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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, with individual differences being 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, Lerdelåg, & Holme, 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.
- PAL paradigms with verbal output are uniquely related to reading ability in children (Lit, 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; Lit et al., 2013).
- PAL paradigms with verbal output are uniquely related to reading ability in children (Lit, de Jong, van Bergen, & Nation, 2013).

Method
- PAL tasks: presented in E-prime
- 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
- Partial correlations between PAL performance (total correct across 5 blocks) and basic numeracy/ arithmetic skills, controlling for age (N=40)

Results
- 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, 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.
- 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.
- 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 (Lit 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 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.

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 – 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.
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References

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