- The Influence of Working Memory on Math and Reading Performance in Children with Math or Reading Disabilities:
- A review of three recent studies

- H. Lee Swanson, University of California
- Presented Archives Jean Piaget, Geneva, July 4, 2008

- Operational Definition of Learning Disabilities
- Children with learning disabilities are defined as those individuals who performance is in the normal range on standardized intelligence tests (e.g., Wechsler series), but perform below the 25th percentile on standardized achievement measures of word recognition and/or arithmetic.
- These reading and/or arithmetic deficits are not due to inadequate opportunity to learn, general intelligence, physical or emotional disorders, but to basic disorders in specific psychological processes that are a reflection of neurological, constitutional, and/or biological factors.

- Largest group served in Special Education

- Thus, to assess LD at the cognitive and behavioral level, systematic efforts are made to detect:
- (a) normal range in psychometric intelligence (> 85),
- (b) below normal achievement (< 25th percentile) on standardized measures of achievement in a specific domain (e.g., word recognition),
- (c) that evidence-based instruction has been presented under optimal conditions but academic deficits remain, and
- (d) that academic deficits are not directly caused by environmental factors or contingencies (e.g., SES).

Working Memory

- Defined as a processing resource of limited capacity, involved in the preservation of information while simultaneously processing the same or other information. It is assumed that tasks that measure WM assess an individual's ability to maintain task- relevant information in an active state and to regulate controlled processing. For example, individuals performing WM tasks must remember some task elements and ignore, or inhibit, other elements as they complete task-relevant operations.

- WM tasks typically engage the participant in at least two activities after initial encoding:
- (1) response to a question or questions about the material (or related material) to be retrieved and
- (2) the retrieval of sets of items of increasing difficulty.
- The first activity (question) serves as a distracter to the initial encoding of items, whereas the second activity taps storage.

Short-term Memory

- In contrast, tasks that measure short-term memory (STM) typically involve situations that do not vary from initial encoding. That is, participants are *not* instructed to infer, transform or vary processing requirements. In most cases, participants are simply asked to reproduce a sequence of items in the order they were presented.

Study 1: The Influence of Working Memory Growth on Mathematical Problem Solving in Children at Risk and not at Serious Risk for Math Problem Solving Difficulties

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Funded by the U.S. Department of Education, Institute of Education Sciences

Study 1 Overview

- (greater detail, Swanson et al., (2008) Growth in working memory and mathematical problem solving in children at risk and not at risk for serious math difficulties, *Journal of Educational Psychology, 100,* 343-379.

Assumptions

1. Word problems constitute one of the most important mediums through which students can potentially learn to select and apply strategies necessary for coping with everyday problems.
2. To comprehend and solve mathematical word problems one must be able to keep track of incoming information. This is necessary in order to understand words, phrases, sentences, and propositions that, in turn, are necessary to construct a coherent and meaningful interpretation of word problems.

Assumptions Cont.

- 3. Temporary storage of material that has been read or heard is said to depend on working memory (WM), which takes into account the storage of items for later retrieval and which is a function of the individual's level of text processing.
- 4. Previous studies have shown that a significant proportion of the variance related to solution accuracy in word problems is related to WM, but the specific sources of variance have not been clearly identified.

Research Questions

1. Which components of WM (central executive, phonological loop, visual-spatial sketch pad) are most directly related to components of word problem solving (e.g., problem representation, solution planning, solution execution) ?

Specifically,we will determine whether growth in WM mediates growth in components of problem solving and how these relationships vary within and between ability groups.

Research Question 2

- 2. What cognitive mechanisms and academic skills underlie the relationship between WM and problem solving accuracy?

- Specifically, we explore the role of several processes (e.g., LTM, fluid intelligence, inhibition, speed, phonological processing) and skills (e.g., calculation fluency, reading, vocabulary) in mediating growth in WM and word problem solving.

Research Question 3

3. Does growth in WM have varying effects on word problem solving as a function of MD vs. Non MD groups?

- We explore if growth in problem solving is isolated to growth in specific components of WM.

Research Significance and Reforms in Mathematics Education

- Reforms in mathematics education call for:
  - conceptual understanding and;
  - decreasing emphasis on routine computational skills.
- The assumption?
  - Higher levels of understanding such as problem solving drawn upon cognitive process---such as working memory.

Needs

  - To identify the cognitive mechanisms of children with weak skills in mathematics and/or reading that underlie mathematical problem solving.

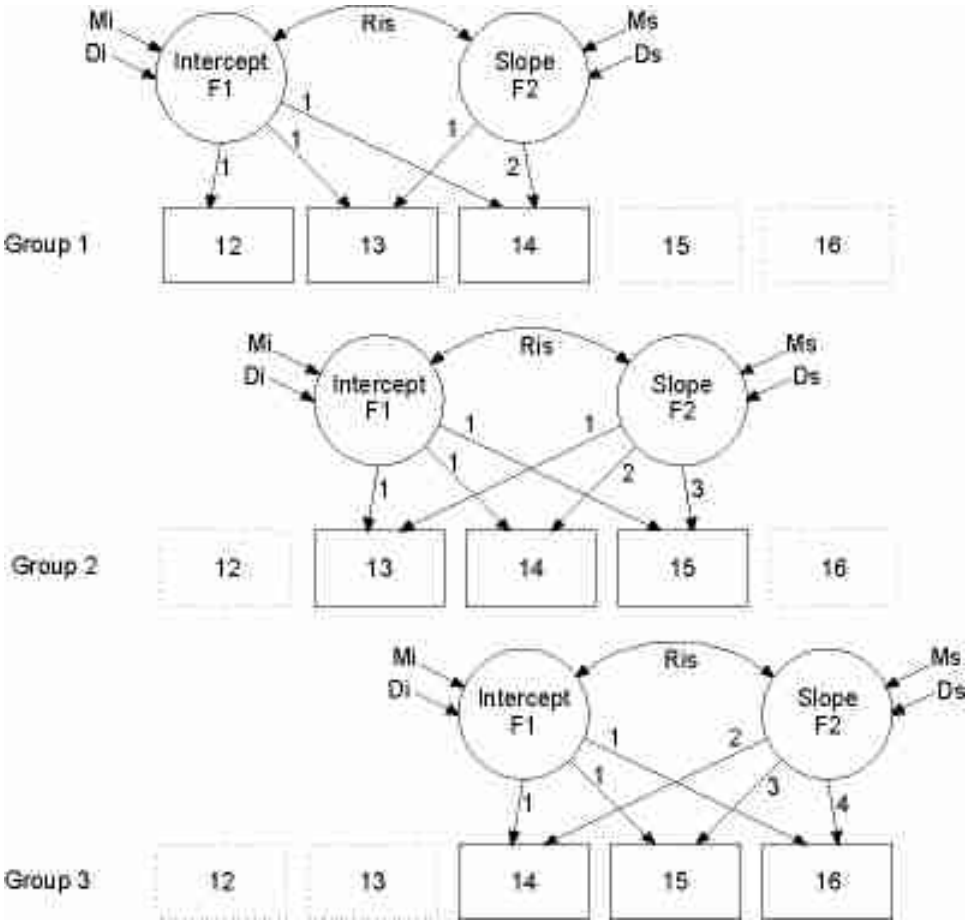
General Significance: Mathematics and Learning Disabilities

- Students at risk for mathematical disabilities are a large segment of the public school population
- There is a need to know the processes that underlie problem-solving difficulty in such a large population.

Research Methods and Design

- **This longitudinal project will study children:**
  - In grades 1, 2, and 3;
  - And follow their development for a three year period.
- **Design-Cohort-Sequential**
  - At risk or not at risk samples

Sample Design



Sample

- Participants were selected from both public and private schools from grades 1, 2 and 3 -two groups were identified.
  - Children who score above the 40th percentile on standardized measures of mathematical problem---such children were not considered as at risk for math difficulties
  - Children who score below the 25th percentile (below a scale score of 8) on the measures of word problem solving and number naming speed were considered “at risk” and eligible for further screening.

Assessments Administered to Students Each Year (30 measures)

- Word problems
- Components of Word Problems
- Computation and Computation fluency skills (CBM)
- Vocabulary (WISC-III)
- Reading Efficiency (Real word, Pseudo-word Efficiency from the TOWRE)
- Rapid naming speed from the CTOPP
- Word attack,identification, and comprehension subtests (WRMT-R)
- Arithmetic (WRAT-3, WIAT)
- Raven Progressive Matrices Test (fluid Intelligence)
- Random Letter and Number Generation (inhibition)
- Battery of STM and WM tasks
- Fluency (speed at naming words that with letter and animals)
- Updating

Sample for Year 1

Table 1

Means and Standard Deviations for Measures as a Function of Children at risk for Serious Math Difficulties (SMD) and not at risk (NSMD) as a Function of Age

	Grade 1 (N=130)				Grade 2 (N=92)				Grade 3 (N=131)			
	SMD (n=73)		NSMD (n=57)		SMD (n=34)		NSMD (n=58)		SMD (n=25)		NSMD (n=106)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Classification												
1. Chronological Age	6.19	.49	6.23	.46	7.41	.50	7.29	.50	8.52	.51	8.20	.49
2. Fluid Intelligence-Raven												
Standard	102.77	14.19	112.72	13.47	106.18	14.00	111.76	16.65	96.00	9.73	108.58	13.08
Raw	18.37	5.12	22.25	5.46	23.50	4.94	25.83	5.83	23.64	4.52	27.70	4.95
3. Mental Computation - WISC-III												
Standard	7.04	2.85	13.10	2.20	7.90	1.77	11.78	2.18	5.87	2.18	11.72	2.08
Raw	8.56	2.75	12.63	1.10	11.82	1.76	14.28	1.35	11.43	3.34	15.75	1.57
4. Digit Naming Speed-CTTOP												
Standard	6.94	.81	8.28	1.45	7.78	1.01	9.35	1.53	9.50	1.85	10.99	2.22

Conceptual Issues

- Factor Invariance (Configural,loadings, errors)
- Convergence (levels,slopes and error terms)—common line—determine if group overlaps in terms of level, slope and error
- Missing data---maximum likelihood estimation
- Scaling---standardized loadings x z-score (IRT ?)
- Residual vs. hierarchical
- Nested effects
- Sample reliability

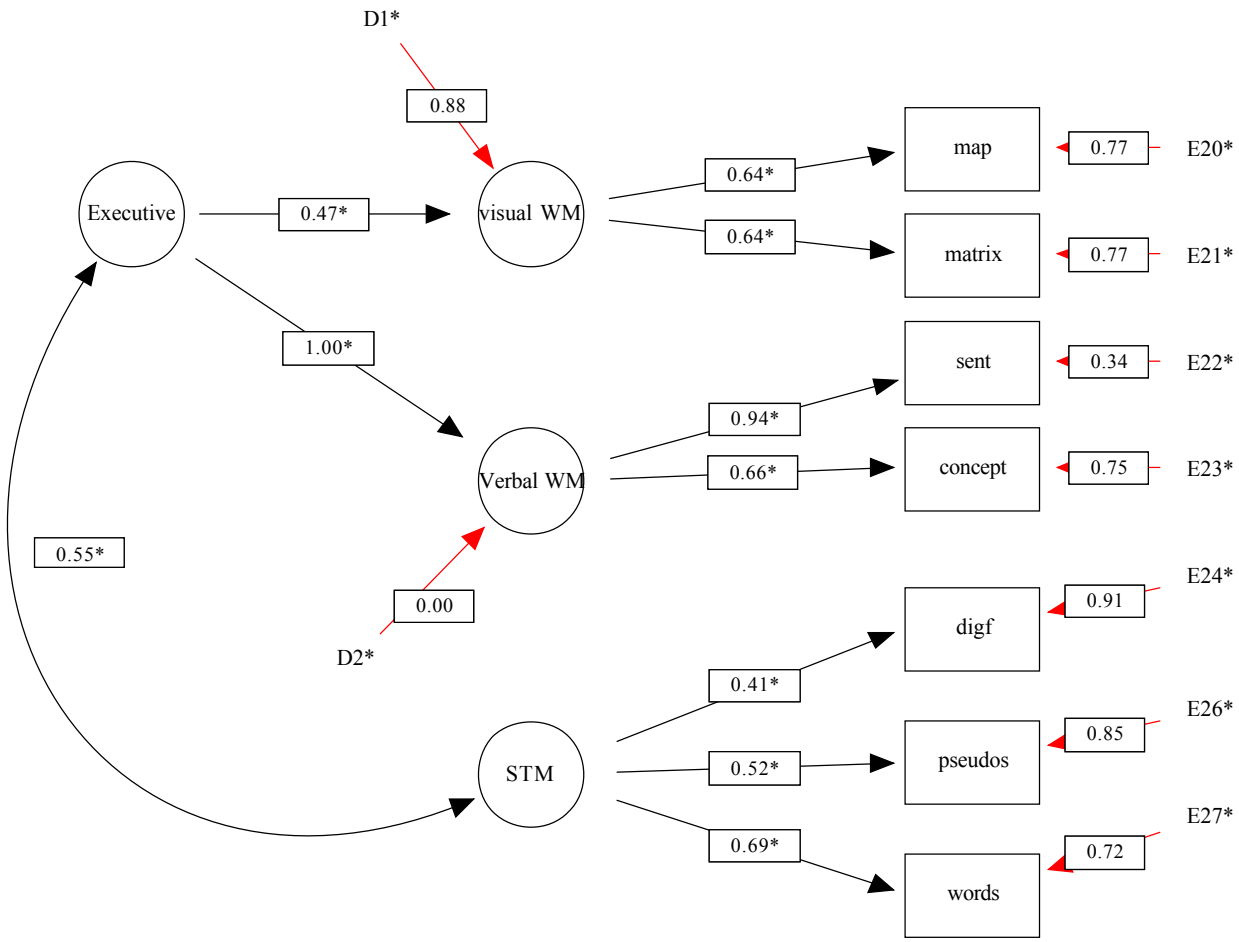

D1*
0.88
Executive
0.47*
visual WM
0.64*
0.64*
map
0.77
E20*
matrix
0.77
E21*
1.00*
sent
0.34
E22*
0.94*
Verbal WM
0.66*
concept
0.75
E23*
0.55*
0.00
D2*
E24*
digf
0.91
0.41*
E26*
pseudos
0.85
STM
0.52*
E27*
0.69*
words
0.72

Table 1
Hierarchical Analysis Predicting Word Problem Solving in Wave 3 from Cognitive and Achievement Variables in Wave 1

	B	SE	ß	t
Model 1				
Sketchpad	0.26	0.04	0.26	5.47***
Phon. Loop	0.20	0.06	0.17	3.02***
Executive	0.48	0.07	0.37	6.63***
Model 2				
Age	0.14	0.04	0.14	2.75***
Sketchpad	0.23	0.04	0.23	4.80**
Phon. loop	0.19	0.06	0.15	2.81**
Executive	0.44	0.07	0.33	5.90***

Model 1 F (3, 289) = 54.82; p<.001; R2 = .36
Model 2 F (4, 288) = 43.94; p< .001; R2 = .38

	Calculation				Problem Solving Components			
	B	SE	ß	*t*	B	SE	ß	*t*
Model 1								
Sketchpad	0.23	0.04	0.23	4.77***	0.22	0.04	0.22	4.49***
Phon. Loop	0.37	0.06	0.22	3.92***	0.25	0.06	0.2	3.55***
Executive	0.47	0.07	0.36	6.39***	0.49	0.07	0.38	6.70***
Model 2								
Age	0.43	0.04	0.44	9.89***	0.63	0.03	0.65	18.69***
Sketchpad	0.14	0.04	0.13	3.22***	0.08	0.03	0.08	2.44*
Phon. loop	0.22	0.05	0.17	3.67***	0.17	0.04	0.14	3.36*
Executive	0.32	0.06	0.25	4.93**	0.28	0.04	0.22	5.41***
	F (3, 289) = 55.51, *p*<.001; *R2* = .37 *F* (4, 288) = 80.05, *p*<.001; *R2* =.52				*F* (3, 289) = 54.20, *p*<.001; *R2* = .36 *F* (4, 288) = 176.92, *p*<.001; *R2* = .71			

Hierarchical Analysis Predicting Word Problem Solving in Wave 3 from Cognitive and Achievement Variables in Wave 1

Model 4	**B**	**SE**	**ß**	***t***
Reading	0.34	0.12	0.34	2.75**
Phon. Know.	-0.01	0.11	-0.01	-0.01
Fluency	0.07	0.07	0.06	1.21
Speed	0.02	0.06	0.02	0.36
Inhibition	0.07	0.08	0.05	1.08
Age	-0.01	0.05	-0.01	-0.17
Sketchpad	0.20	0.04	0.20	4.16 ***
Phon. Loop	0.13	0.06	0.1	1.84
Executive	0.27	0.08	0.21	3.40**

Model 4 F (9,282) = 24.23; p< .001, $R2$ = .44

Table 2

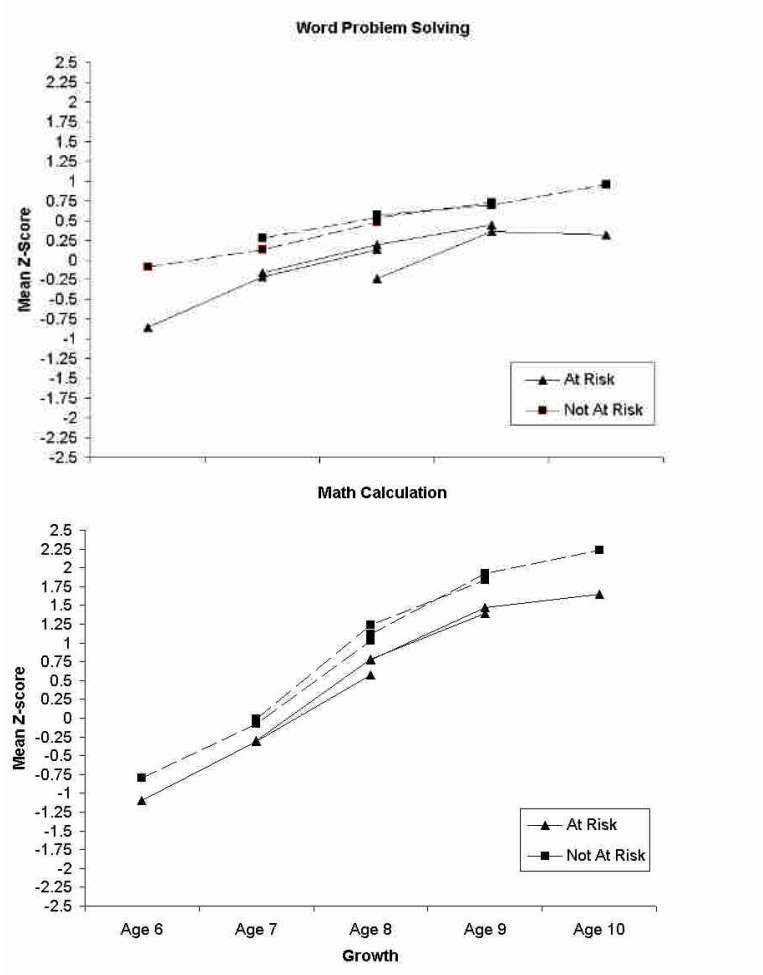
Predictions of Year 3 Problem Solving Accuracy Based on Wave 3 Math Calculation,

Problem Solving Knowledge and Wave 1 Fluid Intelligence, Reading and Cognitive Variables

Model 5	B	SE	ß	*t*
Wave 3 Predictors				
Problem Solving Knowledge	0.25	0.11	0.12	2.13*
Calculation	0.30	0.08	0.27	3.42**
Wave 1 Predictors				
Fluid Intelligence (Raven)	0.13	0.04	0.16	2.85**
Reading	0.12	0.12	0.12	1.00
Phon. Know.	-0.01	0.10	0.10	-0.09
Fluency	0.02	0.07	0.007	0.33
Speed	-0.004	0.06	-0.004	-0.06
Inhibition	0.09	0.06	0.07	1.60
Age	-0.15	0.06	-0.16	-2.39*
Sketchpad	0.15	0.04	0.14	3.23***
Phon. Loop	0.12	0.06	0.09	1.85
Executive	0.19	0.08	0.15	2.34*

Model 5 F (12, 279) = 22.52; p< .001, $R2$ = .49

- Hierarchical Linear Modeling---Focus on Growth and Random Effects
- Key points in the interpretation---
- Intercepts centered at wave 3
- Random Effects are related to wave 1 classroom instruction


Word Problem Solving
Mean Z-Score
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1.25
-1.5
-1.75
-2
-2.25
-2.5
At Risk
Not At Risk
Math Calculation
Mean Z-score
Age 6
Age 7
Age 8
Age 9
Age 10
Growth

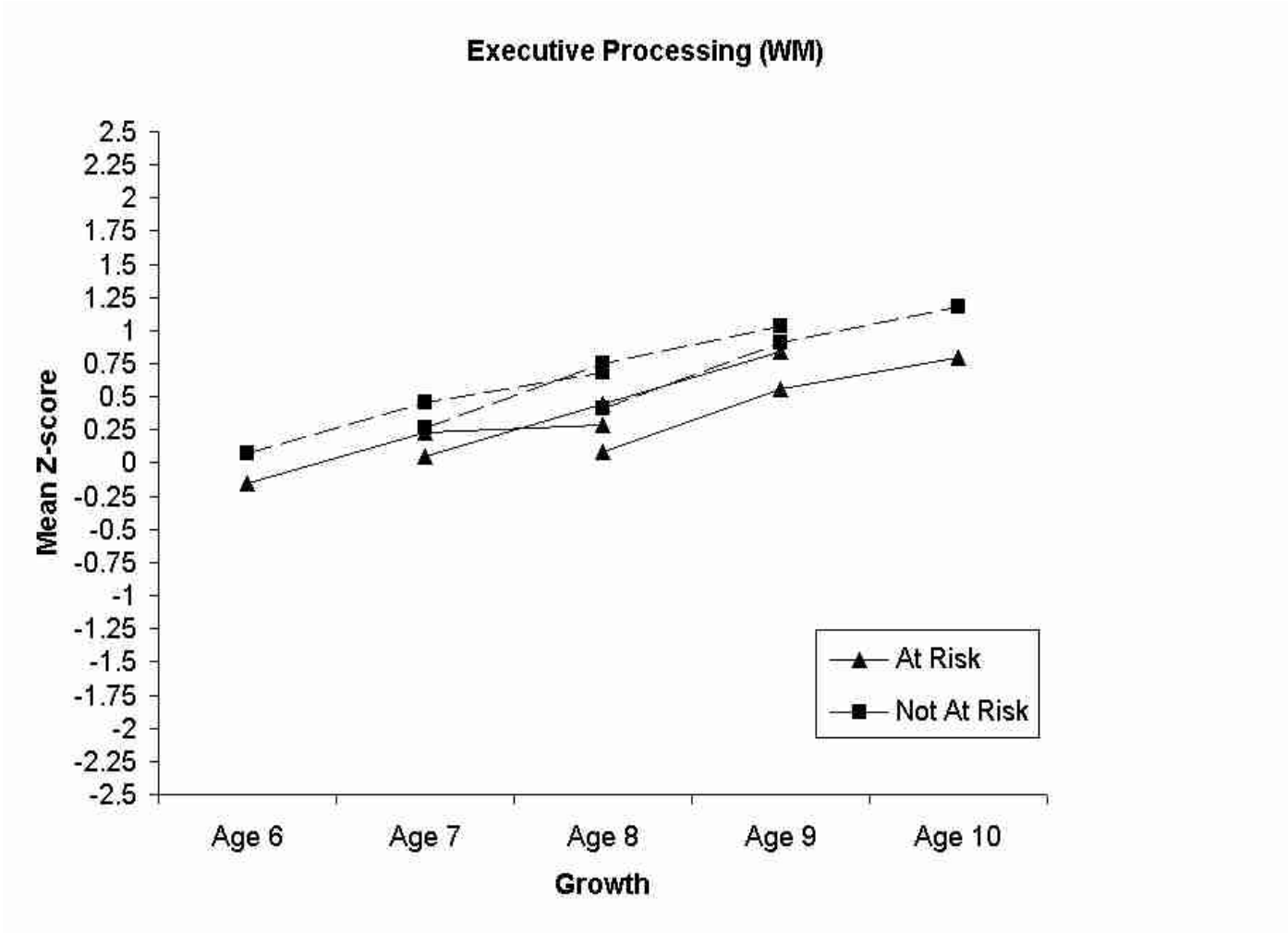

Executive Processing (WM)
Mean Z-score
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1.25
-1.5
-1.75
-2
-2.25
-2.5
Age 6
Age 7
Age 8
Age 9
Age 10
Growth
At Risk
Not At Risk

Table 3

Growth on Word Problem Solving

Unconditional Model

	Parameter Estimate	SE	t-ratio
Fixed Effects			
Intercept	0.58	0.02	20.71***
Growth (linear)	0.28	0.01	19.08***
(average child estimate is .58 at wave 3 and gained .28 points per testing session)			
	Variance Estimate	SE	Z
Random Effects (subjects*teachers)			
Intercept	0.18	0.02	8.23***
Growth (linear)	0.03	0.006	3.95***
Residual	0.09	0.007	12.23***
Intraclass correlation =.55			

Table 3A Conditional Model Divided by Ability Group

Group

	At-risk SMD		Not at risk		
Fixed Effects					
	Estimate	SE	Estimate	SE	F-ratio
Intercept	.32***	0.04	.75***	0.03	62.93***
Growth (linear)	.41***	0.02	.20***	0.02	50.39***

Random effects (subjects*teachers)

	Variance Estimate	SE	Z
Intercept	0.14	0.01	7.38***
Growth	0.02	0.006	2.83**
Residual	0.08	0.007	12.25***

Note. *** p <.0001, ** p <.01, * p <.05

Fixed Effects for the Conditional Model Comparing Intercept and Growth for Children at Risk for SMD and not at Risk on Measures of Achievement and Cognition

Group	At-risk SMD		Not at Risk		
	Estimate	SE	Estimate	SE	F-ratio
Math Calculation*					
Intercept	1.09***	0.07	1.77***	0.05	58.10***
Growth	.58***	0.02	.76***	0.02	28.27***
Reading					
Intercept	.68***	0.05	1.09***	0.04	34.27***
Growth	.48**	0.02	.34***	0.01	32.25**
Phonological Knowledge					
Intercept	.27**	0.05	.70***	0.04	43.48***
Growth	.28**	0.01	.21**	0.01	9.97***
Fluency					
Intercept	.12**	0.04	.35***	0.02	20.72***
Growth	.13***	0.01	.10***	0.01	1.68
Probl. Solving Compon*.					
Intercept	.54***	0.04	.97***	0.03	72.61***
Growth	.33***	0.02	.46***	0.01	22.22***

Note. *** p <.001, ** p <.01, * p <.05

Probl. Solving Compon.=Knowledge of problem solving components

	Group				
	At-risk SMD		Not at Risk		
	Estimate	SE	Estimate	SE	F-ratio
Speed					
Intercept	-.69***	0.05	-.86***	0.04	7.53**
Growth	-.50***	0.02	-.21***	0.02	85.62***
Inhibition*					
Intercept	.91***	0.07	1.35***	0.05	23.98***
Growth	.49***	0.02	.57***	0.02	4.91*
Phonological loop					
Intercept	-0.02	0.04	.32***	0.03	44.54***
Growth	.08**	0.01	.10***	0.01	1.03
Sketchpad*					
Intercept	.15*	0.07	.53***	0.05	19.04***
Growth	.11***	0.03	.25***	0.02	11.34***
Executive*					
Intercept	.36***	0.05	.81***	0.04	38.78***
Growth	.20***	0.02	.31***	0.02	14.27***

Note. *** p <.0001, ** p <.01, * p <.05

Contribution of WM growth to Problem Solving

Conditional Model (Centered)

	Estimate	SE	t-ratio
Fixed effects			
Intercept	0.47	0.02	17.49***
Linear Growth	0.21	0.01	14.51***
Working Memory			
Intercept			
STM	0.14	0.03	3.50**
Executive	0.09	0.02	3.23***
Sketchpad	0.10	0.02	4.50***
Growth (linear)			
Ph. Loop	-0.05	0.02	-2.08*
Executive	-0.10	0.01	-5.51***
Sketchpad	0.005	0.01	0.36

	Variance Estimate	SE	Z
Random effects (subject*teacher)			
Intercept	0.07	0.01	5.55**
Growth (linear)	0.01	0.004	3.95**
Residual	0.09	0.008	13.62**

Note. *** p <.001, ** p <.01, * p <.05

- Problem Solving--Intercept .47
- Phonological Loop (STM)--Intercept .14
- Phonological Loop (STM)-slope -.05

- Interpretation-
- .47 estimates problem solving when predictors are set to zero
- Children who differ by 1 point on Phonological Loop (STM)

differ by .14 points on problem solving

The parameter estimate of -.05 related to the slope indicates that children who differed by 1.0 with respect to STM (the covariate) have growth rates that differ by -.05 (higher levels of STM yield smaller growth rates ?)

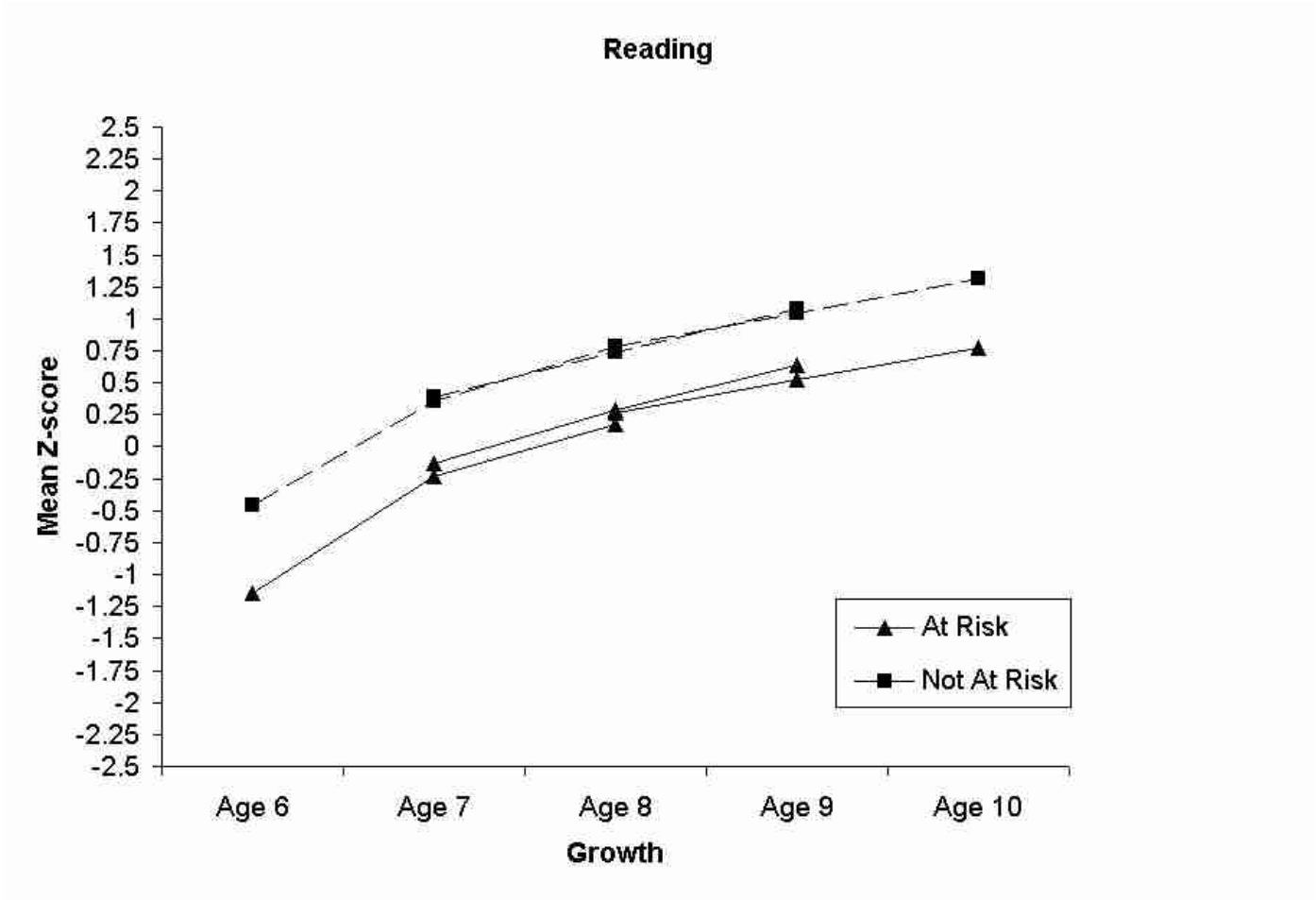
Explained Variance

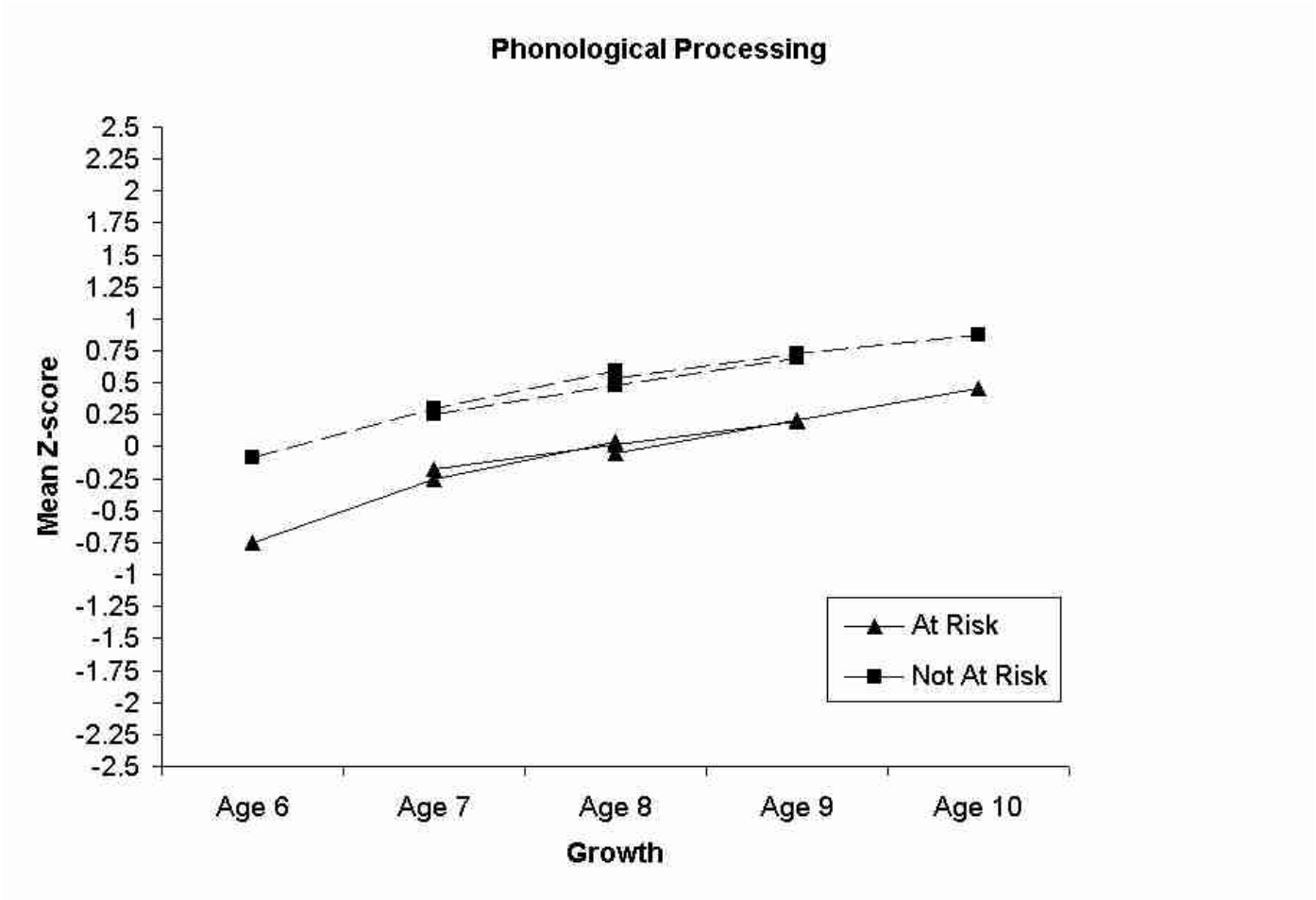
- ***What is the reduction in random effects related to classroom on problem solving when WM is taken into consideration?***
- ***(Focus is on Explainable Variance)***
- ***Between Level of Performance Differences nested within Classroom (Intercept)***

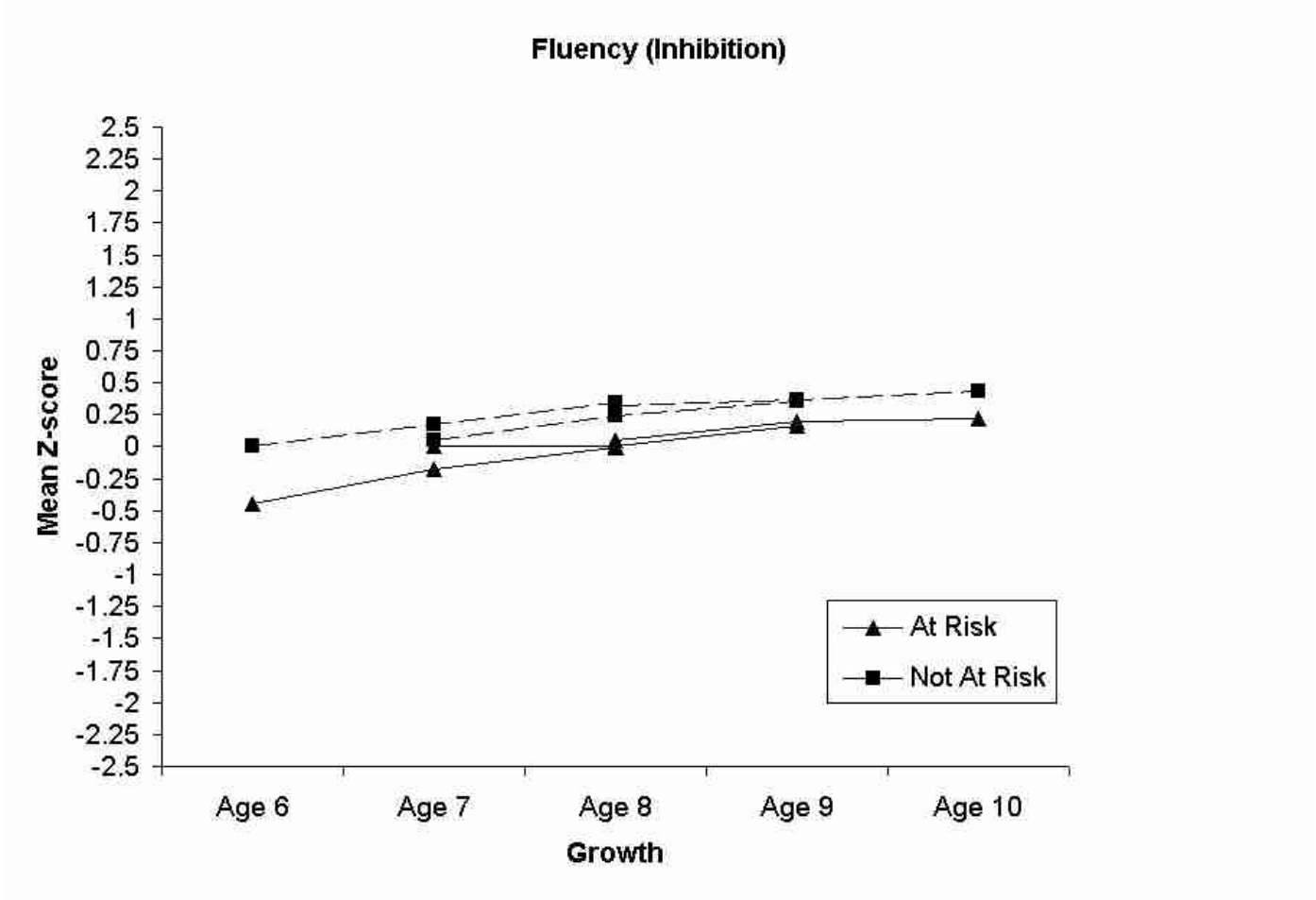
Problem solving (.18-.07)/.18=61%

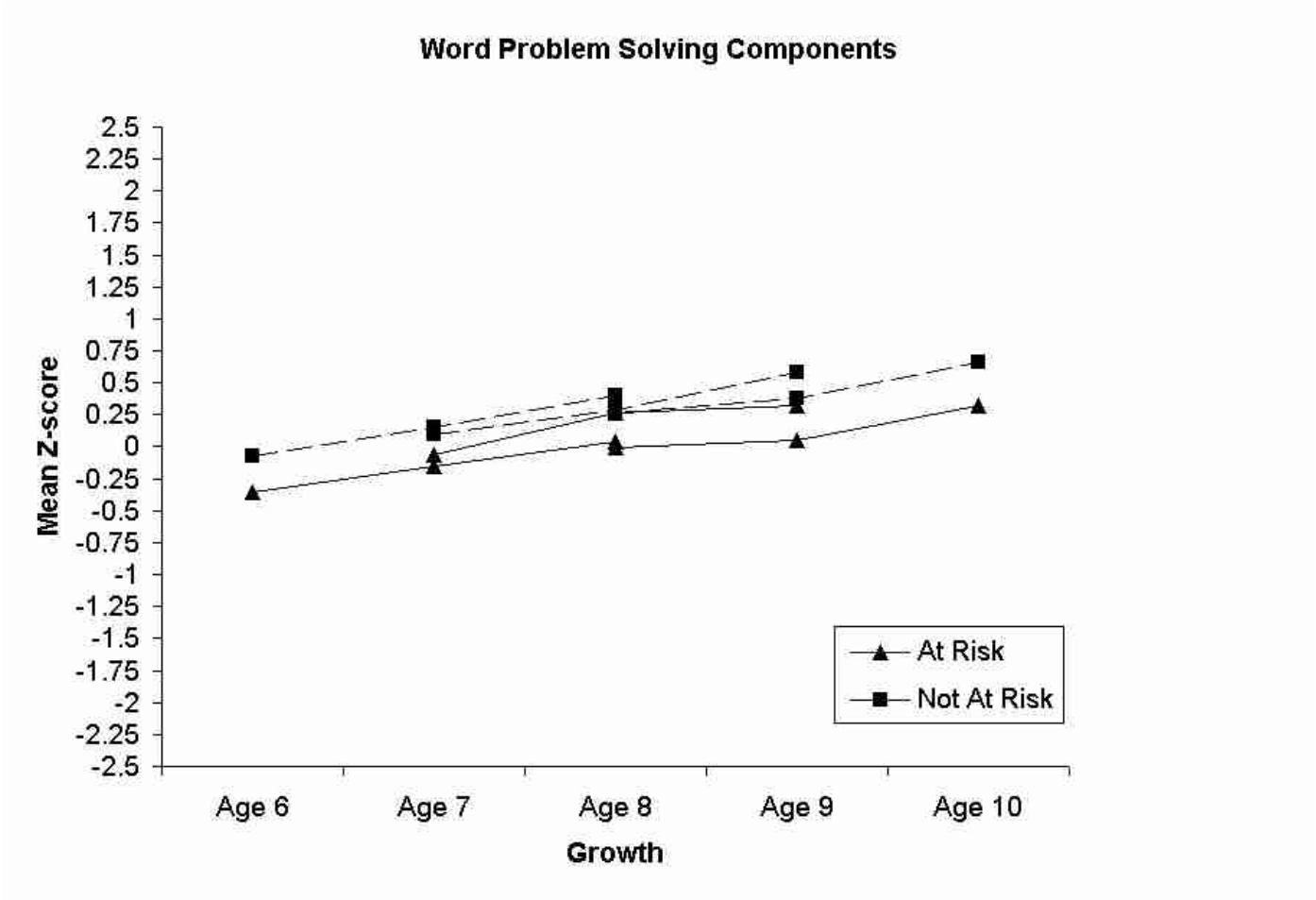
Between Growth Differences nested within Classroom (Slope)

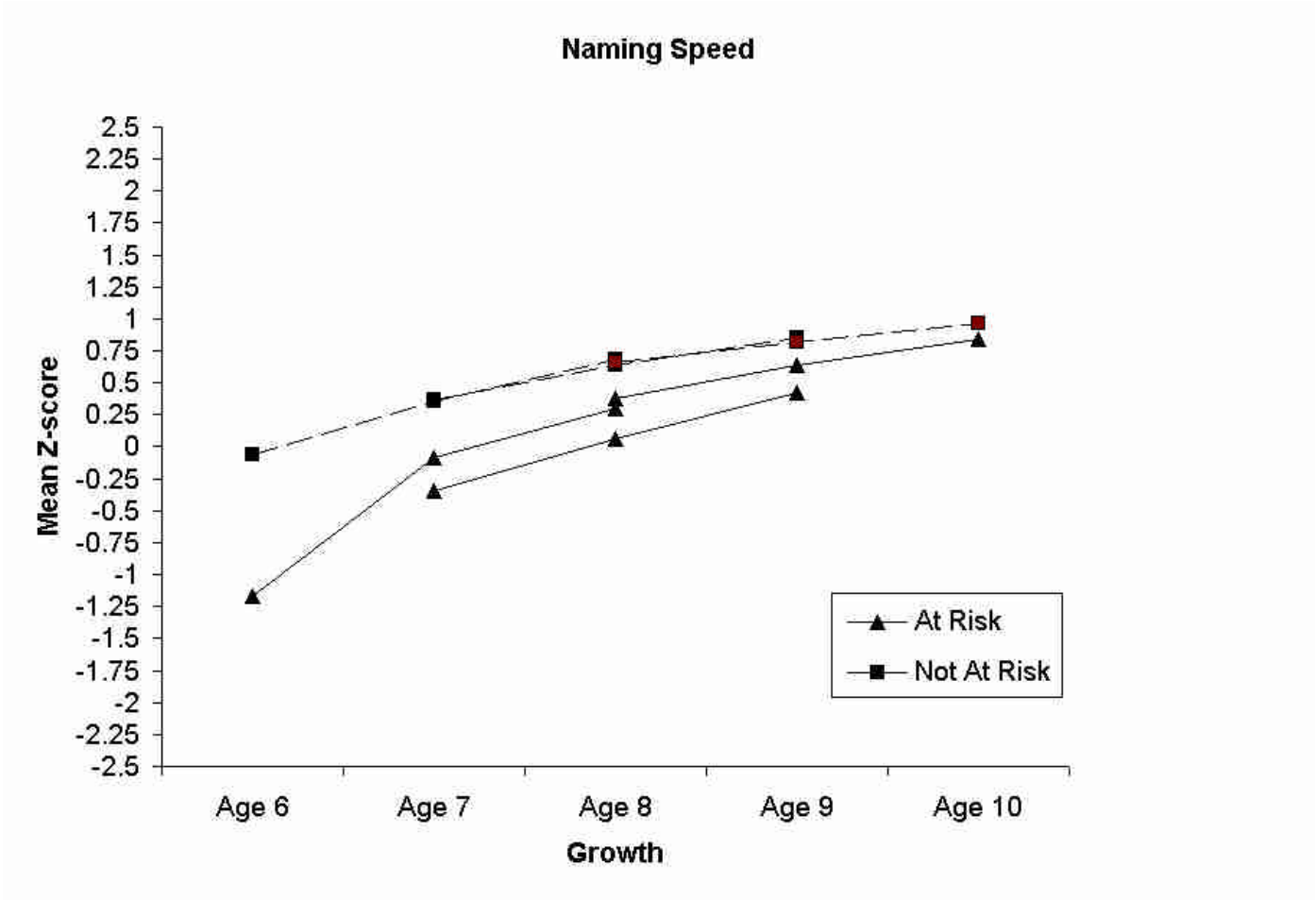
Problem solving (.03-.01)/.03=66%

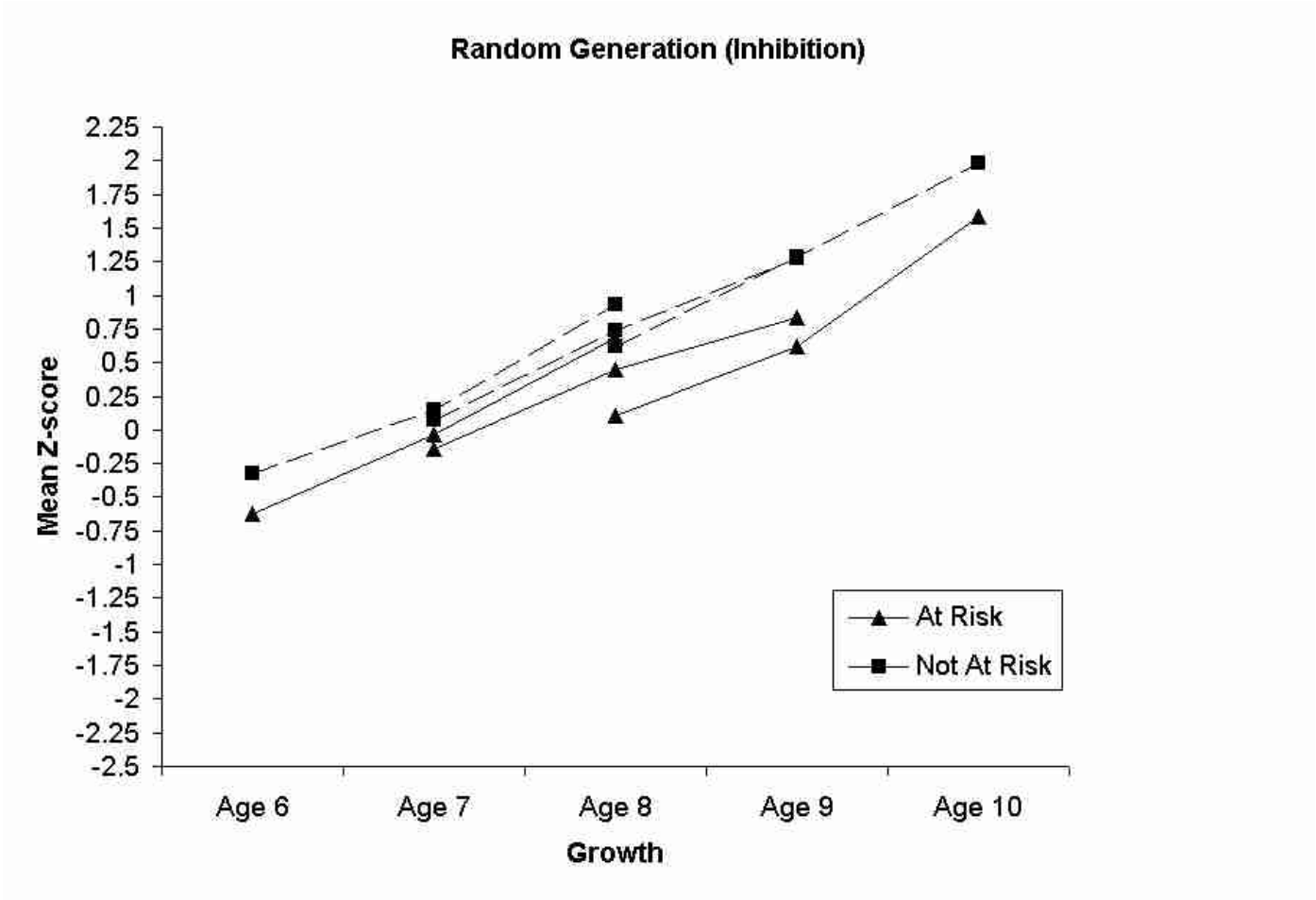

Reading
Mean Z-score
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1.25
-1.5
-1.75
-2
-2.25
-2.5
Age 6
Age 7
Age 8
Age 9
Age 10
Growth
At Risk
Not At Risk

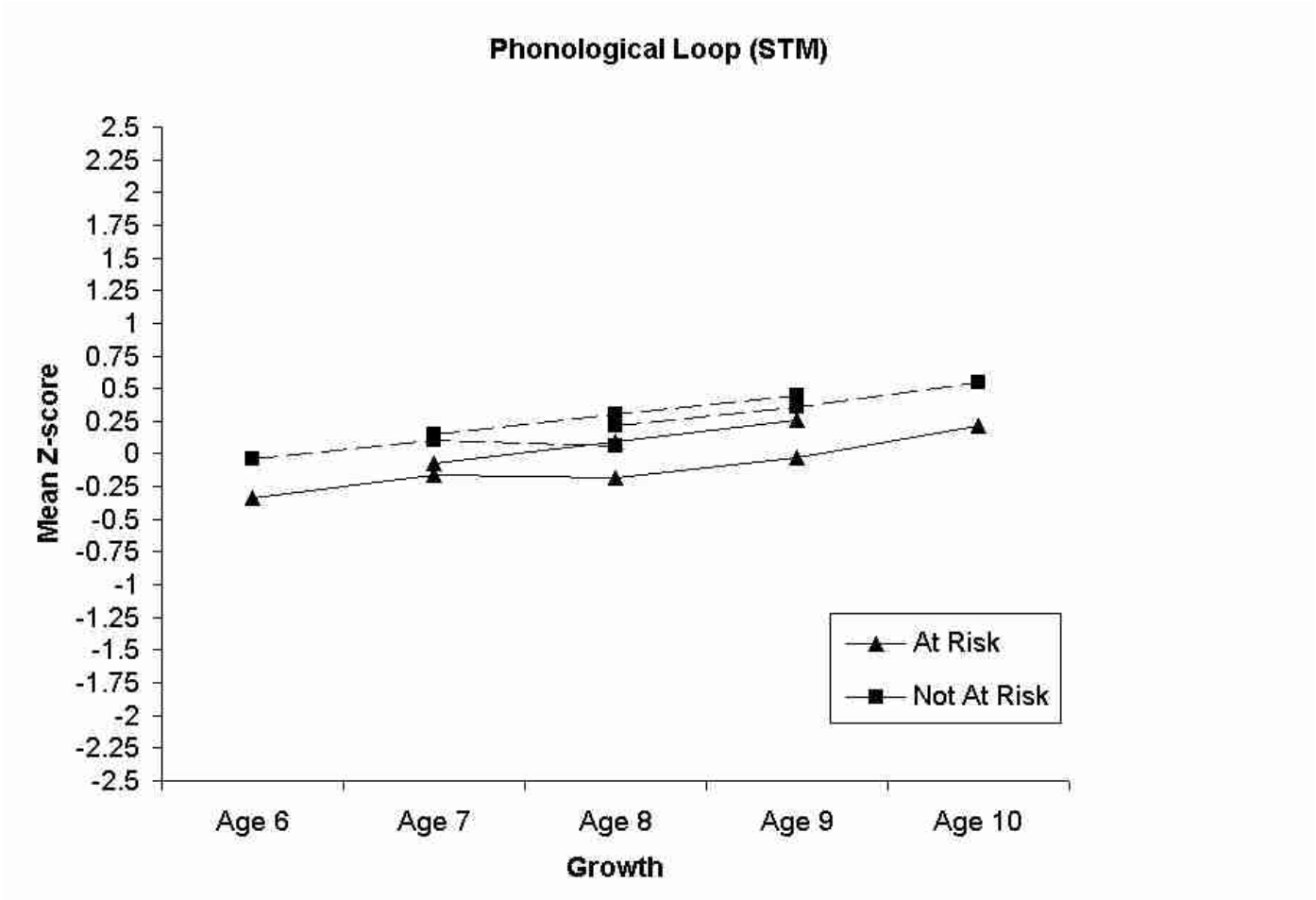

Phonological Processing
Mean Z-score
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1.25
-1.5
-1.75
-2
-2.25
-2.5
Age 6
Age 7
Age 8
Age 9
Age 10
Growth
At Risk
Not At Risk

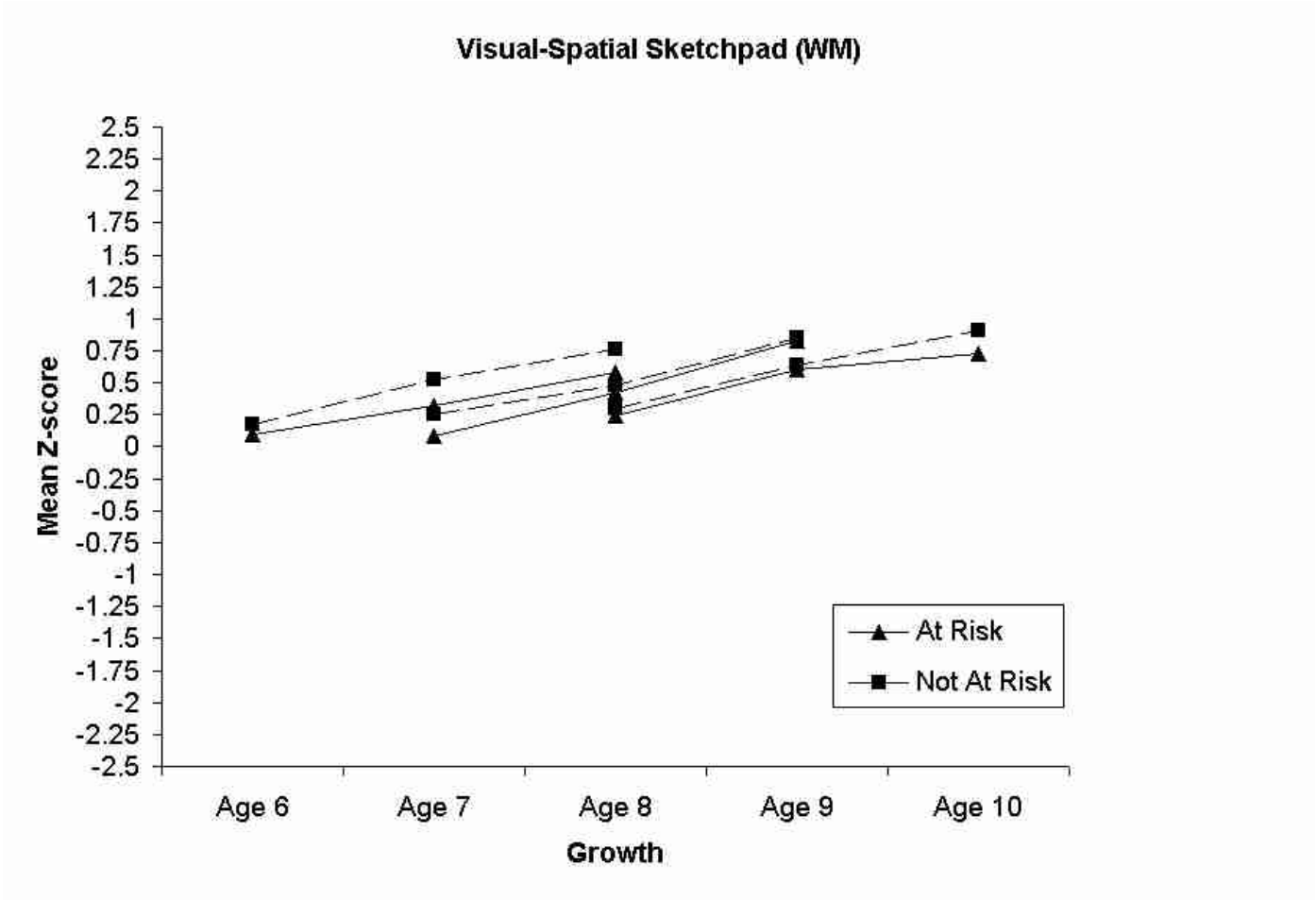

Fluency (Inhibition)
Mean Z-score
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1.25
-1.5
-1.75
-2
-2.25
-2.5
Age 6
Age 7
Age 8
Age 9
Age 10
Growth
At Risk
Not At Risk


Word Problem Solving Components
Mean Z-score
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1.25
-1.5
-1.75
-2
-2.25
-2.5
Age 6
Age 7
Age 8
Age 9
Age 10
Growth
At Risk
Not At Risk


Naming Speed
Mean Z-score
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1.25
-1.5
-1.75
-2
-2.25
-2.5
Age 6
Age 7
Age 8
Age 9
Age 10
Growth
At Risk
Not At Risk


Random Generation (Inhibition)
Mean Z-score
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1.25
-1.5
-1.75
-2
-2.25
-2.5
Age 6
Age 7
Age 8
Age 9
Age 10
Growth
At Risk
Not At Risk


Phonological Loop (STM)
Mean Z-score
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1.25
-1.5
-1.75
-2
-2.25
-2.5
Age 6
Age 7
Age 8
Age 9
Age 10
Growth
At Risk
Not At Risk


Visual-Spatial Sketchpad (WM)
Mean Z-score
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1.25
-1.5
-1.75
-2
-2.25
-2.5
Age 6
Age 7
Age 8
Age 9
Age 10
Growth
At Risk
Not At Risk

Summary thus far

- 1. Age and ability group differences emerged across all measures—

  surprises---classification robust at final wave
- 2. Of the wave 1 predictors, Fluid Intelligence, and Visual-Spatial and Executive processing (WM) best predicted Wave 3 problem solving.
- 3. Growth in WM processes related to the Executive and phonological System is related to Growth in Problem Solving
- 4. Compared to children without SMD, children with SMD rate of growth was significantly behind their counterparts on measure of calculation, problem solving component knowledge, and processes related to the visual-spatial sketchpad and executive component of WM

Summary Cont.

5.Not merely a function of low order skills--- WM contributes unique variance to problem solving beyond the contribution of fluid intelligence, reading and computation skill, phonological processing, STM, and processing speed.

6. Not merely a function of specific executive activities identified in this study--- WM contributes to problem solving beyond measures of inhibition and activation of LTM (measures of math and reading skill)---processes related to executive processing.

What Do We Conclude from this Project ?

1. **The cognitive processes that link working memory to math word problem solution accuracy. (tentative: Executive system and reading)**
2. **How children at risk and average achieving children develop over time in terms of working memory, word problem solution accuracy, and the processes linking them**

(tentative: SMD group varies substantially across an array of measures—).

3. **Which cognitive processes should be targeted for intervention to improve word problem solving skills.**

(tentative: WM)

Caveats

- 1. Some measures not behaving as they do with adults.
- 2. Reconsidering classification criteria (naming speed for numbers may not be stable)
- 3. Not instigating a direct intervention
- 4. Results are correlational---must be followed up with causal models
- 5. Have not isolated the source of variance related to the WM residual.

- Meta-Analysis

Table 2

Effect Size as a Function of Categorical Variables When Compared to Chronological Age and IQ Matched

Category	Number of Studies	M	SD	K	Weighted Effect Size	95% CI for effect size	
						Lower	Upper
Short-Term Memory							
1. Phonological	7	-0.83	1.15	22	-0.39	-0.50	-0.29
2. Pictures	17	-0.90	1.13	53	-0.57	-0.65	-0.49
3. Words	25	-0.50	0.66	76	-0.55	-0.61	-0.48
4. Digits	11	-1.49	2.2	55	-0.63	-0.69	-0.56
5. Letters	4	-1.06	0.52	13	-1.10	-1.24	-0.95
Dual Task-Trade-off-reorder							
6. Backwards	16	-0.70	0.45	59	-0.69	-0.74	-0.63
7. Preload	3	-0.53	0.27	7	-0.49	-0.73	-0.26
8. Sorting	1	-0.52	.	30	-0.52	-0.60	-0.44
Working Memory-D & C format							
9. Counting	10	-0.88	0.55	32	-0.78	-0.84	-0.73
10. Listen/Sentence	19	-1.51	1.21	57	-0.84	-0.89	-0.79
11. Visual- Matrix	26	-0.69	0.63	72	-0.80	-0.86	-0.74
12. Complex Visual.	6	-0.52	0.17	20	-0.48	-0.57	-0.39
13. Semantic Assoc.	10	-0.81	0.44	31	-0.37	-0.44	-0.30
14. Digit/Sentence	10	-1.47	2.25	24	-0.58	-0.68	-0.48
15. Story Retelling	4	-0.80	0.7	9	-0.37	-0.50	-0.24
16. Phonol/Rhyming	7	-0.62	0.32	13	-0.61	-0.74	-0.49

D & C=Daneman and Carpenter task format

Study 2 Abstract

- This three-year longitudinal study determined whether (a) subgroups of children with reading disabilities (RD) (children with RD-only, children with both reading and arithmetic deficits, and low verbal IQ readers) and skilled readers varied in working memory (WM) and short-term memory (STM) growth, and (b) whether growth in an executive system and/or phonological storage system mediated growth in reading performance.

- A battery of memory and reading measures were administered to 84 children (ages 11 to 17) across three testing waves spaced one year apart.

- For more detail see Swanson & Jerman, (2007). The influence of working memory on reading growth in subgroups of children with reading disabilities, *Journal of Experimental Child Psychology,96,* 249-283

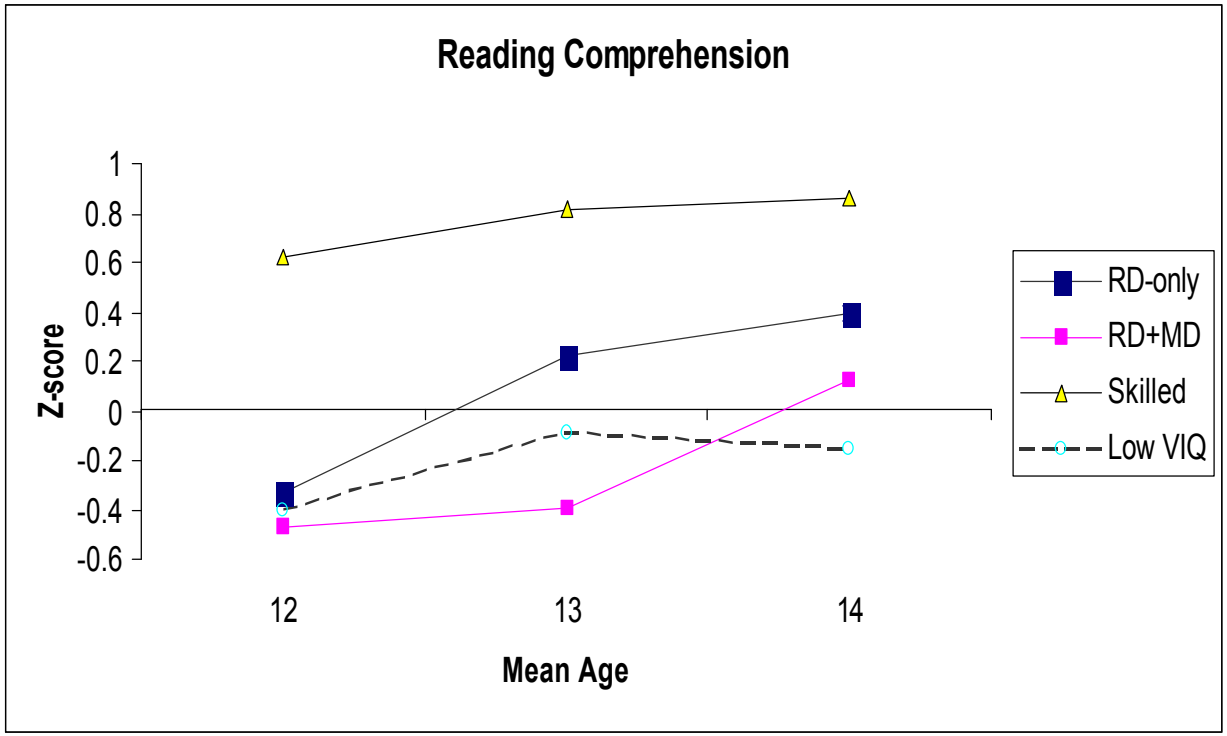
Means and Standard Deviations by Ability Group for Wave 1

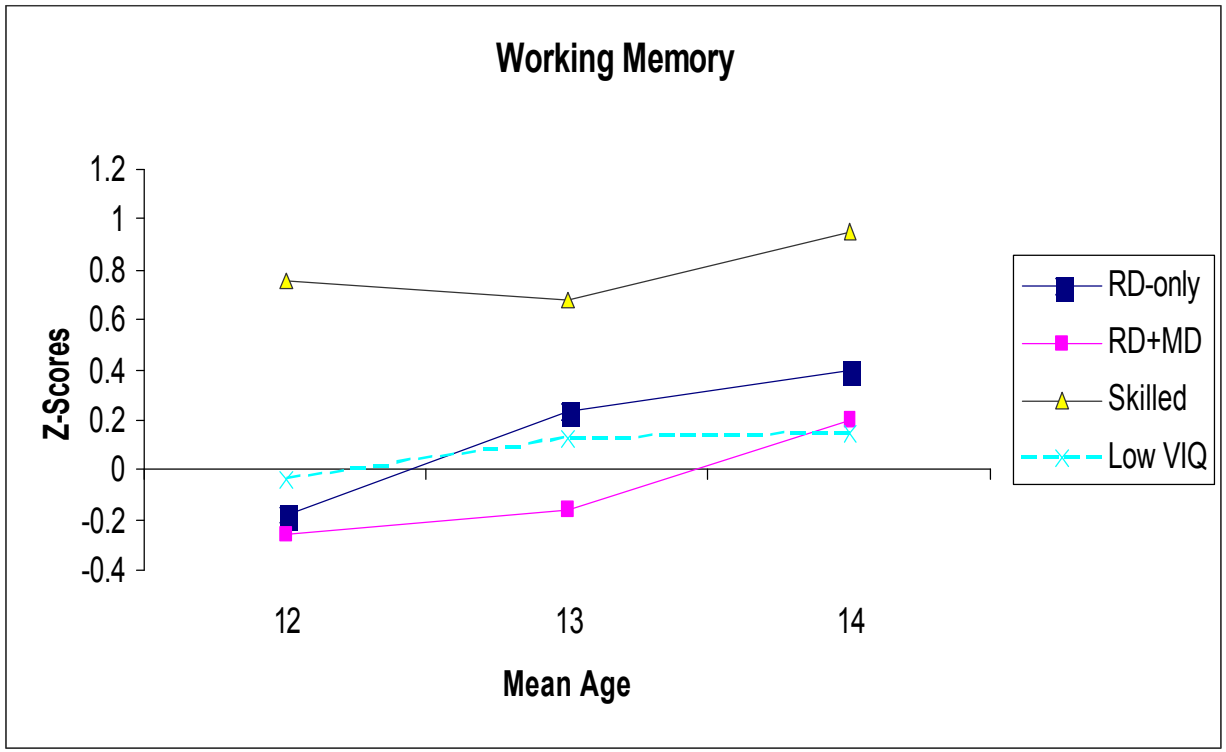
	RD-only (N=18)		Comorbid (N=18)		Skilled Reader (N=23)		Low verbal IQ (N=25)	
Name	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
VIQ	100.86	16.85	106.41	17.79	116.6	27.4	78.64	3.61
Reading	79.94	7.32	81.23	14.32	106.43	10.33	85.12	12.55
Math	105.05	7.57	80.2	8.1	105.52	17.16	88.76	11.97
Compre.	81.00	14.2	80.11	19.32	100.47	17.85	77.36	7.98
Word- Fluency	83.41	10.39	78.83	11.54	104.04	17.14	84.2	8.88
Raven	107.66	16.65	96.25	16.53	107.52	16.67	92.88	16.67
Short-Term Memory								
PM	2.33	1.02	2.94	0.63	2.82	0.49	2.64	0.99
WS	3.5	0.85	3.77	0.87	4.39	1.03	4.08	0.49
DGSF	6.5	2.03	6.88	2.47	8.09	1.99	7.16	2.07
Working Memory								
DGSB	3.18	1.79	4.29	2.99	5.45	1.92	4.16	1.67
RYI	0.72	0.82	1.33	1.08	1.82	0.77	1.36	0.7
ADI	1.23	1.09	1.23	0.97	2.08	1.12	1.8	1.44
update	2.72	3.39	1.66	2.35	5.08	3.8	3.24	3.01

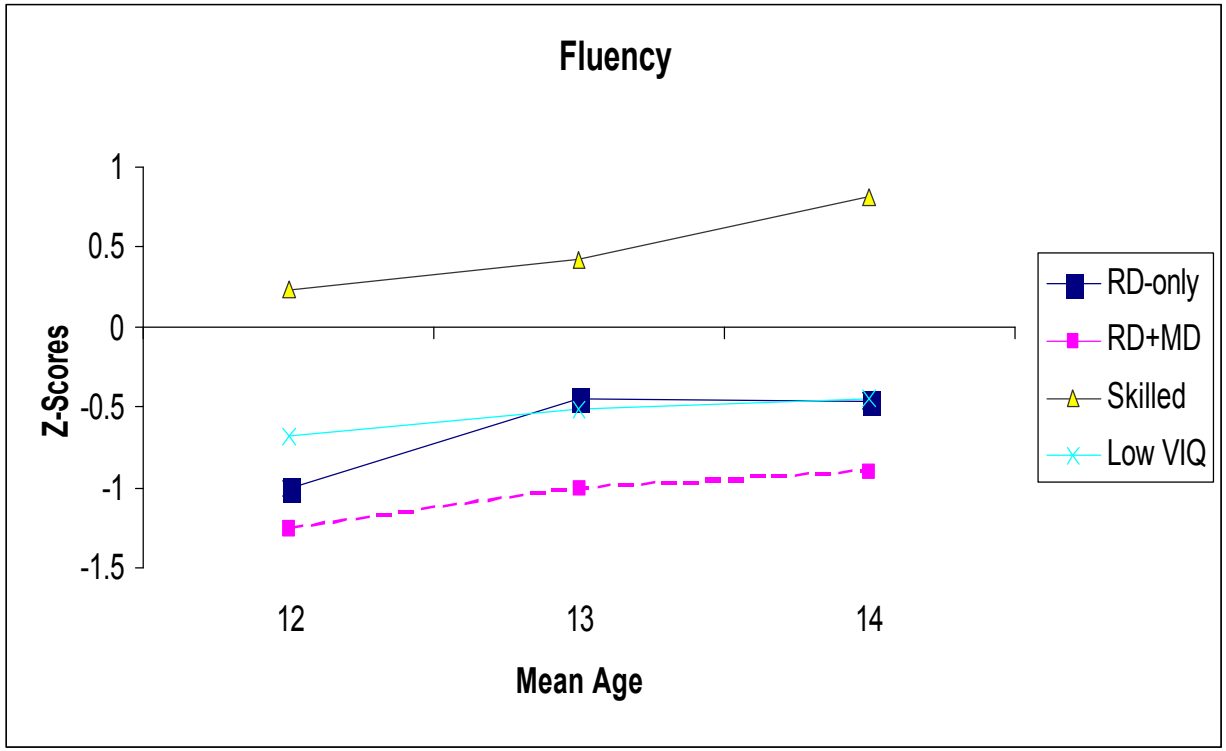
- *Correlation between Composite Scores for Wave 1 and 3 for the total sample*

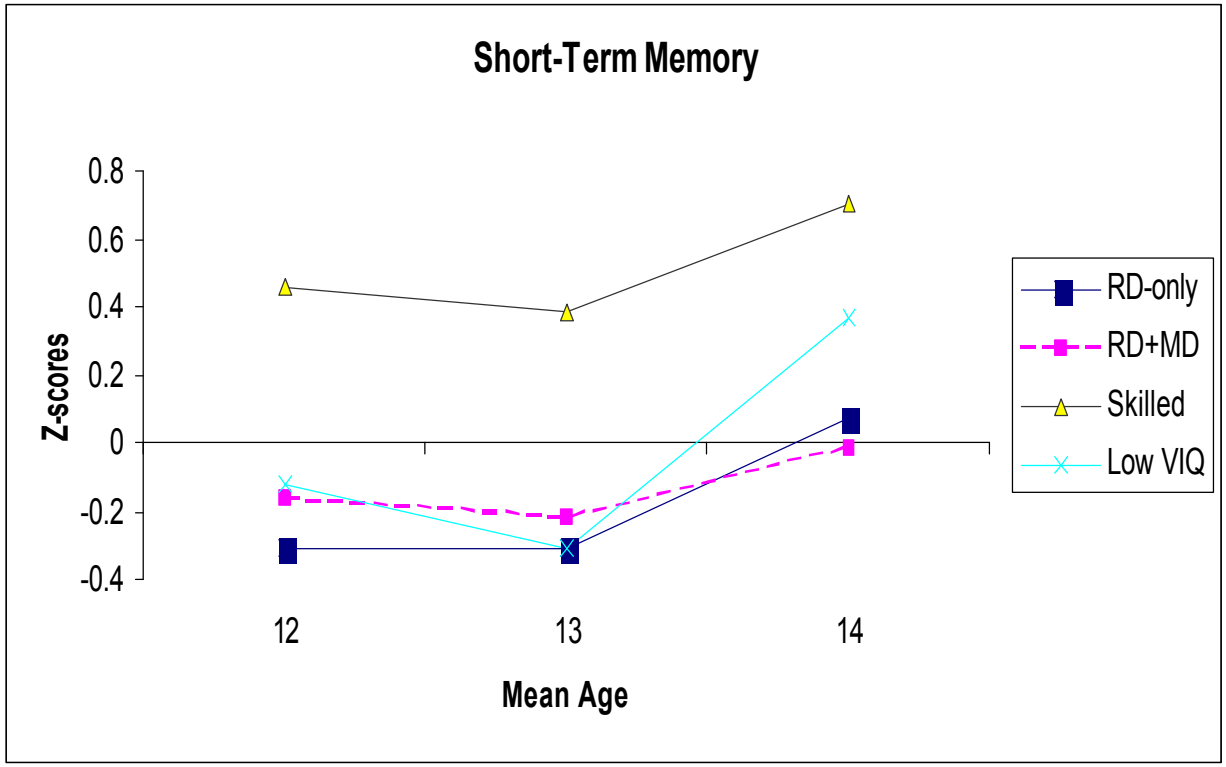
	Age1	STM 3	WM 3	Comp. 3	Fluency 3
STM 1	0.17	.45***	.54***	.33**	.40**
WM 1	.28*	.48***	.64***	.58***	.52***
Comp. 1	.38*	.31*	.57***	.75***	.53***
Fluency 1	.24	.23	.52***	.55***	.74***

- ***p < .001


Reading Comprehension
Z-score
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
12
13
14
Mean Age
RD-only
RD+MD
Skilled
Low VIQ


Working Memory
Z-Scores
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
12
13
14
Mean Age
RD-only
RD+MD
Skilled
Low VIQ


Fluency
Z-Scores
1
0.5
0
-0.5
-1
-1.5
12
13
14
Mean Age
RD-only
RD+MD
Skilled
Low VIQ


Short-Term Memory
0.8
0.6
0.4
0.2
0
-0.2
-0.4
Z-scores
12
13
14
Mean Age
RD-only
RD+MD
Skilled
Low VIQ

Conditional Model

Conditional Growth Model (Not Centered)

	Reading Comprehension		Fluency	
Fixed Effects	**Estimate**	**SE**	**Estimate**	**Variance**
Intercept	.14**	0.06	.32**	0.08
Growth	.13**	0.03	.17**	0.04
Moderating Variables				
RD Classification	.10*	0.05	.27**	0.04
Starting Age at Wave 1	-0.02	0.03	-0.05	0.004
Verbal Intelligence	.009**	0.002	0.003	0.002
Fluency	.19**	0.04	-	-
STM	0.06	0.04	0.03	0.06
WM	0.09	0.05	.22**	0.07
Linear Growth				
STM-growth	-0.008	0.01	-0.02	0.02
WM-growth	-.04**	0.02	-.05*	0.02

Table

Comparison of Ability Groups on Memory with Age and Fluid Intelligence as Covariates

Conditional Model (Not Centered)

	STM		WM	
Random effects	**Variance**	**SE**	**Variance**	**SE**
Intercept	0.16	0.1	.28**	0.11
Growth	.0002**	0.00002	.0004***	0.00007
RD Classification	0.0002	0.01	0.01	0.01
Residual	.35**	0.0	.17***	0.02
Fixed Effects	***Estimate***		***Estimate***	
Intercept	.29*	0.10	.40*	0.10
Growth	0.06	0.05	.14**	0.04
Moderator Variables				
RD classification	.14**	0.04	. 16**	0.04
RD growth	.01	.01	.004	.01
RD vs. RD+MD-Intercept	0.03	0.09	-0.07	0.09
RD vs. RD+MD-Growth	-0.001	0.02	-0.02	0.02
Age Wave 1	0.06	0.06	-0.02	0.04
Fluid Intelligence	.01**	0.004	.01**	0.003

RD classification= RD subgroups vs. skilled readers

Note: * p < .05, ***p* < .001

Tentative Conclusions

- 1. The results show that the level of performance and growth on measures of WM are statistically comparable between the RD-only and children with comorbid deficits even when fluid intelligence and age were partialed from the analysis.
- 2. The results also showed that memory Level for skilled readers differed significantly from subgroups of children with RD.
- 3. Growth modelling for the total sample showed that WM (controlled attention), rather than STM (phonological loop), was significantly related to growth in reading.

Study 3 ---Abstract

- Abstract

- Manuscript in preparation
- Working Memory and Strategies in Children with Reading Disabilities---with Pam Kehler, Olga Jerman

- Two experiments investigated the relationship between working memory (WM), strategy knowledge and strategy training in children with reading disabilities (RD). Experiment 1 examined the relationship between strategy knowledge and WM performance in children (mean chronological age 10.8 yrs) as a function of initial, gain (cued), and maintenance conditions.

- Experiment 2 examined the effects of strategy instruction on WM performance.
- Children (Mean CA 11.2 yrs) were randomly assigned to rehearsal strategy instruction or control conditions to improve performance on an operation span task

Table 1

Means and Standard Deviations for Age, IQ, Math, Reading, and Working Memory Scores for Experiment 1

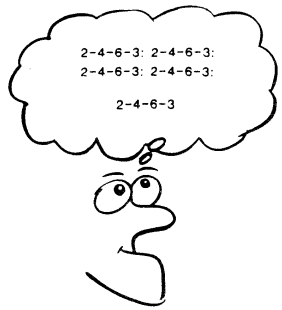
	Reading Disabled		CA-Matched			
Variables	M	SD	M	SD	F-ratio	η^2
Age	10.02	1.77	10.73	1.44	2.99	0.04
IQ (Raven-Percentile)	54.12	22.11	63.29	18.66	3.11	0.04
Reading Standard (TORC)	80.64	8.22	116.37	12.4	158.77***	0.72
Math Standard (WJ)	87.77	13.69	93.04	12.38	2.4	0.03

Table 1

Means and Standard Deviations for Age, IQ, Math, Reading, and Working Memory Scores for Experiment 1

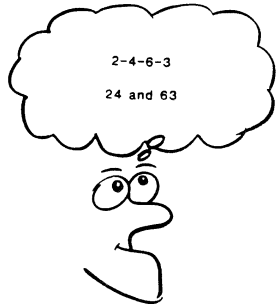
Variables	**Reading Disabled**		**CA-Matched**		**F-ratio**	**η^2**
	M	**SD`**	**M**	**SD**		
Working Memory						
Digit/Sentence						
Initial	1.48	1.32	2.07	0.86	3.87*	0.06
Gain	2.48	0.91	3.64	0.97	22.36***	0.27
ESg	**1.26**		**1.82**			
Main	2.04	0.78	2.94	1.22	10.67**	0.15
ESm	**.42**		**1.01**			
Probe	4.08	1.8	4.67	2.24	1.21	0.02
Mapping/Direct						
Initial	1.52	1.22	2.16	0.89	5.66*	0.09
Gain	3.08	1.35	3.86	1.31	5.18*	0.08
ESg	**1.27**		**1.91**			
Main	2.52	1.29	3.29	1.45	4.66*	0.07
ESm	**.81**		**1.26**			
Probe	3.04	2.0	3.81	3.02	1.25	0.02

Subtest 3 Strategy Card



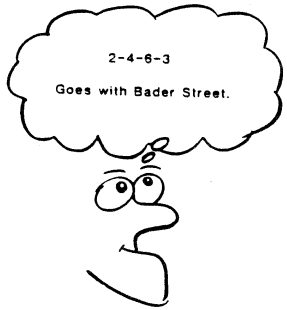
Say numbers to yourself.

A



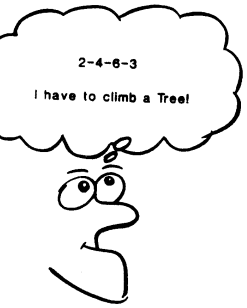
B Say numbers in pairs.

C



Remember that numbers go with a particular street.

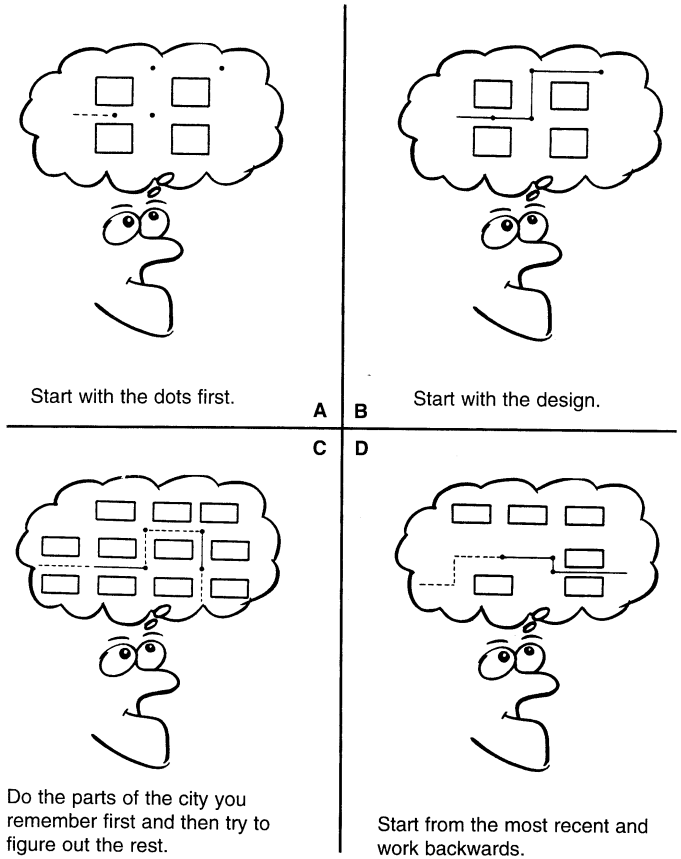
D



Think of other things that go with numbers.

- Verbal Strategy Choice
- RD vs. NRD
- *Unstable* *36* *19*
- *Rehearsal* *16* *24*
- *Clustering* *24* *30*
- *Association* *20* *24*
- *Elaboration* *4* *3*

Subtest 4 Strategy Card



A

Start with the dots first.

B

Start with the design.

C

Do the parts of the city you remember first and then try to figure out the rest.

D

Start from the most recent and work backwards.

- Visual Strategy Choice

	RD	vs.	NRD
Unstable	*28*		*8*
Elemental	*20*		*37*
Global	*32*		*30*
Sectional	*16*		*22*
Backward	*4*		*3*

Table 4

Hierarchical Regression Model on Span Scores for Experiment 1

	Gain WM				Maintenance WM				Reading Comprehension			
	B	SE	β	t-ratio	B	SE	β	t-ratio	B	SE	β	t-ratio
Model 1												
Initial	0.44	0.12	0.42	3.61**	0.58	0.1	0.6	5.86***	0.57	0.14	0.45	3.89**
R^2	0.17				0.36				0.20			
Model 2: Probe and Strategy Stability Scores												
Initial	0.5	0.09	0.48	5.26**	0.37	0.1	0.39	3.53**	0.35	0.19	0.27	1.85
Probe	0.61	0.09	0.58	6.71**	-0.02	0.11	-0.02	-0.19	-0.07	0.19	-0.05	-0.38
Stability	0.23	0.07	0.28	3.30**	0.03	0.07	0.05	0.55	-0.05	0.12	-0.05	-0.41
Gain	-	-	-		0.51	0.12	0.54	4.15**	0.50	0.21	0.4	2.31*
R^2	0.59				0.61				0.30			

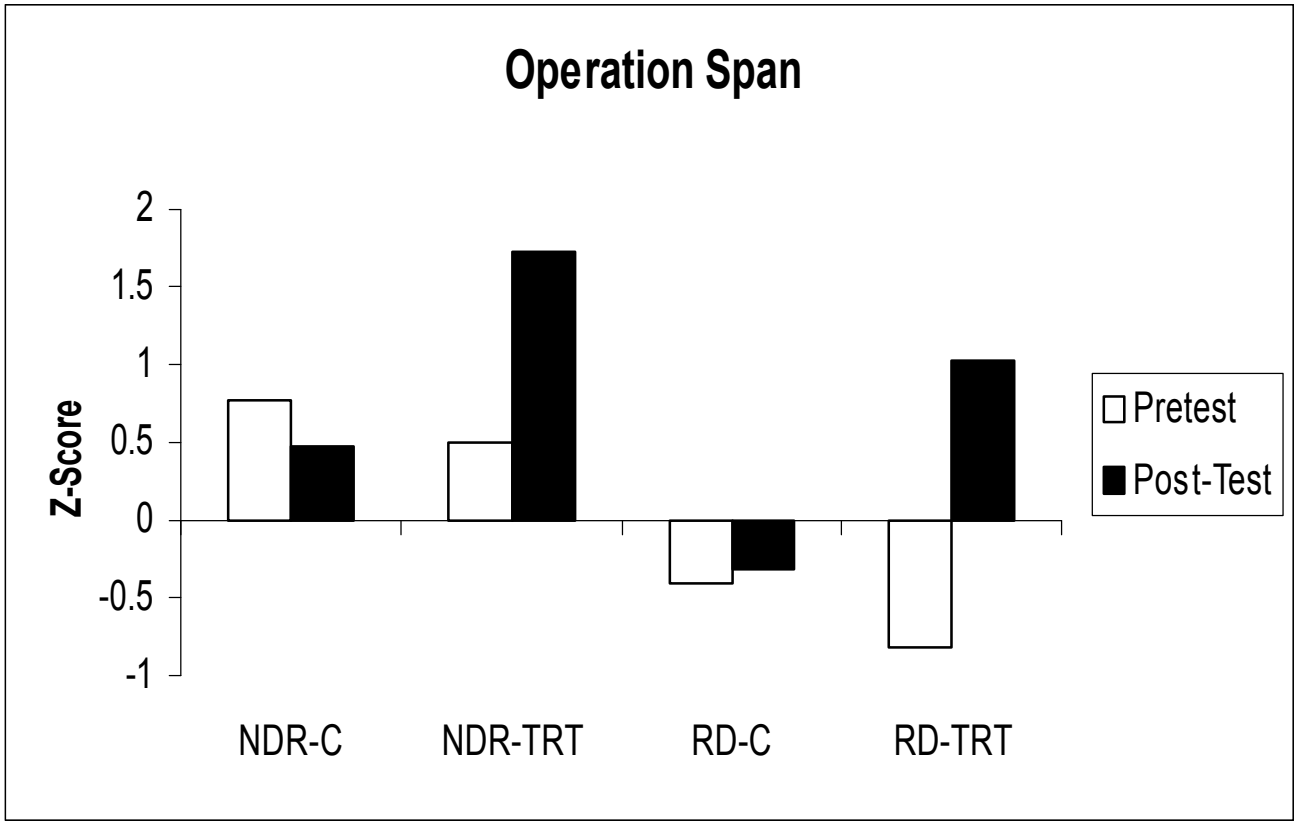
- In summary, the important results of Experiment 1 were that stable strategy choices, rather than unstable choices predicted WM span, and WM performance under cued conditions contributed unique variance to reading comprehension.
- Several Limitations:
- 1. Declarative knowledge was not linked to procedural knowledge.
- 2. Although Experiment 1 showed that WM span of children with RD can be improved upon, there was no control condition. Thus, the gains in WM performance may be due to practice effects.

Means and Standard Deviations for Age and Scores on all measures for Experiment 2

	NRD control N=14		NRD treatment N=15		RD control N=14		RD treatment N=15		Reliability
	M	SD	M	SD	M	SD	M	SD	
Classification									
Age	11.41	0.87	11.07	0.91	11.1	0.63	11.43	0.64	
Raven (%)	55.14	17.49	57.33	19.72	62.21	20.66	49.6	24.05	0.74
Reading (%)	58.43	19.08	52.94	16.98	15.86	7.42	12.87	7.91	0.75
Math (%)	75.29	24.79	76.61	25.05	51.86	27.9	42.27	32.47	0.85

Means and Standard Deviations for Age and Scores on all measures for Experiment 2 (Training Measure)

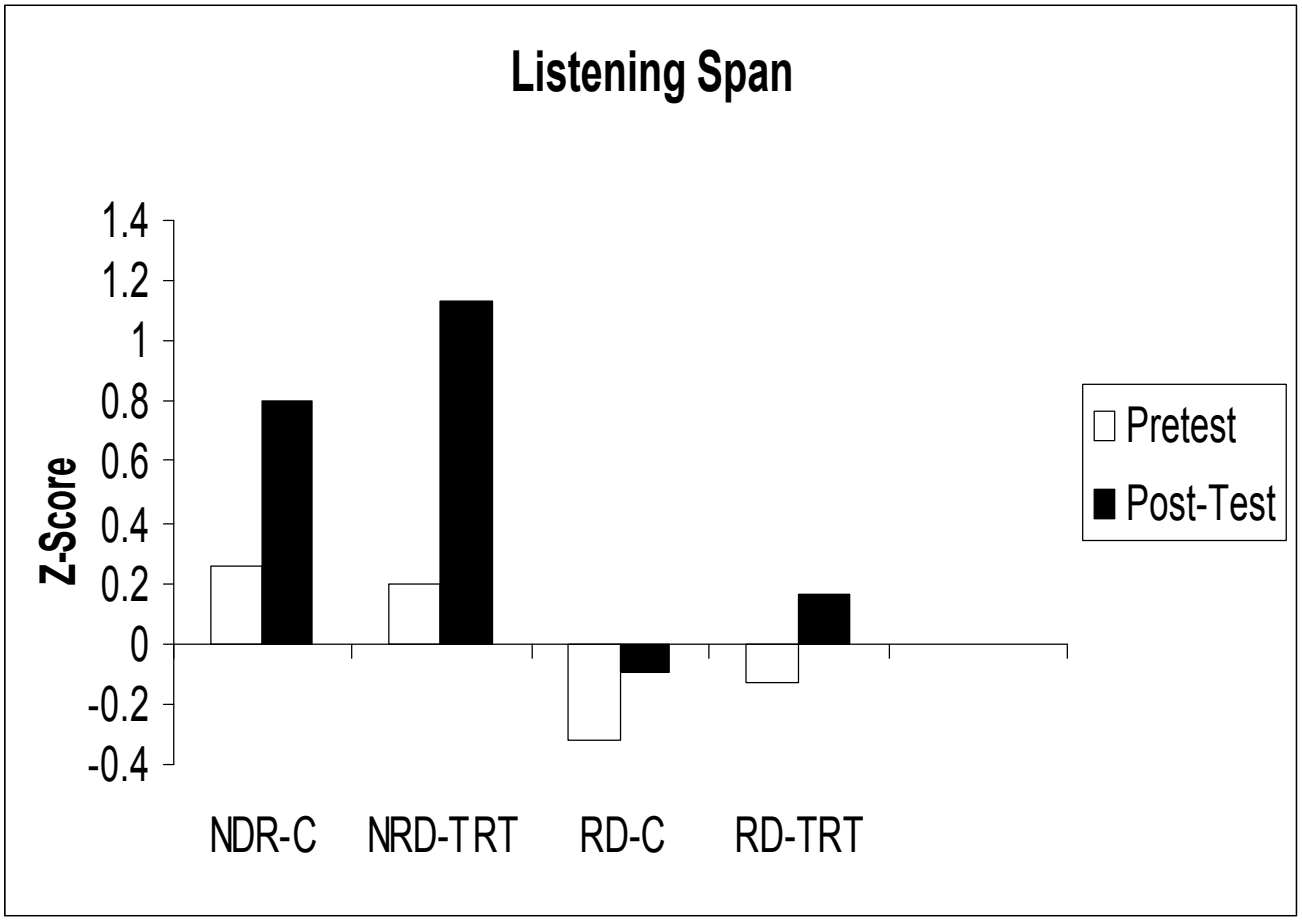
	NRD control N=14		NRD treatment N=15		RD control N=14		RD treatment N=15		
	M	SD	M	SD	M	SD	M	SD	Reliability
Operation Span									
Pre-item	27.36	3.77	25.6	3.56	19.93	5.47	17.53	5.88	0.86
Post-item	25.57	4.64	33.22	2.65	20.64	4.27	28.93	5.68	0.90
Pre-process	27.57	0.85	27.86	0.35	27.21	0.8	26.26	2.28	0.62
Post-process	27.21	1.31	27.86	0.51	27.42	0.64	24.86	3.41	0.84


Operation Span
Z-Score
2
1.5
1
0.5
0
-0.5
-1
NDR-C
NDR-TRT
RD-C
RD-TRT
Pretest
Post-Test

Means and Standard Deviations for Age and Scores on all measures for Experiment 2 (Transfer)

	NRD control N=14		NRD treatment N=15		RD control N=14		RD treatment N=15		
	M	SD	M	SD	M	SD	M	SD	Reliability
Listening Span									
Pre-item	11.57	3.08	11.4	2.93	9.64	4.03	10.27	3.31	0.76
Post-item	13.43	1.74	14.53	1.8	10.71	3.41	11.27	3.84	0.78
Pre-process	1.37	0.84	1.66	1.17	1.0	0.67	1.26	0.79	0.51
Post-process	2.0	1.03	2.0	0.75	1.71	0.99	1.4	1.35	0.43

Transfer Task



Hierarchical Regression Predicting Reading and Math Scores on the WRAT-3 and California's STAR test and Listening Span

	Reading WRAT-III			Math WRAT-III		
	R^2	ΔR^2	F-ratio	R^2	ΔR^2	F-ratio
Model 1						
Pretest	0.35	-	30.56**	0.18	-	12.41**
Model 2						
Pretest	0.36	-	29.13**	0.18	-	11.82*
Condition	0.36	-	0.03	0.18	-	0.05
Post	0.36	-	0.04	0.18	-	0.09
Post*Condition	0.37	0.01	0.31	0.19	0.01	0.22

	Reading STAR			Math STAR			Listening Span		
	R^2	ΔR^2	F-ratio	R^2	ΔR^2	F-ratio	R^2	ΔR^2	F-ratio
Model 1									
Pretest	0.18	-	10.79***	0.12	-	6.52*	0.16	-	11.05**
Model 2									
Pretest	0.18	-	10.81**	0.12	-	6.96*	0.16	-	12.46**
Condition	0.29	0.02	2.49	0.14	0.02	1.13	0.20	0.04	3.0
Post	0.21	0.01	1.18	0.18	0.04	2.43	0.20	-	0.2
Post*Condition	0.24	0.03	2.22	0.23	0.05	2.61	0.30	0.10	6.73**

Summary of Results

- The results of experiment 1 showed that although both verbal and visual-spatial WM performance in children without RD was superior to children with RD, strategy knowledge was comparable between both groups.
- For both groups, stable strategy choices, rather than specific strategy choices predicted WM span, and WM performance was significantly increased as a result of cued conditions.
- Both skilled readers and children with RD were comparable in processing efficiency, but greater processing demands were placed on children with RD when compared to children without RD.
- For both groups in Experiment 2, rehearsal training improved performance on the Operation span measure.
- Training influenced transfer to a related task.
- Overall, these results suggest that poor WM span performance in children with RD is not primarily related to strategy knowledge. Constraints within the WM system appears to be an important concomitant of RD.

Conclusions (3 studies)

- 1. Learning Disabilities in reading and/or math is related to WM.
- 2. Depending on the task, all components, but especially executive processing, are important in predicting problem solving, reading comprehension, and computation performance.
- 3. Ability group differences are more likely related to constraints in capacity (residual differences that exist between groups after speed, inhibition, related processes partialed out) rather than strategies or processing efficiency.

- Problems---the residual variance related to WM has not been adequately accounted for