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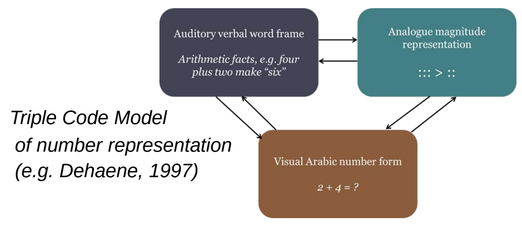
Relationships between paired associate learning (PAL) performance and arithmetic skills in primary-aged children

Lorna G. Hamilton & Sophie Brigstocke
York St John University / University of York

Background

- Foundational numeracy skills at school entry strongly predict later educational attainment (Duncan et al., 2007).
- Children vary widely in arithmetic skills from the earliest stages of education; individual differences are predicted by domain-specific and domain-general cognitive skills (LeFevre et al., 2010).
- Longitudinal work suggests that verbal-symbolic processes , which allow children to learn the verbal labels associated with Arabic numerals, constrain the development of arithmetic (Göbel, Watson, Lervåg, & Hulme, 2014).
- Paired associate learning (PAL) paradigms mimic the creation of mappings between different units (e.g. phonological, visual) thought to underpin the development of complex competencies such as reading and arithmetic.



Triple Code Model of number representation (e.g. Dehaene, 1997)

- PAL paradigms with verbal output are uniquely related to reading ability in children (Litt, de Jong, van Bergen, & Nation, 2013).
- The current pilot study aimed to assess children's ability to learn associations between stimuli simulating verbal, symbolic and non-verbal representations of number (Dehaene, 1997).
- If verbal learning mechanisms are particularly important for arithmetic development (as with reading), performance on PAL tasks requiring verbal output should correlate more strongly with tests of arithmetic skill than PAL tasks with visual output (Göbel et al., 2014; Litt et al., 2013).

Method

PAL tasks: presented in E-prime

Task	Input (*displayed on screen*)	Output (*drawn or spoken*)
Dots → Symbol		
Dots → Non-word		*"gleb"*
Symbol → Non-word		*"frell"*

Learning Block 1: children see/ hear five pairs of stimuli for five seconds each and repeat the output stimulus (drawn or spoken).
Learning Block 2: children see/ hear each pair of stimuli again in randomised order and concentrate on learning which pairs go together.
Test Blocks: 5 blocks of 5 trials. Children see the input stimulus and produce the output stimulus (drawn or spoken). Feedback is given on each trial.

Quantity stimuli (arrays of dots) were piloted for discriminability and non-countability:

Dots-symbol task: sets of 15, 25, 35, 65 &125
Dots-nonwords task: sets of 20, 30, 40, 70 & 130

Each quantity was displayed in one configuration only.

Method contd.

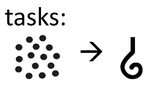
Participants and Procedure:
40 children (22 girls) recruited from a single primary school serving a mixed-SES area (10 children each from Years 3, 4, 5 and 6; mean age: 9 years, 3 months (s.d. 13.33 months)).

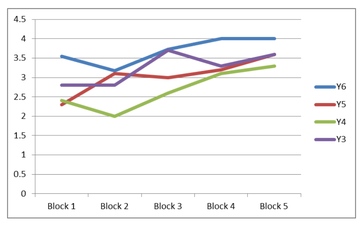
Procedure: Children completed two test batteries separated by 3 to 7 days, comprising 3 PAL tasks (counter-balanced) and standardised tests of arithmetic and basic numeracy:

TOBANS Dot Comparison
TOBANS Dot Counting
TOBANS One-Minute Arithmetic Composite
WIAT Numerical Operations

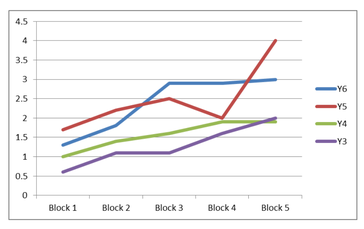
Results

Learning across 5 blocks in 3 PAL tasks:

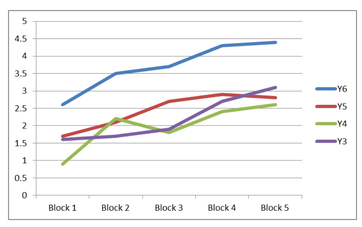
1. Dots → Symbols (DS) 



2. Dots → Non-words (DW)  → *"gleb"*



3. Symbols → Non-words  → *"frell"*



Partial correlations between PAL performance (total correct across 5 blocks) and basic numeracy/ arithmetic skills, controlling for age (N=40)

	1. PAL DS	2. PAL DW	3. PAL SW	4. Dot Comparison	5. Counting	6. Arith-metic⁺
1		.26	.42**	.07	.04	.01
2			.60***	.23	.28	.48**
3				.23	.32	.45**
4					.56***	.53**
5						.73***
6						

⁺*z-scores composite of WIAT Num Ops and TOBANS timed arithmetic*
* *P* < .05; ** *p* < .01; *** *p* < .001

PAL performance as a predictor of arithmetic

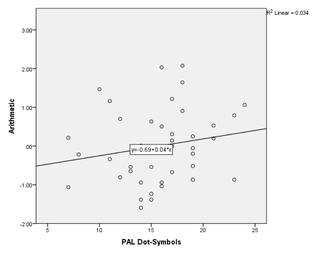
Three hierarchical regressions, predicting arithmetic:

Step 1: child age
Step 2: dot comparison; dot counting
Step 3: PAL task

Taken together, steps 1 and 2 explain 71% of the variance in children's arithmetic skills ($F(1, 38) = 28.770$, $p < .001$; $R^2 = .706$). Age and counting, but not dot comparison, were significant unique predictors.

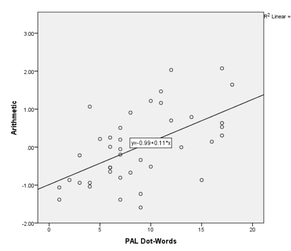
Results contd.

Model 1: dots - symbols PAL



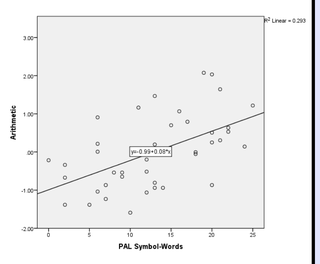
$(F, 1,39) = 20.98$, $p < .001$
Total $R^2 = .706$
PAL DS: $\beta = .00$, $p = .976$
$\Delta R^2 = .000$

Model 2: dots - non-words PAL



$(F, 1,39) = 25.328$, $p < .001$
Total $R^2 = .743$
PAL DW: $\beta = .22$, $p = .030$
$\Delta R^2 = .038$

Model 3: symbols – words PAL



$(F, 1,39) = 24.444$, $p < .001$
Total $R^2 = .736$
PAL SW: $\beta = .197$, $p = .051$
$\Delta R^2 = .031$

The two PAL tasks requiring verbal output explain a small amount of additional variance in arithmetic, after age, dot comparison and counting are controlled.

Conclusions and Next Steps

- Children in all year groups showed learning across the five test blocks in each PAL task.
- Initial performance was poorer, and learning slopes steeper, in the two PAL tasks requiring verbal output (dots – non-words / symbols – non-words) than in the task requiring a drawn (visual) output (dots – symbols).
- Overall verbal-output PAL performance was moderately correlated with children's arithmetic skill, whereas visual-output PAL was not associated with arithmetic skill.
- Taken together, children's age, dot comparison and counting efficiency accounted for 71% of the variance in arithmetic ability. However, dot comparison was not a significant predictor.
- Verbal-output PAL explained a small amount of additional variance in arithmetic (3 – 4%) after controlling for age and numerical predictors.
- The findings of this pilot study suggest that the ability to learn verbal labels for novel stimuli (here arrays of dots or visual symbols) is associated with arithmetic skill, as is the case with reading (Litt et al., 2013).
- It is not clear from the findings whether the ability to learn verbal labels for *quantities* is particularly important for arithmetic development.
- The arrays of dots used here were presented in one configuration only, and so it is possible that children used pattern cues to associate the dot arrays with output stimuli (rather than estimating quantity). In a follow-up study, two alternative arrays of dots for each quantity will be used in order to control for pattern learning.

Further information

Email: l.hamilton1@yorksj.ac.uk

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Acknowledgments

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