



Non-Numerical Features Predict Quantity:

Evidence from Machine Generated, Human-Generated, Children Counting Books & Real-World Images

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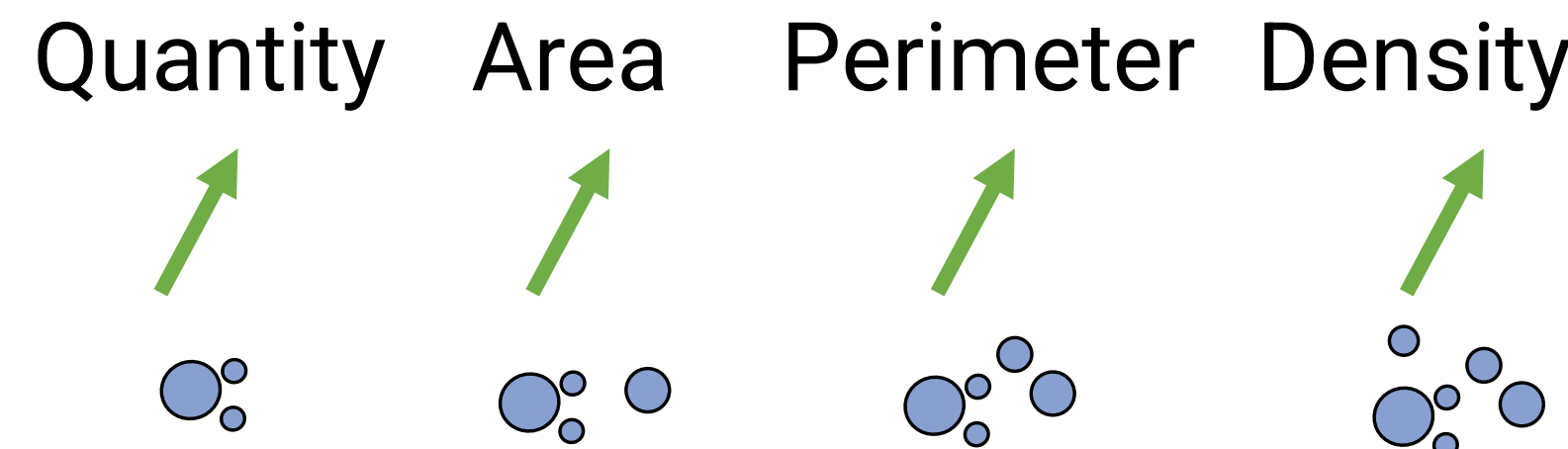
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Do quantities and non-numerical features inherently correlate?

1. Introduction

- Object arrays display natural correlations between non-numerical features and item quantity^{[1], [2], [3], [4], [5], [6]}

Increasing quantity necessarily alters physical properties



- A large body of evidence indicates these natural correlations are utilized in numerical judgments^{[3], [6], [7], [8]}
- Recently, Sanford and Halberda (2024) challenged this consensus, asserting that non-numerical features do not meaningfully predict quantity in real-world stimuli^[9]

2. Purpose

- To examine varying degrees of ecological validity in numerical stimuli
- To establish a comprehensive database of images
- To quantify the predictive relationship between non-numerical features and quantity

3. Hypothesis

Non-numerical features provide meaningful predictions of quantity

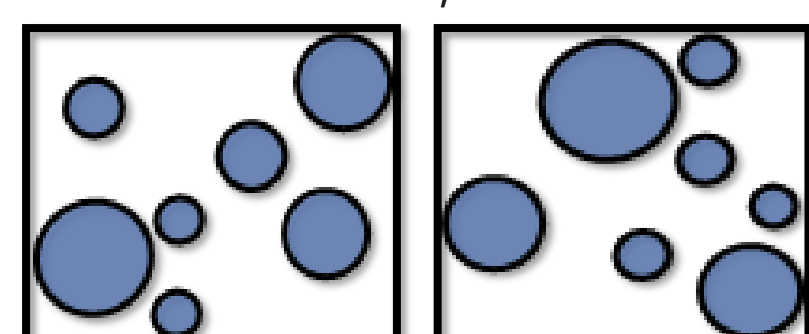
4. Method: Datasets

Four Datasets

Varying level of ecological validity 4-10 items

Machine generated

N = 7,000



Simulated dot arrays

Children counting books^[9]

N = 522

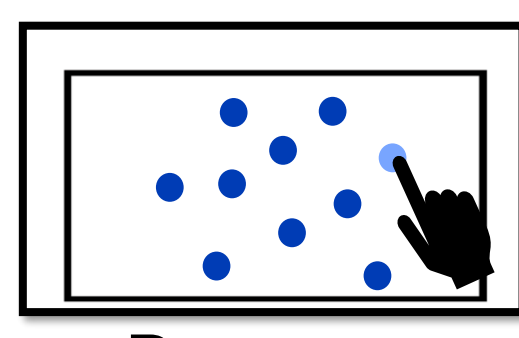


Illustrated counting materials

Human generated^[11]

N = 3,798

Scatter 4-10 dots



Response

Participant-created dot arrays

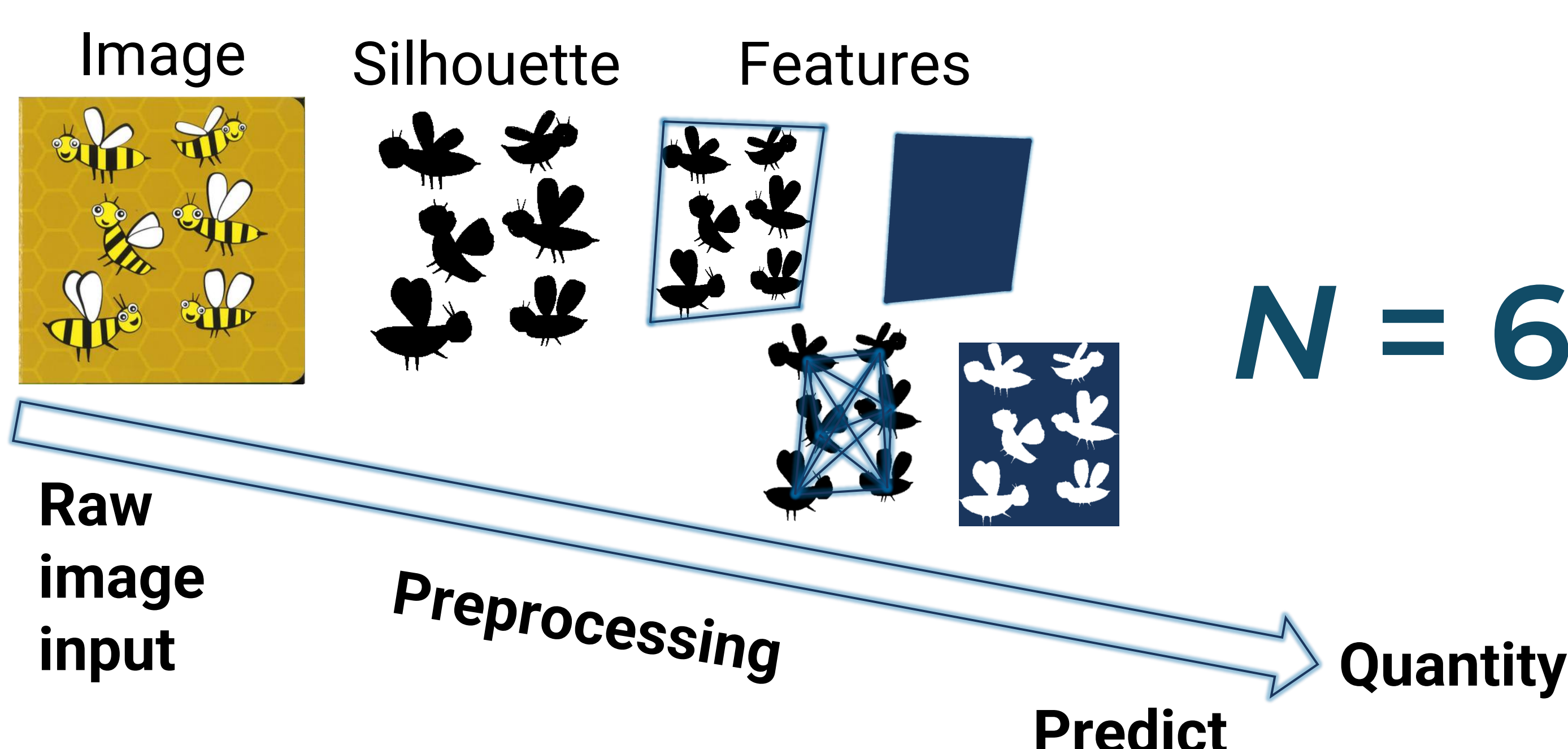
Real-world^[10]

N = 397



Three categories: sheep, birds, motorcycles
Natural object arrays

5. Method: Image Analysis Workflow



6. Method: Analyzed Features

- Twelve non-numerical features across multiple visual dimensions
- Total properties: Total surface area, Total circumference, Additive area
- Average properties: Surface area, Average circumference, Average occupancy
- Spatial configuration: Convex-hull area, Convex-hull perimeter, Convex-hull shape, Density, Interdistance, Spatial frequency

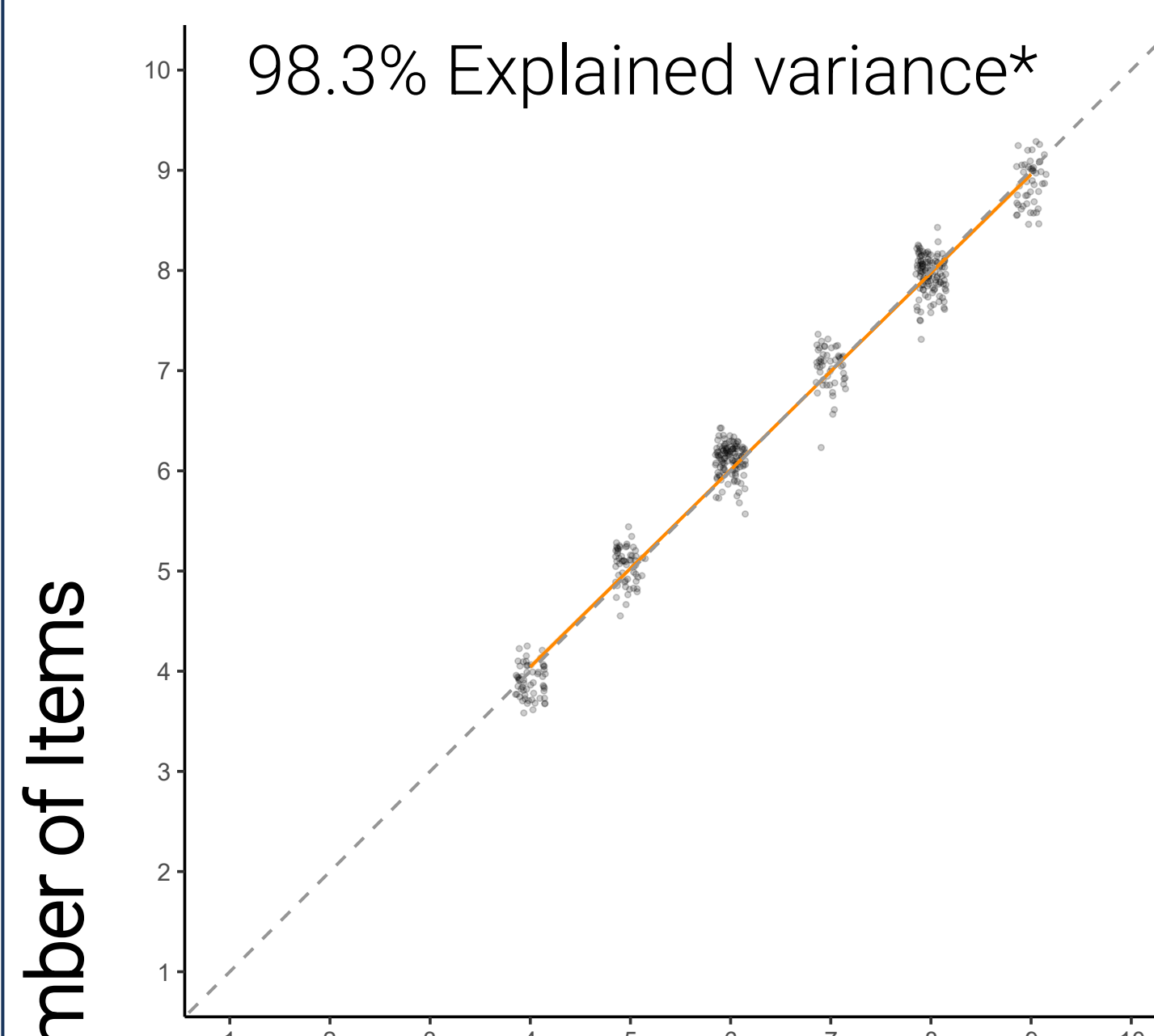
7. Results

Features predict quantity

*Adjusted R² calculated using stepwise multiple linear regression

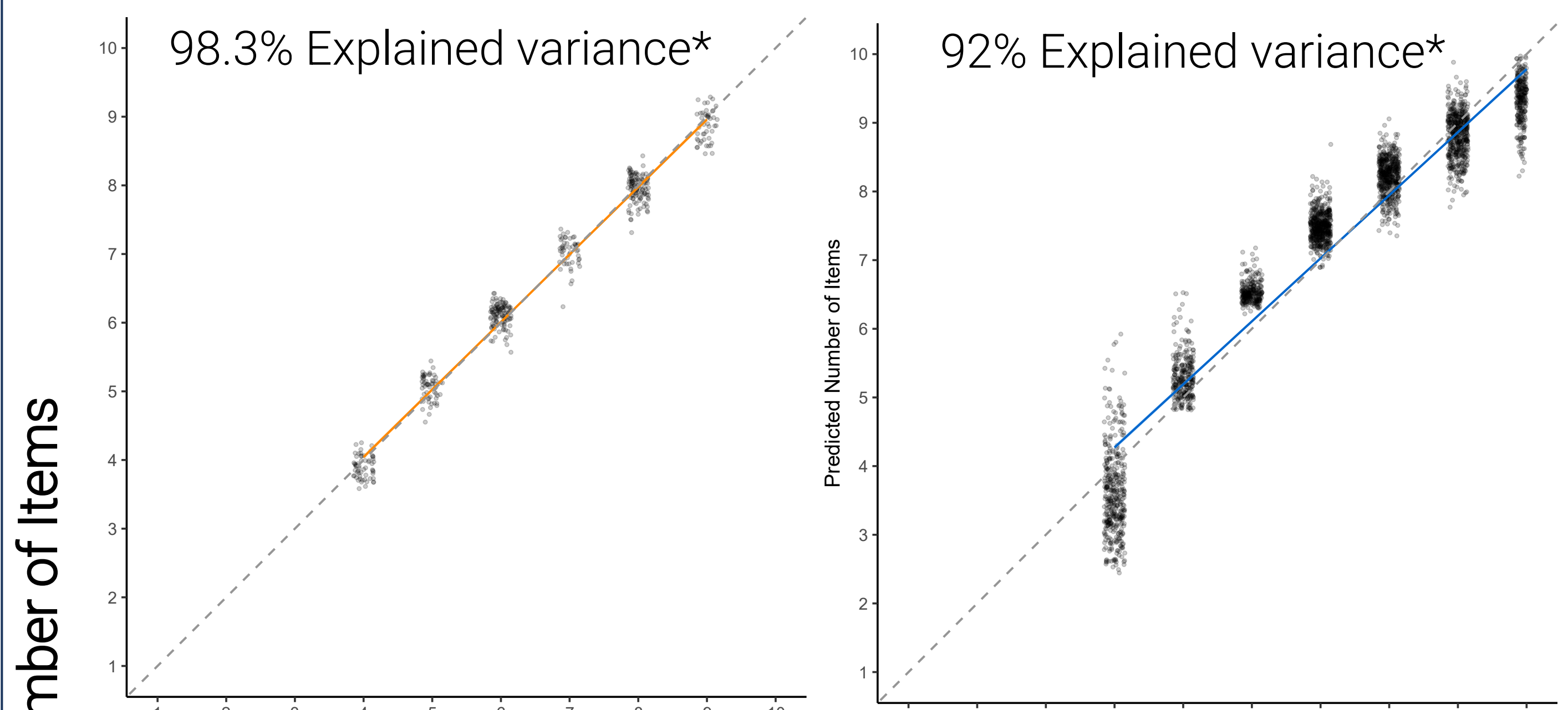
Machine Simulation

98.3% Explained variance*



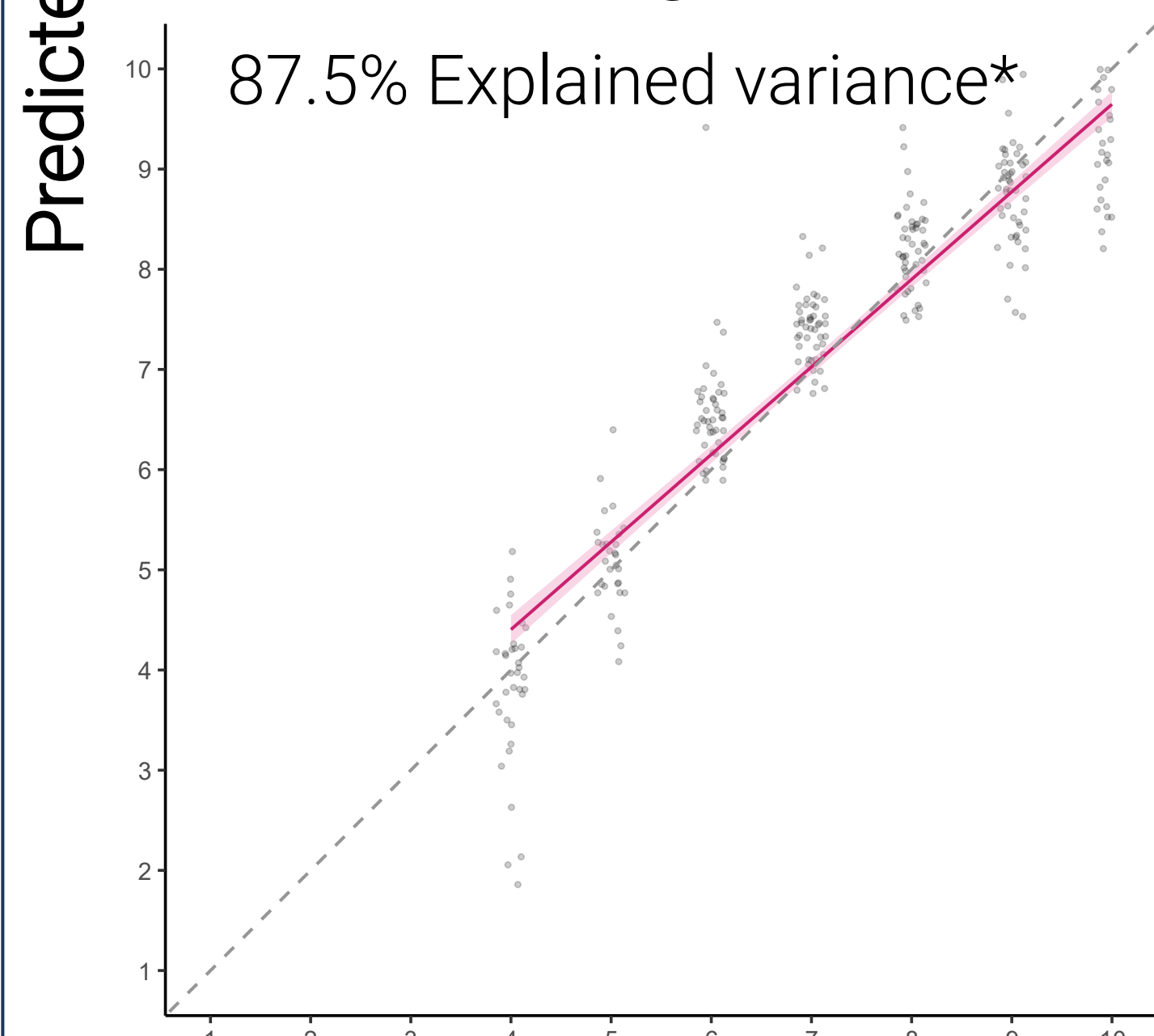
Generation Task

92% Explained variance*



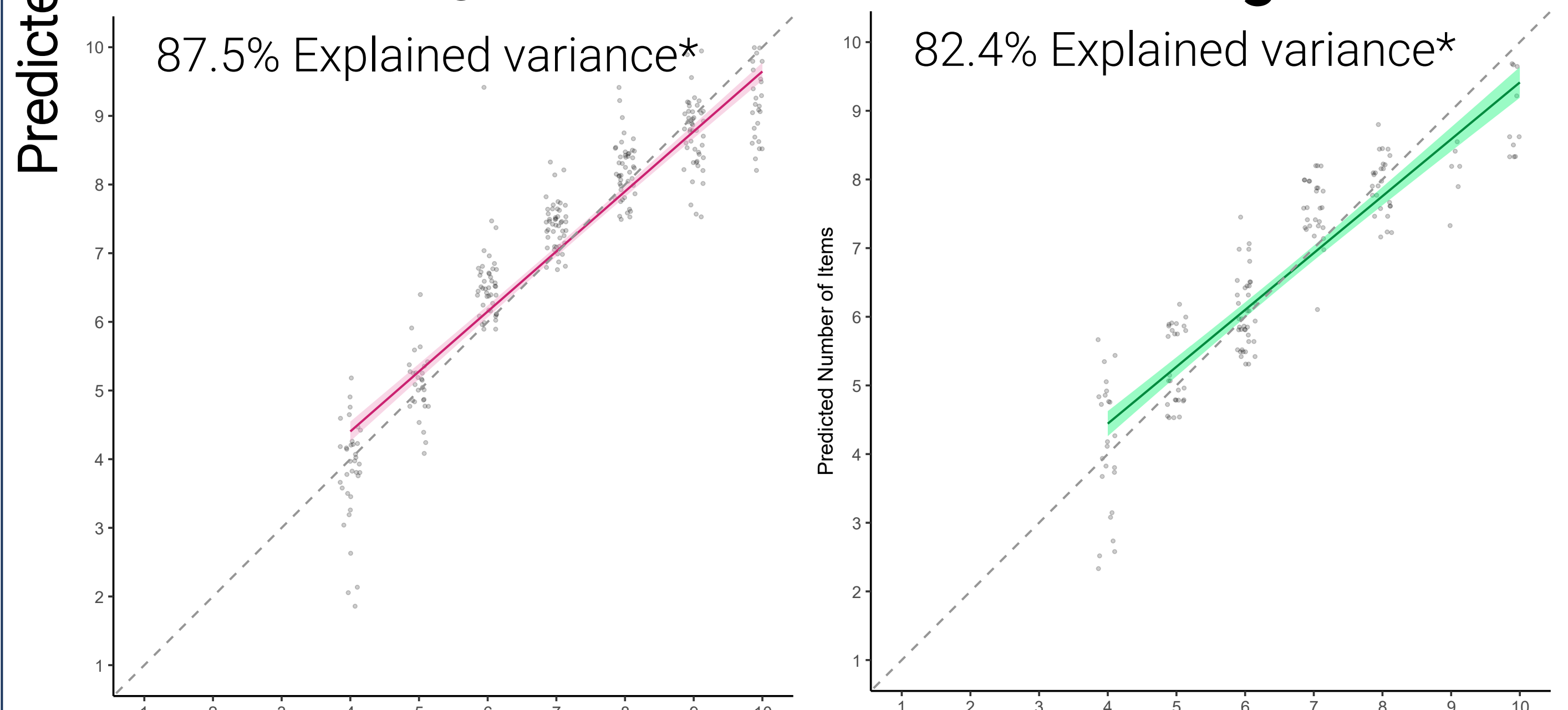
Counting books

87.5% Explained variance*



Real Images

82.4% Explained variance*



- Principal component regression addressed multicollinearity, revealing that non-numerical features accounted for 74-88% of quantity variance

8. Discussion & Conclusion

- Non-numerical features predict quantity
- Results confirm non-numerical features provide substantial numerical information for numerical processing
- Prediction remains robust despite decreasing with ecological validity
- Findings indicate that numerical systems might represent non-numerical information
- Non-numerical features' role needs further study
- Future: Predict participants estimations from features

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