Western

Specific Language and Working Memory Impairments: Evidence and Learning Patterns

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Overview

- Working Memory: Components & measurement
- WM and Language: Are they separable?
- Distinct WM and Language Impairments
- Learning patterns of WMI and LI groups

Why working memory?

Domain-general constraints

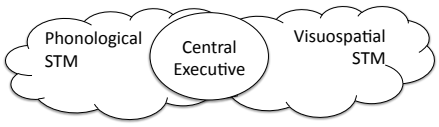
- Bates (1994)
  - Language involves a reconfiguration of mental & neural systems that … serve at least some nonlinguistic functions
  - Fast enough to fall within memory constraints but clear and efficient enough for successful production and comprehension

Working Memory

- System/mechanisms
  - maintenance of task-relevant information
  - during the performance of a cognitive task
  - in the current focus of attention
- The 'hub of cognition'
- An essential role in complex cognition
- More highly related to learning than any other factor

Haberlandt, 1997; Goldman-Rakic, 1992; Shah & Miyake, 2001; Kyllonen, 1996

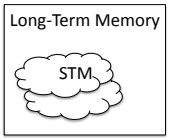
Working Memory Components



Baddeley & Hitch, 1974; Baddeley, 1986
Other models: Cowan, 1999; Kane & Engle, 2000

Short-term Memory

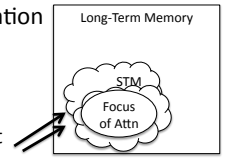
- Brief retention of information
  - Domain-specific processors: phonological, visual, spatial features, and many others (e.g., semantic)
  - Recoding / dual coding
- Some common principles
  - Activation
  - Rehearsal
  - Interference
- Connects with existing knowledge



Baddeley & Hitch, 1974; Gathercole, 1995; Cowan, 1999; Kane & Engle, 2000

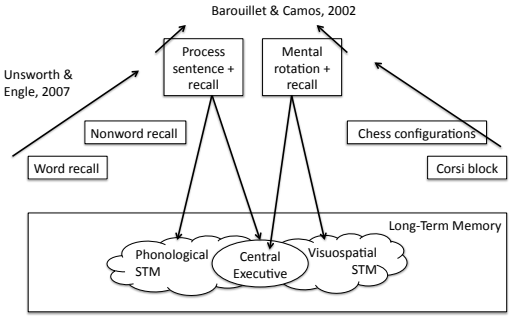
Central Executive

- Directs attention; controls & coordinates currently activated information
- Current focus of attention
  - Voluntary processing
  - Conscious of at the moment
  - Activated state; implicit WM?
- Domain-general resource drives relationship with other complex cognitive activities



Baddeley, 1986; Cowan, 1999; Kane & Engle, 2000; Hassin et al., 2009

Mapping Measures to the Model



Questions

- Model and measure
  - Separate STM & executive components
  - Domain-specificity of STM
  - Domain-free processing resource
- Developmental sample (Alloway et al., 2004)

Idea

- To examine short-term and working memory processes in an independent sample of school-age children

Datasets

Archibald & Joanisse (2009)

- 9 schools
- 400 screened
  - 94% English
  - Sentence recall (Redmond, 2003)
  - Nonword Rep (D&C, 1998)
- 88 assessments
  - CELF-IV
  - AWMA
  - TONI

Archibald et al. (In mulling)

- 34 schools
- 1387 screened
  - 85% English; 82% mother with some college education

⇩

2 samplings

- AWMA study, *n*=178
- Selected sample, *n*=392

AWMA study

Participants

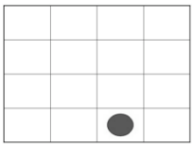
- 16 urban; 4 rural schools
- 40 children randomly selected from large unselected database from each of 5 age groupings

	5;0-5;11	6;0-6;11	7;0-7;11	8;0-8;11	9;0-9;11	Total
Female	17	21	17	21	20	96
Male	9	14	23	16	20	82
Total	26	35	40	37	40	178

- Automated Working Memory Assessment (AWMA; Alloway, 2007)

AWMA

- Short-term memory
  - Phonological
    - Repeat numbers, words, nonwords
  - Visuospatial
    - Recall locations on a grid, blocks on a board, paths through a maze

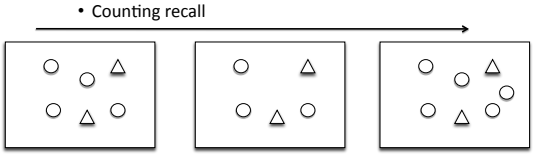


AWMA

- Working memory
  - Verbal
    - Backwards digit recall
    - Listening recall
      - Clocks eat apples — true/false
      - Pianos play music — true/false
      - Recall final words: apples, music

AWMA

- Working memory
  - Verbal
    - Counting recall

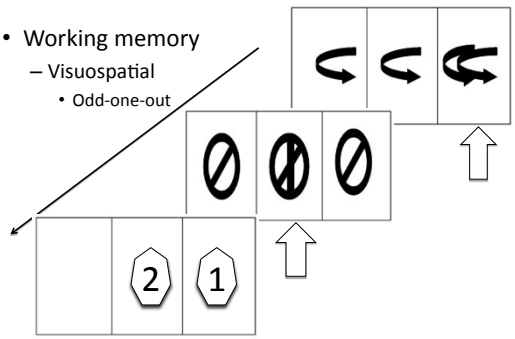


Tally = 4 Tally = 3 Tally = 5

Recall tallies: '4, 3, 5'

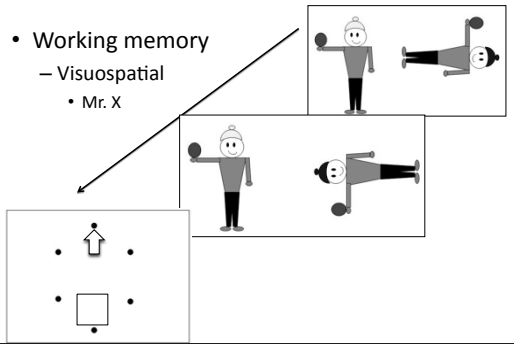
AWMA

- Working memory
  - Visuospatial
    - Odd-one-out



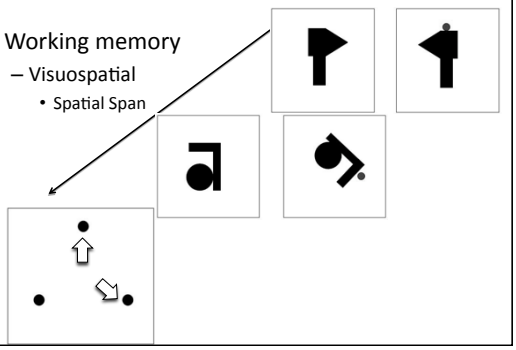
AWMA

- Working memory
  - Visuospatial
    - Mr. X



AWMA

- Working memory
  - Visuospatial
    - Spatial Span



AWMA

- Phonological STM
  - Digit recall
  - Word recall
  - Nonword recall
- Verbal WM
  - Listening recall
  - Counting recall
  - Backwards digit recall
- VSSP STM
  - Dot matrix
  - Block recall
  - Mazes memory
- VSSP WM
  - Odd one out
  - Mr. X
  - Spatial Span

AWMA study

AWMA: Results

	WM Proc	PhSTM
	Component 1	Component 2
Digit recall		.83
Word recall		.88
Nonword recall		.70
Dot matrix	.81	
Block recall	.77	
Mazes memory	.78	
Listening recall	.48	.44
Backward digit recall	.54	.47
Counting recall	.73	.37
Odd one out	.79	
Mr. X	.75	
Spatial recall	.75	

PCA; Eigenvalues > 1; Varimax rotation; Factor loadings > 0.35

Summary: AWMA study

- Phonological STM
- Domain-free processing
- VSSP STM more difficult to distinguish (Gathercole & Pickering, 2000; Miyake et al., 2001)

WM and Language

- Are they separable?
- Different measures of the same underlying factors?
  - Phonological STM
  - Domain-general processing

MacDonald & Christiansen, 2002

WM & Language: Associations

- PhSTM
  - New word learning → MANY STUDIES
  - Long, complex sentences → SEVERAL STUDIES
- WM (complex span)
  - Reading & listening comprehension → SEVERAL STUDIES

Gathercole, 2006; Adams & Gathercole, 2000; Daneman & Carpenter, 1980; King & Just, 1991

WM & Language: Separability

- Marked difficulty with aspects of grammar in SLI
- Intact syntactic processing in low WM groups d/t dementia (Caplan & Waters, 1999)
- Good/poor WM groups comparable simple sentence comprehension (Engle & Conway, 1998; Montgomery & Evans, 2009)

Idea

- Examine WM and language performance in a large group of school age children

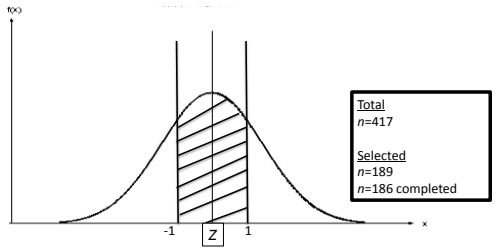
Selected Sample

Participants

- 34 schools; ~6000 invitations; SK to gr. 4
- 1387 participated
- Screening
  - Sentence recall (Redmond, 2003; Archibald & Joanisse, 2009)
  - Math fluency (Woodcock Johnson III)
  - Word/nonword reading (TOWRE)

Selected Sample

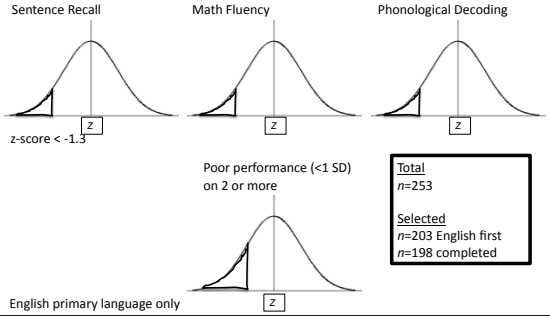
1. Typical screeners



English primary language only

Selected Sample

2. Poor Screeners



English primary language only

Selected Sample

	5;0-5;11	6;0-6;11	7;0-7;11	8;0-8;11	9;0-9;11	♀	Total
Typical Screeners	23	38	54	41	33	95	189
Low Screeners	21	40	59	45	38	93	203
Total	44	78	113	86	71	188	392

Assessment Measures

- Select subtests from AWMA
- Composite Language Score (CELF-IV)
- Wechsler Abbreviated Scale of Intelligence (WASI)(WPPSI for under 6)

- Other measures
  - Sentence recall
  - Grammaticality judgment (Miller et al., 2008)
  - Rapid letter/picture naming
  - (School learning measures)

Selected Sample

Factor Analysis

Language	PhSTM	VSSP STM	Verbal WM	VSSP WM	IQ
Concepts & following directions	Digit recall	Dot matrix	Listening recall	Odd one out	Vocabulary
Recalling sentences	Nonword recall	Block recall	Counting recall	Spatial Span	Similarities
Formulating sentences					Block Design
					Matrix Reasoning

PCA; Eigenvalues > 0.95; Varimax rotation

Selected Sample

	LTM 1	2	3	4
Concepts & FD	.45	.71		
Recalling sentences		.74	.46	
Formulating sentences	.35	.80		
Digit recall		.39	.70	
Nonword recall			.82	
Dot matrix	.74			
Block recall	.73			
Listening recall	.58	.39		
Counting recall	.76			
Odd one out	.74			
Spatial span	.73			
Vocabulary		.67		
Similarities	.35	.72		
Block design				.90
Matrix reasoning		.41		.69

Selected Sample

Factor Correlations

	1 WM Proc	2 Language	3 PhSTM	4 PIQ
Sentence Recall	ns	.55**	.26**	ns
Grammaticality Judgment	ns	.36**	.20**	.19**
Rapid Letter Naming	-.25**	-.21**	ns	ns
Rapid Picture Naming	-.27**	-.22**	ns	ns

Partial correlations controlling for age; $n = 372$; $^{**}p < .001$

Summary: WM & Language

- Separable factors
  - WM: Domain-free processing
  - PhSTM
  - Language
  - PIQ

- Separable impairments?

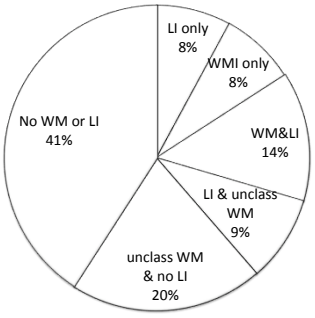
Specific Language Impairment: Theories

Domain-general
- Processing capacity
- Processing speed

Domain-specific
- Phonological processing
- Grammatical learning deficit

Bishop, 1992; Kail, 1994; Gathercole & Baddeley, 1990; Chiat, 2001; van der Lely, 2004; Ullman & Pierpont, 2005; Leonard, 1998; Rice, 2003

WM & Language: Distinct Impairments?



- Archibald & Joanisse, 2009
- *n* = 88

Idea

- Investigate specific and co-occurring language and working memory impairments in a large unselected group of school age children using cluster analysis

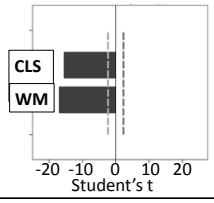
Selected Sample Data

- Selected sample: 392 assessments
  - Language: CELF-IV
  - Working Memory: AWMA
  - (Nonverbal intelligence: WASI)

Selected Sample

Cluster Analysis

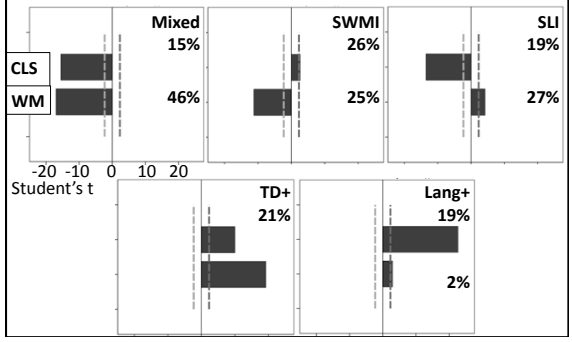
- Subdivision of cases into homogeneous groups
- t-statistic plot
  - comparing mean of the variable in cluster to overall mean



Archibald, Joanisse, Ansari, Cardy, In early preparation

Selected Sample

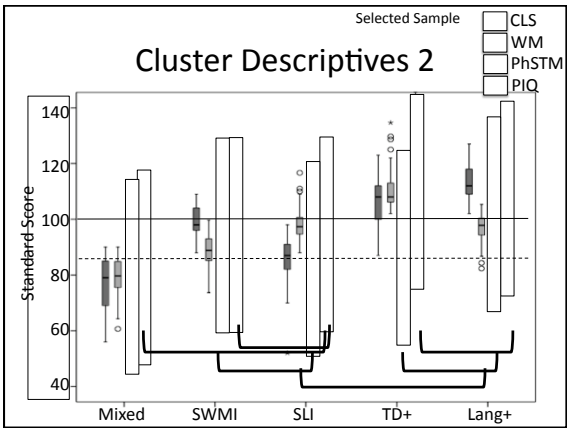
Cluster Analysis Results



Selected Sample

Cluster Descriptives 1

	%	Sex	Age (yrs)	Maternal Ed
Mixed	15		7.3 ± 1.5	High school; some college*
SWMI	26		7.1 ± 1.0	Completed college
SLI	19	♂	8.1 ± 1.1*	Completed college
TD+	21	♀	7.4 ± 1.2	Completed college
Language+	19		7.4 ± 1.3	Completed college



Summary: Specific Impairments

- Deficits in language and WM often co-occur
  - However, subgroups with specific impairments do exist
- Does WM impact language learning?
  - The case of SWMI

Leonard et al., 2007; Waters & Caplan, 2005

WM Impacts on Language Learning

- Causal
- Limiting
- Developmental

WM Constraints on Language

- PhSTM
  - retains activated features
  - new learning; rechecking
- WM
  - Attention-demanding situations
    - Maintain active representations
    - Suppress/abandon irrelevant activations
    - Long distance dependencies

Engle & Conway, 1998

WM&L: Developmental Relationship

- Demands on new learning diminishes as long-term language knowledge increases
  - Lexical/grammatical (bidirectional) bootstrapping (Marchman & Bates, 1994)
- Domain-relevant mechanisms may become more domain-specific over time (Karmiloff-Smith, 1998)
  - Emerging modularity

Idea

- Examine profile designations across development from our previous samples

2 studies

Study 1
(Archibald & Joanisse, 2009)

- *n* = 88

Study 2
(Archibald et al.)

- Selected Sample
- *n* = 392

- CELF-IV
- AWMA

↓

- SLI, SWMI, Mixed, Typical

Developmental Trends

Study 2	Typical	SLI	SWMI	Mixed
5 yr olds	67%	10%	13%	10%
6 yr olds	68%	0%	18%	15%
7 yr olds	70%	7%	16%	7%
8 yr olds	64%	19%	6%	10%
9 yr olds	72%	26%	0%	2%

Study 1	Typical	SLI	SWMI	Mixed
6 yr olds	38%	8%	26%	25%
7 yr olds	35%	8%	46%	12%
8 yr olds	50%	35%	5%	10%
9 yr olds	45%	25%	25%	5%

WM&L: Development

- Cross-sectional data
  - SWMI decreases
  - Mixed profile decreases
  - SLI increases
- Impact of WMI and LI

Studies

Language

- Grammaticality judgment
- Story retelling (SRCLD, 2009)

Working Memory

- Hebb learning (In preparation)
- Paired associate learning
- Cognitive load (SRCLD, 2011 – Harder)

Related Processes

- Rapid automatic naming
- School learning
- Divided attention (SRCLD, 2011 – Levee)
- Motor speech & NwrdRep – impact on LI not WMI (with Munson; SRCLD, 2010; In preparation)
- Classroom observation – similar social, behavioural, academic characteristics (SRCLD, 2009; CLTT – in press)
- Intervention – domain-specific effects (SRCLD, 2010; CLTT – in press)

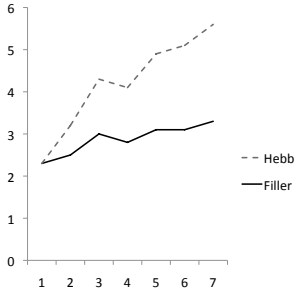
WM in Word Learning

- Beyond PhSTM capacity
- Formation of long-term phonological representations
- One aspect: sequence learning
  - Hebb implicit learning effect

Gathercole, 2006; Page et al., 2006; Mosse & Jarrold, 2008; Bayliss et al., 2005

Hebb Learning

- 2 7 5 6 1 3 9
- 7 6 3 2 5 9 1
- 9 5 6 3 2 1 7
- 7 6 3 2 5 9 1
- 6 3 2 7 9 1 5
- 7 6 3 2 5 9 1



Donald Hebb, 1961

Hebb Repetition Effect

- Domain general
  - Verbal
  - Visually presented verbal information
    - Cross-modality learning via recoding
  - Spatial
- Domain-general mechanism involved in long-term learning of serial order information

Page et al., 2006; Mosse & Jarrold, 2008; Bayliss et al., 2005; Couture & Tremblay, 2006

Idea

- To examine long-term sequence learning in children with SLI, SWMI, Mixed, or typical development with PhSTM demands equated

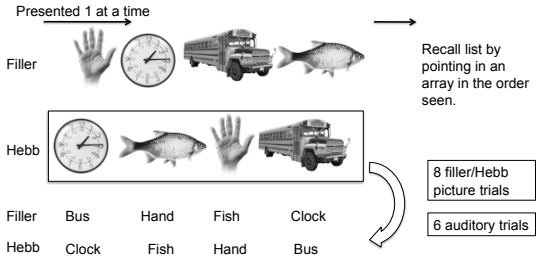
A&J, 2009

Participants

- SLI, *n*=15
- SWMI, *n*=8
- L&WMI, *n*=8
- Typical, *n*=25
- Age: 8.5 years ± 1
- Males: 29/56
- A&J, 2009

A&J, 2009

Cross-modality Hebb Learning



**Sequence length = digit span + 1

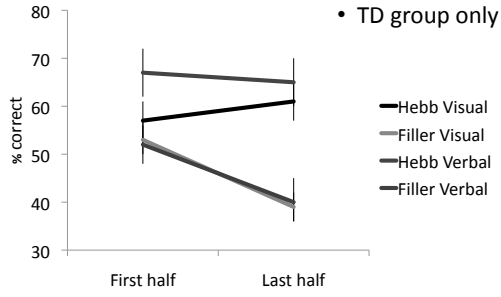
A&J, 2009

Hebb Learning: Factors

- List type: Hebb > filler
- Half: first / second half
- Modality: visual / verbal
- Predicted interactions:
  - List x half: Hebb > filler on 2nd half
  - List x modality: Hebb verbal > Hebb visual

A&J, 2009

Hebb Learning: TD Results



- TD group only

Mosse & Jarrold, 2008

A&J, 2009

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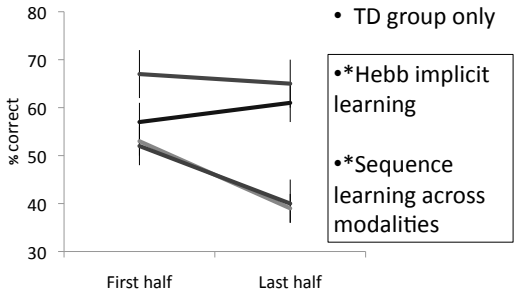


- TD group only

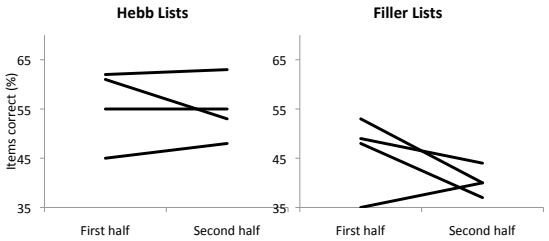
•*Hebb implicit learning

•*Sequence learning across modalities

Mosse & Jarrold, 2008

A&J, 2009

Hebb Learning: Group Results



☐TD ☐SWMI ☐SLI ☐Mixed

A&J, 2009

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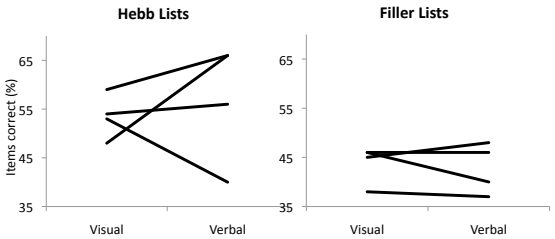

☐TD ☐SWMI ☐SLI ☐Mixed

Hebb Learning: Summary

- Implicit cross-modal sequence learning in TD 8-9 yr olds
- Children with WM Impairment showed reduced implicit learning
- Children with Language Impairment showed reduced learning from auditory modality

Johnson, 2001; Evans et al., 2009; Joanisse et al., 2000; Chiat, 2001

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WM, Language, & School Learning

- WM better predictor of school success than IQ
- Language impairments associated with learning difficulties across the curriculum

Alloway, 2009; Conti-Ramsden et al., 2009

Idea

- To explore how language, WM, PhSTM, and PIQ account for children's school learning

Selected Sample

Participants & Measures

Participants
- Selected sample
  - 6-9 yrs; *n* = 344

Predictors
- CLS
- WM
- PhSTM
- PIQ

Dependent variables
- Math fluency
- Calculations
- Sight word reading
- Nonword reading
- Reading fluency
- Phonological awareness

Selected Sample

Results: Significant Predictors

Std Tests	Predictors	Total
Math Fluency	Language (7.5%), PIQ (4%)	19%
Calculations	Language (10%), PIQ (2.2%), WM (1.4%)	30%
Word Reading	Language (11.5%), WM (1.7%), PhSTM (1.4%)	24%
Nonword Reading	Language (5%), WM (1%), PIQ (1.5%) PhSTM (1.2%)	24%
Reading Fluency	Language (16.5%), PIQ (1.3%), WM (1.1%)	38%
Phonological Awareness	Language (3.4%), PhSTM (1.8%), PIQ (1.4%)	15%

Significant Predictors: Thoughts

- Language is a better predictor of school learning than WM or IQ
  - – Also taps WM
  - – Measuring crystalized knowledge / LTM
- Population of interest
- Measurement

Conclusions

- WM measures tap phonological short-term memory; domain-general controlled attention
- WM components separable from language abilities, nonverbal intelligence
- WM & language impairments are separable also

Conclusions

- WM and/or language impairment have different impacts on learning
  - —Language: auditory learning; school learning
  - —WM: learning efficiency, reading
- Language is a better predictor of school learning than WM or IQ

Directions

- Developmental patterns related to WM, language, and learning
- Impact of WMI on language, broadly defined
- Intervention

Thank you!

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LWM Lab

Thank you!

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Supplemental

- AWMA – 3 components
- Discriminant function for clusters
- Paired associate learning
- Language subtest predictors for school learning
- Cluster differences in school learning
- Predictors of grammaticality judgment & RAN

AWMA study

Results

	Component 1	Component 2
Digit recall	.19	.83
Word recall	.20	.88
Nonword recall	.26	.70
Dot matrix	.81	.11
Block recall	.77	.29
Mazes memory	.78	.20
Listening recall	.48	.44
Backward digit recall	.54	.47
Counting recall	.73	.37
Odd one out	.79	.25
Mr. X	.75	.20
Spatial recall	.75	.32

PCA; Eigenvalues > 1; Varimax rotation; Factor loadings > 0.4

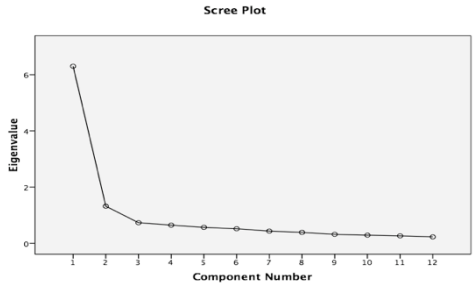
AWMA study

	Component 1	Component 2	Component 3
Digit recall		.80	
Word recall		.84	
Nonword recall		.75	
Dot matrix	.82		
Block recall	.78		
Mazes memory	.78		
Listening recall			.79
Backward digit recall	.40	.36	.51
Counting recall	.67	.32	.36
Odd one out	.73		.33
Mr. X	.54		.64
Spatial recall	.63		.46

PCA; Eigenvalues > 0.7; Varimax rotation

AWMA study

AWMA: PCA Scree Plot



Selected Sample

Discriminant Function

Added with CLS:	Classification of Clusters
WM	96%
Odd one out	80%
Counting recall	75%
Spatial recall	72%
Block Design	58%
Matrix reasoning	61%
PIQ	60%

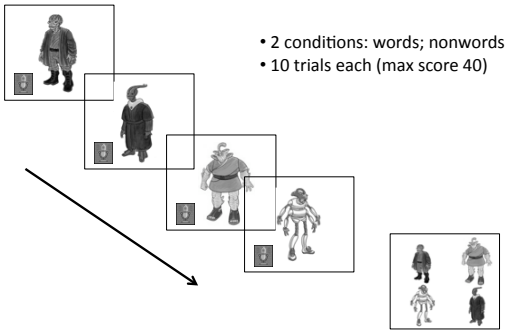
Selected Sample

Discriminant Function

Added with WM:	Classification of Clusters
CLS	96%
Concepts & FD	81%
Recalling sentences	77%
Formulating sentences	77%
Formulating + Odd One Out	67%
All other 2-test combos	58-64%

A&J, 2009

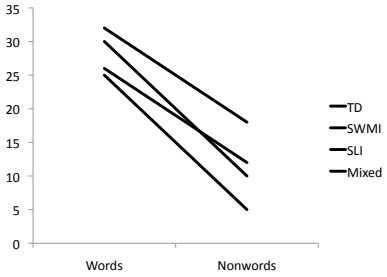
Paired associate learning



- 2 conditions: words; nonwords
- 10 trials each (max score 40)

A&J, 2009

Paired associate: Results



A&J, 2009

Learning Relationships: Results

	Words	Nonwords
Hebb 2nd half – visual	.17	.38*
PhSTM	.24	.44*
WM	.34*	.44*
CLS	.20	.48*
PIQ	.21	.43*

*$p < .01$

Word Learning: Summary

- Nonword/<u>new</u> learning taps multiple cognitive processes
- Particularly challenging for children with LI
  - Auditory modality
- Children with WMI less efficient learning across modalities, word type

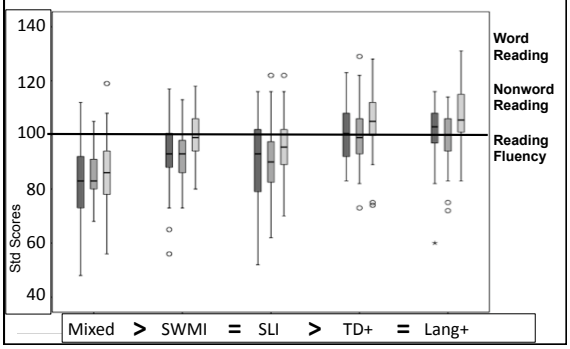
Selected Sample

Language Subtest Predictors: School Learning

Std Tests	Predictors
Math Fluency	Formulating Sentences & Concepts + FD
Calculations	
Reading Fluency	(+PhSTM)
Word Reading	Formulating Sentences (+PIQ)
Nonword Reading	
Phonological Awareness	

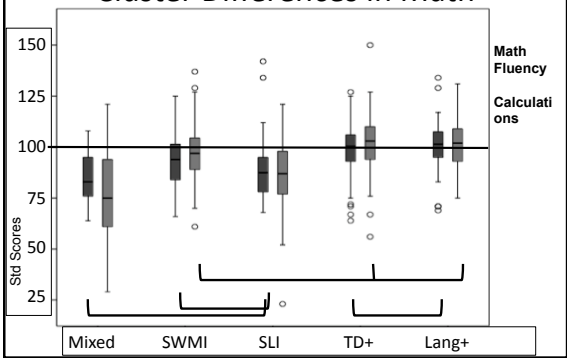
Selected Sample

Cluster Differences in Reading



Selected Sample

Cluster Differences in Math



Cluster Differences: Summary

- Co-occurring L&WMI ➔ lowest attainment scores
- SLI & SWMI ➔ lower reading & math fluency scores than TD but not distinguished

References

Adams, A.M., & Gathercole, S.E. (2000). Limitations in working memory: Implications for language development. *International Journal of Language and Communication Disorders, 35*, 95-117.

Alloway, T.P., Gathercole, S.E., Willis, C. & Adams, A.M. (2004). A structural analysis of working memory and related cognitive skills in early childhood. *Journal of Experimental Child Psychology, 87*, 85-106.

Alloway, T.P. (2007). *Automated Working Memory Assessment* (AWMA). UK: Psychological Corporation.

Alloway, T.P. (2009). Working memory, but not IQ, predicts subsequent learning in children with learning difficulties. *European Journal of Psychological Assessment, 25,* 92-98.

Archibald, L. M. D., Joanisse, M. F. (2009). On the sensitivity and specificity of nonword repetition and sentence recall to language and memory Impairments in Children. *Journal of Speech, Language, and Hearing Research, 52,* 899-914.

Archibald, L.M.D., Edmunds, A., & Joanisse, M.F. (In press). Specific language or working memory impairments: Are there observable differences? *Child Language and Teaching Therapy*.

Baddeley, A.D. (1986). *Working memory.* Oxford, UK: Oxford University Press.

Baddeley A.D., & Hitch G. (1974). Working memory. In G. Bower (Ed.*), The psychology of learning and motivation* (pp. 47-90), *8*. New York: Academic Press.

Baddeley, A.D., Gathercole, S.E., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105*, 158-173.

Bates, E. (1994). Modularity, domain specificity and the development of language. *Discussions in Neuroscience, 10, 1/2,* 136-149.

Bayliss, D. M., Jarrold, C., Baddeley, A. D., Gunn, D. M. and Leigh, E. (2005). Mapping the developmental constraints on working memory span performance. *Developmental Psychology,* 41, 579-597

Botting, N. (2005). Non-verbal cognitive development and language impairment. *Journal of Child Psychology and Psychiatry, 46*, 317-326.

Caplan, D., & Waters, G.S. (1999). Verbal Working Memory and Sentence Comprehension. Behavioral and Brain Sciences 22 (1):77-94.

Chiat, S. (2001). Mapping theories of developmental language impairment: Premises, predictions and evidence. *Language and Cognitive Processes,* 16, 113-42.

Conti-Ramsden GM, Durkin K, Simkin Z, Knox E. (2009). Specific language impairment and school outcomes. I: identifying and explaining variability at the end of compulsory education. *Int J Lang Commun Disord*, 44(1), 15-35.

Couture, M. & Tremblay, S. (2006). Exploring the characteristics of the visuospatial Hebb repetition effect. *Memory & Cognition,* 34, 1720-1729.

Cowan, N. (1999). An embedded-processes model of working memory. In A. Miyake & P. Shah (Eds.), *Models of Working memory* (pp62- 101). New York: Cambridge University Press.

Daneman, M., & Carpenter, P.A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behaviour, 19*, 450-466.

Engle, R. W., & Conway, A. R. A. (1998). Comprehension and working memory. In R. H. Logie and K. J. Gilhooly (Eds.), *Working Memory and Thinking.* Lawrence Erlbaum Associates.

Engle, R.W., Kane, M.J., & Tuholski, S.W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 102-134). New York: Cambridge University Press.

Evans, J.L., Saffran, J.R., & Robe-Torres, K. (2009). Statistical learning in children with specific language impairment. Journal of Speech Language and Hearing Research, 52, 321-335.

Gathercole, S.E. (1995). Is nonword repetition a test of phonological memory or long-term knowledge? It all depends on the nonwords. *Memory and Cognition, 23*, 83-94.

Gathercole, S. E. (2006). Nonword repetition and word learning: The nature of the relationship. Applied Psycholinguistics, 27, 513-543.

Gathercole, S.E., & Pickering, S.J. (2000). Assessment of working memory in children. *Journal of Education Psychology*, *92*, 377-390.

Goldman-Rakic, P. (1992). Dopamine-mediated mechanisms of the prefrontal cortex. *Seminars in Neuroscience*, *4*, 109–118.

Haberlandt, K. (1997). *Cognitive Psychology*. Boston: Allyn & Bacon.

Hassin, R., Bargh, J., Engell, A., & McCulloch, K. (2009). *Implicit working memory*. Consciousness and Cognition, 18, 665-678.

Hebb, D. O. (1961). *Distinctive Features of Learning in the Higher Animal. In Brain Mechanisms and Learning* (ed. Delafresnaye J. F.), pp, 37-46- Oxford, UK; Blackwell.

Hill, E.L. (2001). The non-specific nature of specific language impairment: a review of the literature with regard to motor impairments. *International Journal of Language and Communication Disorders, 36*, 149-171.

Hsu, H. J. & Bishop, D. V. M. (2010). Grammatical difficulties in children with specific language impairment (SLI): is learning deficient? *Human Development, 53, 264–277.*

Joanisse, M.F., Manis, F.R., Keating, P., & Seidenberg, M.S. (2000). Language deficits in dyslexic children: Speech perception, phonology, and morphology. *Journal of Experimental Child Psychology, 77*, 30-60.

Johnson, M. (2001). Functional brain development in humans. *Nature Reviews, 2*, 475-483.

Kane, M. J., & Engle, R. W. (2003). Working memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General, 132*, 47-70.

Karmiloff-Smith, A. (1998) Development itself is the key to understanding developmental disorders. *Trends in Cognitive Sciences*, 2 (10), 389-398.

King, J., & Just, M.A. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language, 30*, 580-602.

Kyllonen, P. C. (1996). Is working memory capacity Spearman's *g*? In I. Dennis, & P. Tapsfield (Eds.), *Human Abilities: Their nature and measurement* (pp. 49-76). Mahwah, NJ: Lawrence Erlbaum.

Leonard, L.B., Ellis Weismer, S., Miller, C.A., Francis, D.J., Tomblin, J.B., Kail, R.V. (2007). Speed of processing, working memory, and language impairment in children. *Journal of Speech, Language, and Hearing Research, 50*, 408-428.

MacDonald, M. C., & Christiansen, M. H. (2002). Reassessing working memory: A comment on Just & Carpenter (1992) and Waters & Caplan (1996). *Psychologic Review*, 109, 35–54.

Marchman, V. A. & Bates, E. (1994). Continuity in lexical and morphological development: A test of the critical mass hypothesis. Journal of Child Language, 21(2), 339-366.

Marton, K. (2008). Visuo-spatial processing and executive functions in children with specific language impairment. International Journal of Language and Communication Disorders, 43, 181-200.

Miller, C.A., Kail, R., Leonard, L.B., & Tomblin, J.B. (2001). Speed of processing in children with Specific Language Impairment. *Journal of Speech, Language and Hearing Research, 44*, 416-433.

Miller, C.A., Leonard, L.B., and Finneran, D. (2008). Grammaticality judgments in adolescents with and without language impairment. International Journal of Language and Communication Disorders 43, 343-360.

Miyake, A., Friedman, N.P., Rettinger, D.A., Shah, P., & Hegarty, M. (2001). How are visuo-spatial working memory, executive functioning and spatial abilities related? A latent-variable analysis. *Journal of Experimental Psychology General, 130*, 621-640.

Montgomery, J.W., & Evans, J.L. (2009) Complex Sentence Comprehension and Working Memory in Children With Specific Language Impairment. *Journal of Speech, Language, and Hearing Research*. 52: 269-288.

Mosse, E. K., & Jarrold, C. (2008). Hebb learning, verbal short-term memory, and the acquisition of phonological forms in children. *The Quarterly Journal of Experimental Psychology*, 61, 505-514.

Moyle, M.J., Ellis Weismer, S, Lindstrom, M., & Evans, J. (2007). Longitudinal relationships between lexical and grammatical development in typical and late talking children. *Journal of Speech, Language, and Hearing Research*, 50, 508-528

Oliver, B., Dale, P. S., & Plomin, R. (2004). Verbal and nonverbal predictors of early language problems: an analysis of twins in early childhood back to infancy. *Journal of Child Language, 31*, 609-631.

Page, M. P., Cumming, N., Norris, D., Hitch, G. J. and McNeil, A. M. (2006). Repetition learning in the immediate serial recall of visual and auditory materials. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* 32 , pp. 716-733.

Redmond, S.M. (2003). Children's productions of the affixed in past tense and past participle contexts. *Journal of Speech, Language, and Hearing Research, 46*, 1095-1109.

Shah, P., & Miyake, A. (2001). The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology: General, 125*, 4-27.

Tomblin, J.B., Mainela-Arnold, E., & Zhang, X. (2007). Procedural learning in adolescents with and without Specific Language Impairment. *Language Learning and Development, 3*, 269-293.

Torgesen, J., Wagner, R., & Rashotte, C. (1999). *Test of word reading efficiency*. San Antonio: Pro-Ed.

Ullman, M.T. & Pierpont, E.I. (2005). Specific language impairment is not specific to language: the procedural deficit hypothesis. *Cortex, 41*, 399-433.

Unsworth, N., & Engle, R.W. (2007). On the division of short-term and working memory: An examination of simple and complex spans and their relation to higher-order abilities. *Psychological Bulletin, 133*, 1038-1066.

Waters, G., & Caplan, D. (2005). The relationship between age, processing speed, working memory capacity, and language comprehension. *Memory, 13*, 403-13.

Wener, S., & Archibald, L.M.D. (In press). Domain-specific treatment effects for children with language and/or working memory impairments – A pilot study. *Child Language and Teaching Therapy*.

Woodcock, R., McGrew, K., & Mather, N. (2001). *Woodcock-Johnson Tests of Cognitive Abilities.* Itasca: Riverside Publishing.