



Executive Control Operations for Updating of Verbal Working Memory

Adam Krawitz, Shane T. Mueller, David E. Kieras, and David E. Meyer
University of Michigan, Department of Psychology, Ann Arbor, Michigan, USA

Abstract

The maintenance and updating of temporary stored information in verbal working memory (VWM) has typically been studied through popular procedures like the immediate serial recall and N-back recognition tasks. However, these procedures are problematic because they confound memory-updating operations with other processes such as encoding, rehearsal, and retrieval. To help solve this problem, we have developed new procedures that enable various types of updating (e.g., appending and deleting ordered items in working memory) to be isolated and characterized through analytical measurements of “cumulative” and “rolling” forward or backward overt rehearsal. Mean response latencies, durations and error rates based on these measurements reveal that simple “append” operations are relatively easy and invariant with changes in memory load, whereas memory load strongly affects more difficult combinations of “delete” and “append” operations. Our findings have potentially significant implications for theoretical modeling of updating and other related executive control operations in verbal working memory.

Updating Operations

VWM updating is the intentional modification of the current contents of verbal working memory. In terms of Baddeley’s (2000) model this involves the central executive interacting with the phonological loop.

Types of updating operations may include:

- Addition: “a b c” → “a b c d”
- Deletion: “a b c” → “b c”
- Replacement: “a b c” → “a f c”
- Reordering: “a b c” → “a c b”

Operations can occur at the start, middle, or end of the list of items.

Some operations may be primitive, while others are composite, e.g.:

Replacement: “a b c” → “a f c”
versus

Deletion and insertion: “a b c” → “a c” → “a f c”

The relationship between the time taken to perform an operation and memory load will depend on both the particular operation and the storage mechanism for serial order. For example, consider deletion of the first item in a list, e.g. “a b c d” → “b c d”.

In a ‘pointer’ model of serial order, # of operations is constant:

↓ ↓
a ⇒ b ⇒ c ⇒ d → a ⇒ b ⇒ c ⇒ d

While in a ‘slot’ model of serial order, # of operations varies linearly with memory load:

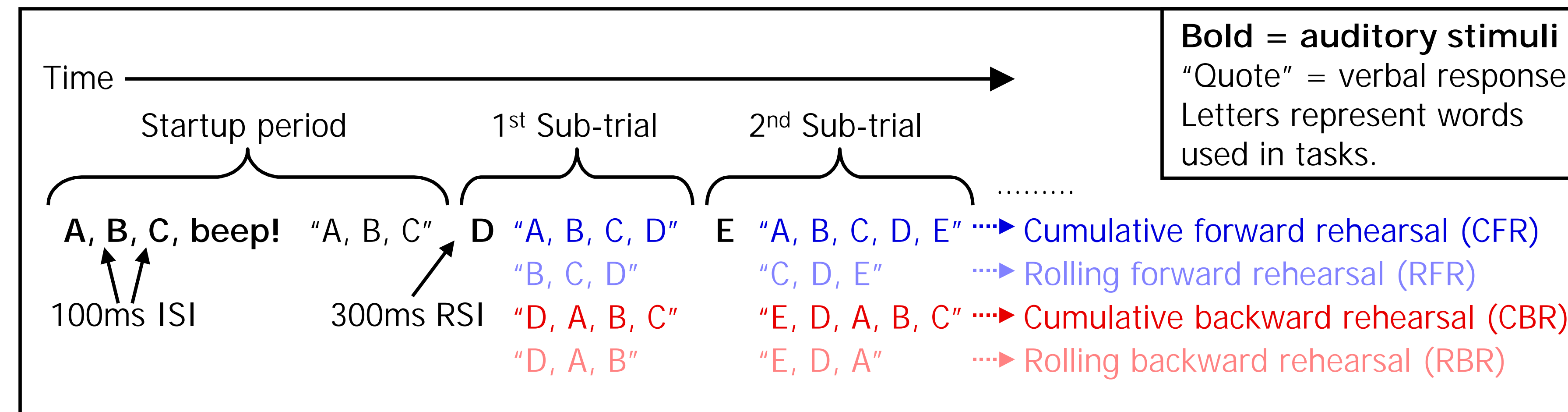
[a] [b] [c] [d] → [b] [c] [d] []

Benefits of New Rehearsal Tasks

- Use of chronometric analysis (RTs and articulation times)
 - Speeded responses encouraged by performance bonuses
- Control over rehearsal strategy
 - Overt rehearsal and short RSIs constrain strategy
- Localization of errors in memory contents
 - Full overt rehearsal after each memory update
- Comparison of different updating operations (See methods)
- Application of results to other VWM tasks (See memory span and CFR results)

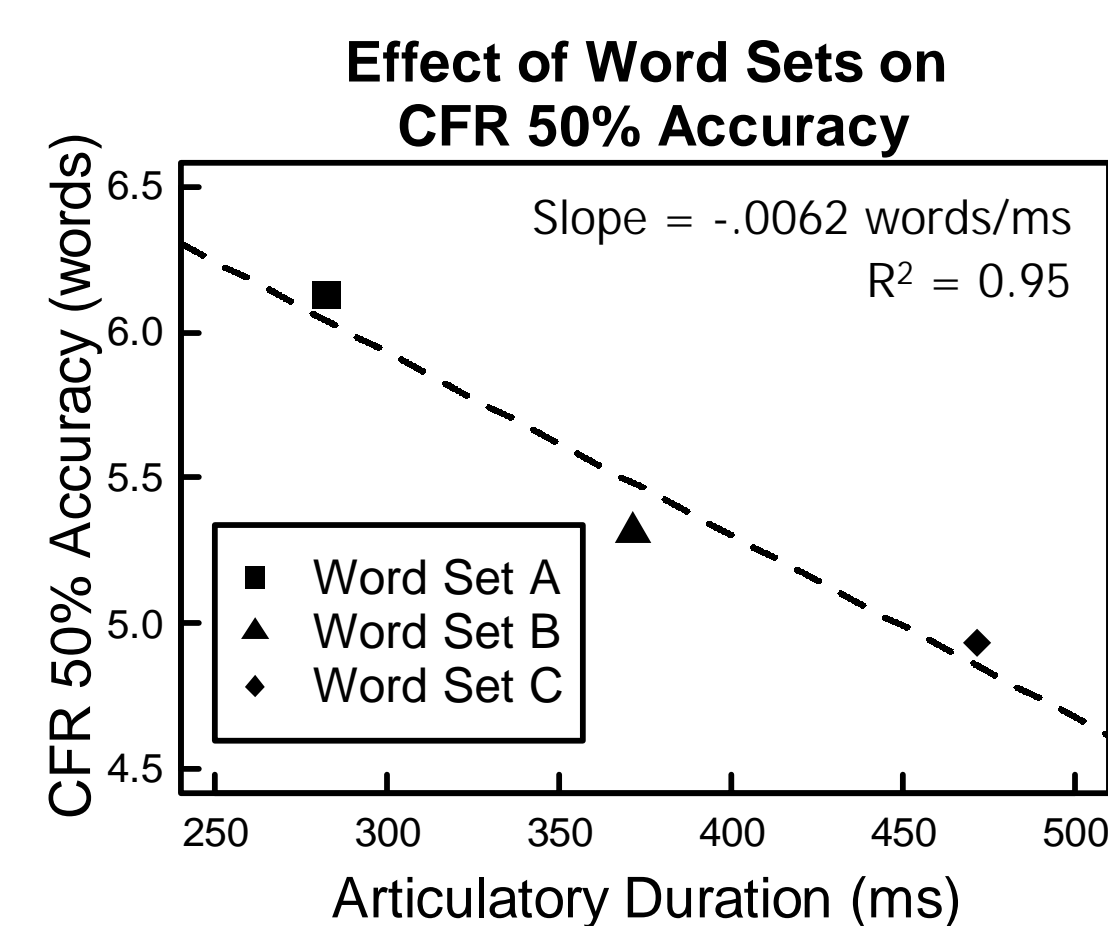
Methods for New Rehearsal Tasks

- Startup period:
- n (2,3,4, or 5) words presented auditorily with 100ms ISI
 - After signal, participant recites the entire sequence
- Sequence of sub-trials:
- On each sub-trial, one word presented auditorily
 - Participant immediately recites updated sequence
 - Next sub-trial begins after a 300ms RSI

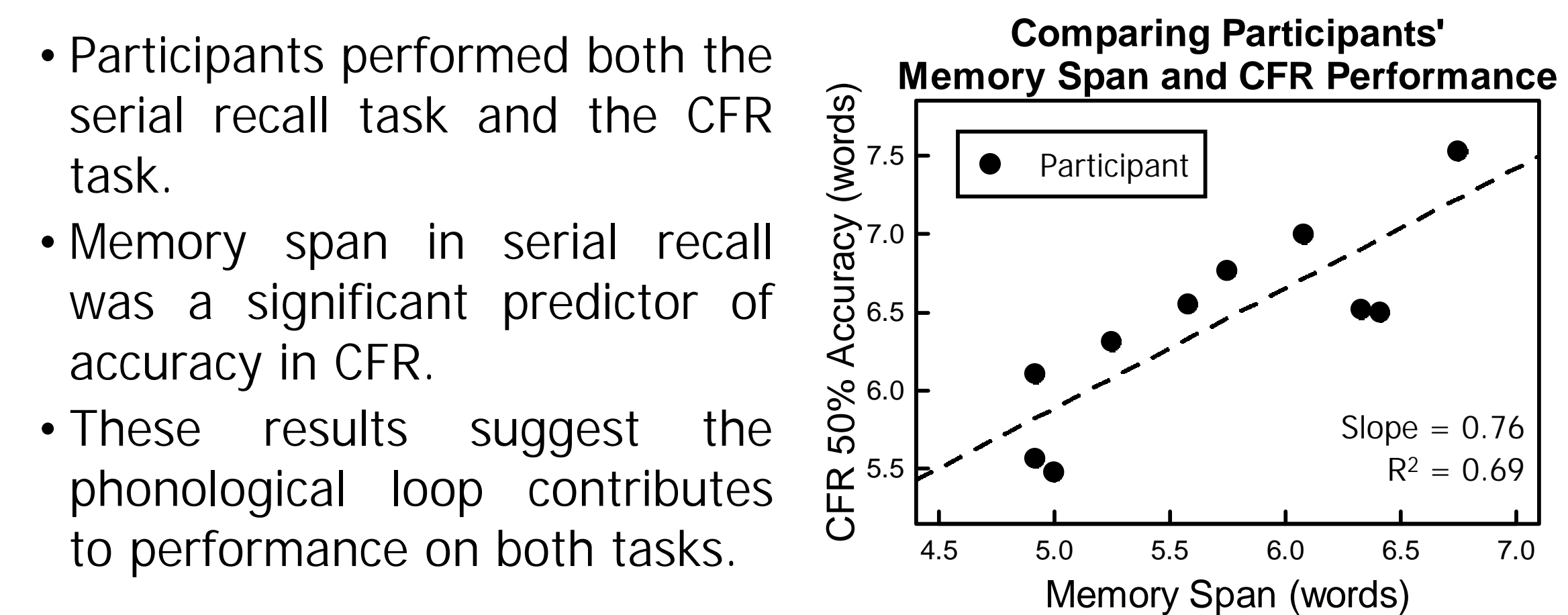


- Trial details:
- Trial ends after recital when an error occurs, or when maximum number of sub-trials are completed
 - Participants monetarily encouraged to start response promptly and recite sequence quickly and accurately
 - Accuracy, RT, and articulation time recorded for startup period and each sub-trial
- Word sets:
- Used 3 word sets (A, B, and C) of 10 short, medium, or long words
 - Equated on mean phonological onset dissimilarity, using PSIMETRICA (Mueller et al., 2003)
 - Varying in mean articulatory duration, determined experimentally using articulatory duration technique of Mueller et al. (2003)
 - Task, word-set and n were blocked, within-subject
 - Order of tasks and word-sets counterbalanced across subjects

Results: Serial Recall and CFR



- Word sets with greater measured articulatory duration produced lesser accuracies on the CFR task.
- The cost in accuracy for increased articulatory duration (0.0062 words/ms) was similar to that reported for serial recall (0.0057 words/ms) (Mueller et al., 2003).



- Participants performed both the serial recall task and the CFR task.
- Memory span in serial recall was a significant predictor of accuracy in CFR.
- These results suggest the phonological loop contributes to performance on both tasks.

References

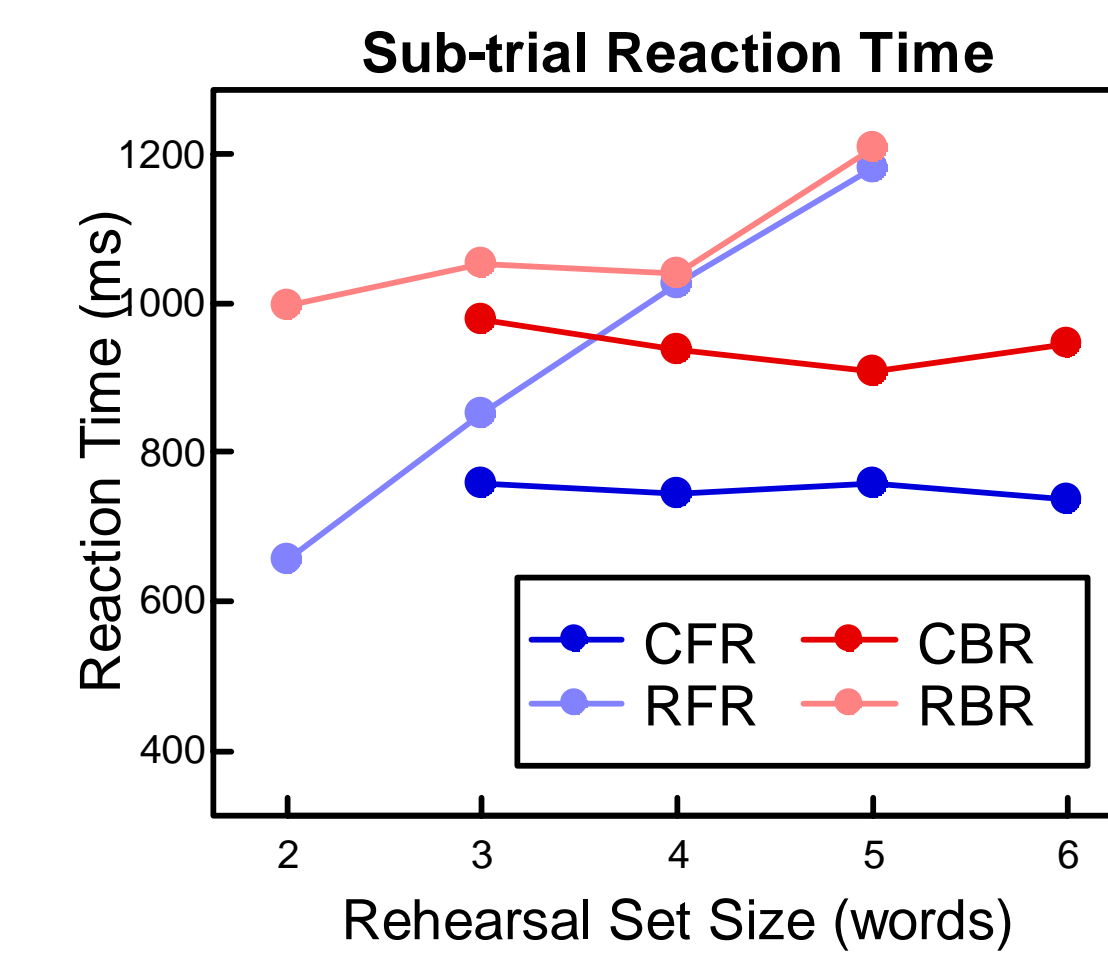
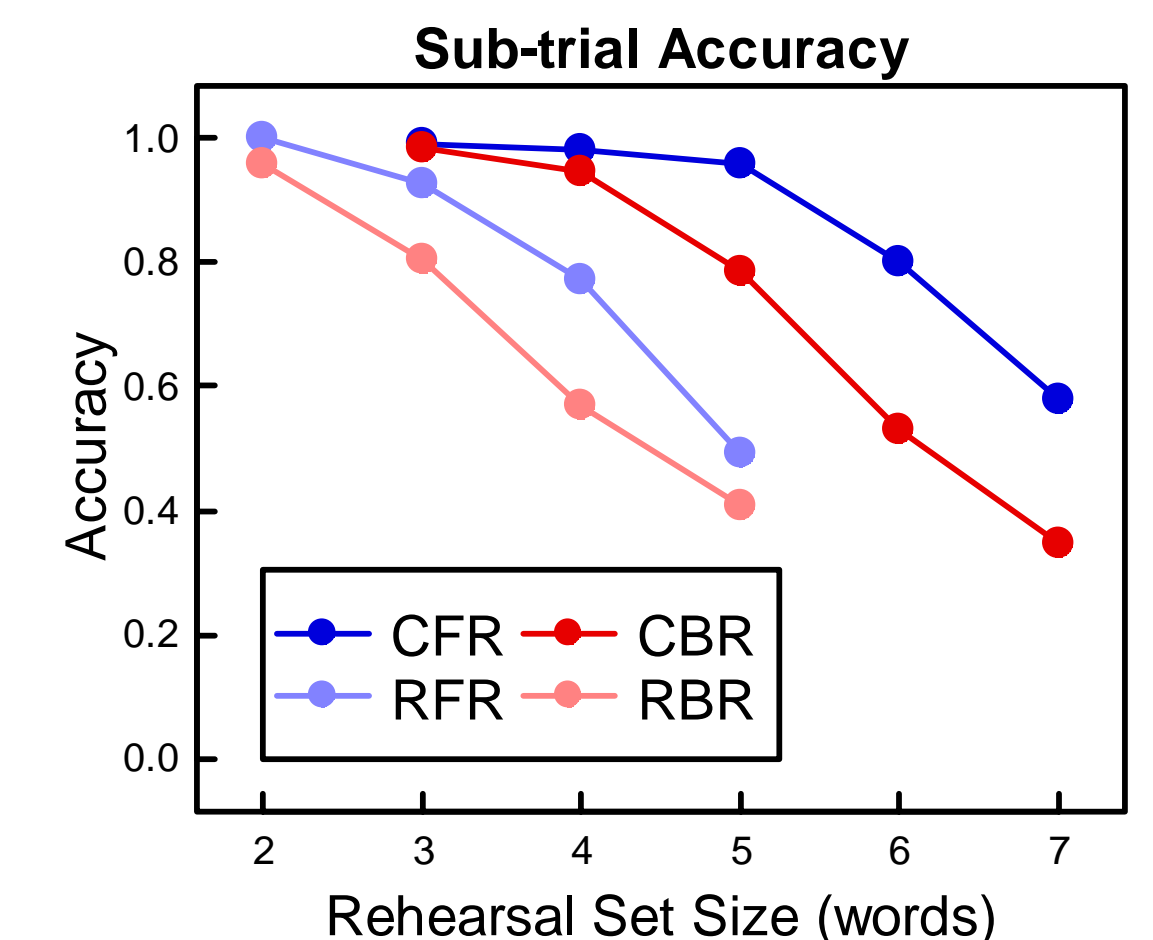
Baddeley, A. D. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences*, 4(11), 417-423.

Morris, N., & Jones, D. M. (1990). Memory updating in working memory: The role of the central executive. *British Journal of Psychology*, 81(2), 111-121.

Mueller, S. T., Seymour, T. L., Kieras, D. E., & Meyer, D. E. (2003). Theoretical implications of articulatory duration, phonological similarity, and phonological complexity in verbal working memory. *Journal of Experimental Psychology-Learning Memory and Cognition*, 29(6), 1353-1380.

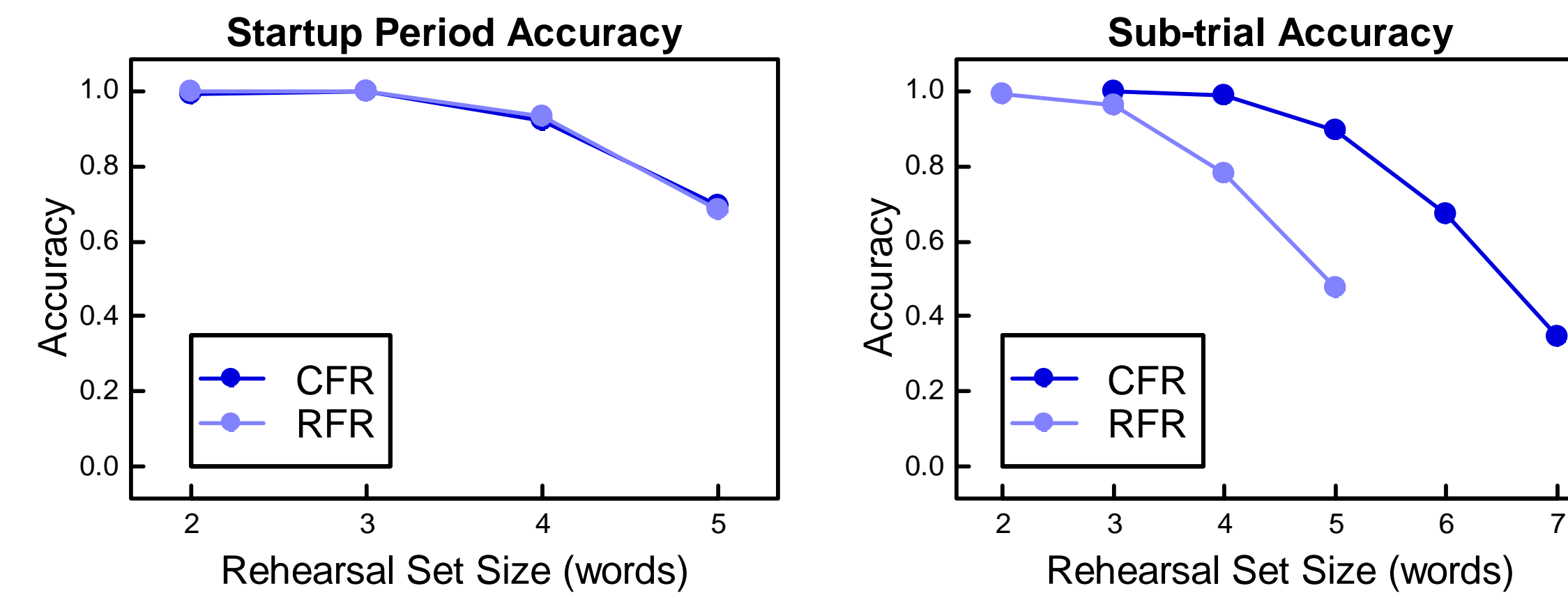
Results: CFR, RFR, CBR, and RBR

- Sub-trial accuracy decreased significantly with rehearsal set size for all four tasks.
- Approximately additive effects on sub-trial accuracy of rolling vs. cumulative and backward vs. forward tasks.
- Both update type and update location influenced accuracy.

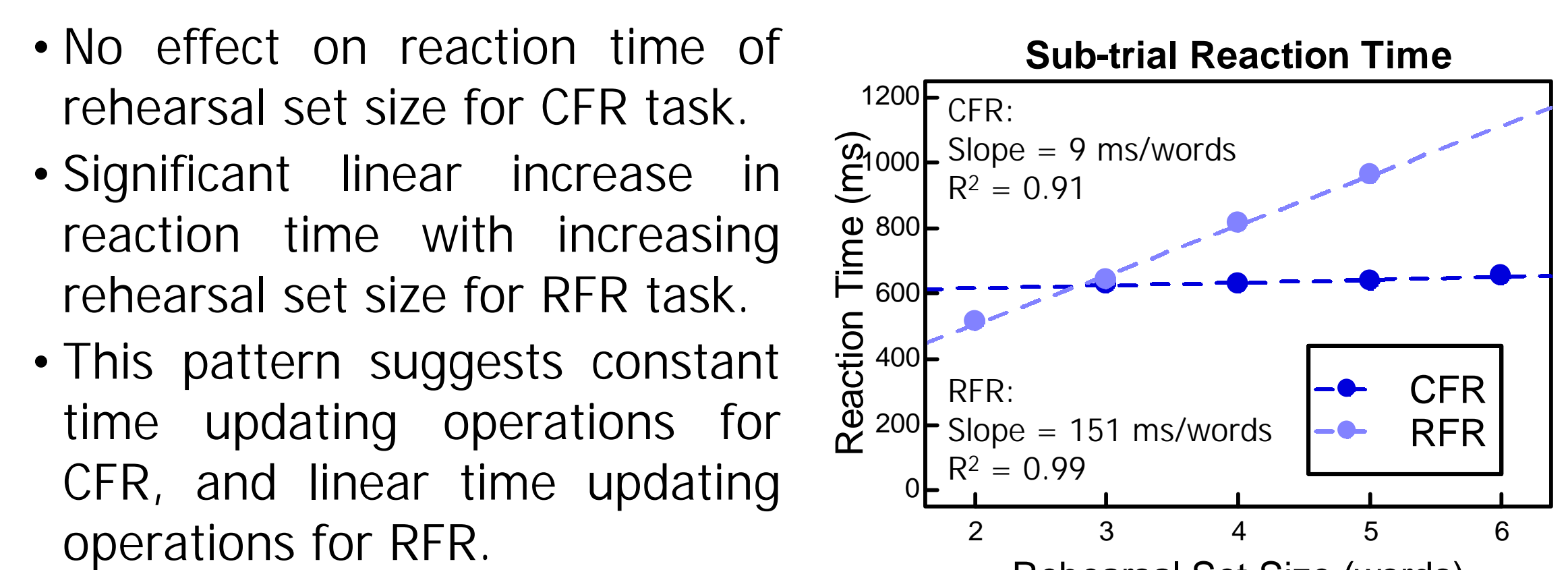


- Sub-trial reaction times for CBR showed no effect of rehearsal set size, and significant constant cost compared to CFR.
- Sub-trial reaction times for RBR are more difficult to interpret, with RTs significantly longer than RFR at small set sizes, and equivalent at larger set sizes.

Results: CFR and RFR



- Accuracy decreased significantly with rehearsal set size.
- No effect of task on accuracy during startup period suggests similar initial states before updates began.
- Significantly lower accuracy in RFR than CFR during sub-trials indicates differential effects of different updating operations.

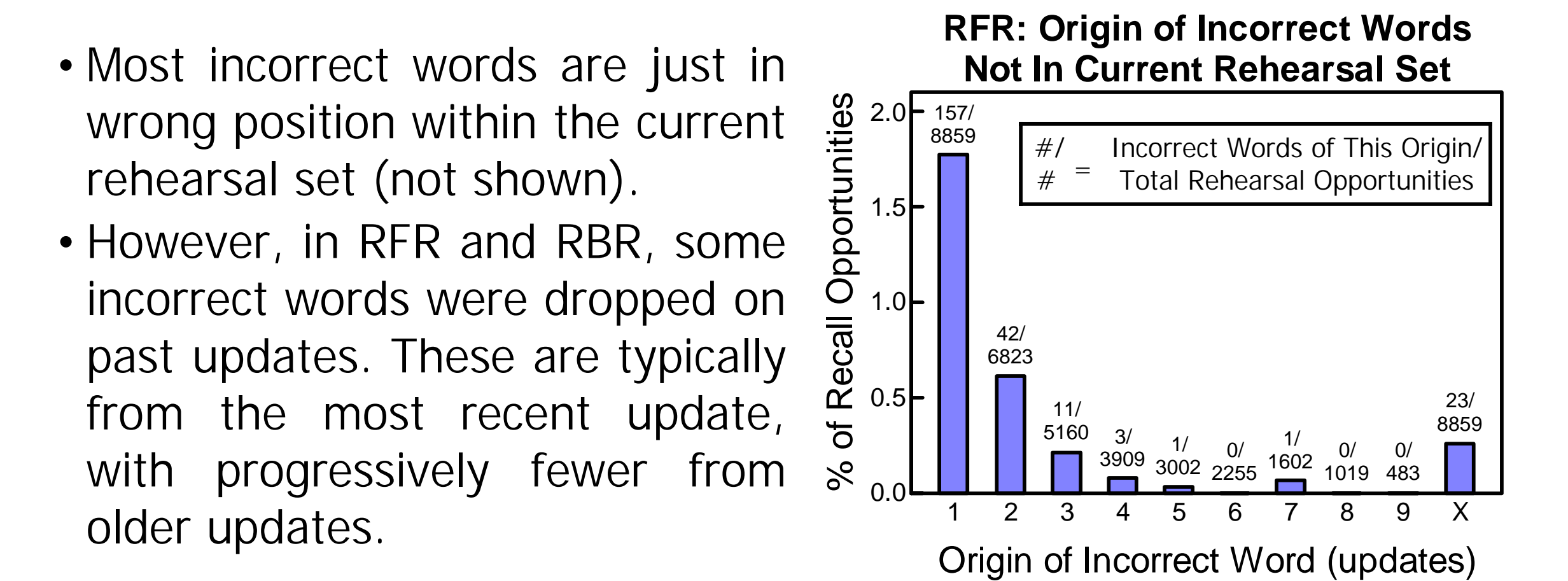


Why the difference in RT by rehearsal set size between tasks?

- Option A – Type of operation: deletion vs. addition
 - Perhaps, deleting any item in a list requires rebuilding the list?
- Option B – Location of operation: beginning vs. end
 - Perhaps, any modification to beginning of list requires manipulation of all items in the list?

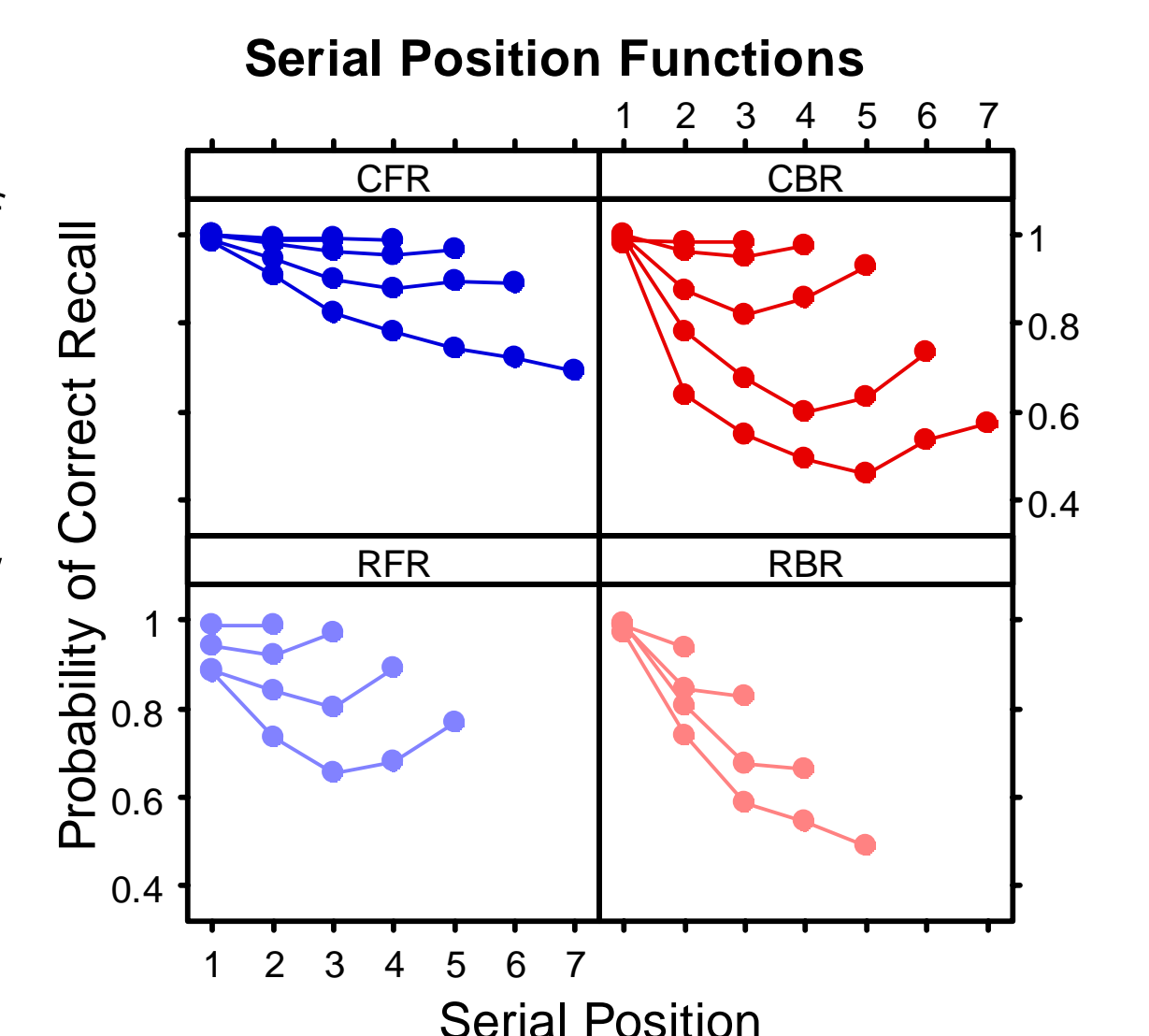
“Backward” tasks provide further constraints on possible architectures:

Update operation	Update location	
	Beginning	End
Addition	CBR, RBR	CFR, RFR
Deletion	RFR	RBR



Each task has a set of distinct serial position functions.

- All tasks show an effect of rehearsal set size.
- CFR shows a primacy effect at the start of the list.
- RFR and CBR show a primacy effect (at start for RFR; at end for CBR) and a recency effect (at end for RFR; at start for CBR).
- RBR shows a recency effect at the start of the list.



Future Plans

- Construct a model of the rehearsal tasks within the Executive-Process Interactive Control (EPIC) architecture:
 - Necessary to develop and test detailed theories of processes involved in VWM updating operations.
 - Will simultaneously test assumptions of past work with other VWM tasks (e.g. serial recall) and provide independently motivated constraints on new model.
- Adapt the rehearsal tasks for use in fMRI experiments:
 - Use the methods of parametric variation and temporal isolation to identify brain regions participating in updating operations.
- Use the rehearsal tasks in training studies and ageing studies to gain further insight into the executive control operations involved in the updating of verbal working memory.