NEW INSIGHTS INTO AN OLD PROBLEM: DISTINGUISHING STORAGE FROM PROCESSING IN THE DEVELOPMENT OF WORKING MEMORY

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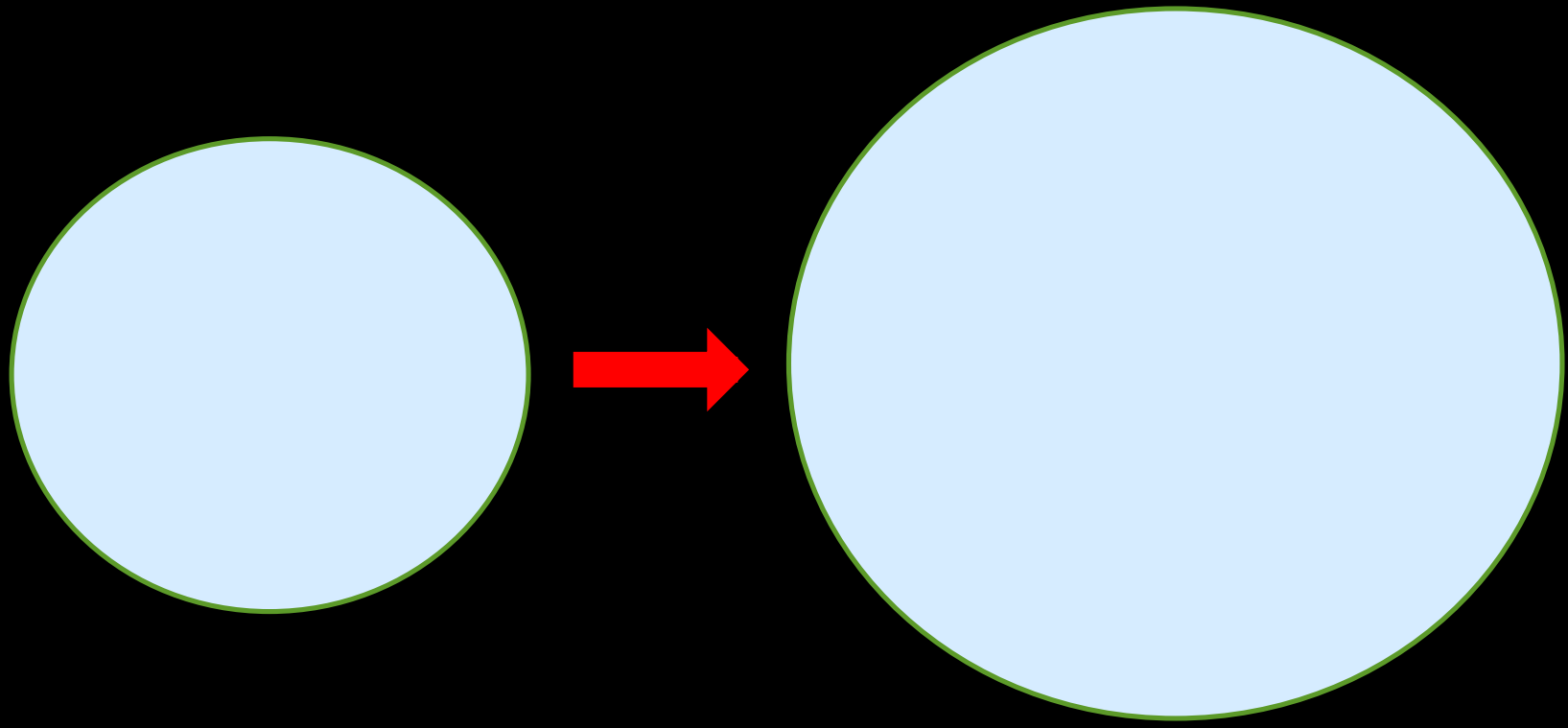
Main question

- Why is there a developmental increase in working memory span?
- Emphasis here on a *central resource* used for working memory storage and also for related processing

Definition of working memory (WM):

- WM is the limited amount of information that is temporarily in a readily accessible state, in order to facilitate cognition
- WM does not include the related mnemonic processing, by my definition – but this processing is still of great interest
- WM is not the same as attention, but uses attention in various ways

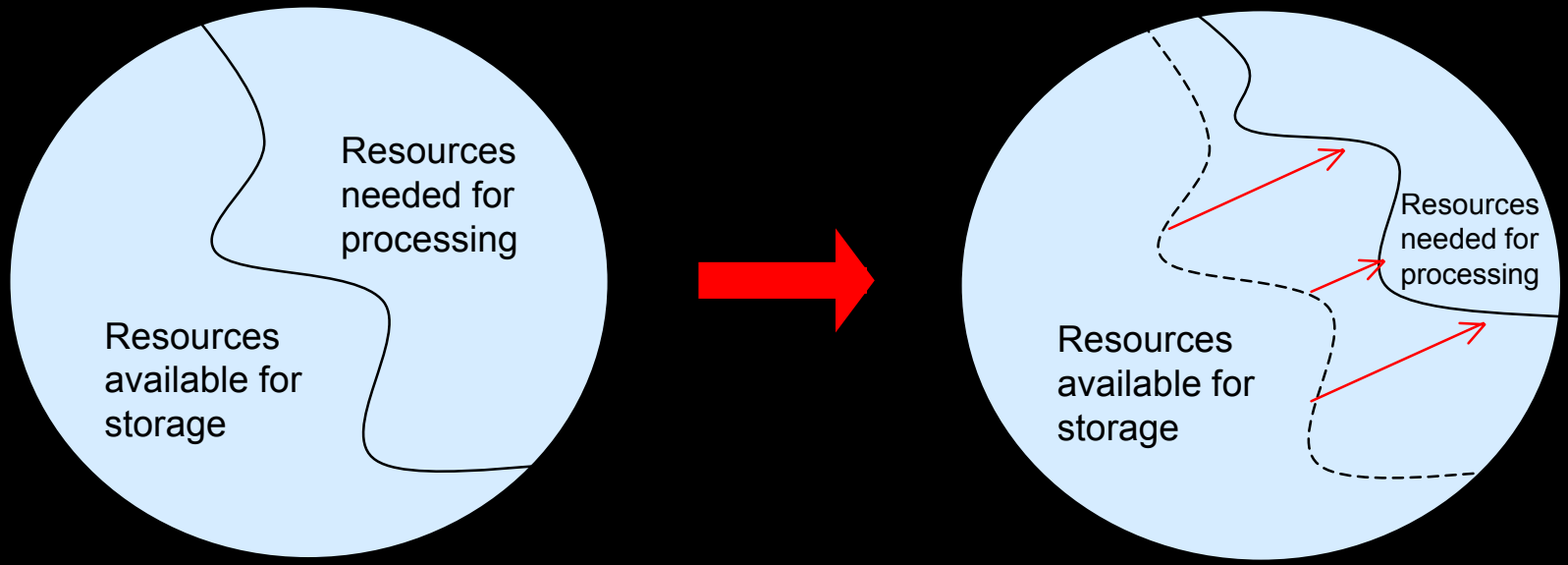
Developmental Model 1: increasing storage capacity of WM



Younger child

Older child

Developmental Model 2: increasing efficiency of processing



Younger child

Older child

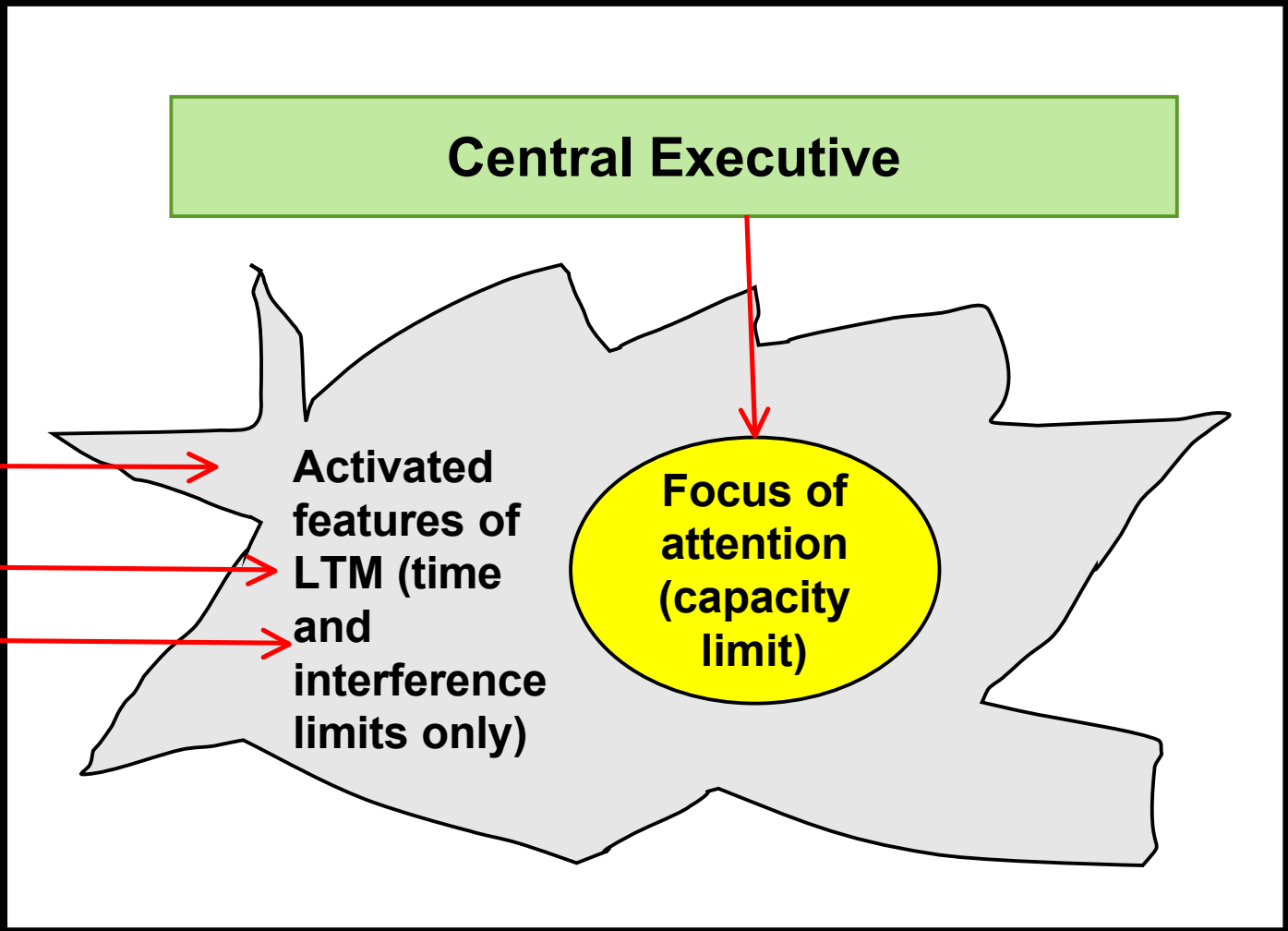
One type of empirical evidence to assess the models

- Does storage increase with age even if the processing is kept simple?
  - If so, evidence for the increased-capacity model
- Does processing efficiency increase with age even when the memory load is kept low?
  - If so, evidence for the increased-efficiency model

What is the shared resource?

- Attention
- Needed for some storage, though not all
  - e.g., needed for attending to abstract items
  - e.g., not needed to retain sensory information briefly
- Needed for some processing, though not all
  - e.g., needed to search through items in memory
  - e.g., not needed for adults to rehearse a short verbal list covertly

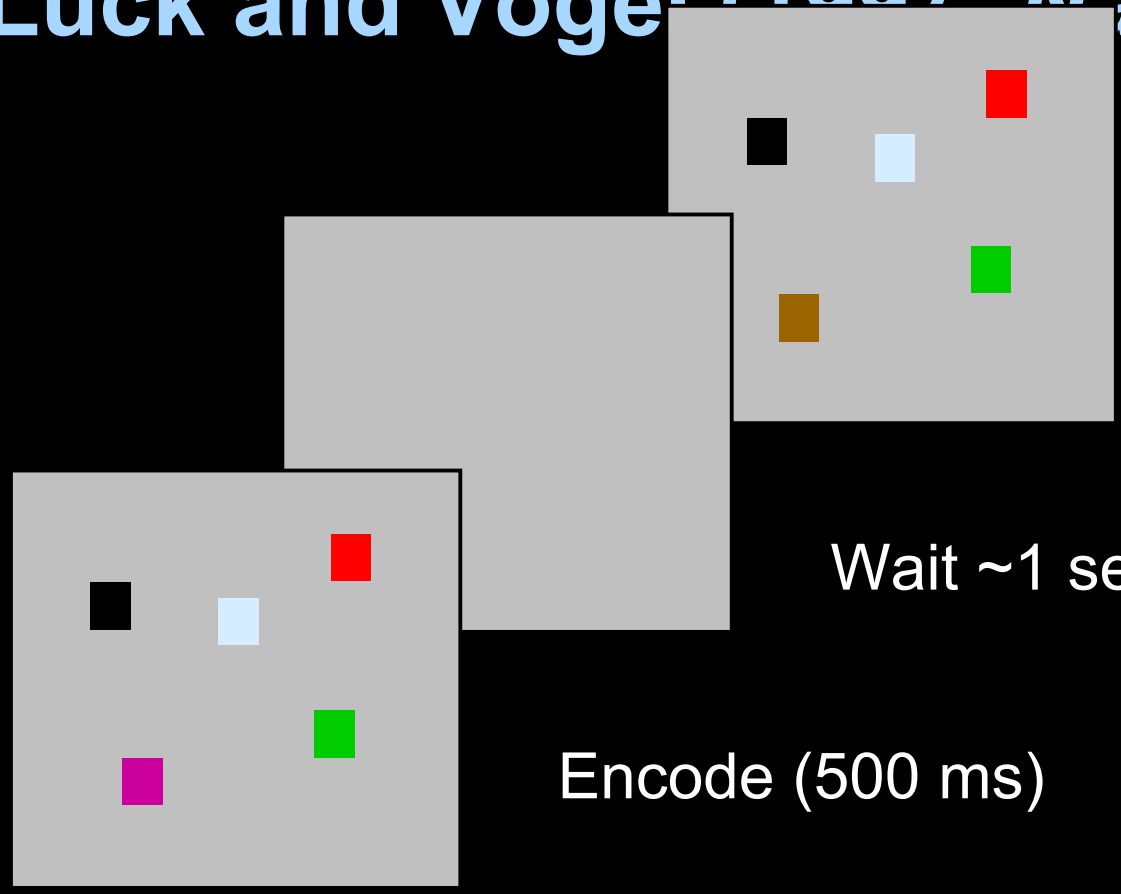
Embedded processes model of working memory



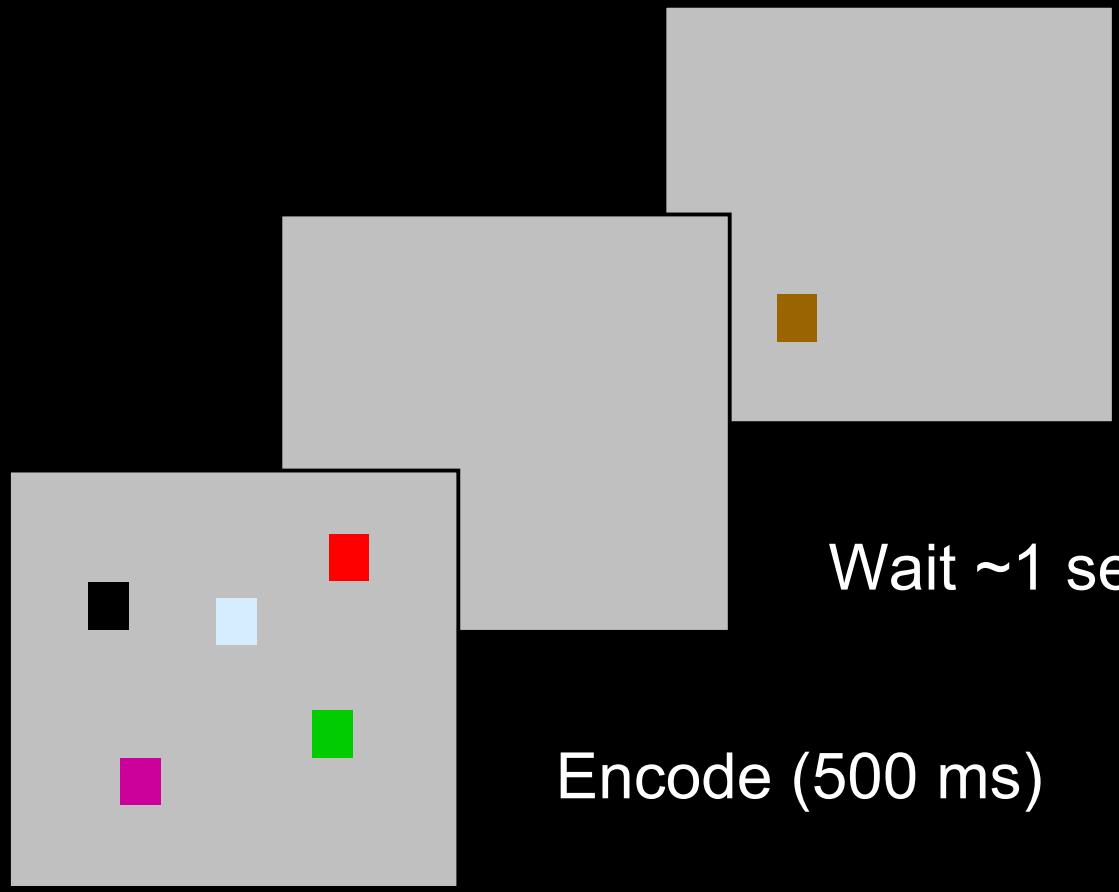
Cowan model and Baddeley model: similar in function

- Both models have central executive
- Focus of attention is similar to Baddeley's new episodic buffer
- Activated elements of long-term memory (with feature similarity effects for interference) is similar to Baddeley's passive buffers, just less modular

Basic procedure to be discussed next:
Luck and Vogel (1997, *Nature*) task



Modified task in some studies



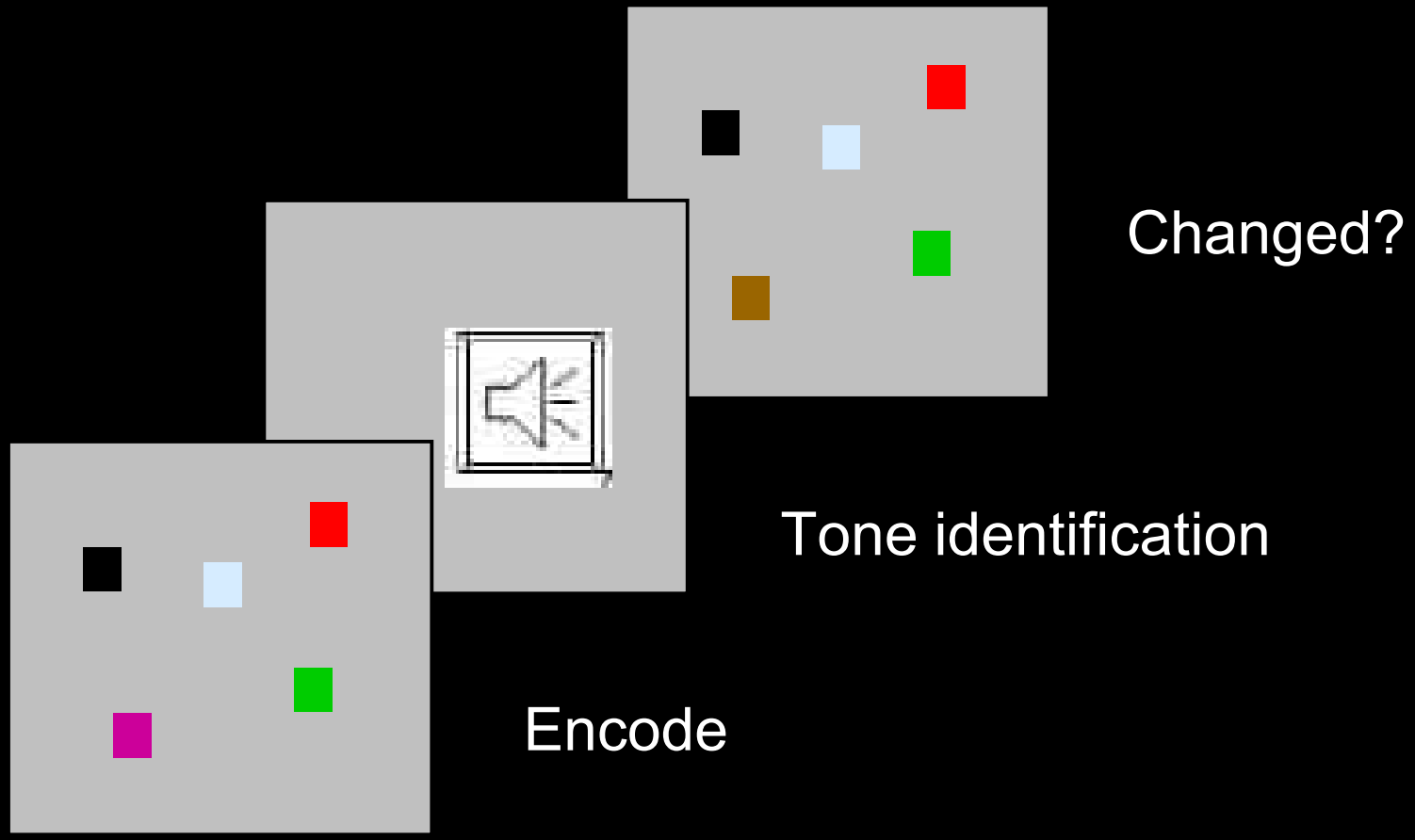
Changed?

Wait ~1 second

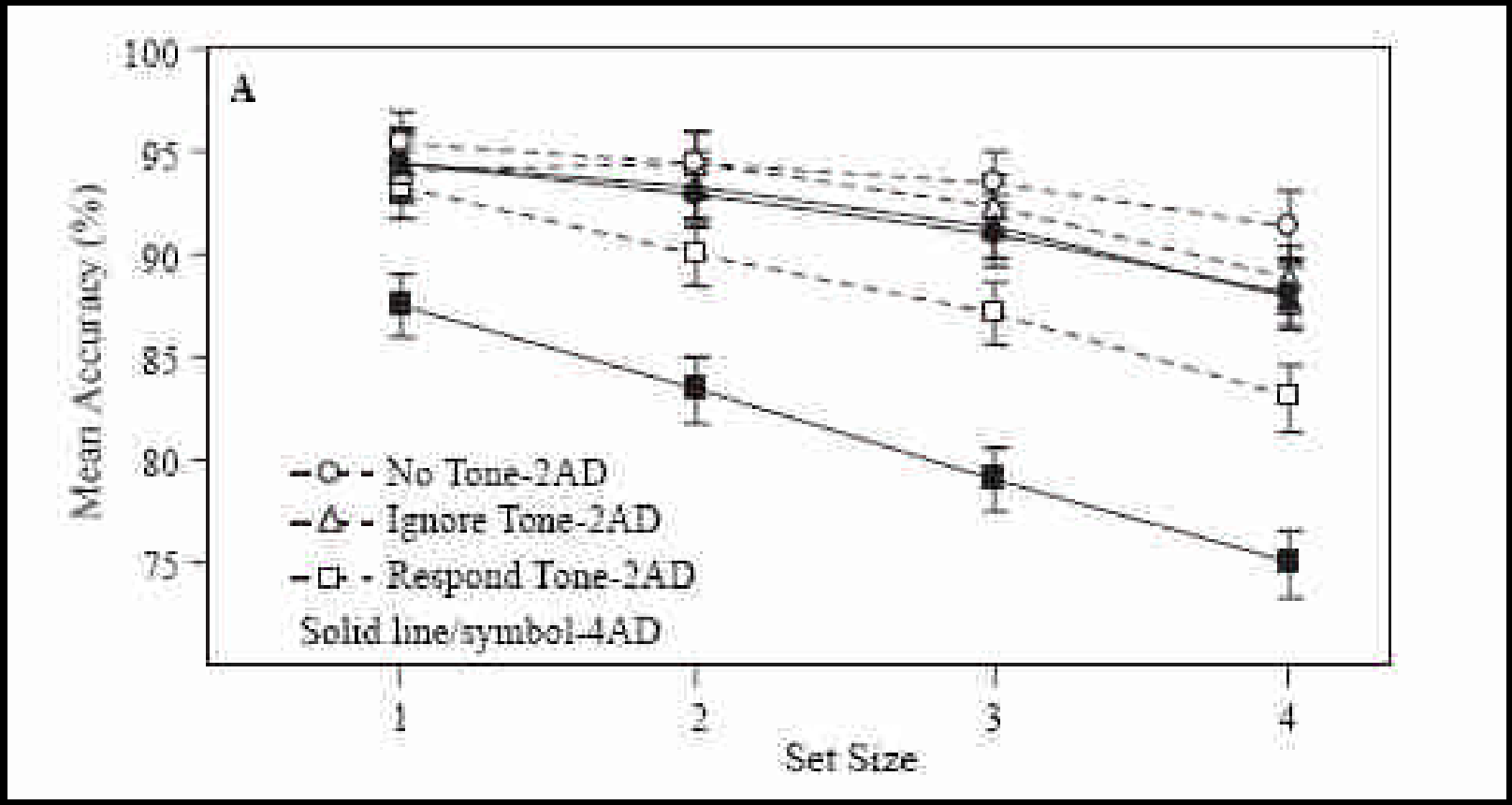
Encode (500 ms)

The shared resource is attention

Storage and processing: **(Stevanovski & Jolicoeur, 2007, *Visual Cognition*)**



The shared resource is attention



k Measure of Items in Working Memory

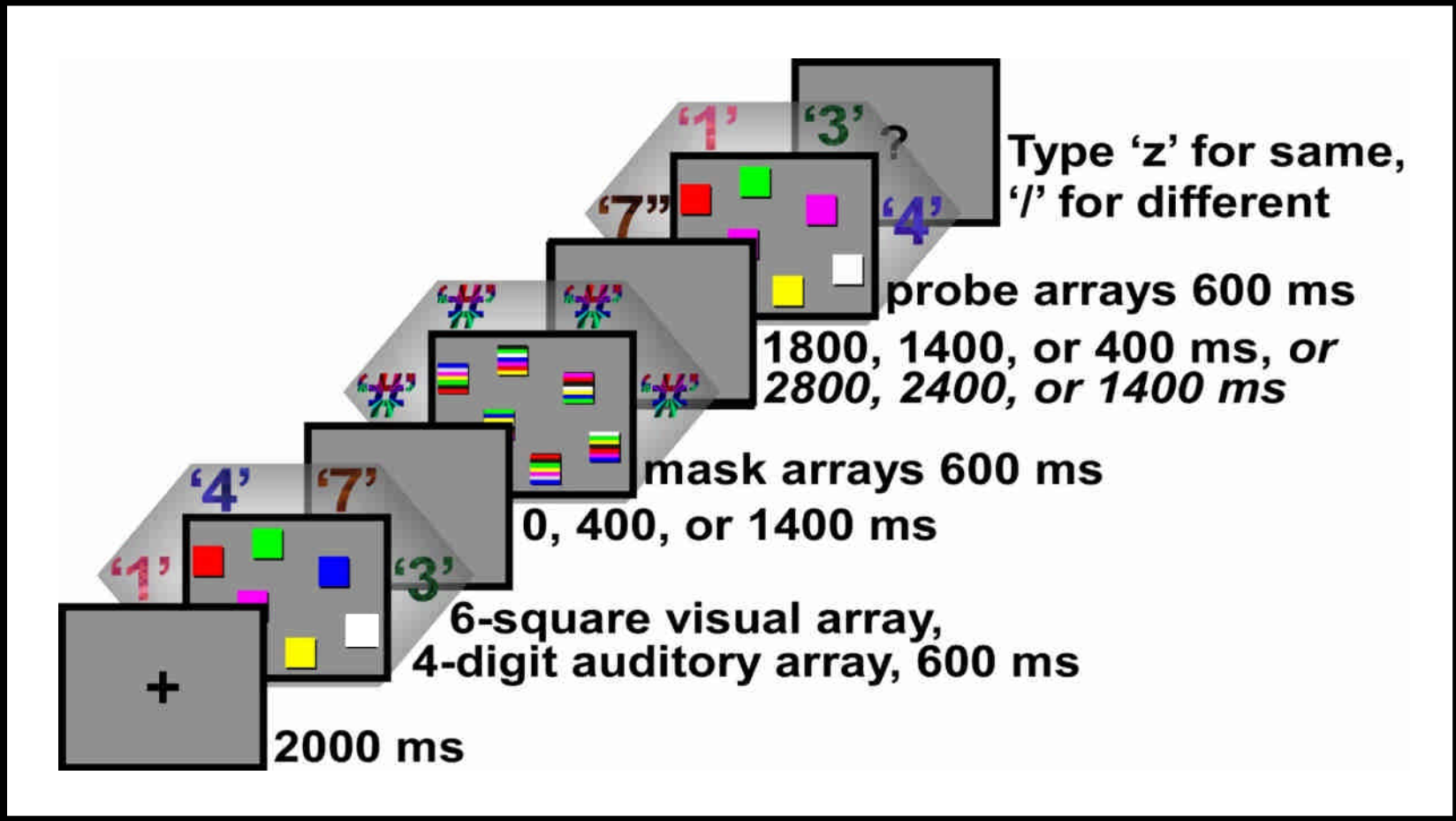
- N = number of items in array
- k = number of array items in working memory
- k/N = probability probed item is in working memory, which yields the correct answer; if not in working memory, guess
- k = N * [p(“change”|change) – p(“change”|no)]

The shared resource is attention

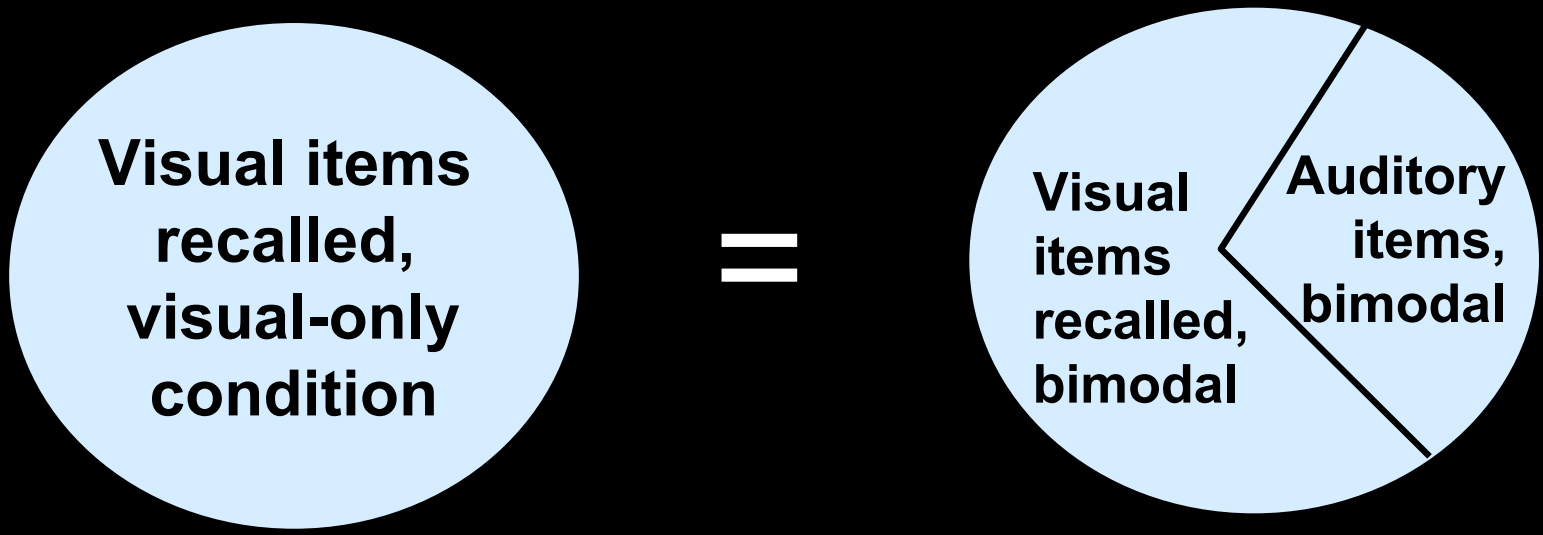
Equivalence of visual and auditory stimuli if sensory memory is eliminated; constant total k
(J. Scott Saults & N. Cowan, 2007, *JEP:G*)

Multi-modal Array Task

Procedure in our best experiment (5) with unimodal versus bimodal instructions



Performance is capacity-limited for this shared resource



~4 visual items, unimodal condition

~4 items total, bimodal condition

More on shared resource across modalities (Cowan & Morey, 2007, Psych. Sci.)

- Suppress rehearsal (“the, the, the…”)
- Receive Set 1 (visual array or spoken list)
- Receive Set 2 (visual array or spoken list)
- Get cue to retain Set 1, Set 2, or both sets
- 3-second delay
- Test on one of the lists that were retained
- There is a cost of retaining 2 lists (~0.60 item)
- *Cost does not depend on whether the sets are the same or different in modality*

What uses of the shared resource develop?

- Storage capacity?
- Processing efficiency?

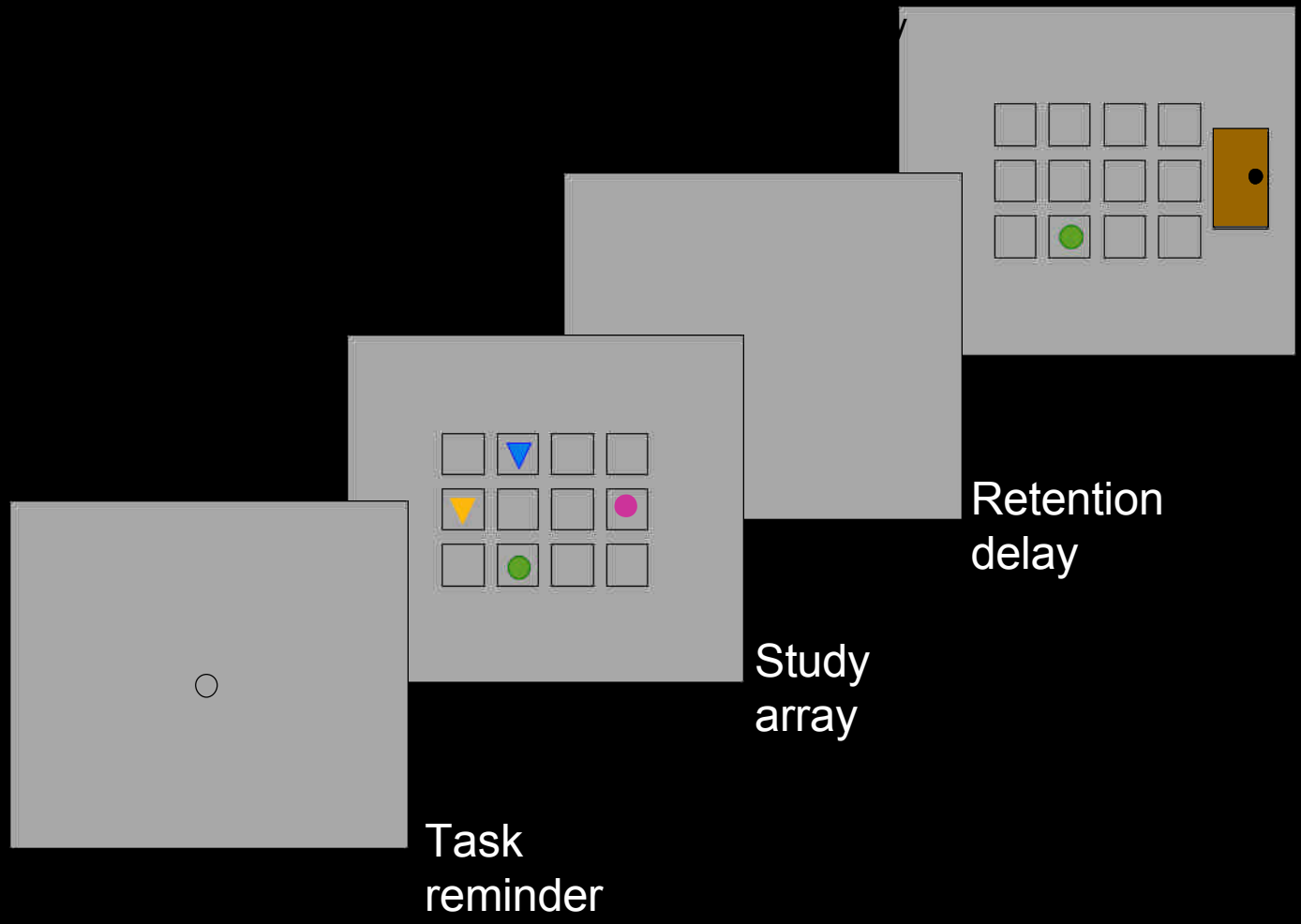
Studies of 3 processes:

- Selection of items for working memory
- Grouping of items to form larger chunks
- Strategies to ease the use of attention for processing

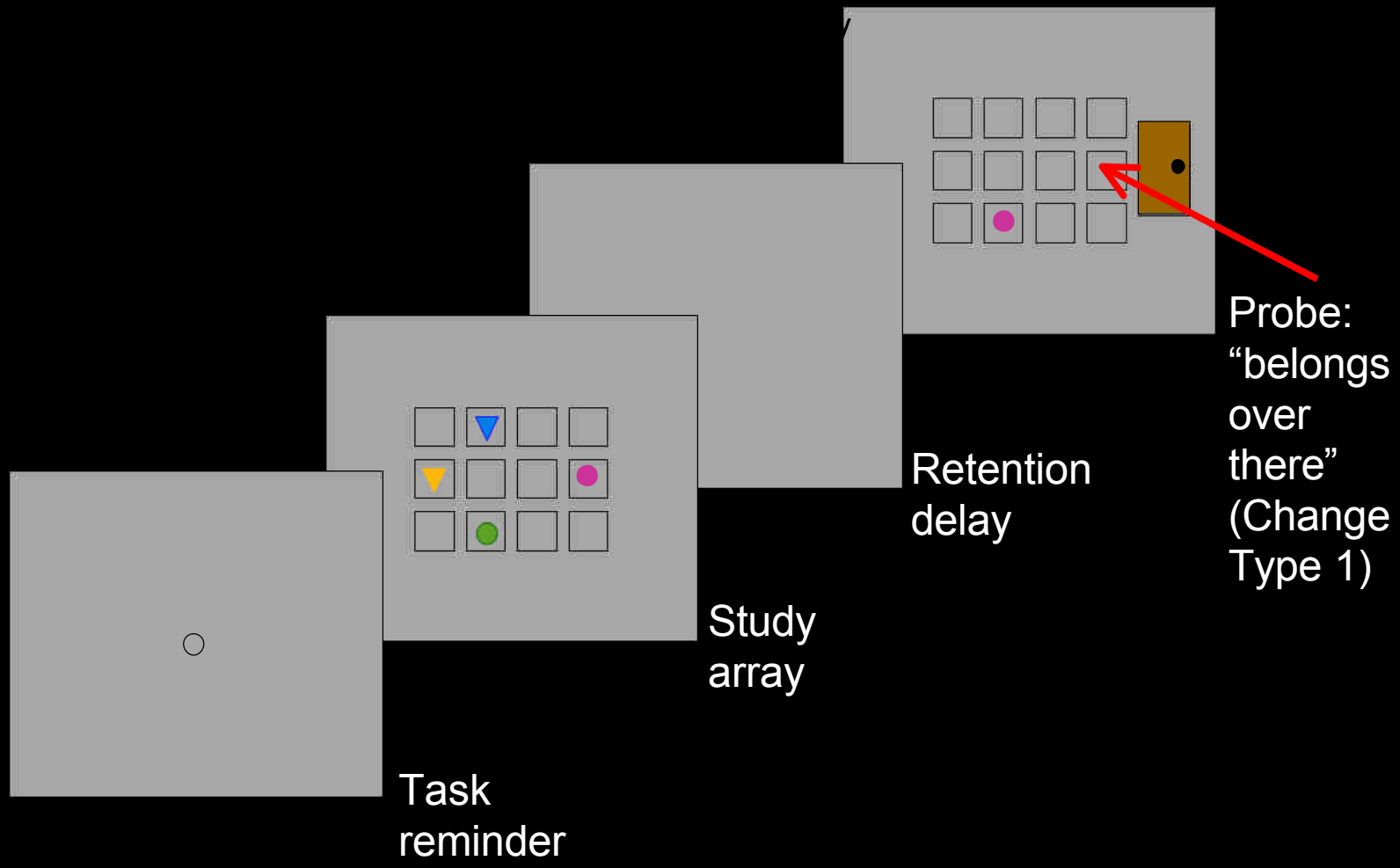
1. Development of storage versus selection process:

(Cowan, Morey, AuBuchon, Zwilling, & Gilchrist, in prep.)

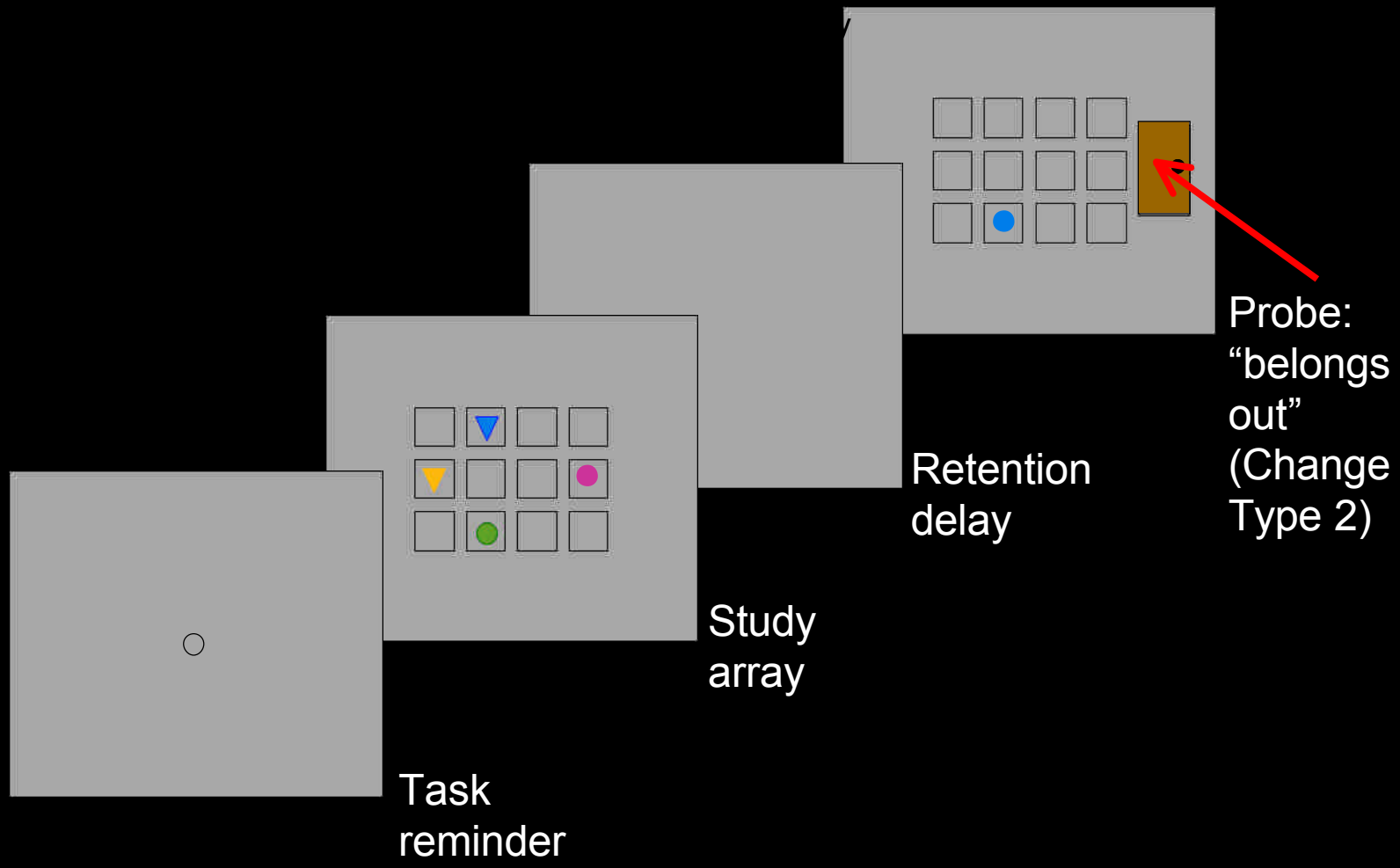
Storage vs. selection: classroom task



Storage vs. selection: classroom task



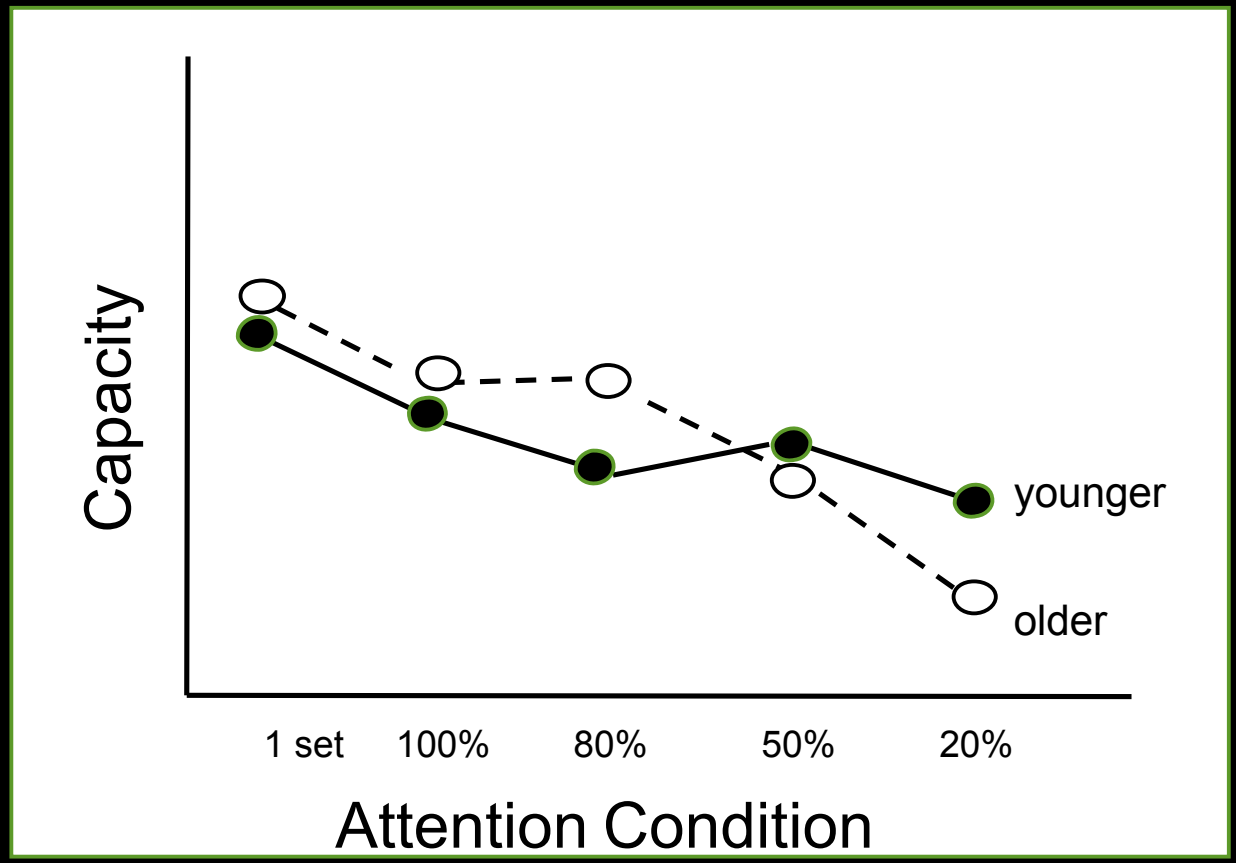
Storage vs. selection: classroom task



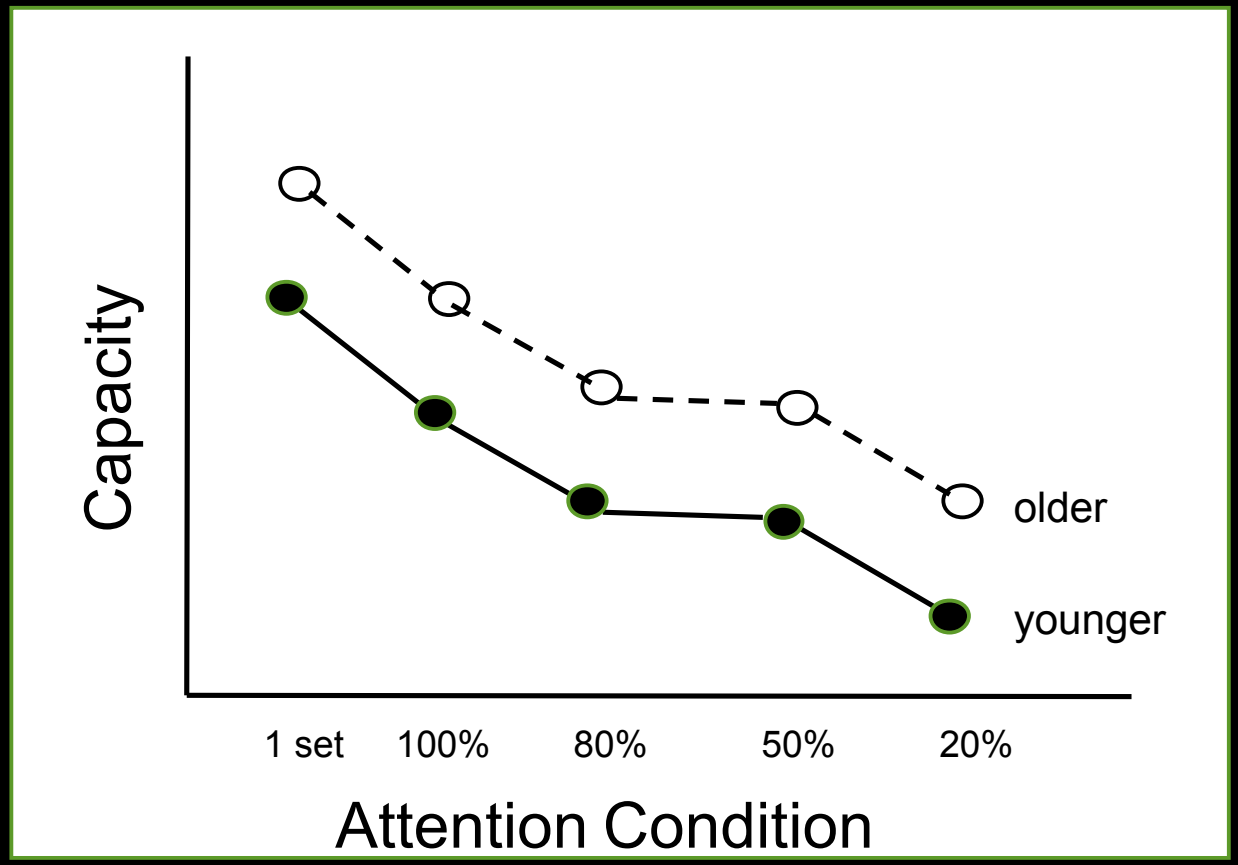
Participants and selective attention conditions

- Grades 1-2, Grades 6-7, and College
- 1-shape blocks. [2, 3, 4, 6 items, same shape]
- 100% valid blocks. [2 or 3 items per shape]
  - Always tested on one of the two shapes
- 80% valid blocks. [2 or 3 items per shape]
  - Attended shape tested 80% of the time, unattended shape tested 20% of the time
- 50% valid blocks. [2 or 3 items per shape]
  - Each of the two shapes tested 50% of the time

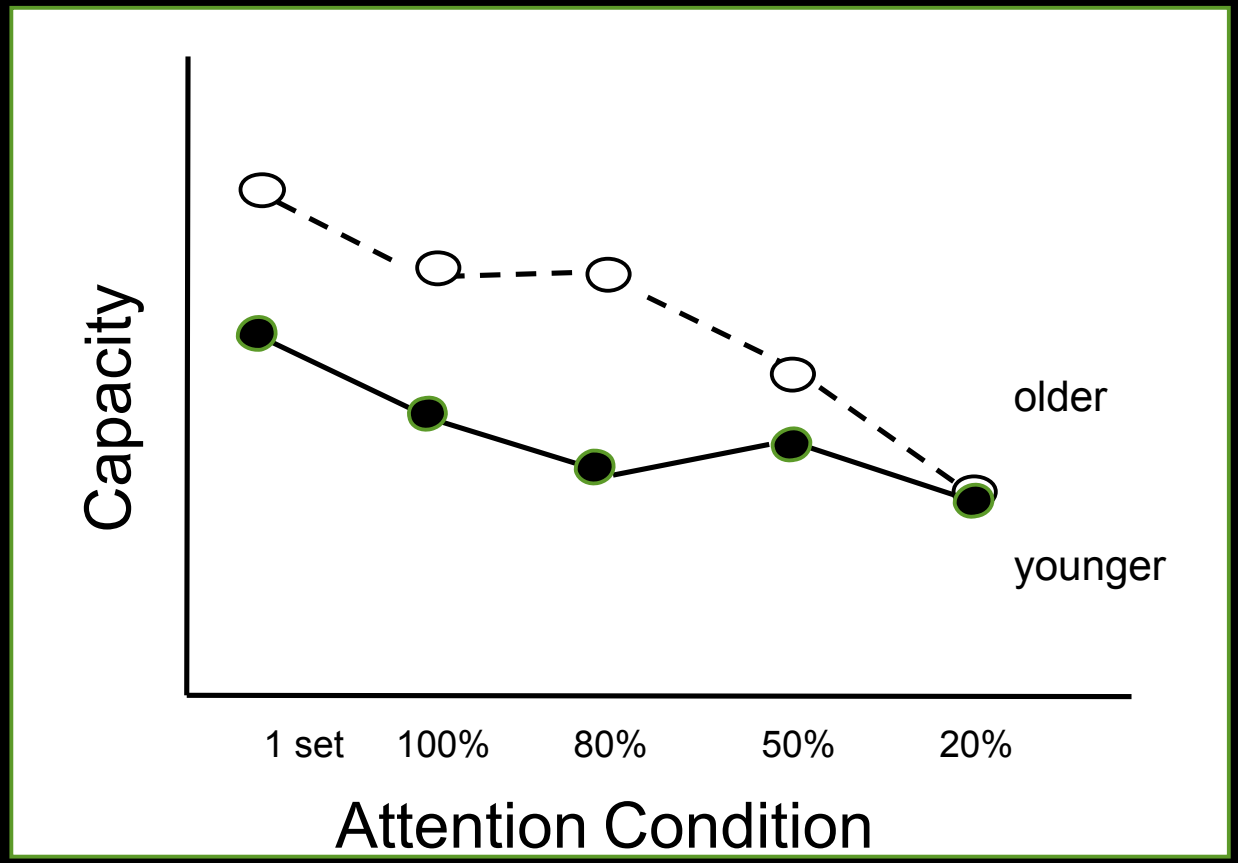
Prediction – age difference in selection efficiency



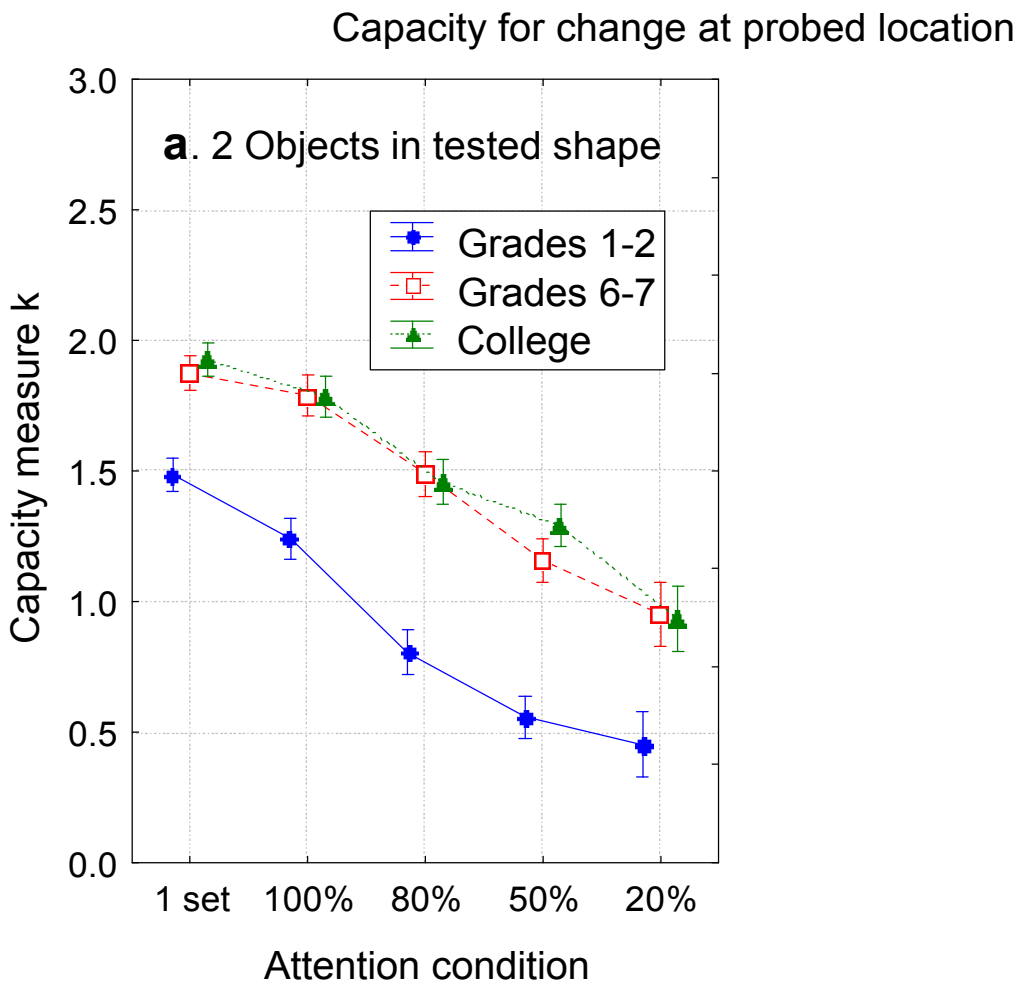
Prediction – age difference in storage capacity



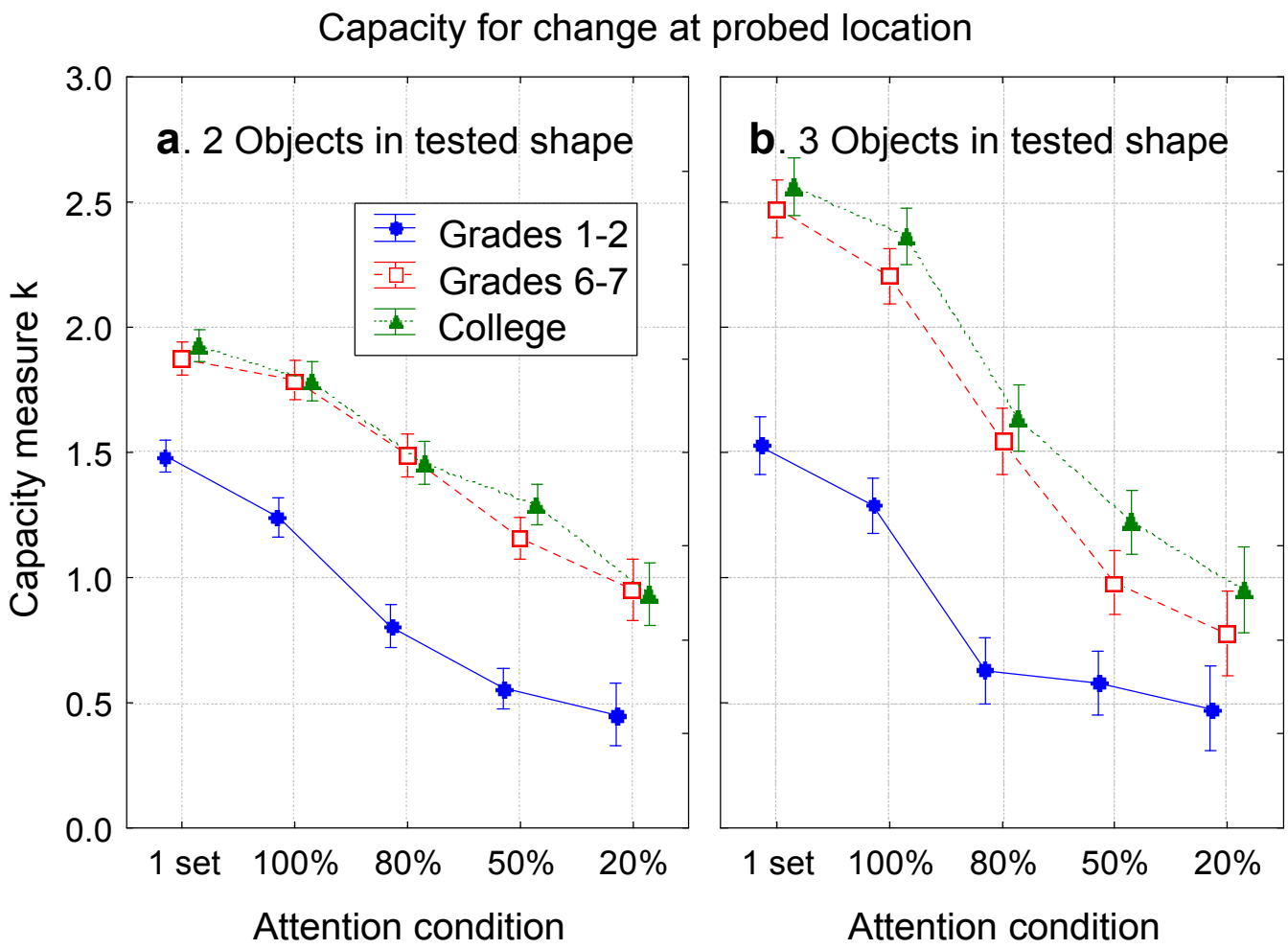
Prediction – both factors



Results: across conditions



Results: across conditions



Conclusions (development of storage versus selection process):

- Storage capacity increases with development
- When the working memory load is low (2 items in the tested shape), young children select items for storage as efficiently as older children and adults do.
- When the working memory load is raised (3 items in tested shape), young children's selection efficiency suffers a bit

2. Development of storage versus grouping / chunking process (A. Gilchrist & N. Cowan)

Chunking

- After George Miller (1956): Formation of a group of items that are associated.
- Can be based on prior knowledge
  - (e.g., remember these 11 letters: “breadsitday”)
- Can be based partly on new processing
  - (e.g., remember these 12 letters: “formonegroup”)
- The actual limit on storage is in terms of the number of meaningful chunks
- Baddeley: You can remember a bit more if the items can be verbally rehearsed quickly
- Without such rehearsal, ~4 chunks in adults

Gilchrist & Cowan: Free recall of lists of unrelated sentences

- Children in first and sixth grades
- Materials too long to be rehearsed quickly
- Within-sentence structure that can be treated as a chunk if the information can be integrated

Trial types

- 4 short sentences (1 clause)
- 8 short sentences
- 4 long sentences (2 clauses each: overall, same length as 8 short)
- 4 random (jumbled) sentences

Stimulus Examples (spoken sentences)

4 short:

The yellow dog howled.
The witch kicked him.
Dad saw them leave.
Thieves took the painting. -> Recall

	Ideal Chunks
4S	4
8S	8
4L	4*
4R	Each word

4 long:

The yellow dog howled as the witch kicked him.
Thieves took the painting and Dad saw them leave.
Turn the block over and place it by the toy.
Give the crab flavor and add some salted butter. -> Recall

4 random:

Thieves witch yellow them.
It crab some block by.
Saw him the took dog.
Leave give toy butter . -> Recall

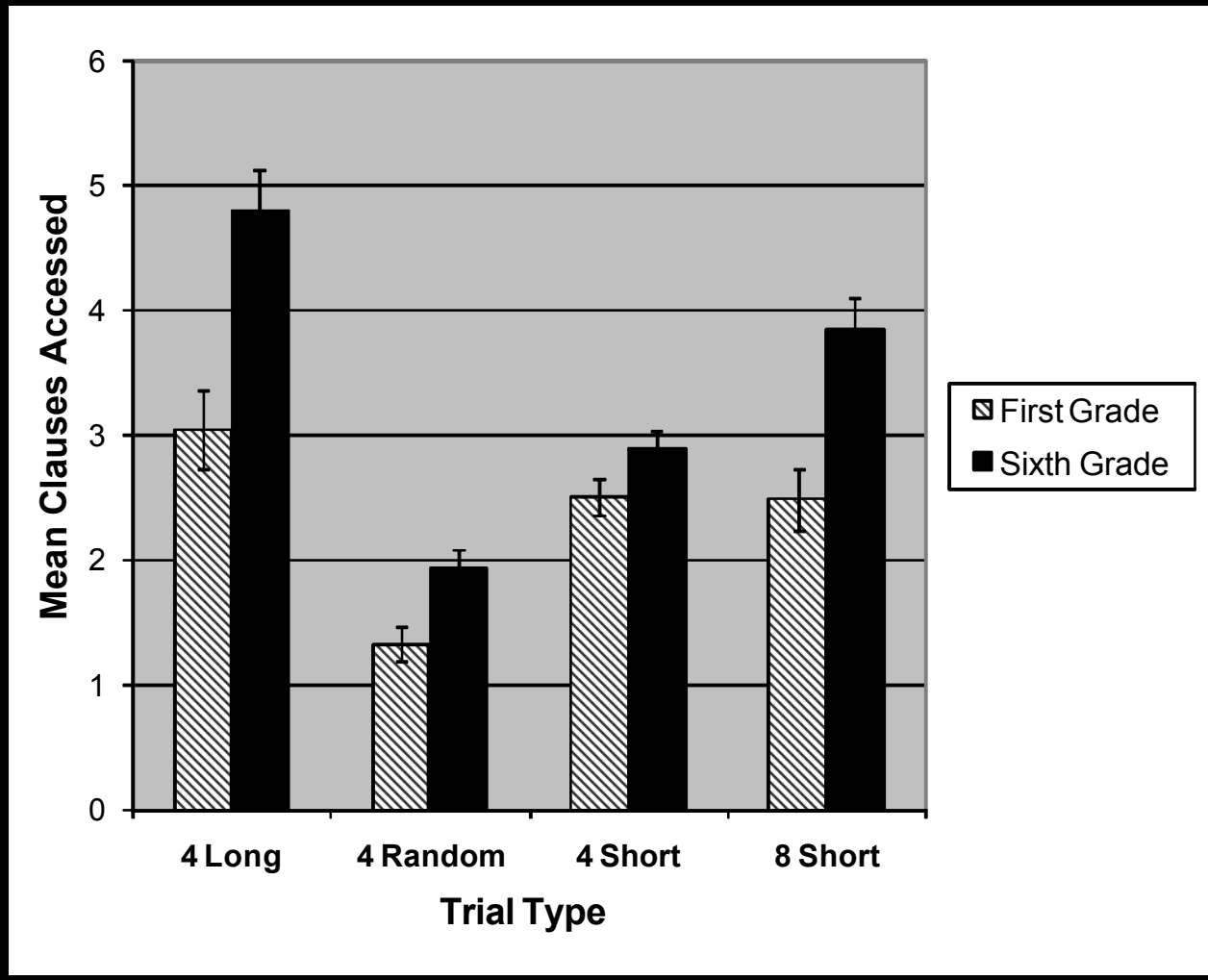
8 short:

8 sentences like above. -> Recall

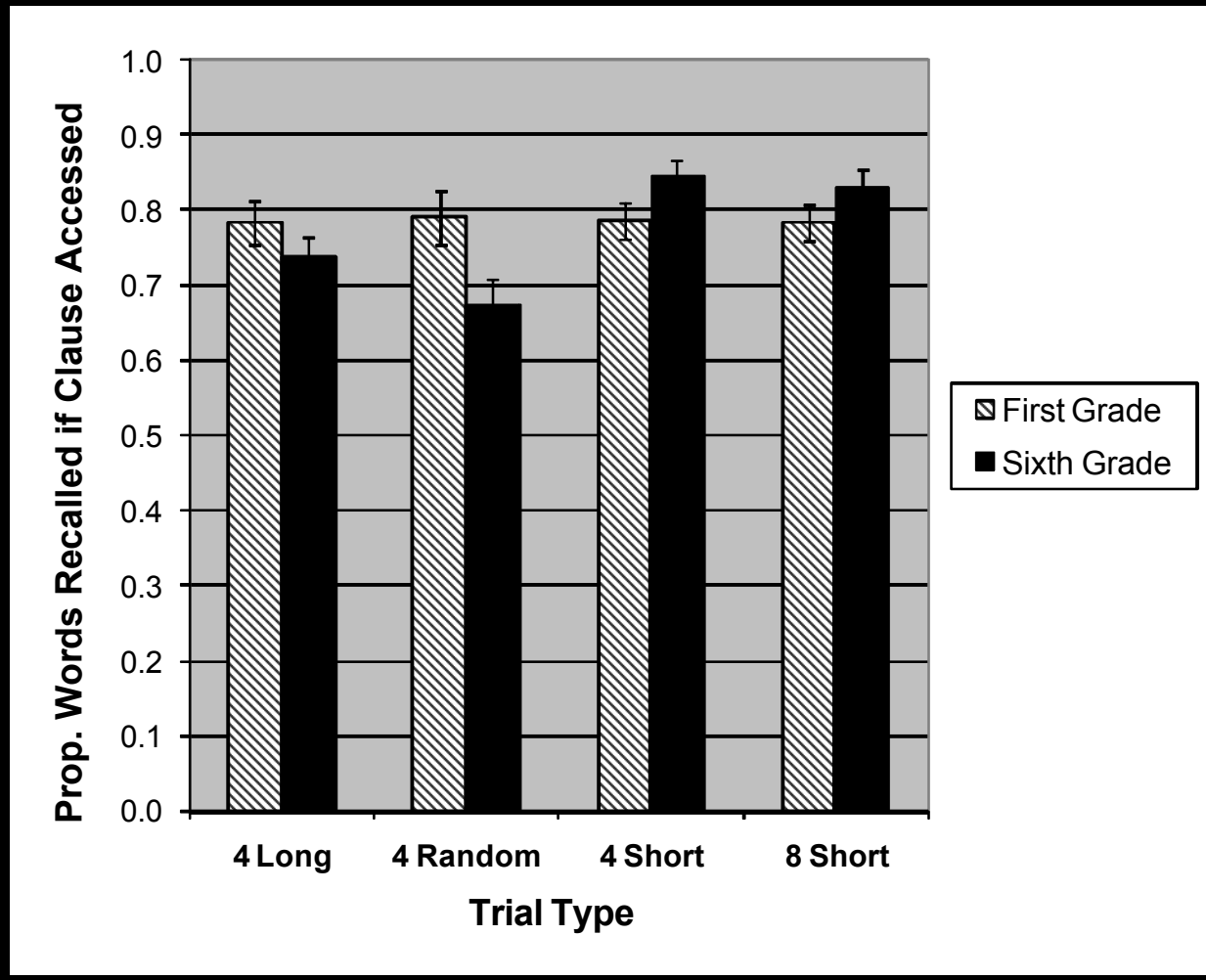
Main measures of capacity and chunking

- Capacity measure – Access to clauses
  - the number of clauses from which at least one content word was recalled
- Chunking measure – Completion of clauses
  - the proportion of words recalled from those clauses that were accessed

Results – Clauses accessed



Results – completion of accessed clauses



Conclusions (development of storage versus chunking processes in sentences):

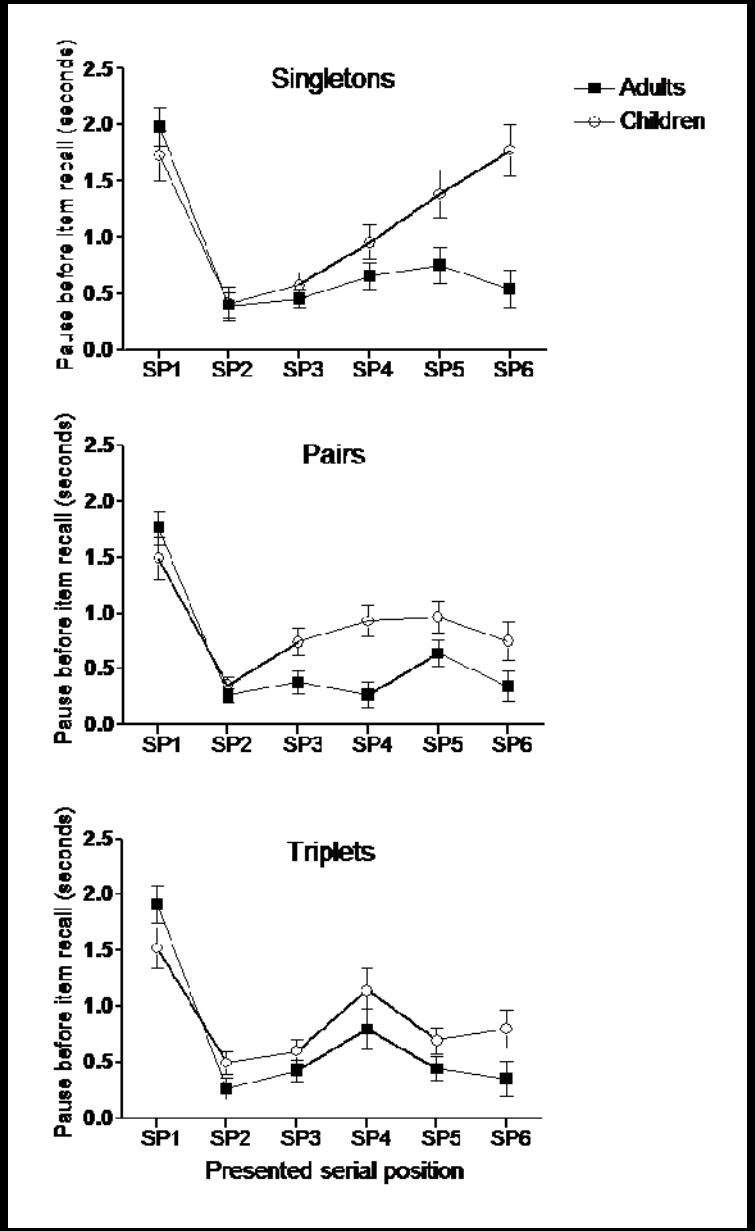
- There was a marked age difference in capacity (access to clauses)
- There was no age difference in chunking (completion of accessed clauses)
- -- with the possible exception of grouping clauses together to form larger, somewhat arbitrary structures in the long-sentence condition

Timing as a measure of chunking (N. Cowan, John Towse and others)

Timing and chunking: method

- 10-year-olds and college students
- Training with nameable pictures of common objects – singletons, pairs, triplets
- Serial recall test with 6-item lists
  - 6 singletons (use of own strategies?)
  - 3 pairs (smaller chunks to use; higher WM load)
  - 2 triplets (larger chunks to use; lower WM load)
- Adults recall more, but why?
  - About the same advantage of pairs, triplets
- Look for gaps at the chunk boundaries

Timing results



Conclusions (development of storage versus chunking):

- There is a capacity increase across age groups for lists of unrelated verbal units (sentences; learned associates)
- When the memory load is relatively low, there is no change in the ability to form basic chunks (clause completion) or to use learned associations (recall timing)
- With high memory load (8-clause materials; 3 learned pairs) or complex task (long sentences) the ability to use chunks begins to break down

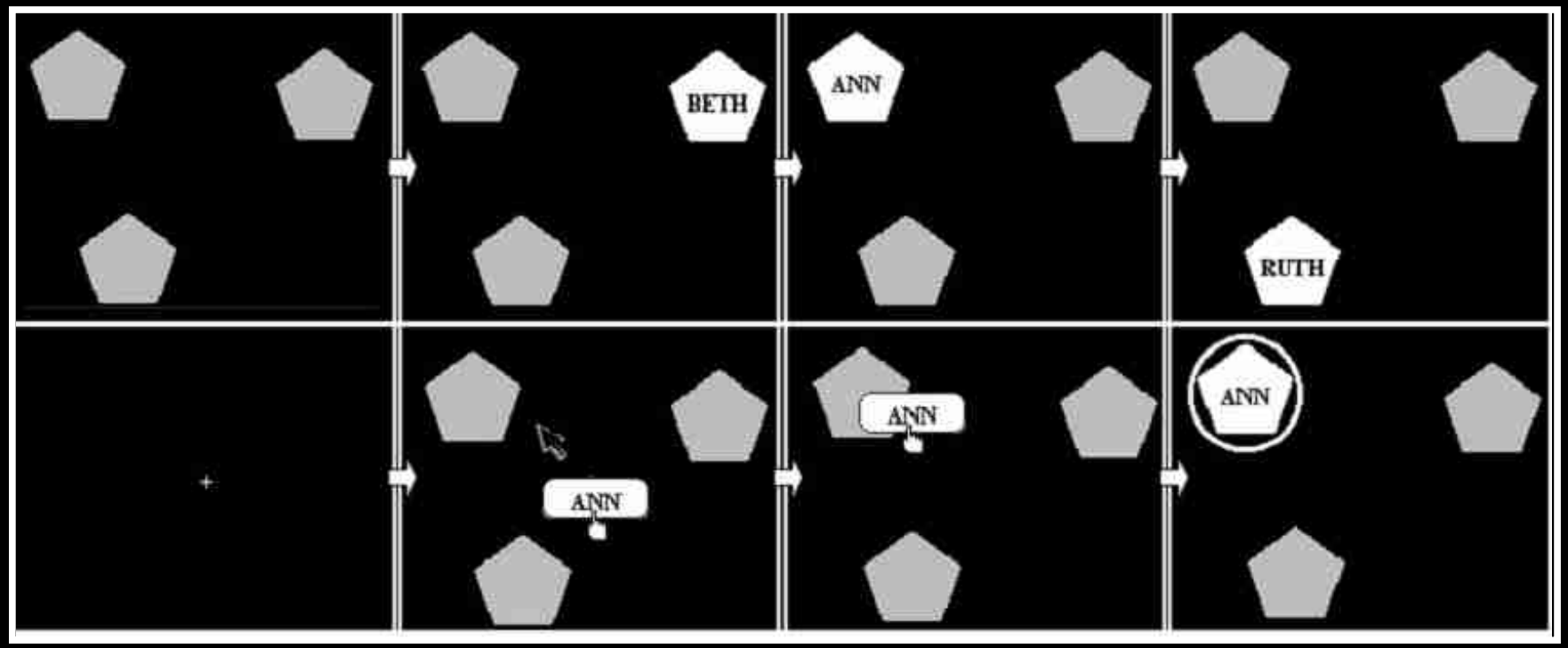
3. Development of storage versus advanced rehearsal & strategic processes

(Cowan, Saults, & Morey, 2006, *J. Memory and Language*)

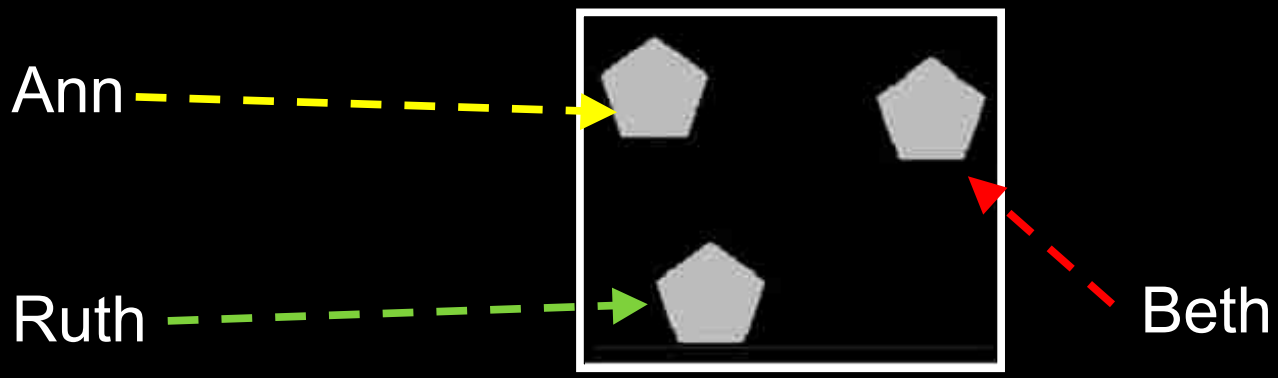
Working memory for verbal-spatial associations

- 9-10 years, 12-13 years, college students
- Present set of locations
- Present names in the locations
- Present a probe name
- In which location does it belong?
  - Clue: two different conditions favor different strrategies

Verbal-spatial association task (3-item trial; 3-7 was used in expt.)

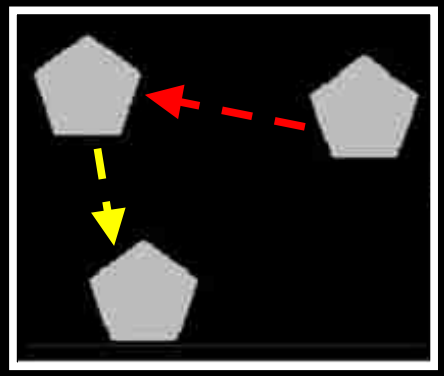


Associative strategy



Parallel-codes strategy

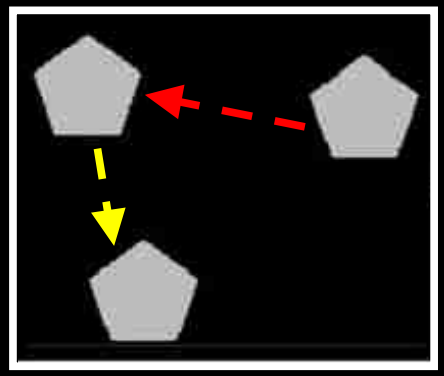
“Beth, Ann, Ruth”



Parallel-codes strategy

"Beth, Ann, Ruth"

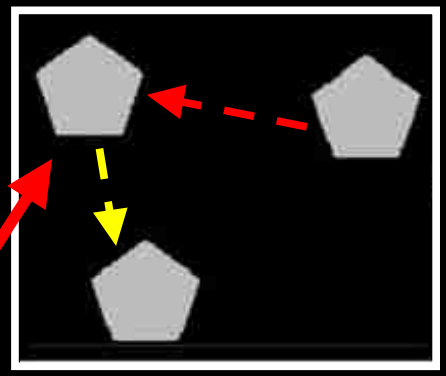
Probe: "Ann" -> 2nd



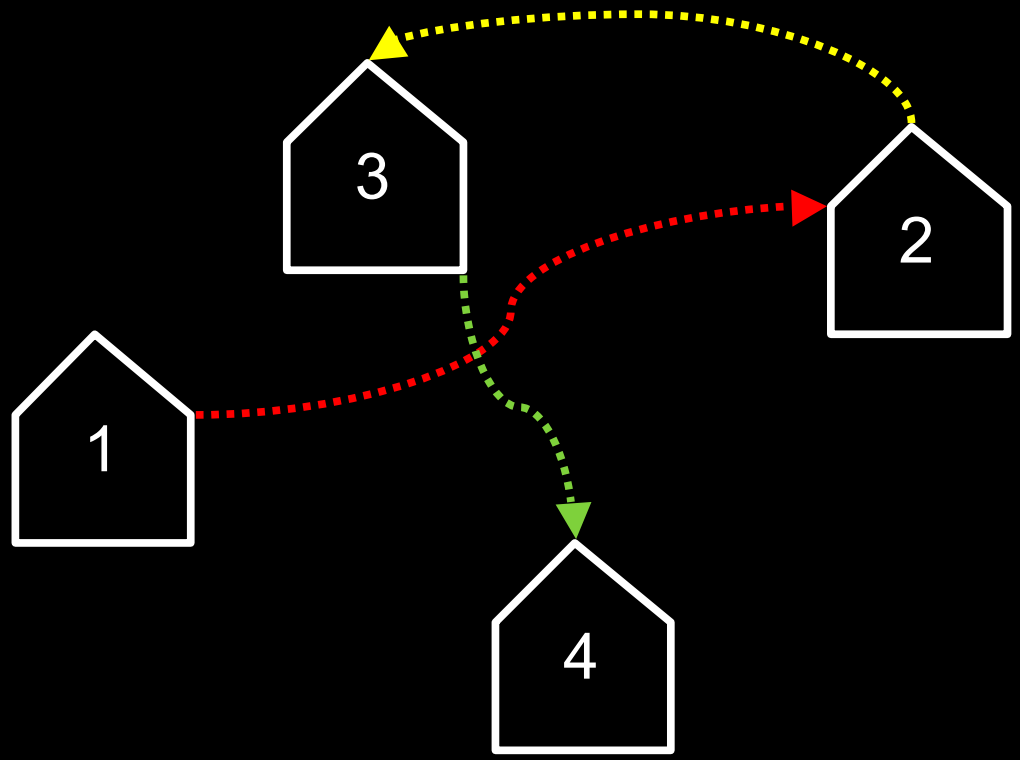
Parallel-codes strategy

Beth, Ann, Ruth”

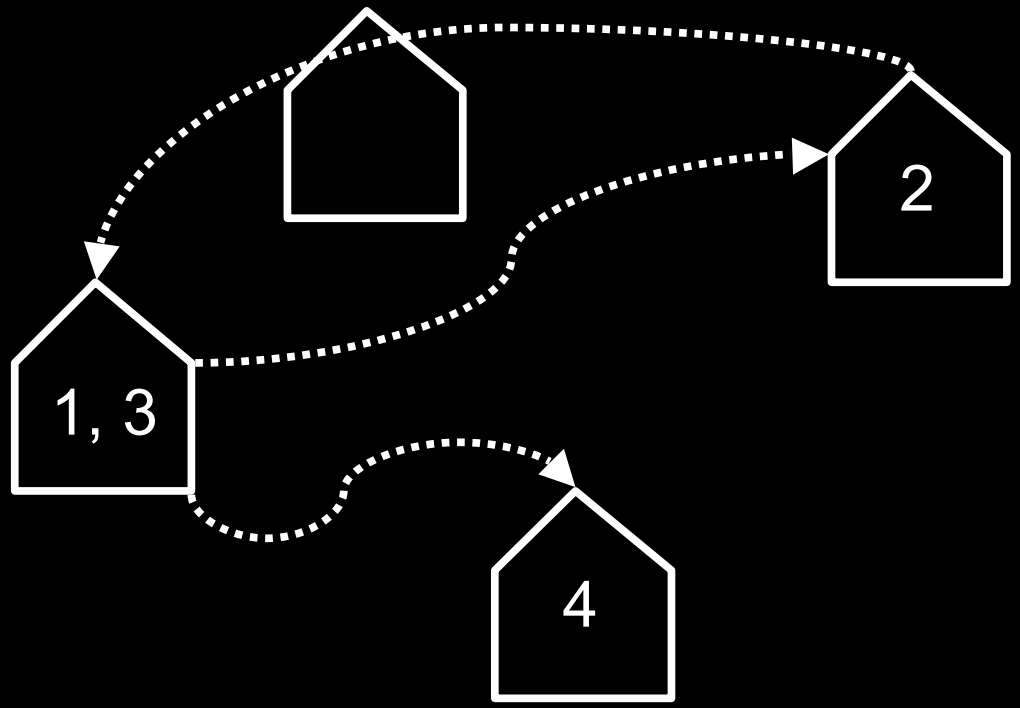
Probe: “Ann” -> 2nd

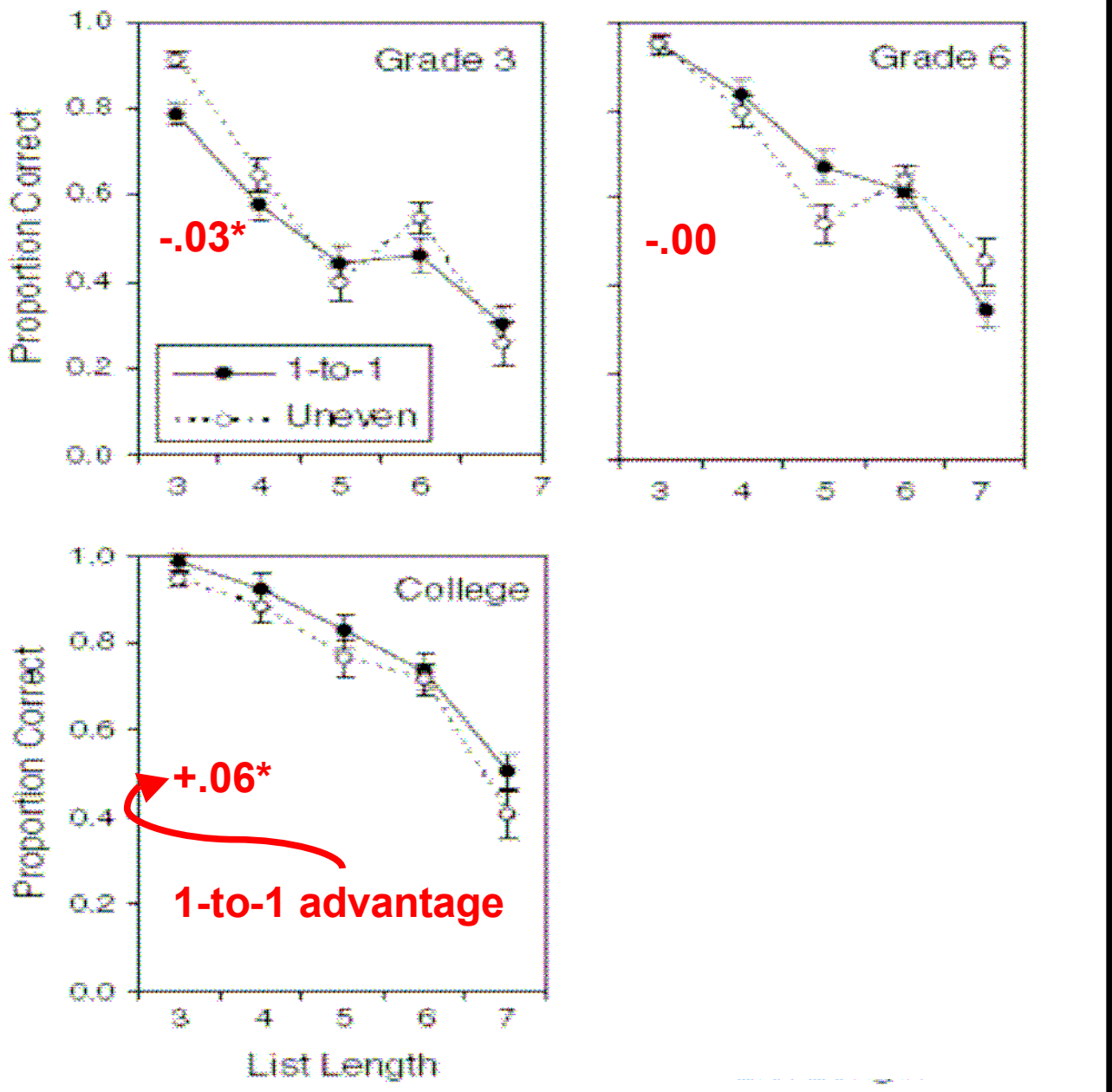


One-to-one mapping condition: allows parallel codes strategy IF one can use rehearsal



Uneven mapping condition: impedes parallel codes strategy (through spatial path confusion), encourages association method (fewer objects)




Grade 3
Grade 6
College
Proportion Correct
List Length
1.0
0.8
0.6
0.4
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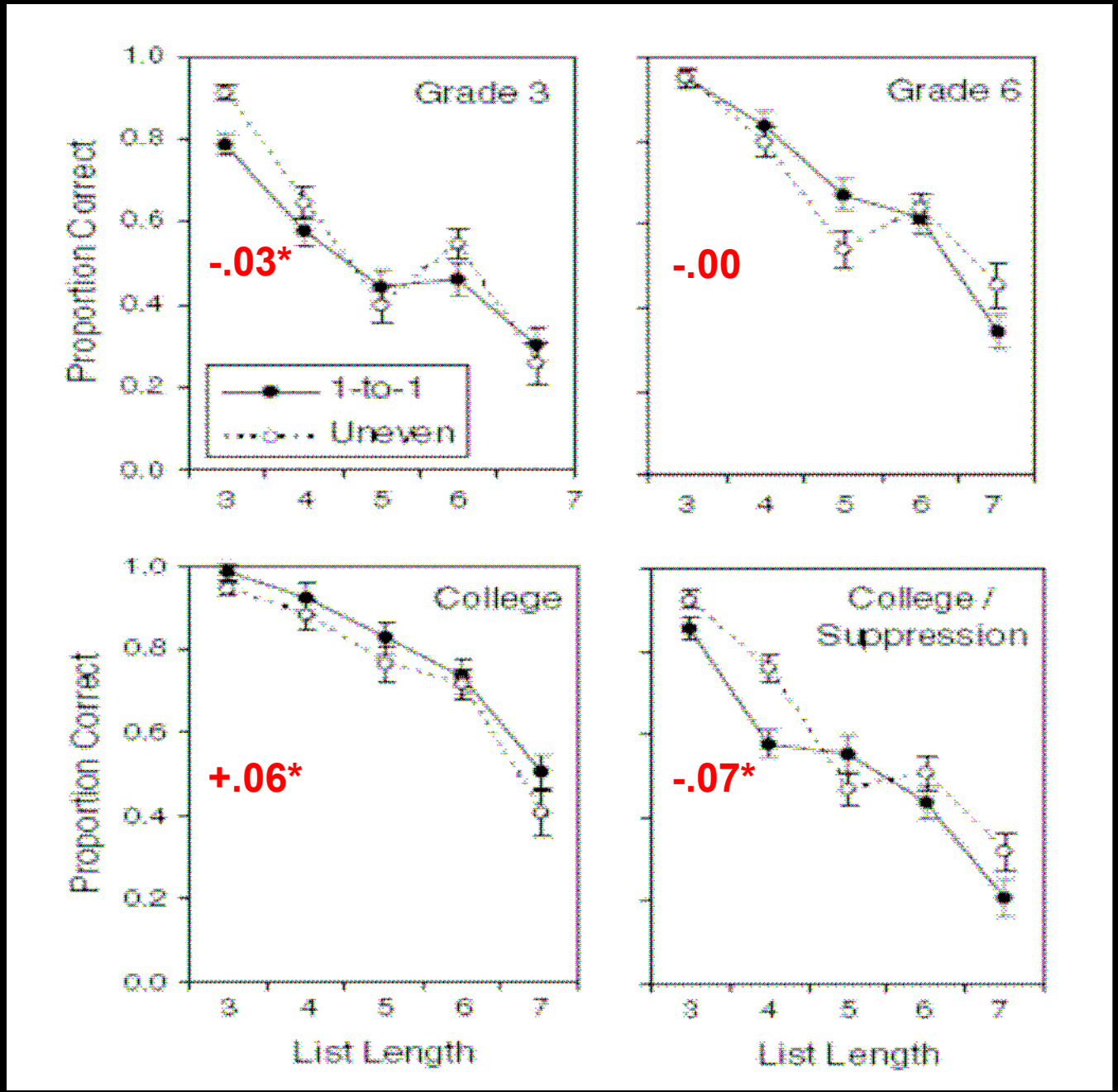
3
4
5
6
7
-.03*
-.00
+.06*
1-to-1
Uneven
1-to-1 advantage


Grade 3
-.03*
1-to-1
Uneven
Grade 6
-.00
College
+.06*
College / Suppression
-.07*
Proportion Correct
List Length
1.0
0.8
0.6
0.4
0.2
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4
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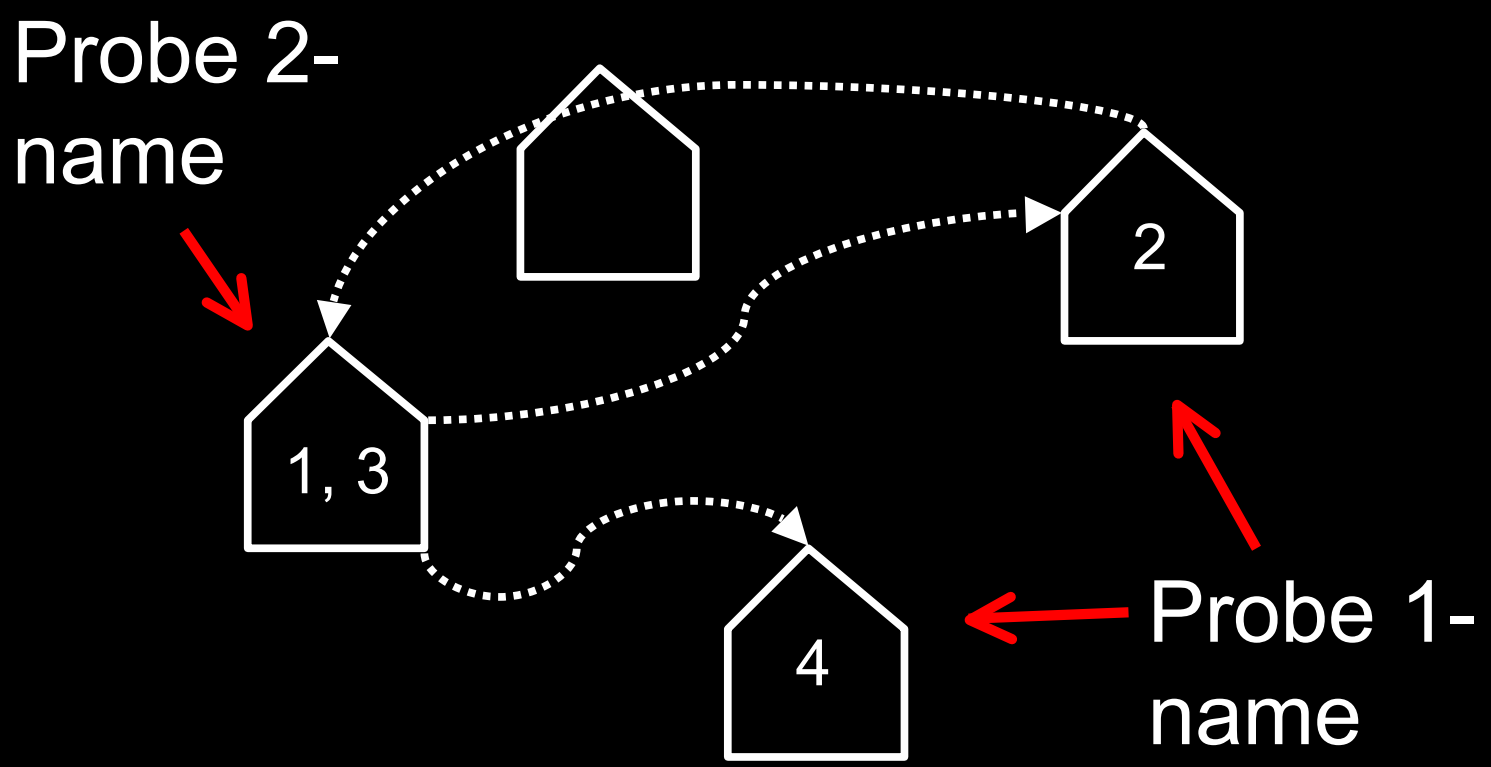
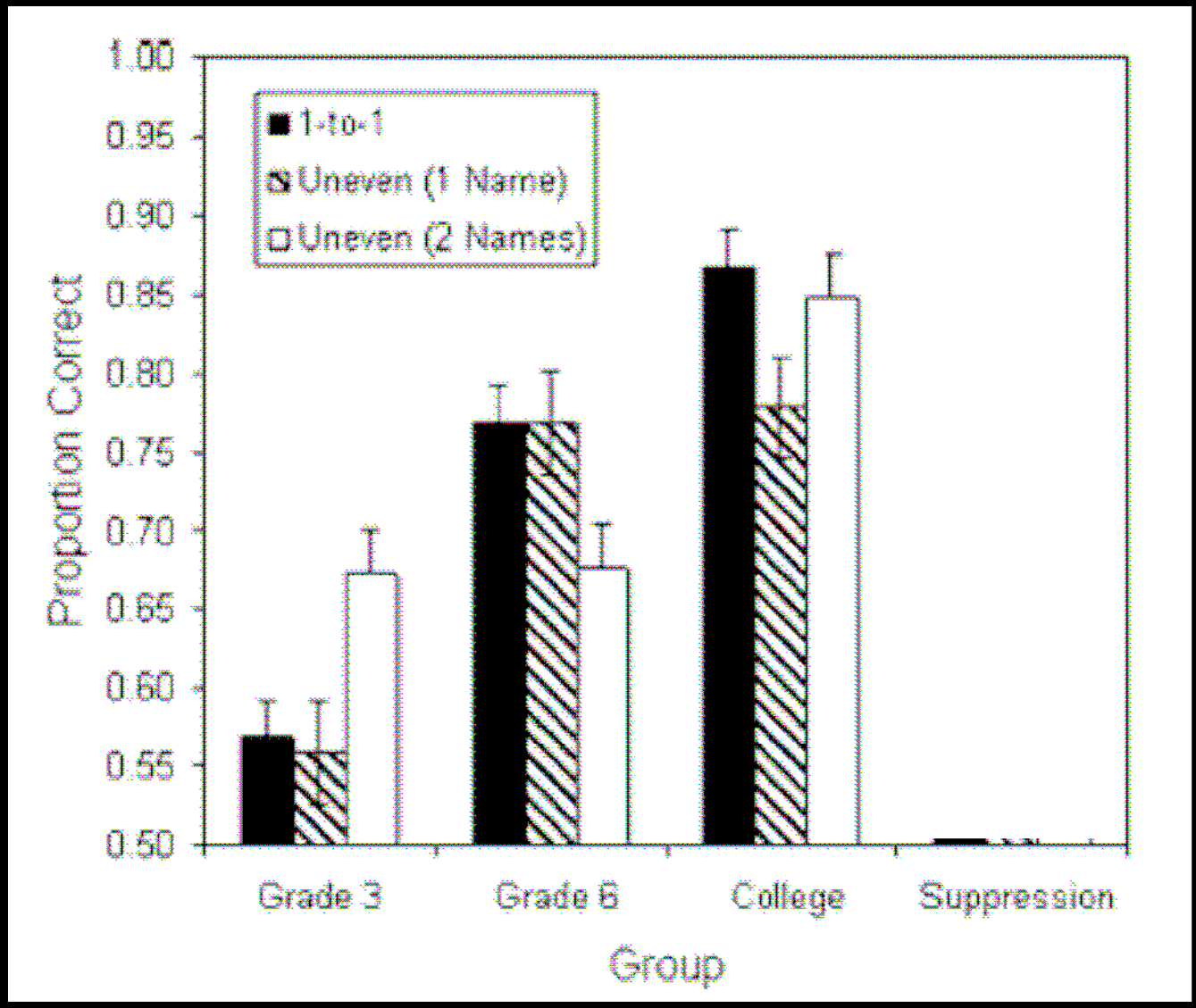
7

Two trial types in uneven condition




1.00
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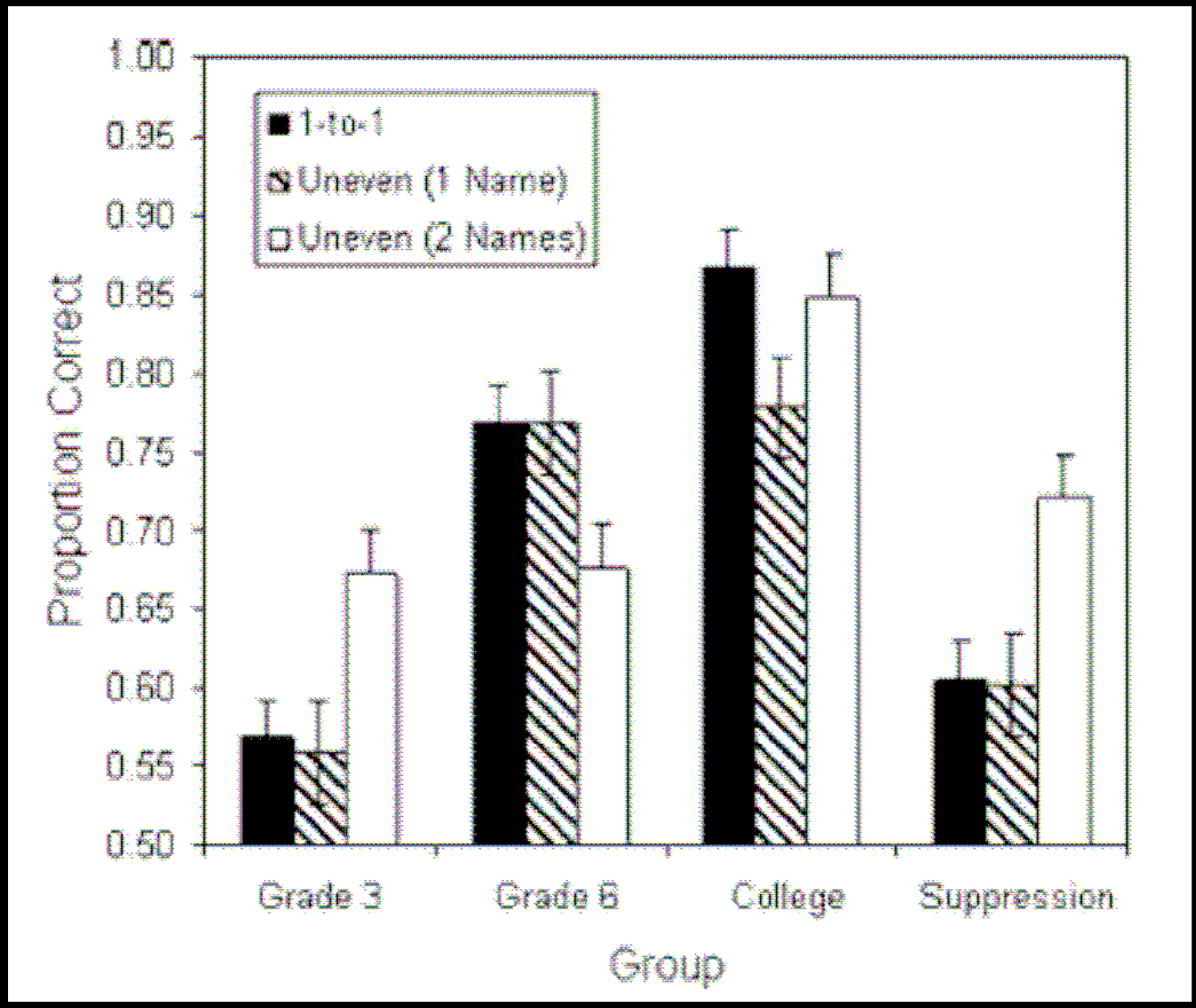
Proportion Correct
1-to-1
Uneven (1 Name)
Uneven (2 Names)
Grade 3
Grade 6
College
Suppression
Group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0.60
0.55
0.50
Proportion Correct
1-to-1
Uneven (1 Name)
Uneven (2 Names)
Grade 3
Grade 6
College
Suppression
Group

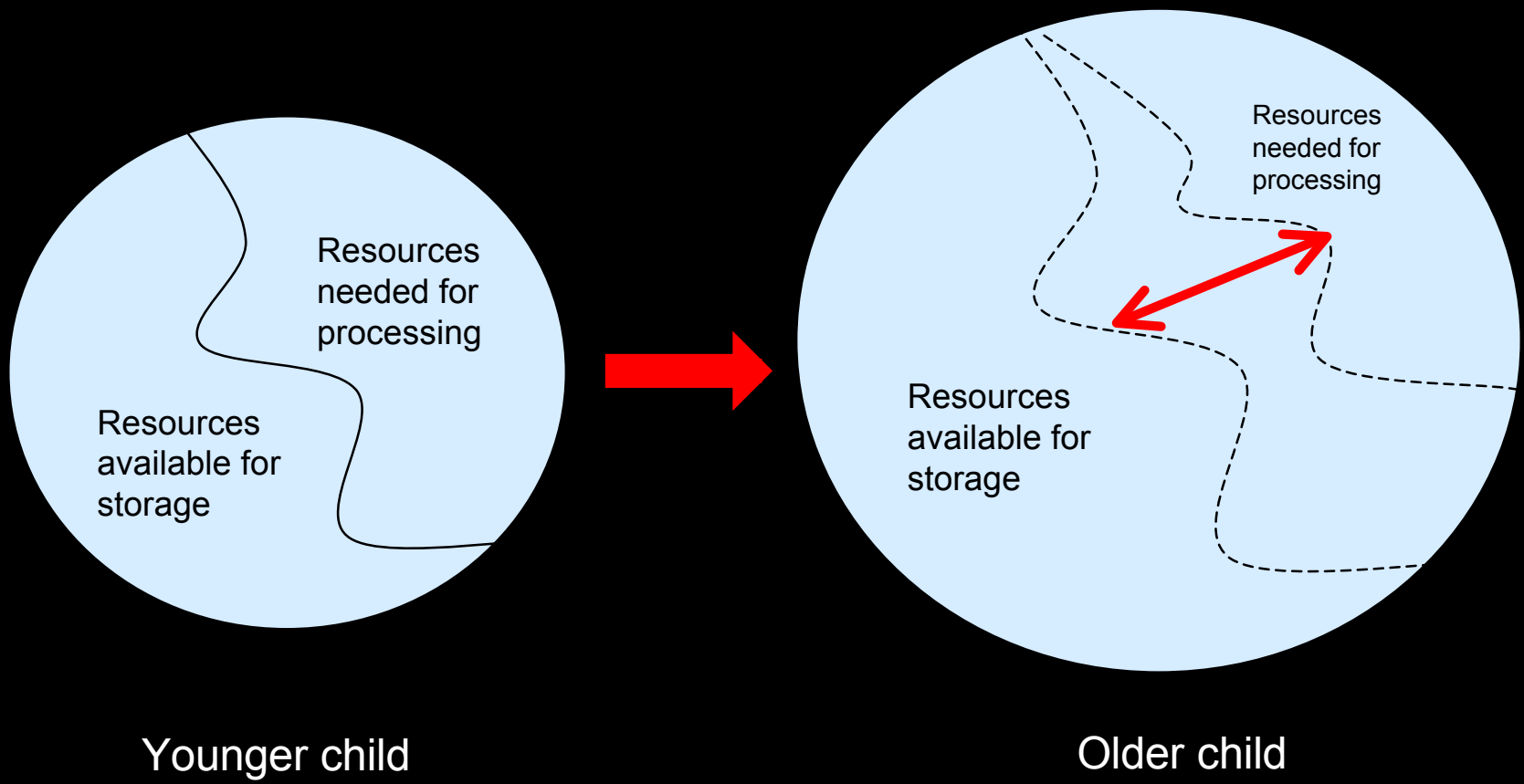
Conclusions (development of storage versus advanced rehearsal & strategies):

- There are storage capacity differences even when advanced strategy is prevented
- There are clear developmental changes in strategy, regardless of memory load
- Without the advanced strategy, the pattern of performance is very similar across age groups

Overall conclusions

- There are important increases across age groups in storage capacity (shared resource)
- These capacity differences have effects on the ability of relatively young children to implement simple processes (selection, chunking)
- There are complex strategies (coordination of verbal + spatial passive storage) deficient in young children even under low memory load

A Hybrid Developmental Model



END

- This
  - is
    - the
      - end