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Individual differences in underlying cognitive correlates of reading and arithmetic in 5-year-olds

Kiran Vanbinst[1], Elsje van Bergen[2], Pol Ghesquière[1], & Bert De Smedt[1]

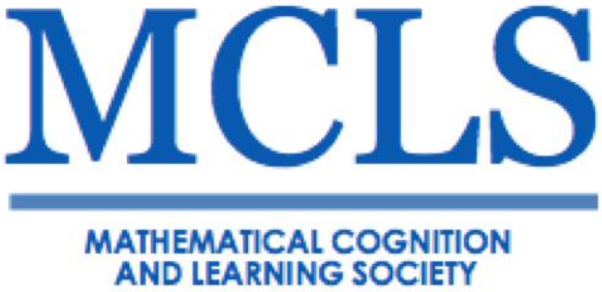
[1]*University of Leuven, Belgium*

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Introduction

- Reading and arithmetic have been investigated in relatively segregated research fields





- Cognitive/environmental/neurobiological underpinnings of individual differences
- Origins of atypical development

➔ Distinct vs. overlapping???

Behavioural overlap

- Reading - arithmetic highly correlated

- Comorbidity dyslexia - dyscalculia

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ACAMH
Journal of Child Psychology and Psychiatry 51:3 (2010), pp 287–294 doi:10.1111/j.1469-7610.2009.02164.x

Comorbidity of learning disorders: prevalence and familial transmission

Karin Landerl[1] and Kristina Moll[2]

- Even in the absence of comorbidity
  - Children with dyslcalculia ➔ lower reading abilities
  - Children with dyslexia ➔ lower arithmetic performance

Neural overlap

- Brain activity profiles of children with learning disorders are strikingly similar

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Dyscalculia and dyslexia: Different behavioral, yet similar brain activity profiles during arithmetic

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ABSTRACT

Brain disorders are often investigated in isolation, but very different conclusions might be reached when studies directly contrast multiple disorders. Here, we illustrate this in the context of specific learning disorders, such as dyscalculia and dyslexia. While children with dyscalculia show deficits in arithmetic, children with dyslexia present with reading difficulties. Furthermore, the comorbidity between dyslexia and dyscalculia is surprisingly high. Different hypotheses have been proposed on the origin of these disorders (number processing deficits in dyscalculia, phonological deficits in dyslexia) but these have never been directly contrasted in one brain imaging study. Therefore, we compared the brain activity of children with dyslexia, children with dyscalculia, children

Genetic overlap

CURRENT DIRECTIONS IN PSYCHOLOGICAL SCIENCE

Learning Abilities and Disabilities

Generalist Genes, Specialist Environments

Yulia Kovas and Robert Plomin

- Reading-arithmetic genetic correlations around .70
- Shared genetic basis lies at the basis of developing proficiency (or difficulties) in reading and arithmetic

Cognitive mechanisms underlying individual differences in reading and arithmetic might be intertwined

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Domain-*specific* cognitive correlates

- Reading

Psychological Bulletin
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Phonological Skills and Their Role in Learning to Read: A Meta-Analytic Review

Monica Melby-Lervåg and
Solveig-Alma Halaas Lyster
University of Oslo

Charles Hulme
University College London and University of Oslo

  - Phonological awareness – reading: r = .57, [.54, .59], k = 140

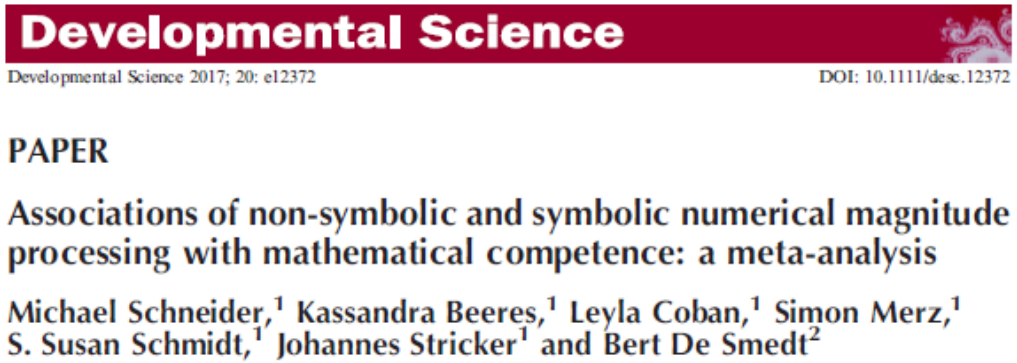
  - Phonological awareness also correlates with arithmetic

(De Smedt et al., 2010, *Dev. Sci.*; Hecht et al., 2001, *JECP*)

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Domain-*specific* cognitive correlates

- Arithmetic
  - Numerical magnitude processing (NMP)
    - Non-symbolic NMP – math: r = .24, [.19, .28], k = 195
    - Symbolic NMP – math: r = .30, [.24, .36], k = 89



Developmental Science

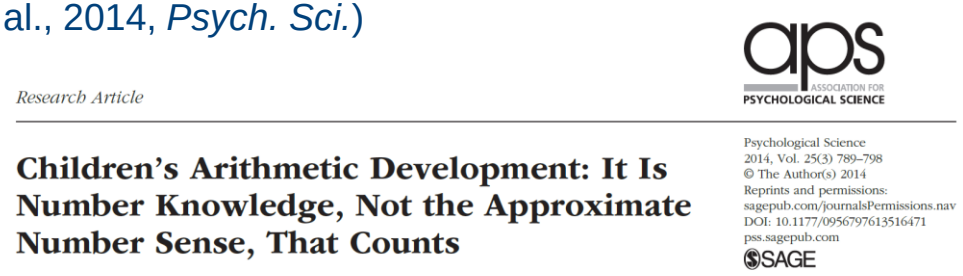
Developmental Science 2017; 20: e12372 DOI: 10.1111/desc.12372

PAPER

Associations of non-symbolic and symbolic numerical magnitude processing with mathematical competence: a meta-analysis

Michael Schneider,[1] Kassandra Beeres,[1] Leyla Coban,[1] Simon Merz,[1] S. Susan Schmidt,[1] Johannes Stricker[1] and Bert De Smedt[2]

  - Numeral knowledge (Göbel et al., 2014, *Psych. Sci.*)



Research Article

aps ASSOCIATION FOR PSYCHOLOGICAL SCIENCE

Children's Arithmetic Development: It Is Number Knowledge, Not the Approximate Number Sense, That Counts

Psychological Science
2014, Vol. 25(3) 789–798
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DOI: 10.1177/0956797613516471
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Silke M. Göbel[1], Sarah E. Watson[1], Arne Lervåg[2], and Charles Hulme[3]

Study goal

Enrich our understanding of the cognitive correlates that are shared between reading and arithmetic, rather than focusing on what sets these learning abilities apart.

- Investigating associations between reading and arithmetic before formal instruction

- Exploring whether key underlying cognitive skills of one learning ability also correlate with the other

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Participants

- 188 children (101 girls, 98 boys)
- M_{age} = 5.65 years (range: 5.08 – 6.23 years)
- Dutch native speakers
- Kindergarten (non-formal, non-compulsory)

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Measures

- Early reading
  - Active letter knowledge (Vandermosten et al. 2017, *B&L*)
  - 16 letters

- Early arithmetic
  - Addition and subtraction (Jordan et al., 2006, *Child. Dev.)*
  - 2 + 3 = ? 5 – 2 = ?
  - 8 items

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Measures

- Cognitive correlates of reading
  - Phonological awareness (de Jong et al., 2000, *JECP*)
    - End-rhyme identification
    - End-phoneme identification



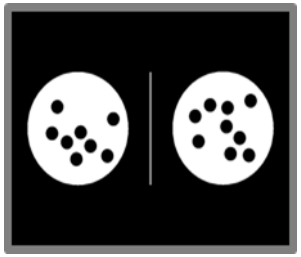
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Measures

- Cognitive correlates of arithmetic
  - Numerical magnitude processing (Schneider et al., 2017, *Dev. Science*)
    - Number comparison

Non-symbolic



Symbolic



  - Numeral recognition
    - Single-digit and multi-digit numerals (up to 5-digits)

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Measures

- Controlling variables
  - Age
  - Intellectual ability
    - Matrix reasoning (WPPSI-III NL)

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Results

Descriptive statistics

	M	*SD*	*Min*	*Max*	*Theo. Max*
Learning abilities					
Reading	6.3	4.7	0	16	16
Arithmetic	3.4	1.8	0	8	8
Cognitive correlates					
Phonological awareness	15.8	4.0	2	22	24
Non-symbolic NMP	29.0	5.0	4	36	36
Symbolic NMP	29.6	5.8	15	36	36
Numeral recognition	13.1	5.4	0	29	30
Controlling variables					
Intellectual ability	13.7	4.2	5	26	

early reading – early arithmetic

- Before the start of formal education, surprisingly large individual differences exist between kindergartners in early reading as well as early arithmetic

- These learning abilities are already connected at this early stage, indicating that they share a cognitive basis.

  r = .465***

  BF_{10} = 4.734e +8

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(Cross-over) correlations

Cognitive variables		Reading	Arithmetic
Phonological awareness	*r*	.568***	.489***
	BF_{10}	3.4×10^{14}	7.4×10^{9}
Non-symbolic NMP	*r*	.140	.264***
	BF_{10}	0.56	70
Symbolic NMP	*r*	.228**	.294***
	BF_{10}	12	374
Numeral recognition	*r*	.548***	.533***
	BF_{10}	1.7×10^{13}	2.1×10^{12}

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Regression analyses: reading

Early reading	*Beta*	*t*	*p*	BF_{incl}
Step 1				
Age	-.04	-0.56	.57	0.23
Intellectual ability	.30	4.05	< .01	288

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Regression analyses: reading

Early reading	*Beta*	*t*	*p*	BF_{incl}
Step 1				
Age	-.04	-0.56	.57	0.23
Intellectual ability	.30	4.05	< .01	288
Step 2				
Phonological awareness	.427	6.900	<.001	1462e +8
Non-symbolic NMP	-.007	-0.129	.897	0.163
Symbolic NMP	-.023	-0.361	.718	0.173
Numeral recognition	.412	6.160	<.001	1268e +7

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Controlling for overlap between early reading and early arithmetic

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Regression analyses: reading

Early reading	*Beta*	*t*	*p*	BF_{incl}
Step 1				
Age	-.04	-0.56	.57	0.23
Intellectual ability	.30	4.05	< .01	288

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Regression analyses: reading

Early reading	*Beta*	*t*	*p*	BF_{incl}
Step 1				
Age	-.04	-0.56	.57	0.23
Intellectual ability	.30	4.05	< .01	288
Step 2				
Early arithmetic	.45	6.17	< .01	2.7×10^9

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Regression analyses: reading

Early reading	*Beta*	*t*	*p*	BF_{incl}
Step 1				
Age	-.04	-0.56	.57	0.23
Intellectual ability	.30	4.05	< .01	288
Step 2				
Early arithmetic	.45	6.17	< .01	2.7×10^9
Step 3				
Phonological awareness	.40	6.90	< .01	2.7×10^9
Non-symbolic NMP	-.02	-0.13	.78	0.18
Symbolic NMP	-.03	-0.36	.68	0.19
Numeral recognition	.37	6.16	< .01	1.2×10^5

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Numeral recognition is connected to individual differences in early reading, also after controlling age, intellectual ability, phonological awareness and early arithmetic.

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Regression analyses: arithmetic

Early arithmetic	*Beta*	*t*	*p*	BF_{incl}
Step 1				
Age	.21	3.03	< .01	11.3
Intellectual ability	.37	5.53	< .01	1.4×10^5

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Regression analyses: arithmetic

Early arithmetic	*Beta*	*t*	*p*	BF_{incl}
Step 1				
Age	.21	3.03	< .01	11.3
Intellectual ability	.37	5.53	< .01	1.4×10^5
Step 2				
Phonological awareness	.261	4.157	<.001	639
Non-symbolic NMP	.075	1.277	.203	0.381
Symbolic NMP	.035	0.550	.583	0.202
Numeral recognition	.318	4.685	<.001	34922

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Knowledge of Arabic numerals before formal education seems even more important for learning arithmetic than children's understanding of numerical magnitude.

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Regression analyses: arithmetic

Early arithmetic	*Beta*	*t*	*p*	BF_{incl}
Step 1				
Age	.21	3.03	< .01	11.3
Intellectual ability	.37	5.53	< .01	1.4×10^5

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Regression analyses: arithmetic

Early arithmetic	*Beta*	*t*	*p*	BF_{incl}
Step 1				
Age	.21	3.03	< .01	11.3
Intellectual ability	.37	5.53	< .01	1.4×10^5
Step 2				
Early reading	.38	6.17	< .01	2.9×10^9

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Regression analyses: arithmetic

Early arithmetic	*Beta*	*t*	*p*	BF_{incl}
Step 1				
Age	.21	3.03	< .01	11.3
Intellectual ability	.37	5.53	< .01	1.4×10^5
Step 2				
Early reading	.38	6.17	< .01	2.9×10^9
Step 3				
Phonological awareness	.21	2.97	< .01	14
Non-symbolic NMP	.08	1.30	.20	0.43
Symbolic NMP	.04	0.60	.55	0.23
Numeral recognition	.27	3.59	< .01	385

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The *association between phonological awareness and early arithmetic already exists before formal education.

* remains significant after controlling for age, intellectual ability, non-symbolic numerical magnitude processing, symbolic numerical magnitude processing, numeral recognition and early reading ability

Conclusion and discussion

- early reading and early arithmetic are correlated before the start of formal education
- These learning abilities *share multiple* underlying cognitive correlates
  - ➔ Phonological awareness
  - ➔ Numeral recognition

- Cognitive correlates that were considered be specific to one learning domain, do not seem so domain-specific after all

Conclusion and discussion

- Unlikely that one (cognitive) factor explains everything:
  - Multiple-deficit models (Pennington, 2006, *Cogn.;* van Bergen et al., 2014, *Front. Hum. Neuro.*)

- Future work should jointly study reading and arithmetic at different levels of explanation to uncover their shared vs. distinct risk/protective factors

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