Integrating perceptual and cognitive processes in mental arithmetic

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Whole Number Arithmetic

- Domain-specific: Recognizing numbers and operations and knowledge about the magnitude of numbers
- Domain-general: Working memory
  - 7% to 19% reduction in response time while computing arithmetic under a working memory load (Chen & Bailey, 2020)
  - Visuospatial working memory and arithmetic tasks recruit similar neural regions (Matejko & Ansari, 2022)

The Spacing Effect and Perceptual Processes

- Spacing: the proximity between operands and operators
- When spacing is **consistent** with the order of operations (with narrower spacing associated with earlier procedures), individuals make **fewer errors** and **respond more quickly**
  - Consistent: 2 + 3x4
  - Inconsistent: 2+3 x 4

Why does the spacing effect persist?

- Central executive (Rivera & Garrigan, 2016)
- Inhibitory control (Closser et al., 2023)
- Working memory

Research Questions

1. How does working memory influence multi-operand arithmetic performance?
2. **Does spacing influence working memory?**
3. Do parentheses reduce the spacing effect (and effect of spacing on WM)?

Hypothesis

Individuals perform better when there is less demand for working memory and when spacing is consistent with order of operations.

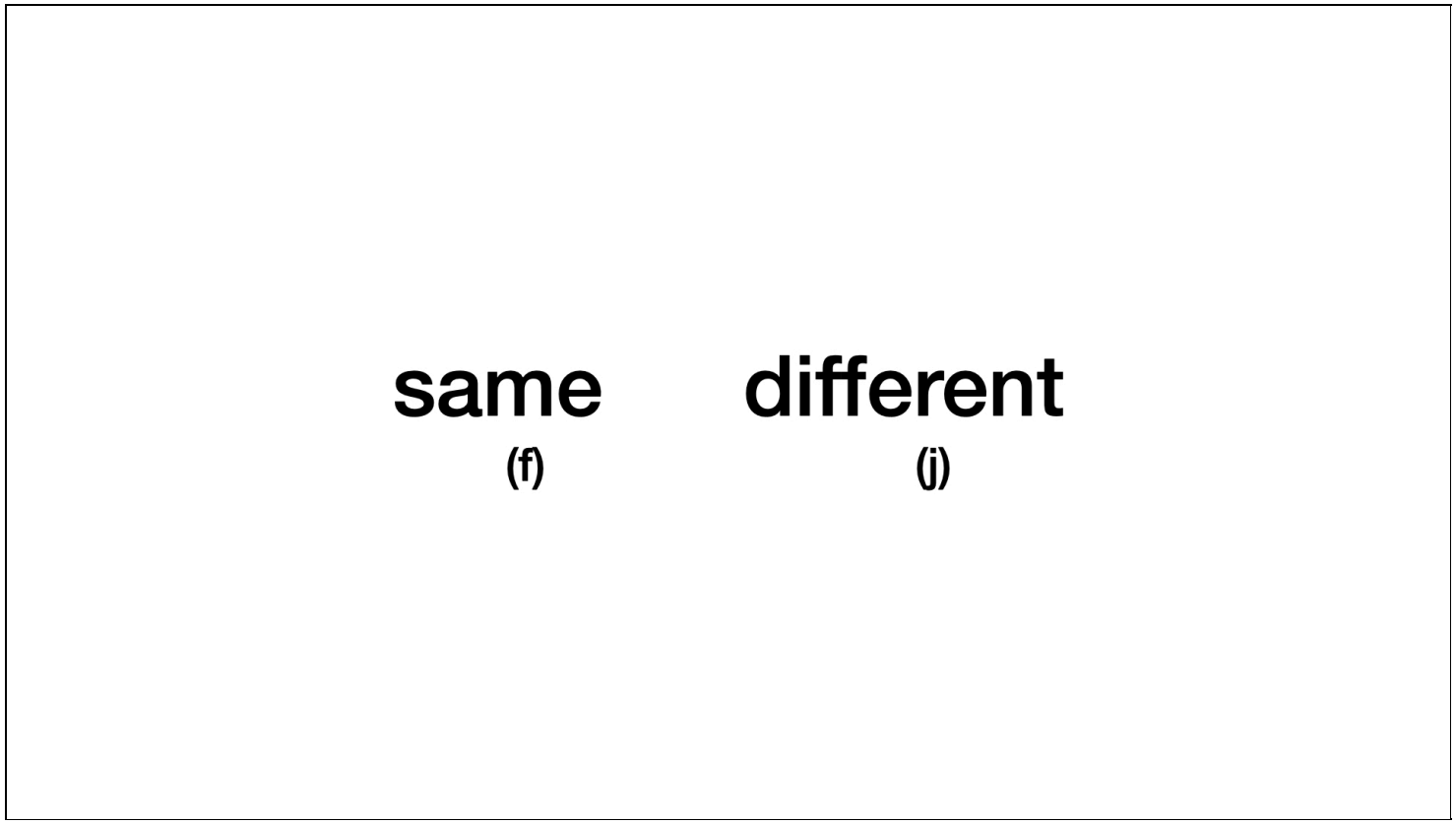
Sample & Procedure

- *N* = 114 adults, convenience sample
- Demographic background + math anxiety
- Baseline WM tasks: recall for dot patterns (visuospatial) and letters (verbal)
- Completed dual tasks

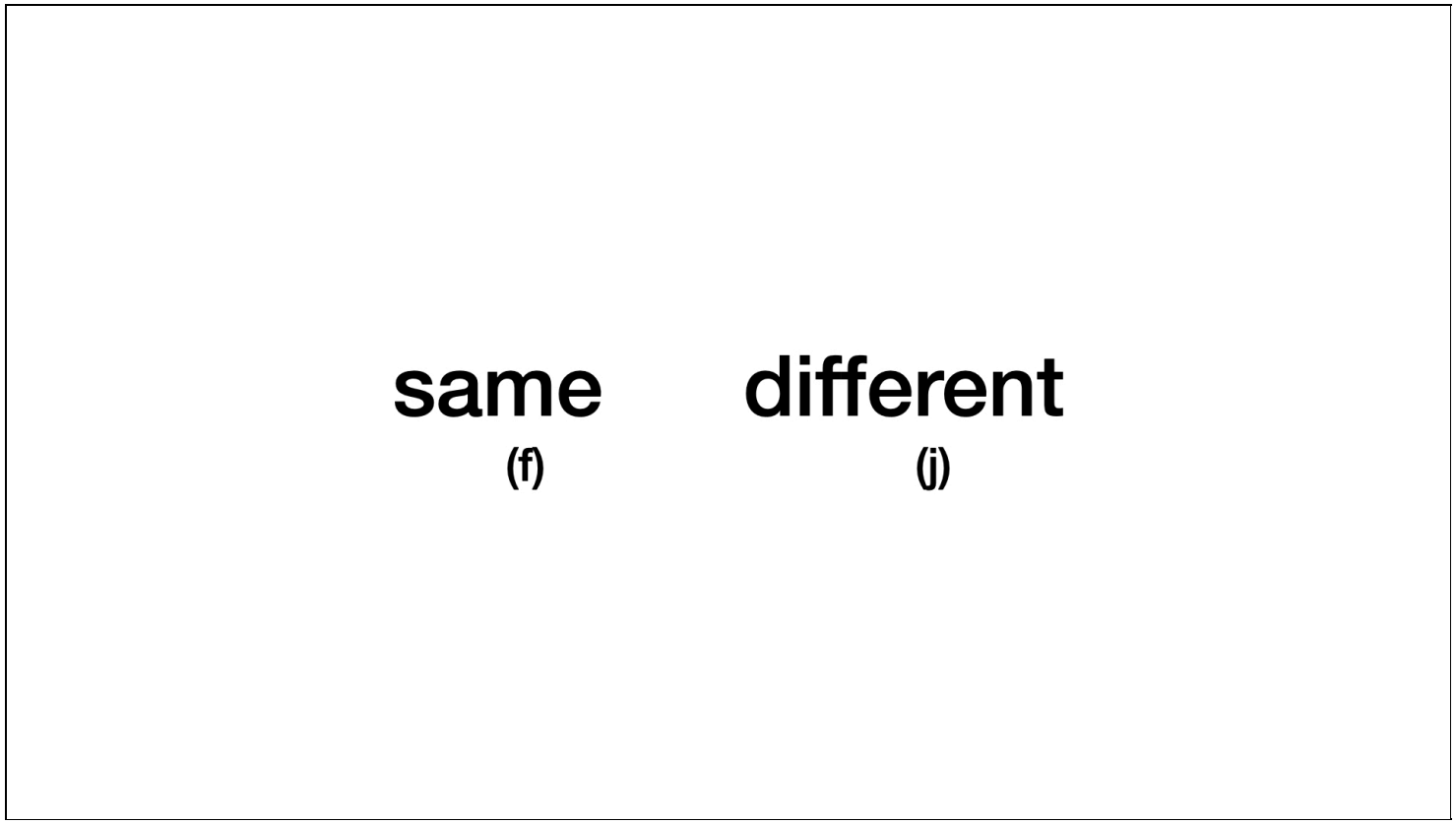
Dual Task Methodology

- Primary Task: Arithmetic
  - Each expression had 3 operands with either +x, x+, ++, or xx operations
- Secondary Task: Working Memory
  - 2 Types: dot patterns (visuospatial) and letters (verbal)
  - 2 Load Difficulties: Low and High from baseline WM performance

Trial 1



Trial 2



Task Conditions

- 3 dual-task conditions with 60 trials each
- Each condition had all WM Loads and Types
- Conditions differed in arithmetic expressions

1. no-spacing variation
2. **spacing-varying** (consistent, inconsistent, neutral)
3. **spacing-varying** and **parenthesis** around multiplied operands in expressions with consistent and inconsistent spacing; e.g., 2+(3 x 4)

Findings, so far…

- 34 participants (30%), aged 19.4 to 68.1 years (*M*=31.6, *SD*=12.8)
- Highly educated with low math anxiety (*M*=2.8, *SD*=)
- Load difficulties from baseline WM tasks

	Low Load	High Load
Dots	2 (*SD*=)	7 (*SD*=)
Letters	2 (*SD*=)	9 (*SD*=)

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Does Spacing Influence WM?

Working memory recall after solving expressions in spacing-varying condition

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Does Spacing Influence WM?

- Spacing does not influence working memory
  - Note small sample size and skew of education
- Arithmetic interfered with working memory
  - Visuospatial working memory is more involved for expressions with both addition and multiplication operations

Thank You

Some Statistics

- One in three individuals in the U.S. with a Bachelor's degree lack important numeracy skills (e.g., understanding complex quantitative information, recognizing mathematical patterns and relationships, and solving problems that require multiple steps)
- Among 16-34-year-old individuals' numeracy in 30 countries, U.S. is ranked 26
- For every standard deviation increase in numeracy, there is an increase in 9.4% of monthly earnings

Findings for RQ 1

1. How does working memory influence multi-operand arithmetic performance?

- Across all task conditions, there is an effect of load and type (separately) on arithmetic accuracy and RT.

Expected Findings for RQs 2 & 3

2. Does spacing influence working memory?
    - Better arithmetic performance when spacing is consistent or neutral
    - Better memory for letters/dots when spacing is consistent or neutral
3. Do parentheses reduce the spacing effect (and effect of spacing on WM)?
    - Better arithmetic performance overall in the parenthesis dual task condition