessible (milliseconds) (Sternberg, 1966)



Short-term recall related to delay interval in the Peterson task



Recognition time related to memory set size in the Sternberg item recognition task

Why WM Is So Important

- Critical component of higher-level cognition
  - Many cognitive operations performed on contents of WM
  - Exs: Mental arithmetic, following spatial directions, understanding text, planning a chess move, etc.

Why WM Is So Important

- Evidence:
  - Correlations between WM span and reading comprehension (Daneman & Carpenter, 1980; Engle, 2000)
  - Correlation with measures of fluid intelligence (Duncan et al., 2000)
  - Decline in cognitive performance with aging primarily due to decline in WM (Salthouse, 1993; Park et al., 2004)

Modes of Operation

- A proposal about organization of frontal cortex that may be useful for WM (Owen, 1997; Petrides, 1995)
- Simple maintenance

  Ex: Remembering telephone number
- Maintenance in the face of distraction

  Ex: Remembering your point while listening to another person
- Maintenance plus manipulation

  Ex: Planning ahead in chess

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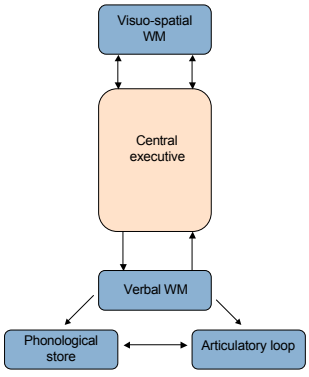
Buffer Models of WM

- Broadbent (1958) two systems
  - Special-purpose buffer between input and long-term memory (LTM)
- Atkinson & Shiffrin (1968)
  - Buffer is gateway to LTM
- Baddeley & Hitch (1974)
  - Separate buffers for verbal and visual-spatial information
  - Central executive for scheduling use of buffers
- Buffers compatible with basic facts



Simplified representation of the Baddeley and Hitch model

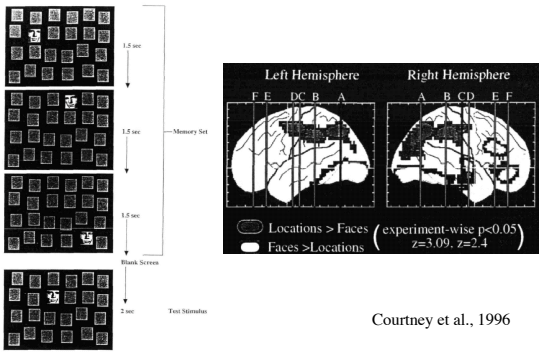
Buffers Are Modality Specific

- Verbal buffer maintains phonological and articulatory information
- Spatial and visual-object buffers maintain spatial and object information

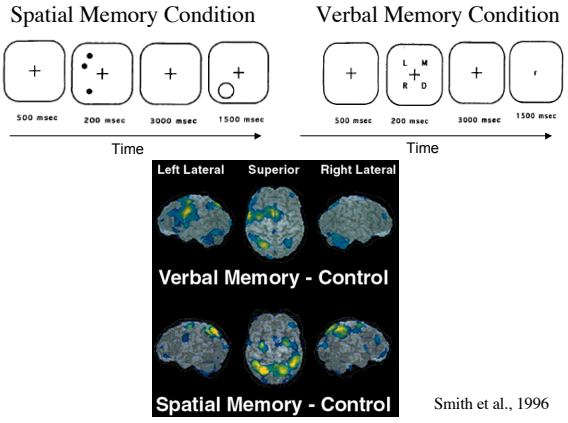
Buffers Are Modality Specific

- Evidence
  - Single-cell recordings: Different frontal neurons for spatial and object information (Goldman-Rakic, 1986; Wilson et al., 1993)
  - Behavioral: Secondary task causes more interference if it uses same modality as WM task (Brooks, 1968)
  - Neuropsychological: Some patients selectively impaired on object but not spatial WM, or vice versa
  - Neuroimaging: In item recognition task, different neural networks for verbal, spatial, and object WM
  - Will emphasize neuroimaging evidence: delay-period only

Spatial vs. Object WM



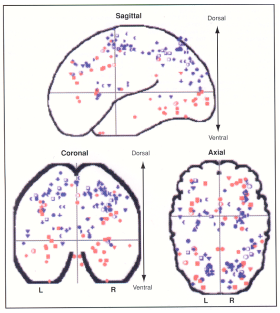
Courtney et al., 1996



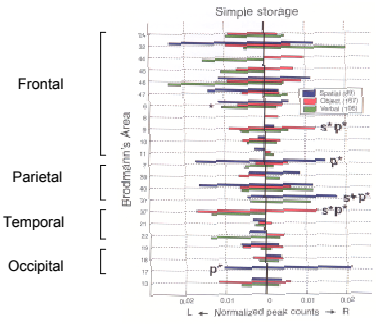
Smith et al., 1996

Meta-Analyses of Imaging Data

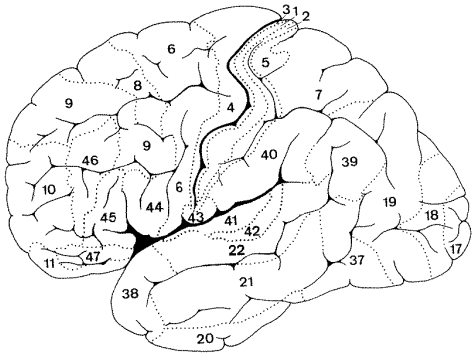
- Early analysis of verbal vs. spatial vs. object information: 12 studies
- More recent analysis: 60 studies
- Delay-period only
- Both analyses support modality-specificity, but not exclusively in frontal cortex



Neuroimaging results for spatial (blue) and object (red) WM tasks (Smith & Jonides, 1999)



Comparison of material types in maintenance tasks (Wager & Smith, 2003)



Modality-Specific Buffers Reconsidered

- Evidence for modality-specificity in WM tasks, but is it due to special-purpose buffers in frontal cortex?
- Some frontal activation due to rehearsal, not storage
  - Subtract out verbal rehearsal: remove much of frontal activation
- Some frontal areas (e.g., dorsolateral) are also involved in non-WM tasks (e.g. stroop)

Modality-Specific Buffers Reconsidered

- More modality-specificity in posterior than frontal cortex (Smith & Jonides, 1999)
- Need to postulate too many buffers; recapitulating distinctions made in posterior cortex (Postle, 2006)
- Reinterpretation of single-cell evidence: Frontal cells are not dedicated to a single modality (Duncan & Miller, 2002)

Reinterpretation of Modality Specificity in WM Studies

- WM = Reactivation of LTM (Cowan, 1995; Postle, 2006; Ruchkin et al., 2004)
  - Ex: Representations of letters or words in WM studies are the LTM representations
- Stable representations are in posterior cortex

Reinterpretation of Modality Specificity in WM Studies

- LTM representations contain modality-specific information
  - Phonological representations, structural descriptions for object recognition
  - Semantic representations: Answering questions about familiar objects (e.g., Martin et al., 1999)
- Reactivation hypothesis compatible with basic findings - e.g., limited capacity due to limited attention

Some Difficulties for the Reactivation Hypothesis

- Rehearsal
- Remembering the order of items
- Need a frontal buffer that activates appropriate region in LTM ("Context"; Braver & Cohen, 2000)
- Still an open issue

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Maintenance During Distraction: Behavioral Findings

- Distractors vs. no-distractors: minimal memory vs. good memory
- More similar distractors cause more interference
- Usurping attention vs. creating interfering representations (cross-talk) vs. dual-tasking

Neural Evidence that Distractors Require Special Processing

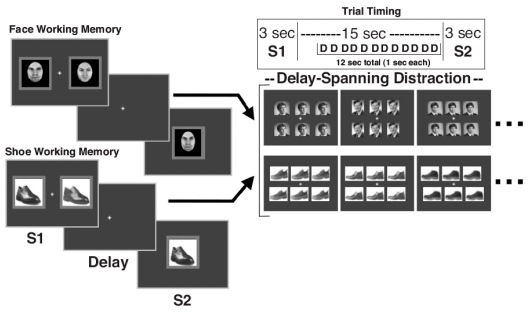
- Patient studies: Frontal patients impaired in WM mainly when distractors presented
  - Frontal patients not impaired on memory span (D'Esposito & Postle, 2000)
  - Frontal patients impaired in auditory item recognition only when distractors present (Chao & Knight, 1995)

Neural Evidence that Distractors Require Special Processing

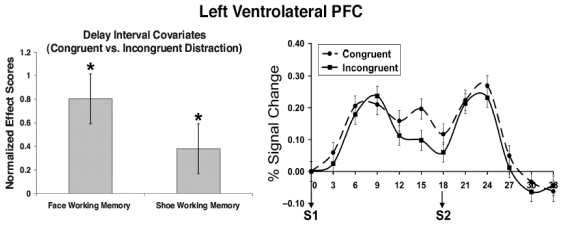
- Dorsolateral PFC may be inhibiting posterior areas that represent distractors (Chao & Knight, 1998)
- Compatible with Reactivation hypothesis

Imaging Evidence for Role of PFC in Offsetting Distraction

- Focus on PFC activity when just seeing distractors: minimize dual-tasking (Jha et al., 2004)
- Two different regions:
  - Ventral PFC - selection among alternatives (Thompson-Schill et al., 2005)
  - Dorsolateral PFC - executive attention/inhibition
- Results for delay period (15000 msec)
  - Both Left ventral and dorsal PFC activated by distractors
  - Only Left ventral PFC affected by similarity of distractors: more selection needed
  - Face area more activated when maintaining face than non-face (compatible with Reactivation)



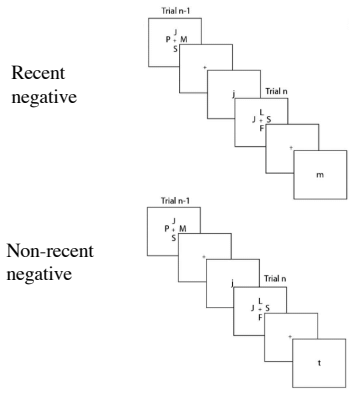
Schematic of Jha et al. (2004) behavioral paradigm and task design



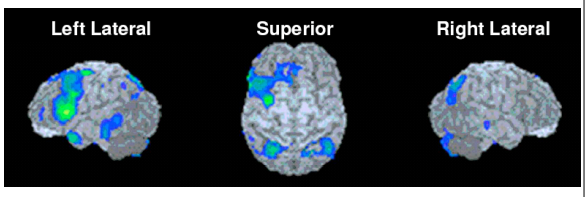
Left Ventrolateral PFC activity by working memory domain (Jha et al., 2004)

A Related Phenomenon: Proactive Interference in WM

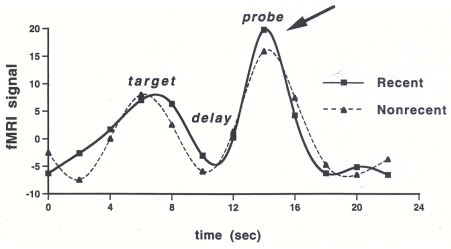
- Interference from prior trial: Recent negatives in item recognition
- Behavioral finding: Longer RTs to recent negative probes (Monsell, 1978)
- Effect due to conflict about probe: Familiarity vs. list marker
- Imaging finding: Recent vs. nonrecent probes: Left, ventrolateral PFC - selection (Jonides et al., 1998)



A schematic of the Recent-Probes task



Activation for recent vs. non-recent negatives (Jonides et al., 1998)



Activation for recent vs. non-recent negatives in left ventrolateral PFC (D'Esposito et al., 1999)

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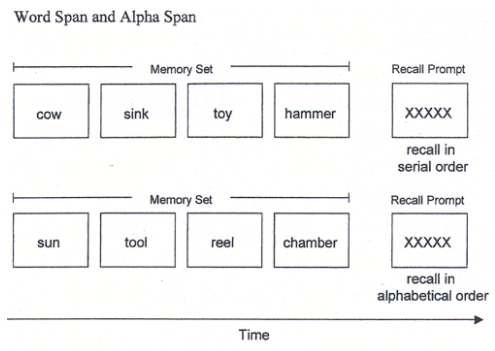
Manipulation: Some Basics

- Maintenance vs. manipulation
  - Maintenance = storage plus rehearsal
  - Manipulation = operating on target information, or other information concurrently in WM
- Exs. Of manipulation
  - Reordering items alphabetically in WM
  - Reading span; Operations span



Operations Span

Time	Task	
↓	(6 x 2) - 2 = 10?	BEAR
	9/3 - 1 = 1	CASE
	-	
	-	
	-	
		Recall Words

Manipulation: Some Basics

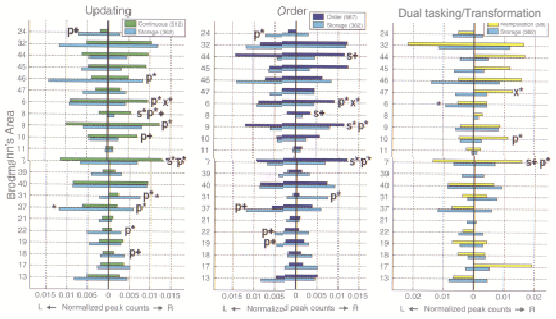
- Basic finding
  - Manipulation leads to additional activations in PFC compared to maintenance
  - Ex: serial vs. alphabetic recall of words (Collette et al., 1999)
  - Only alphabetic recall leads to activation in dorsolateral PFC

Meta-Analysis of Some Manipulation Processes

- Problem: No taxonomy of manipulation
- Meta-Analysis distinguished between three kinds of manipulation process (Wager & Smith, 2003)
  - ◆Continuous updating of WM (e.g., n-back)
  - Attending to order information (e.g., alpha span, n-back)
  - Dual tasking (e.g., Operation span) and/or transformation (e.g., mental arithmetic)

Major Findings of Meta-Analysis

- Frontal and parietal areas most involved in all three processes
  - Posterior parietal most frequently activated site
- Some differences between three kinds of manipulation
  - e.g., Anterior frontal (BA 10) - Updating but not Order
    Posterior frontal (BA 44) - Order but not Updating



Frequencies for each executive function in comparison with storage-only tasks for each Brodmann's area

Connections to Schizophrenia Research

- General: Task-related hypofrontality
- Maintenance tasks
  - Schizophrenics relatively unimpaired
  - No evidence for poorer performance with one modality than another (Lee & Park, 2007)
  - Compatible with hypofrontality: PFC not critical for maintenance
  - But hypofrontality might manifest with higher memory loads (Manoach, 2003)

Connections to Schizophrenia Research

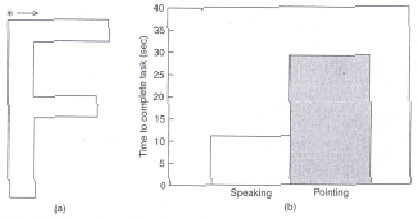
- Interference tasks
  - Schizophrenics impaired when distractors present (Fleming et al., 1995)
  - Impairment associated with less activation than normals in dorsolateral PFC
  - Impaired components: selection and attention/inhibition?
  - Pattern of connectivity?

Connections to Schizophrenia Research

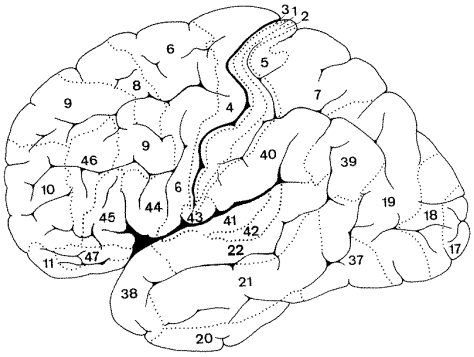
- Manipulation tasks
  - Schizophrenics impaired on numerous manipulation tasks (Barch, 2006; Kim et al., 2004)
  - Impaired tasks include components of updating, attending to order, and dual-tasking
  - Impairment associated with less activation in dorsolateral PFC (Barch, 2006)

Some Critical Constructs

- Reactivation of modality-specific LTM representations
  - Retrieval from LTM
  - Rehearsal of LTM representations
- Offsetting distractors
  - Selecting (tagging) irrelevant items
  - Suppressing irrelevant items
- Continuous updating of WM
- Temporal indexing
- Switching goals and procedures
- etc.



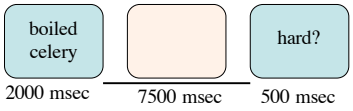
A visuospatial imagery and interference task



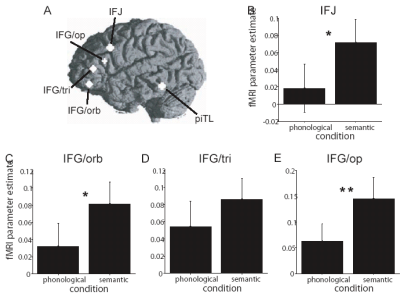
Maintenance of Meaning as a Case of Reactivation

- Evidence for modality-specificity in LTM often involves semantic information; WM studies do not
- WM must be able to maintain semantic information for higher-level processes to manipulate
- Evidence for semantic WM: Comparison of semantic and phonological WM (Fiebach et al., 2007)

- Task



- Results for delay period
  - Posterior inferior temporal: modality-specific representations
  - Same area activated in semantic memory studies
  - Left inferior frontal areas-retrieve and maintain (attend-to) LTM area



Fiebach et al., 2007