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fwo Opening new horizons

Unraveling symbolic number processing and the implications for its association with mathematics

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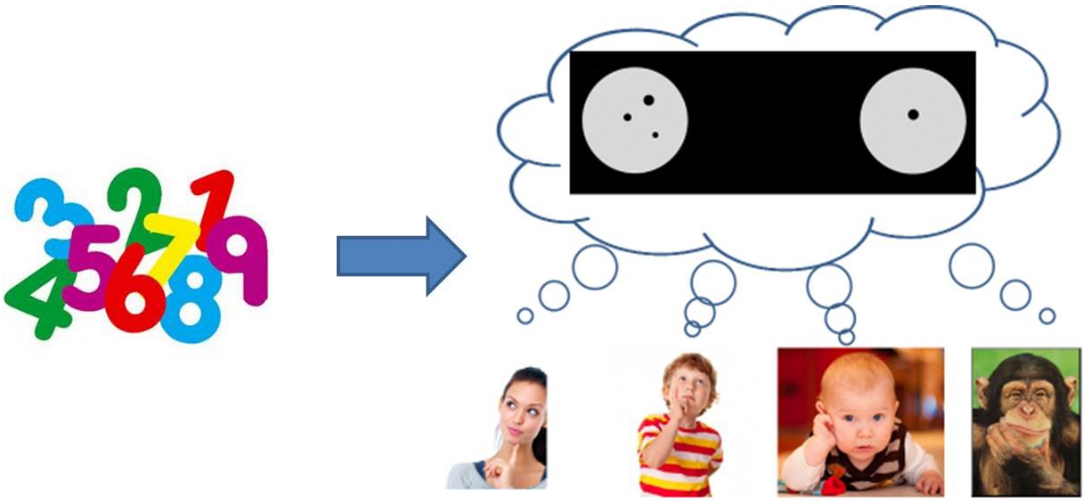
1. Introduction

Mapping hypothesis

- Innate approximate representation of number (ANS)
- Symbols are learned/acquire meaning by being ‘mapped’ onto this ANS



2. Problems with the traditional mapping account

No consistent association between ANS and symbolic number processing

- Sasanguie et al., BJDP, 2012; MBE, 2012; JECP, 2013: no association between NS and S comparison

- We tested this ANS-S association explicilty in 3rd year kindergarteners (i.e. learning symbolic numbers in Flanders)
  - ANS performance at T1 not correlated to S processing at T2
  - (ANS at T1 correlated with ANS at T2)

Sasanguie, Defever, Maertens & Reynvoet, QJEP, 2014

2. Problems with the traditional mapping account

No consistent association between ANS and symbolic number processing

- In older children: relation ANS and calculation skills relying on symbolic processing

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Not consistent!

- Review De Smedt et al., 2013
- Meta-analyses Chen et al., 2013; Fazio et al., 2014; Schneider et al., 2015

→ Association ANS and math is robust, but effect size of association between symbolic processing and math is larger!

←→ ANS as ground for symbol acquisition

2. Problems with the traditional mapping account

Experimental manipulations showing dissociations between non-symbolic and symbolic processing

Sasanguie, De Smedt & Reynvoet, Psychological Research, 2015

- Experiment 1: N = 34 (M_{age} = 21.59 years; SD = 3.63; 26 females)
- audiovisual matching -> is there a match between what you hear and see?
- Stimuli: same trials (4-4), different trials with two ratios: easy (2-4; 5-9) and difficult (3-4;7-9)

(a) digit-number word matching task (b) dots-number word matching task (c) digit-tones matching task (d) dots-tones matching taks

(a) color-color word matching task (b) letter-speech sound matching task

2. Problems with the traditional mapping account

Experimental manipulations showing dissociations between non-symbolic and symbolic processing

Sasanguie et al., Psychological Research, 2015

- Hypotheses:

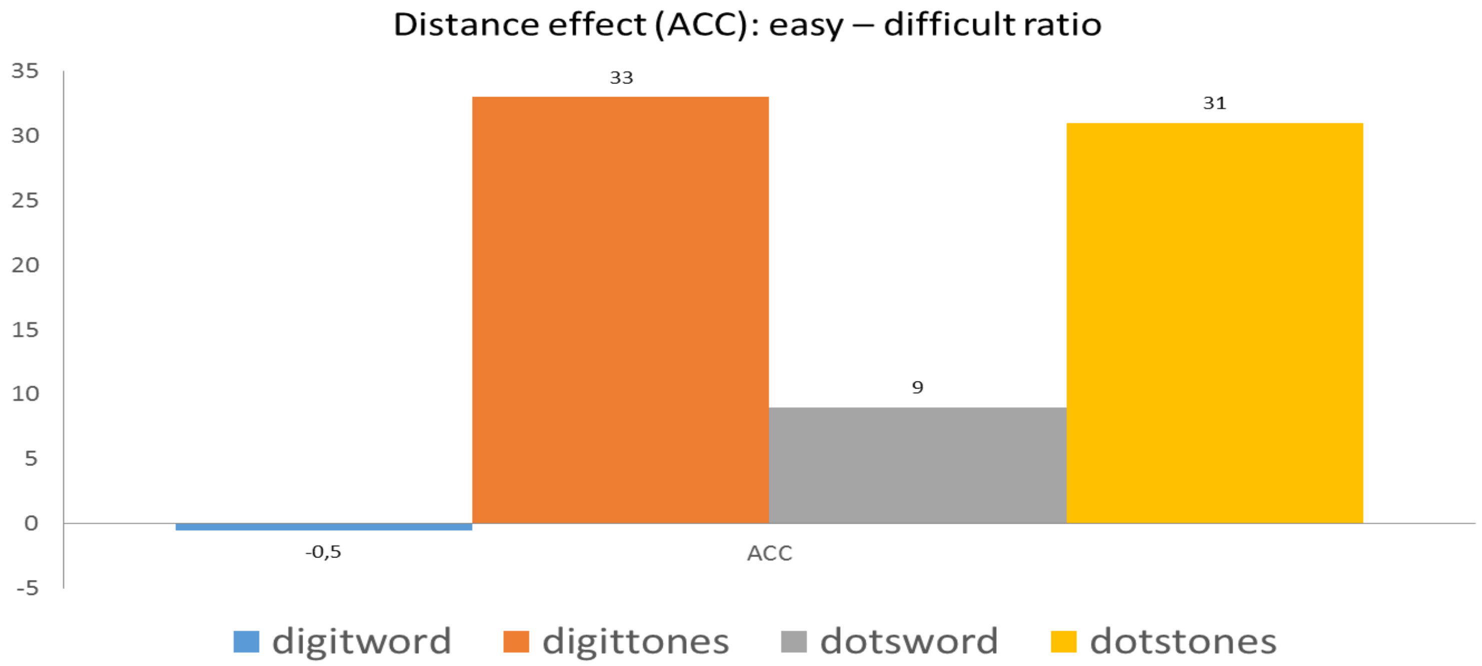
If there is indeed one abstract magnitude representation system,

1) All tasks should show a ratio effect (~ address that system)
2) Performances on all tasks should be correlated

2. Problems with the traditional mapping account

Experimental manipulations showing dissociations between non-symbolic and symbolic processing

Sasanguie et al., Psychological Research, 2015



2. Problems with the traditional mapping account

Experimental manipulations showing dissociations between non-symbolic and symbolic processing

Sasanguie et al., Psychological Research, 2015

Partial correlations between the mean accuracies on the audio-visual matching tasks, controlled for general matching ability (mean accuracy on the color-color word matching task)

	Digit-number word matching	Dots-number word matching	Digit-tones matching	Dots-tones matching
Letter-speech sound matching	.44*	.22	.16	.09
Digit-number word matching		.16	.06	.04
Dots-number word matching			.40*	.35*
Digit-tones matching				.36*

$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$

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2. Problems with the traditional mapping account

Experimental manipulations showing dissociations between non-symbolic and symbolic processing

Sasanguie et al., Psychological Research, 2015

- No ratio effect in pure symbolic tasks -> no overlapping representations
- Correlations confirmed the dissociation between pure symbolic tasks and non-symbolic or mixed format tasks

- But…is the task conducted semantically? Or phonologically?

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2. Problems with the traditional mapping account

Experimental manipulations showing dissociations between non-symbolic and symbolic processing

Sasanguie et al., Psychological Research, 2015

- Experiment 2: N = 23 (M_{age} = 25.48 years; SD = 2.56; 17 females)
- audiovisual matching + go-nogo instruction (e.g. if the numbers are smaller or equal to 4, math visual and auditory stimulus)
- Stimuli: same trials (4-4), different trials with two ratios: easy (2-4; 5-9) and difficult (3-4;7-9)

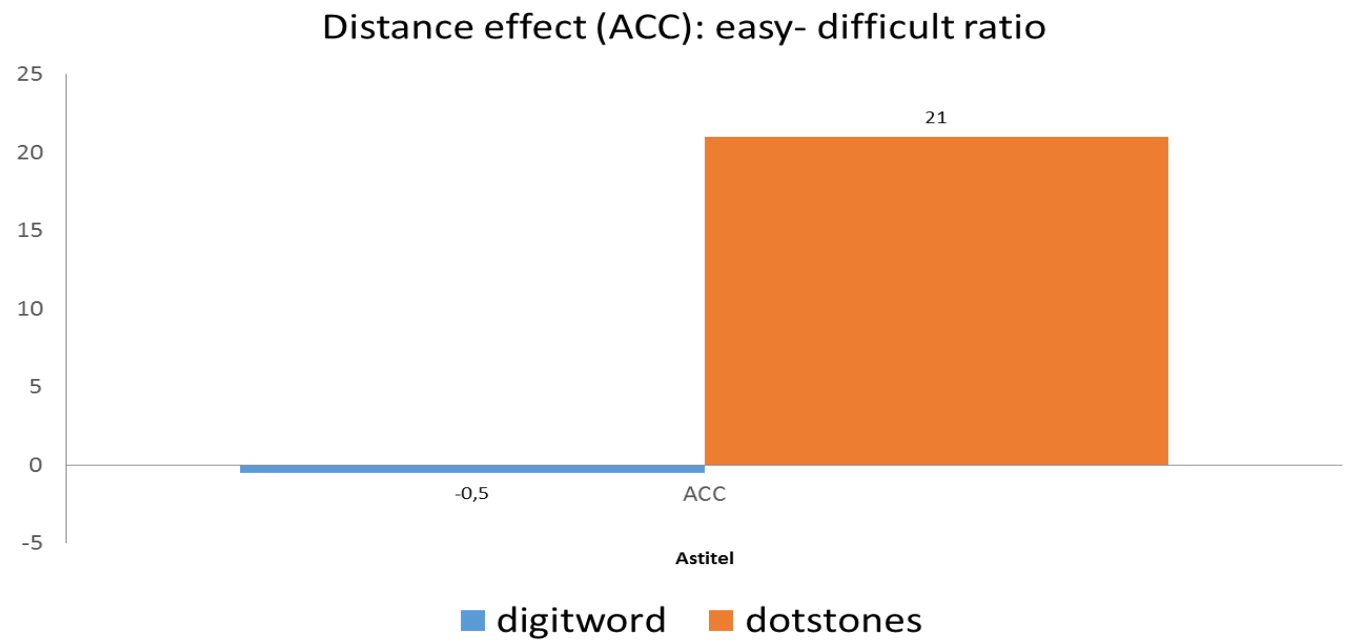
(a) digit-number word matching task

(d) dots-tones matching taks

2. Problems with the traditional mapping account

Experimental manipulations showing dissociations between non-symbolic and symbolic processing

Sasanguie et al., Psychological Research, 2015



2. Problems with the traditional mapping account

Experimental manipulations showing dissociations between non-symbolic and symbolic processing

Sasanguie et al., Psychological Research, 2015

- No distance effect in pure symbolic tasks, also not when task requires semantics
- Different representations for symbolic and non-symbolic number

←→ ANS as ground for symbol acquisition

←→ one abstract magnitude representation

3. Unraveling symbolic number processing

Sasanguie, Lyons, De Smedt & Reynvoet, in preparation

Fast digit identification

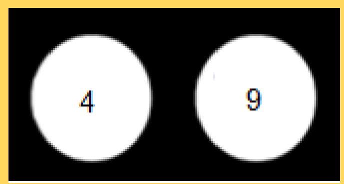
"4 is a digit"

e.g. Cirino, 2011

Audiovisual matching

"4 matches with /four/"

e.g. Purpura, Baroody & Lonigan, 2013; Sasanguie & Reynvoet, 2014



Digit order knowledge

"4 comes after 3 and before 5"

e.g. Lyons & Beilock, 2009

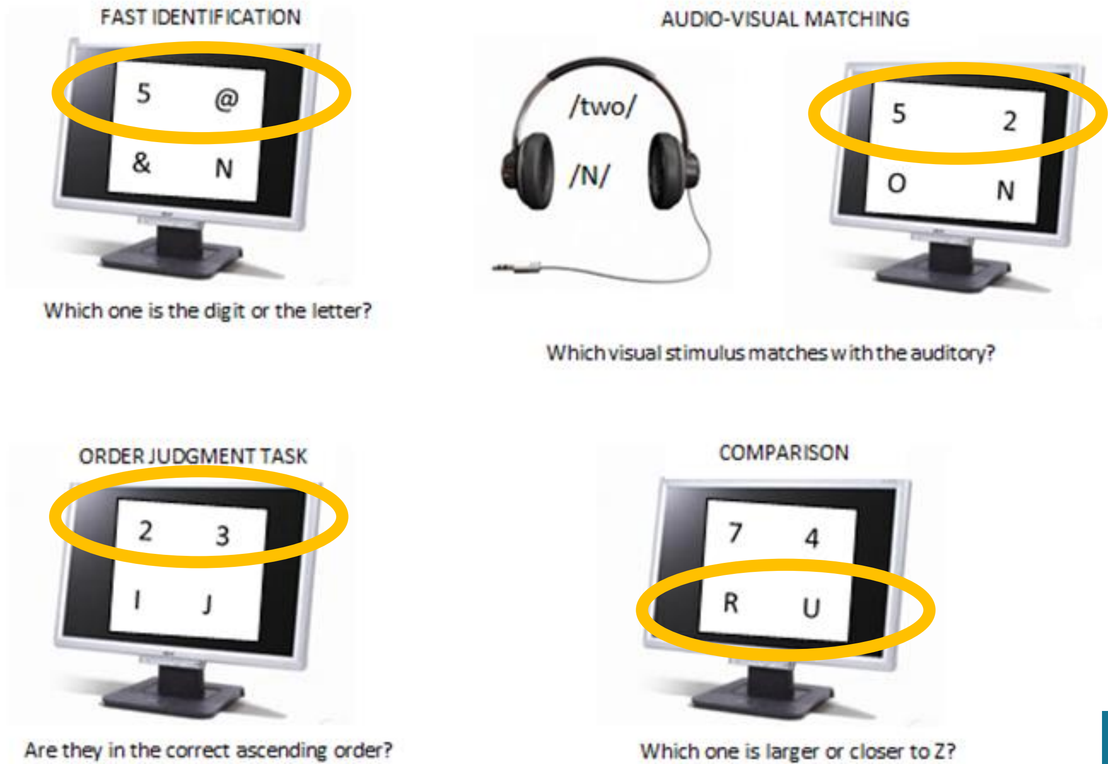
Digit comparison

"4 is smaller/less than 9"

3. Unraveling symbolic number processing

Sasanguie et al., in prep

- N = 60 (M_{age} = 20.43 years; SD = 2.73; 50 females)
- Timed arithmetic test
- Four experimental tasks with in numerical (digits) and non-numerical (letters) condition



3. Unraveling symbolic number processing

- Relations with digit comparison

Table 2. *Zero-order correlations among the experimental tasks*

		1	2	3	4	5
1	Arithmetic	1				
2	Digit identification	-.01	1			
3	Digit audiovisual matching	-.04	.43**	1		
4	Digit order judgment	-.44**	.20	.26*	1	
5	Digit comparison	-.39**	.41**	.33**	.51**	1
6	Letter comparison	-.37**	.08	.14	.42**	.35**

*$p < .05$; **$p < .01$

3. Unraveling symbolic number processing

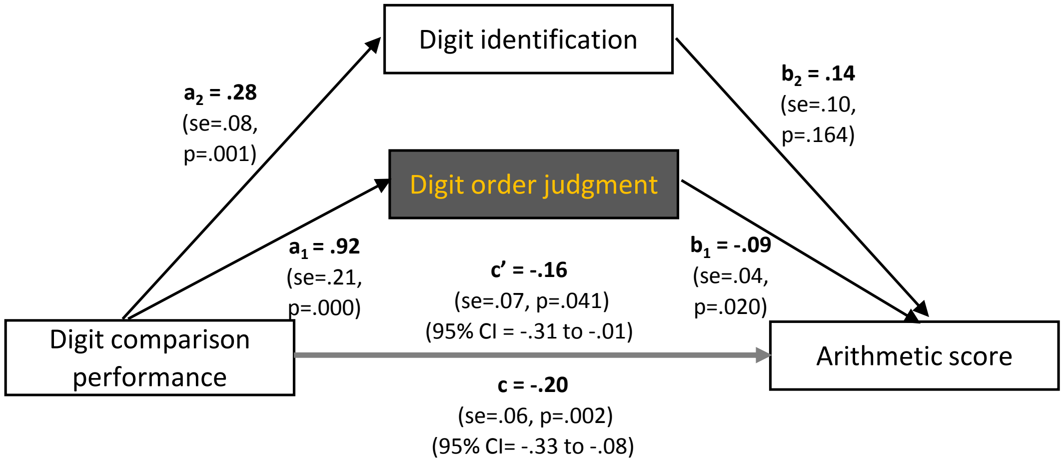
- Relations with digit comparison

Table 3. *Multiple regression analysis with the three digit tasks and letter comparison as predictors and digit comparison as dependent variable.*

	Standardized β	t	p
Digit identification	.291	2.487	.016
Digit audiovisual matching	.091	.768	.446
Digit order judgment	.359	3.006	.004
Letter comparison	.163	1.407	.165
$F(4,55) = 8.851$, $p < .0001$, $R^2 = .391$			

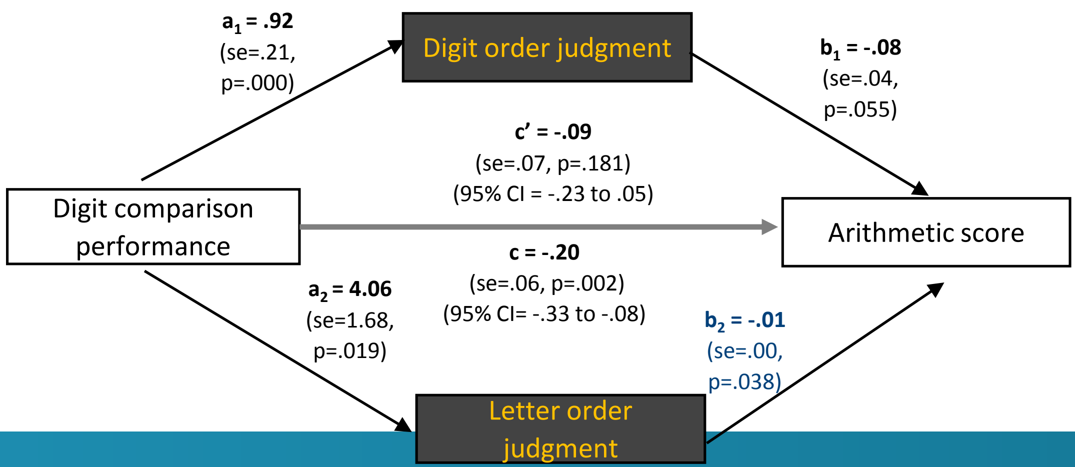
3. Unraveling symbolic number processing

- Accounting for the relation between digit comparison and arithmetic



ab path digit identification:
bootstrap point estimate = .038; *SE*= .03;
95% CI= -.010 to .110; *p* = .206.

ab path digit order judgment:
bootstrap point estimate = -.085; *SE*= .04;
95% CI= -.176 to -.013; *p* = .037.

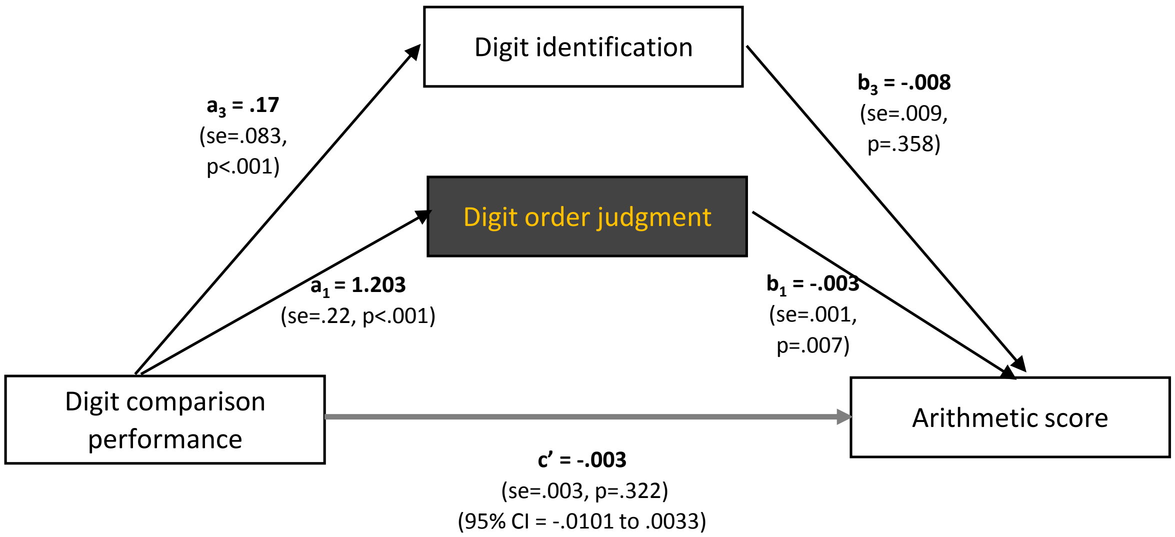


ab path digit order judgment:
bootstrap point estimate = -.069; SE= .04;
95% CI= -.162 to -.005; p = .078

ab path letter order judgment:
bootstrap point estimate = -,040; SE= .03;
95% CI: -.107 to -.0001; p = .127

3. Unraveling symbolic number processing

- **<u>Children</u>:** N = 104 (M_{age} = 7,43 years; *SD* = 0,31; 62 boys)



ab path digit identification:
bootstrap point estimate = -.0014; *SE*= .0016; *95% CI*= -.0044 to .0019.

ab path digit order judgment:
bootstrap point estimate = -.0041; *SE*= .0018; *95% CI*= -.0088 to -.0015.

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3. Unraveling symbolic number processing

Sasanguie et al., in prep

- Possible explanation for different results:
  - In adults:
    - Digit order: already ‘over-learned’ (~accessing and activating existing ordinal representations)
    - Letter order: reflects control processes in working memory on order (cf. operations on the serial position) e.g. say the alphabet starting from k backwards
  - In children:
    - Digit order still in learning phase, so here also reflection of control processes in working memory on order

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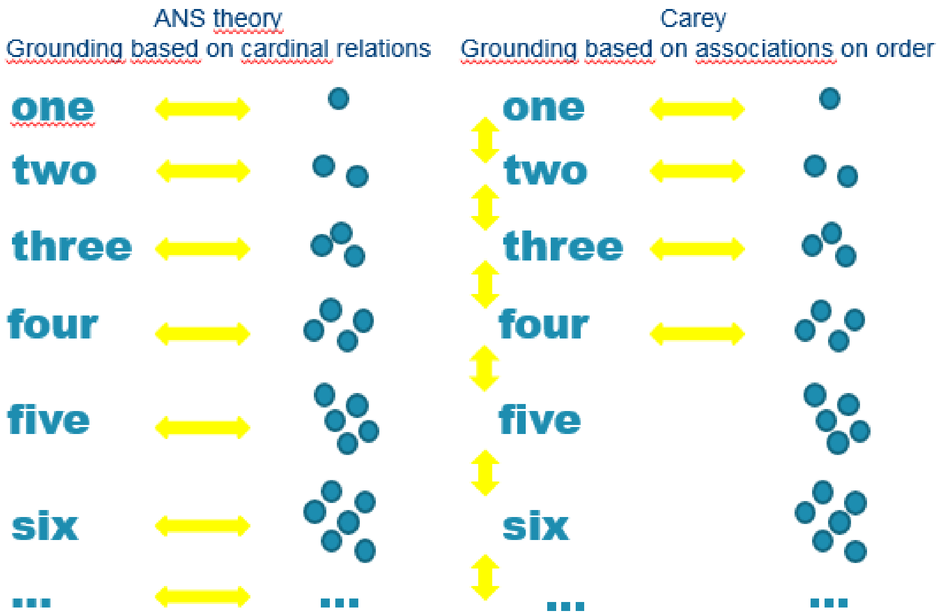
Follow-up study including serial order WM task

4. Ordinality vs cardinality

- Alternative for the mapping account by Carey (2001)
  - initially symbols are associated with set sizes of which number can be extracted without counting (subitizing)
  - On the basis of these associations, principles are learned like successor principle (i.e. next number is 1 more) and order relations



Implications

- Important for
  - Formal math instructions
  - Informal numeracy activities
  - Prevention for at-risk children
  - Remediating children with math difficulties

- Concrete:
  - Early focus on counting sequence
  - Insight in ordinal relations (e.g. also proportions)
  - Effectiveness? ➔ future research

➔ Need for longitudinal and intervention studies!

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4. Link with home numeracy and calculation

Mutaf, Sasanguie, De Smedt & Reynvoet, submitted

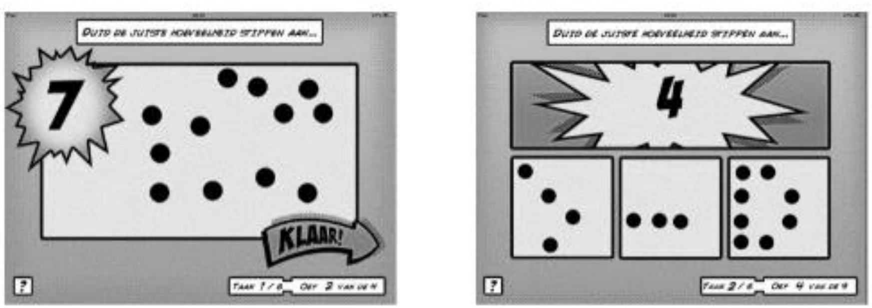
- Association between home numeracy and math achievement inconclusive so far
  - LeFevre and colleagues: formal (direct) ←→ informal (indirect) home numeracy activities
  - Use of composite scores of mathematical batteries, including a variety of skills (also basic number processing skills)
  - Our study:
    - Formal and informal home numeracy skills
    - Basic number processing
    - Calculation

4. Link with home numeracy and calculation

Mutaf, Sasanguie, De Smedt & Reynvoet, submitted

- 3rd year kindergartners (N= 128 children; M_{age} = 5.43 years)
- Dutch translation of HN questionnaire (LeFevre et al., 2009)
- S and NS comparison tasks + number line estimation tasks
- Mapping tasks: enumeration and connecting tasks

Enumeration task　　　　Connecting task



- Calculation: 2 subtests Tedimath (pictorially calculation and simple addition)

4. Link with home numeracy and calculation

Mutaf, Sasanguie, De Smedt & Reynvoet, submitted

Hypotheses:

- home numeracy related to symbolic number processing and to mapping skills, not to non-symbolic number processing

- basic number processing skills related to calculation skills

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- home numeracy would be associated with calculation skills through the effects of symbolic and mapping skills

4. Link with home numeracy and calculation

Mutaf, Sasanguie, De Smedt & Reynvoet, submitted

- Principal Components Analysis (PCA) on home numeracy questionnaire items
- PCA on basic number processing tasks
- Correlations
- Mediation analysis

Factor loadings and mean reported frequencies of home numeracy activities.

Items	Number practices	Number books	Games	Applications	*M*	*SD*
Identifying names of written numerals	.81				3.01	1.18
Counting objects	.73			.35	3.60	1.17
Sorting things by size, color or shape	.58			.34	2.43	1.13
Learning simple sums	.69				2.63	1.2
Writing numbers	.63	.49			2.43	1.2
Using number flashcards		.60			1.66	.93
Doing 'connect the dot' activities		.71			1.76	.83
Using number activity books		.65			2.14	.97
Reading number story books		.70			1.74	.95
Playing card games			.87		2.33	1.06
Playing board games with die or spinner			.75		2.47	.97
Talking about money when shopping				.61	2.36	1.03
Measuring ingredient while cooking				.60	1.93	.98
Being timed				.71	3.67	1.32
Collecting objects	.34			.63	2.63	1.31
Using calendars and dates				.55	2.95	1.5

Note. Factor loadings < .3 are not displayed

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4. Link with home numeracy and calculation

Mutaf, Sasanguie, De Smedt & Reynvoet, submitted

Factor loadings of children's basic number processing skills.

Measures	Number Line Estimation	Comparison	Mapping
Symbolic NLE	.87		
Non-symbolic NLE	.89		
Symbolic Comparison		.59	
Non-symbolic Comparison		.91	
Enumeration			.69
Connecting			.91

Note. Factor loadings < .3 are not displayed

4. Link with home numeracy and calculation

Mutaf, Sasanguie, De Smedt & Reynvoet, submitted

Correlations among the home numeracy activities, children's basic number processing and calculation skills.

Variables	1	2	3	4	5	6	7	8
1. Number practices	-							
2. Number books	.47**	-						
3. Games	.15	.35**	-					
4. Applications	.40**	.25**	.24**	-				
5. Number line estimation	-.18*	-.06	-.01	.16	-			
6. Comparison	.04	-.06	-.00	.03	-.16	-		
7. Mapping	.21*	.12	.16	.07	-.19*	.28**	-	
8. Calculation	-.02	-.02	.14	.01	-.12	.38**	.33**	-

* p <.05, ** p <.01

4. Link with home numeracy and calculation

Mutaf, Sasanguie, De Smedt & Reynvoet, submitted

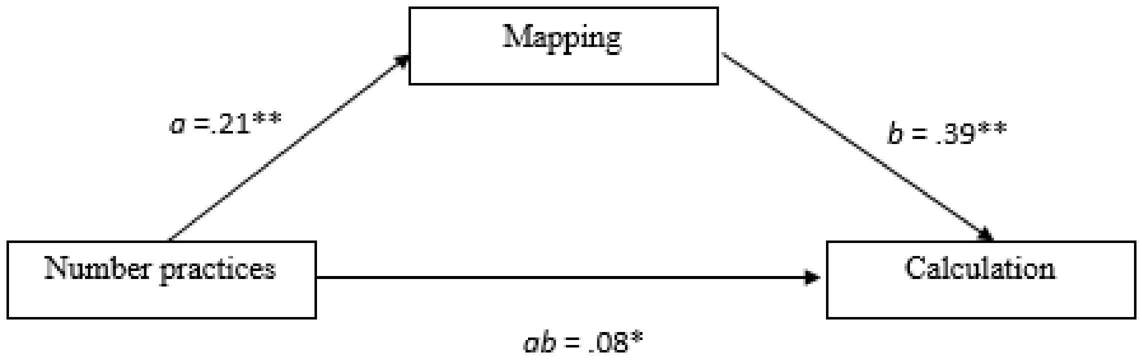

Figure. 2. The mediation model with Number Practices as the predictor variable, Mapping as the mediator, and Calculation as the outcome variable. Path *a* represents the effect of number practices on mapping, path *b* represents the effect of mapping on calculation in children, and path *ab* represents the indirect effect of number practices on calculation through mapping. The paths are quantified as the standardized regression coefficients.

4. Link with home numeracy and calculation

Mutaf, Sasanguie, De Smedt & Reynvoet, submitted

- In line with longitudinal findings (Manolitsis et al., 2013): frequency of formal HN activities in kindergarten predicted math fluency in 1st grade through verbal counting

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- Extra analysis: only enumeration (*r* = .20, *p* = .03), but not connecting (*r* = .15, *p* = .09) was related to number practices

- 5 year olds: use of fingers for counting (e.g. Geary et al., 2000) ~ similar requirement in enumeration task

➔ counting abilities are most affected by formal home numeracy activities (i.e. number practices), which in turn affect the calculation skills.

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Conclusion

➔ Ordinal relations

= the answer to the symbol grounding problem?

= very important for calculation performance!

Thank you for listening!

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