Linking Executive Functions and Math Intelligence in Preschool Children: A Meta-Analysis

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Background

What we know

- EFs are linked to broader math skills (any math test)
- EF subdimensions differ in their relation to broad math skills
- in both school students and adults
  - E.g., Friso-van den Bos et al., 2013; Peng et al., 2016

What is still debated

- What is the relation between EFs and (narrow) math intelligence?
- How strong is this relation in preschool children?
- Do EFs subdimensions differ?
- Preschool children can’t read → how does assessment influence this link?
Research Questions 1 & 2

RQ 1: Overall correlations
- All EFs
  - Inhibition
  - Shifting
  - Updating

RQ 2: Moderator effects
- Study
- Sample
- EF measurement
- Math intelligence measurement
RQ 3: Model Testing

- To what extent do the three subdimensions of EFs (i.e., inhibition, shifting, updating) differ in their ability to explain variation in math intelligence?
- How much variation do they explain jointly?
RQ 3: Model Testing

- To what extent do the three subdimensions of EFs (i.e., inhibition, shifting, updating) differ in their ability to explain variation in math intelligence?
- How much variation do they explain jointly?

Model 1

Inhibition → $\beta_{\text{IN}}$ → MATH
Updating → $\beta_{\text{UP}}$ → MATH
Shifting → $\beta_{\text{SH}}$ → MATH

Model 2

Inhibition → $\beta$ → MATH
Updating → $\beta$ → MATH
Shifting → $\beta$ → MATH

Model 3

Inhibition → $\lambda_{\text{IN}}$ → EF
Updating → $\lambda_{\text{UP}}$ → EF
Shifting → $\lambda_{\text{SH}}$ → EF

EF → $\beta_{\text{EF}}$ → MATH
Literature Search

- English, published 2000 or later
- Preschool children (0 - 6:11)
- No medical condition
- Report an effect size of at least one EF and one kind of math intelligence

- Screened: 4034 titles/abstracts
- Screened: 191 full texts
- Included: 29 studies

- Agreement: $\kappa = 93\%$ to $\kappa = 98\%$
Included Data

- Three-level meta-analysis
- 29 studies
- 268 effect sizes
  - 120 inhibition
  - 60 shifting
  - 78 updating
- 25,510 preschool children
Methods

- Inter-coder agreement between $\kappa = 93\%$ to $\kappa = 98\%$

- RQ 1: Overall correlation
  - Random-effects three-level meta-analysis
  - 4 meta-analyses: 1) overall, 2) inhibition, 3) shifting, 4) updating
  - metafor (Viechtbauer, 2010) & metaSEM (Cheung, 2015)

- RQ 2: Moderator effects
  1. Study (e.g., publication year)
  2. Sample (e.g., age)
  3. Measurement (e.g., tasks used to test EFs)

- RQ 3: Model Testing
  - Correlation-based meta-analytic structural equation modelling (MASEM)
  - One-stage (Cheung & Cheung, 2016) and two-stage MASEM (Jak & Cheung, 2020)
Mean correlation with math intelligence in preschool children:

<table>
<thead>
<tr>
<th>EFs</th>
<th>Correlation</th>
<th>95% CI</th>
<th>Effect sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>All EFs</td>
<td>$\bar{r} = .35$</td>
<td>[.31, .39]</td>
<td>$k = 268$</td>
</tr>
<tr>
<td>Inhibition</td>
<td>$\bar{r} = .30$</td>
<td>[.34, .42]</td>
<td>$k = 120$</td>
</tr>
<tr>
<td>Shifting</td>
<td>$\bar{r} = .38$</td>
<td>[.24, .36]</td>
<td>$k = 60$</td>
</tr>
<tr>
<td>Updating</td>
<td>$\bar{r} = .36$</td>
<td>[.31, .44]</td>
<td>$k = 78$</td>
</tr>
</tbody>
</table>

Nonsignificant differences between EFs
Descriptive Results – Measurement moderators

- Most frequently used tasks:
  - Stroop-like tasks \((k = 66 \text{ of } 120)\) to measure inhibition
  - Dimensional change tasks \((k = 46 \text{ of } 60)\) to measure shifting
  - Difficult span tasks \((k = 28 \text{ of } 78)\) to measure updating

- Administration of EF measures (total \(k = 268\))
  - verbally \((k = 96)\)
  - apparatus-based \((k = 75)\)
  - computer-based \((k = 48)\)
  - paper-and-pencil \((k = 5)\)

- Math intelligence measures
  - predominantly administered **verbally** \((k = 222; 83\%)\)
RQ 2: Moderator Effects

1. **Continent**: Larger effect for American samples

2. **EF Subdimension**: Order of effects,
   - Inhibition < Shifting = Updating

3. **EF task type**:
   - Largest effects for Composite, Tap (inhibition), Simon (inhibition), Random generation (updating), and Difficult span (updating) tasks

4. **Mode of math intelligence testing**:
   - Largest effects for verbal and behavioral testing

5. **Reliability of math intelligence measures**:
   - Measures with greater reliability showed closer link to EFs
RQ 3: Model Testing

- **Model 1**
  - inhibition \((\beta_{\text{inhibition}} = 0.16, 95 \% \text{ CI } [0.07, 0.24])\)
  - shifting \((\beta_{\text{shifting}} = 0.27, 95 \% \text{ CI } [0.19, 0.35])\)
  - updating \((\beta_{\text{updating}} = 0.27, 95 \% \text{ CI } [0.20, 0.34])\)
  - residual variance \(\sigma^2_e = 0.75 (95 \% \text{ CI } [0.69, 0.80])\)
  - Explained math intelligence variance: 25 %

- **Model 2** (equal regression coefficients for EFs)
  - overall regression coefficient \(\beta = 0.23 (95 \% \text{ CI } [0.21, 0.26])\)
  - residual variance \(\sigma^2_e = 0.75 (95 \% \text{ CI } [0.69, 0.80])\)
  - Explained math intelligence variance: 25 %

- **Model 3** (EFs as one latent variable)
  - inhibition \((\lambda_{\text{inhibition}} = 0.49, 95 \% \text{ CI } [0.41, 0.57])\)
  - shifting \((\lambda_{\text{shifting}} = 0.53, 95 \% \text{ CI } [0.45, 0.61])\)
  - updating \((\lambda_{\text{updating}} = 0.53, 95 \% \text{ CI } [0.45, 0.60])\)
  - overall regression coefficient \(\beta = 0.70 (95 \% \text{ CI } [0.62, 0.79])\)
  - residual variance was \(\sigma^2_e = 0.51 (95 \% \text{ CI } [0.37, 0.62])\)
  - Explained math intelligence variance: 49 %  → One latent variable better than distinct variables
**Limitations**

- **Limited to preschool children** (without medical condition or disorder)
  - **Why:** Generalizability to the general public (e.g., Kingdon et al., 2016)
  - Not generalizable over other age groups or with medical conditions

- **WEIRD sample**
  - **Why:** ~74% of all effect sizes from US samples
  - Further evidence from other countries is needed

- **Small study pool**
  - **Why:** Strict exclusion criteria & lack of reporting
  - Not all moderators of interest could be investigated

- **Pragmatic categorization of EF task types**
  - **Why:** Large variety of possible categorizations (e.g., Garon et al., 2008)
  - Might lead to divergent findings to other meta-analyses
Discussion & Conclusion

- Overall correlations are similar to previous meta-analyses
  - Indicate relation, but not redundancy of EFs and math intelligence

- Age was not a significant moderator. However:
  - Trend over the previous meta-analyses,
  - Decreasing relations between math intelligence and inhibition and shifting with age.

- Moderators showed importance of task choice and psychometric quality when measuring EFs and math intelligence

- MASEM could not confirm the three core EFs to be differentially related to math intelligence
Conclusion

EF moderators:
- Task type
- Subdimension

Math moderators:
- Reliability
- Verbal / behavioral mode of testing

$r = .35$
<table>
<thead>
<tr>
<th>1) Are EFs and math intelligence related?</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Yes, EFs, as a composite as well as three subdimensions, are positively and significantly related to math intelligence in preschool children.</td>
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<tr>
<td>2) What does this imply?</td>
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<tr>
<td>• It implies an overlap in some skills and measures and, ultimately, the involvement of EFs in solving math intelligence tasks and vice versa.</td>
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<td>3) Does this mean, we should only measure one of the two skills?</td>
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<td>------------------------------------------</td>
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<tr>
<td>• No, the evidence presented does not suggest that assessing one of the two constructs may make assessment of the other redundant.</td>
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<td>4) Does the measurement of EFs and math intelligence influence their relation?</td>
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<td>------------------------------------------</td>
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<tr>
<td>• Yes, measurement characteristics explained more variance than sample or study characteristics, showing the importance of considering the psychometric quality of both EFs and math intelligence assessments (e.g., reliability &amp; appropriateness).</td>
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<td>5) Are EFs best represented by three distinct EFs or with one latent variable?</td>
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<td>------------------------------------------</td>
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<tr>
<td>• Representing EFs with a latent variable (capturing their covariance) explained substantially more variance in math intelligence in preschool children.</td>
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References


University of Luxembourg

Thank you!
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