Spatial Biases in Arithmetic: The Effect of Operation Order and Visual Spacing on Calculations

Michał Obidziński[1*], Martyna Sroka[1], Krzysztof Cipora[1,2], & Mateusz Hohol[2]
[1]Jagiellonian University in Kraków; [2] Loughborough University; [*] michal.obidzinski@uj.edu.pl https://mcll.edu.pl

Mathematical Cognition and Learning Lab

Jagiellonian University in Kraków

Loughborough University

Conceptual replication of the third experiment of Landy & Goldstone (2010) – conducted online

Key changes to the procedure: forced-choice test instead of open tasks; smaller, more natural spacing between operands and operators

SHORT OVERVIEW

Math4Speed test was used to investigate relationship between overall mathematical performance and congruency/incongruency effect

There are significant differences between congruent (*C*) and incongruent (*I*) stimuli: RTs are faster, and accuracy is significantly better for *C* vs *I*

Equations in Landy & Goldstone's experiment replication → Mathematical problems in form of either $a \times b + c$ or $a + b \times c$ → The middle operand (*b*) was equal to either 3 or 4 → The outer operands (*a* and *c*) could be 2, 3, 6, 8, or 9 → The congruent condition (multiplication closer to operands than addition) and incongruent condition (addition closer to operands than multiplication) were created for each possible equation → Used distances were equal 64px and 160px (keeping 2:5 ratio of original distances) e.g.: 3 × 4 + 8 → In this way, 200 items were created for the experiment

Procedure in Landy & Goldstone's replication:

- Stimuli: mathematical problems
- Presented with 4 possible answers (similar to a school test)
- Among the four options: one is correct, one reflects an operation-order error, and two are ±2 from the former two
- Example: for $3 \times 4 + 8$, the options could be 20, 36, 18, and 38
- Responses were given using the computer keyboard (D, F, J, and K keys)
- A short training session preceded the main task

Math4Speed:

- Speeded arithmetic task involving the four basic operations: addition, subtraction, multiplication, and division (Loenneker et al., 2024)
- There were 4 separate sections for operations
- Each section consisted of 50 items and ended after a 2-minute deadline or when all equations had been answered
- Answers were given in an open format

Participants

N = 201 after excluding 20 participants

- 17 due to poor performance: overall accuracy below 25% and/or consistently short reaction times (less than 500 ms in at least 15% of responses)
- 3 due to duplicate participation

N = 176 after exclusion of outliers

- Participants who scored below 25% accuracy in any condition
- All analyses were conducted separately with and without outlier participants

Results – ANOVA for Congruency (2) × Operation Order (2), and Correlation

Accuracy

Overall

- Congruency, $F(1, 200) = 22.85$, $p < .001$, $\eta^2_p = .1$
- Both, main effect of Order ($p = .099$) and Interaction ($p = .331$) are not significant

Without outliers

- There is no significant effect

Reaction Time

Overall

- Congruency, $F(1, 185) = 75.27$, $p < .001$, $\eta^2_p = .29$
- No significant effect of Order ($p = .088$)
- Interaction effect, $F(1, 185) = 13.18$, $p < .001$, $\eta^2_p = .07$

Without outliers

- Congruency: $F(1, 175) = 126.85$, $p < .001$, $\eta^2_p = .42$
- *Order: $F(1, 175) = 8.14$, $p = .005$, $\eta^2_p = .04$*
- *Interaction:* $F(1, 175) = 8.77$, $p = .004$, $\eta^2_p = .05$

Error type

Overall

- Congruency: $F(1, 200) = 25.74$, $p < .001$, $\eta^2_p = .11$
- Order: $F(1, 200) = 5.54$, $p = .020$, $\eta^2_p = .03$
- No significant Interaction ($p = .912$)

Without outliers

- Congruency: $F(1, 175) = 11.37$, $p < .001$, $\eta^2_p = .06$
- No significant effect of Order ($p = .240$)
- No significant interaction ($p = .850$)

Correlation with Math4Speed

Overall

- M4S x Accuracy: $r = .21$, $p = .002$
- M4S x RT: $r = -.64$, $p < .001$

Without outliers

- M4S x Accuracy: $r = .16$, $p = .04$
- M4S x RT: $r = -.65$, $p < .001$