Developmental Changes in Children's Processing of Nonsymbolic Ratio Magnitudes: A Cross-Sectional fMRI Study

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Background

- Lewis, Matthews & Hubbard (2015) hypothesized that there is a neurocognitive architecture that processes nonsymbolic ratio magnitude— the ratio processing system (RPS)—and this system is recycled to process symbolic fractions.[1,2,3]
- Emerging studies suggest that both nonsymbolic and symbolic ratios are processed by parietal-prefrontal network and, in particular, by the intraparietal sulcus (IPS).[1,3]
- In this study, we aimed to explore the differences in behavioral and neural signatures of RPS prior to receiving fractional instructions (2nd graders) and after substantial instruction with symbolic fractions (5th graders) through a cross-sectional approach.

Methods

Participants: 41 2nd graders and 42 5th graders. Among them, we excluded 27 children due to excessive movement (20), signal loss (2), claustrophobia (1), falling asleep (1), low behavioral performance (2), and ADHD diagnosis (1). Final sample included 25 2nd graders and 31 5th graders.

Cross-Notation Comparison Tasks (XFC)

3x3 within-subjects design

- 3 notation conditions
- 3 numerical distance bins
  - Near, Medium, and Far

Task administration

- 6 runs of 36 trials

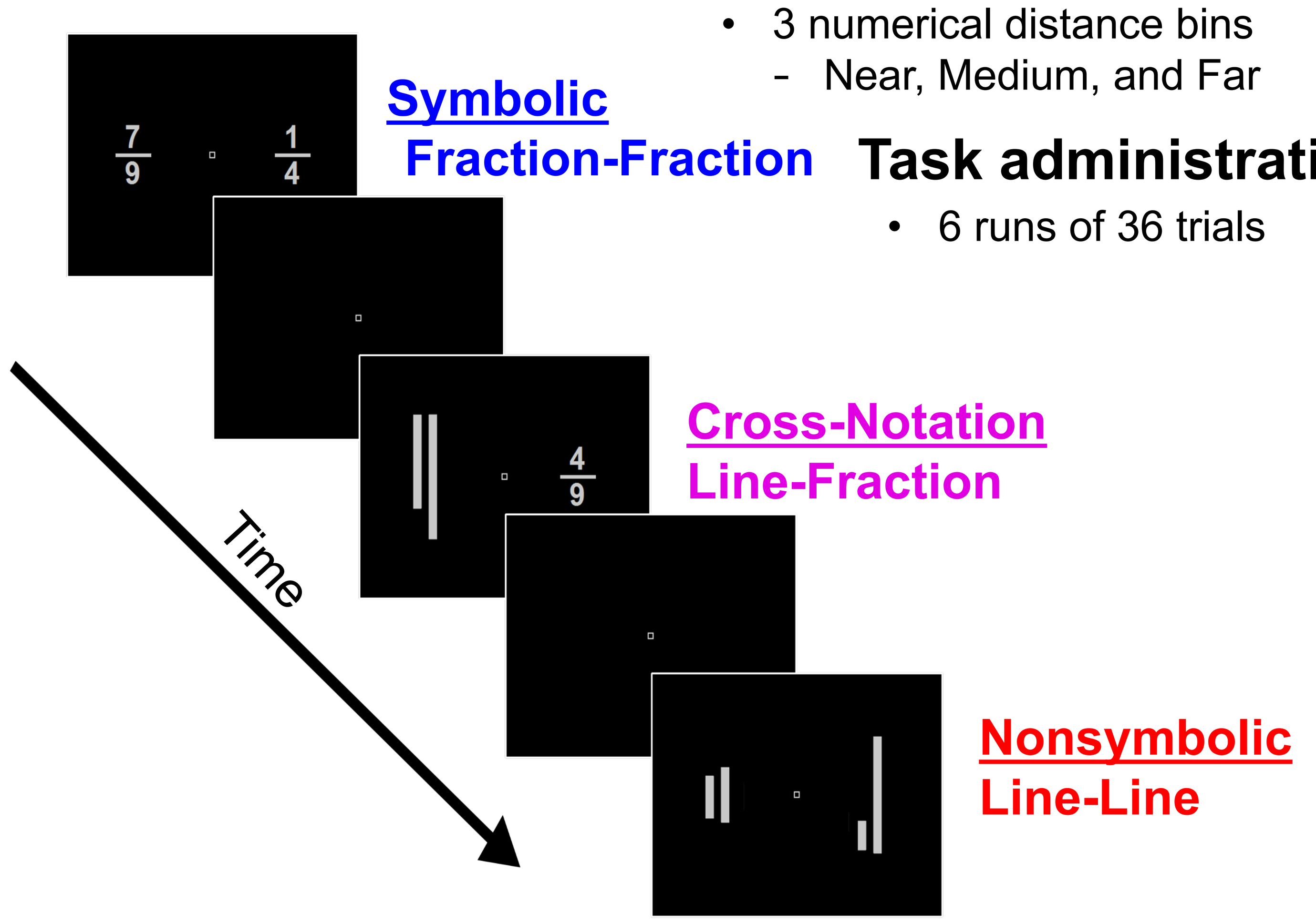

Figure 1. XFC task procedure

Results

1. Behavioral Analysis

A) Error Rates **B) Reaction Times**

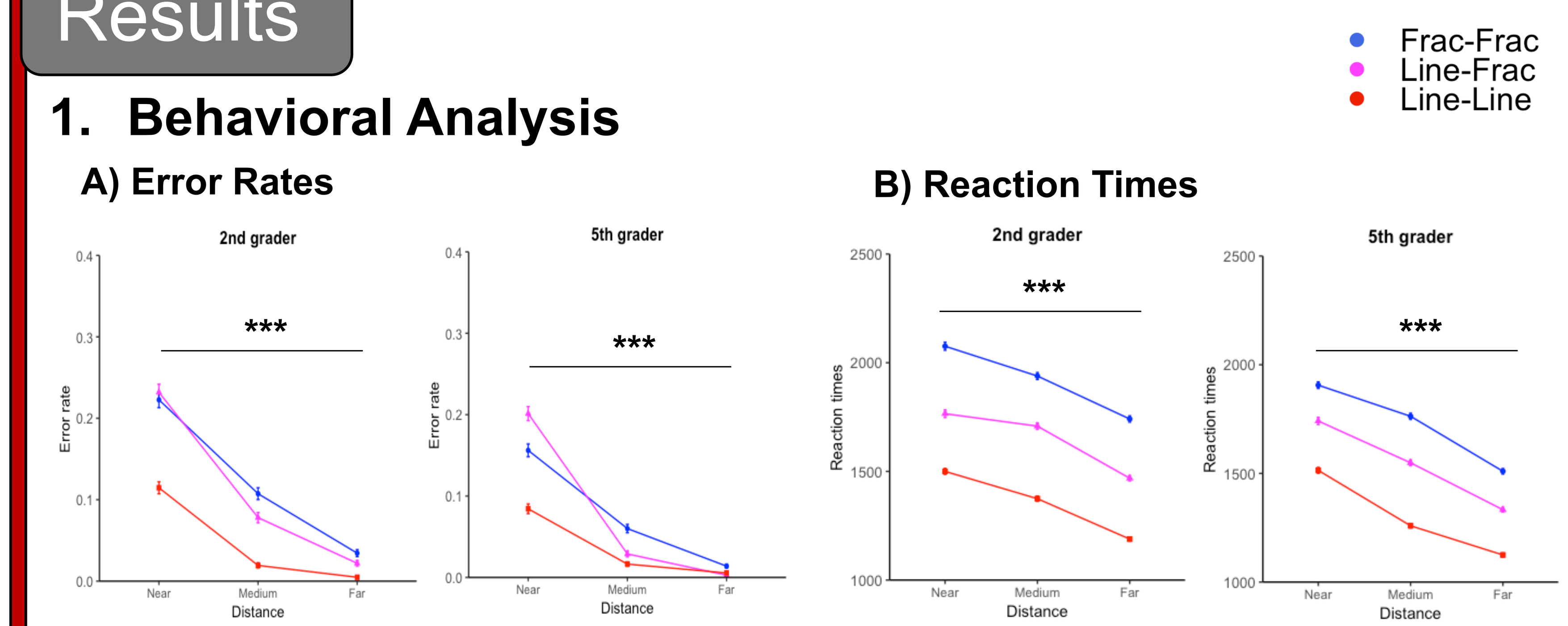

Figure 2. A) Error rates and B) reaction times for each notation as a function of distance (*** p <.005)

- 5th graders were more rapid and accurate compared to 2nd graders.
- Non-symbolic (line-line) comparison was the most accurate and the fastest among all notations (p<.001).
- For all notations, there was a significant distance effect (p<.0001)

2. Whole-brain Analysis

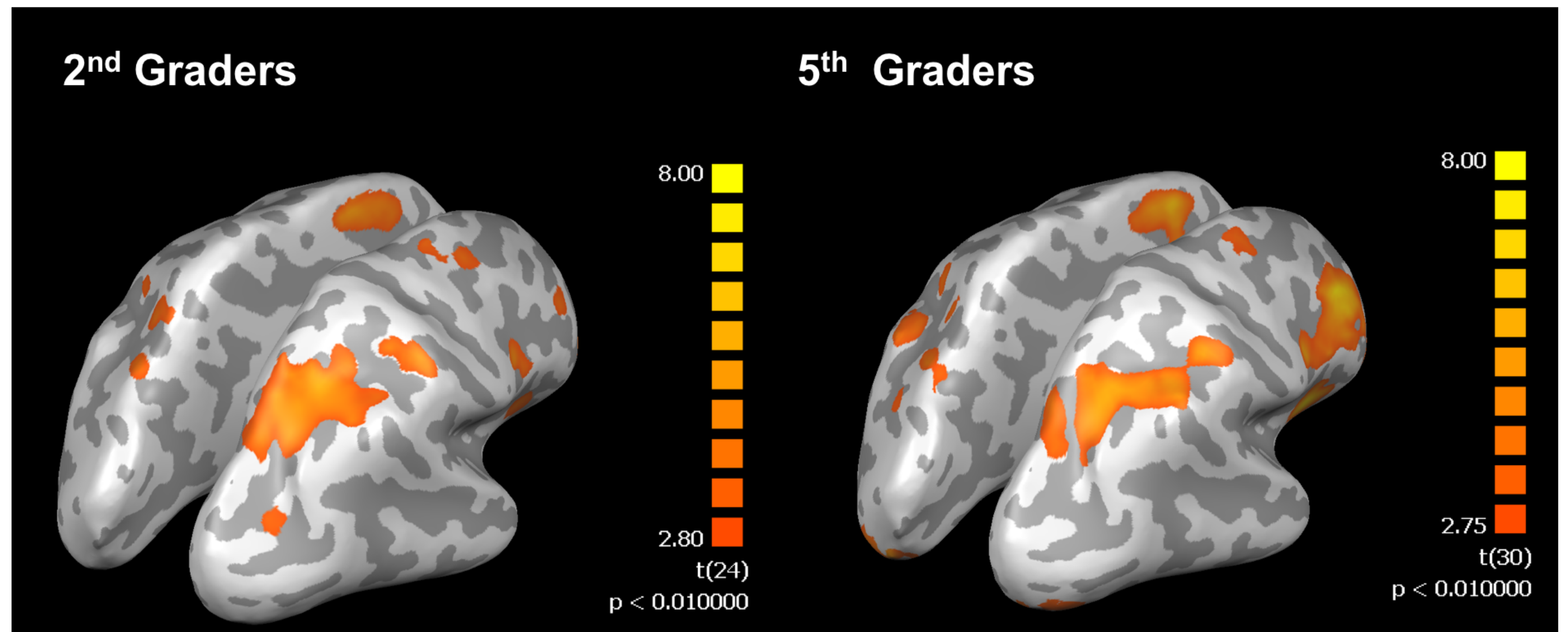

Figure 3: The neural distance effect collapsing across all notations in 2nd (left) and 5th graders (right) (p<.01, cluster corrected). 5th graders showed larger bilateral activations in the parietal and the prefrontal areas compared to 2nd graders.

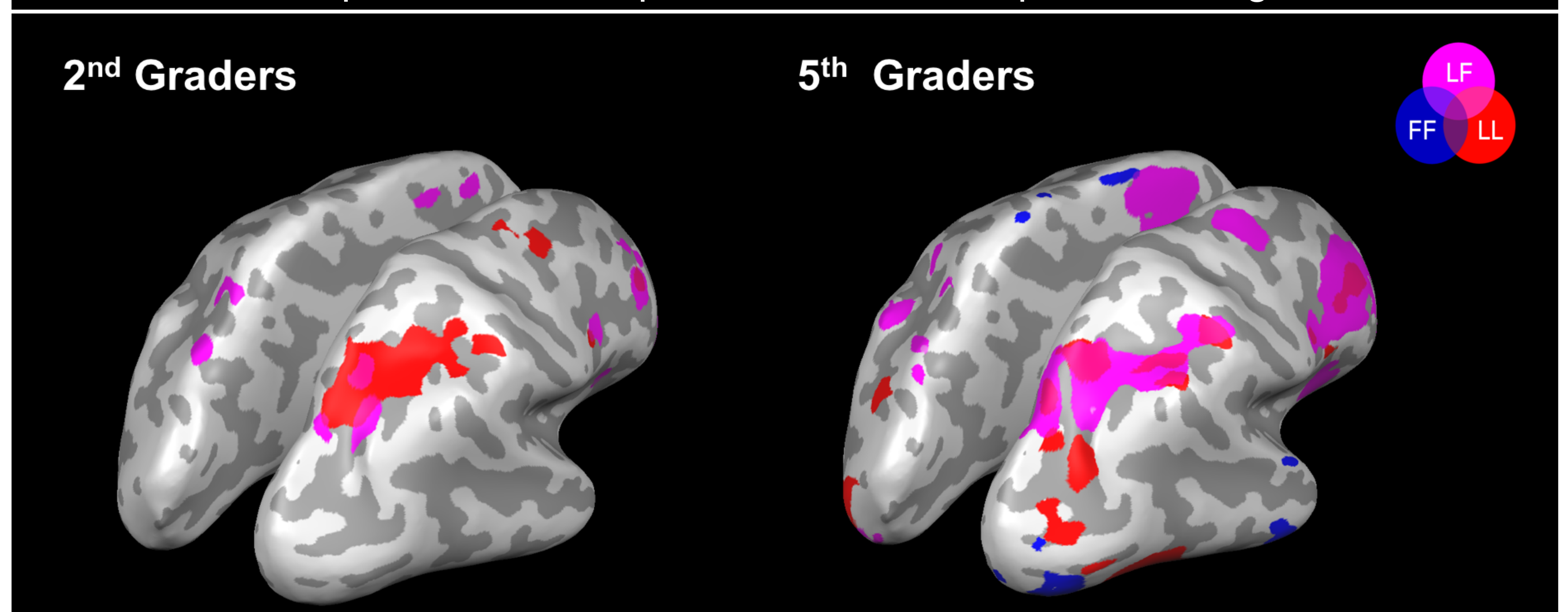

Figure 4: The neural distance effect in each notation in 2nd and 5th graders (p<.01, cluster corrected). 5th graders showed larger overlaps among notation conditions in both parietal and prefrontal areas, whereas 2nd graders' distance effect was mostly from the non-symbolic notation.

3. Region of Interest (ROI) Analysis

**p<.01, *p<.05, ┼ p <.1

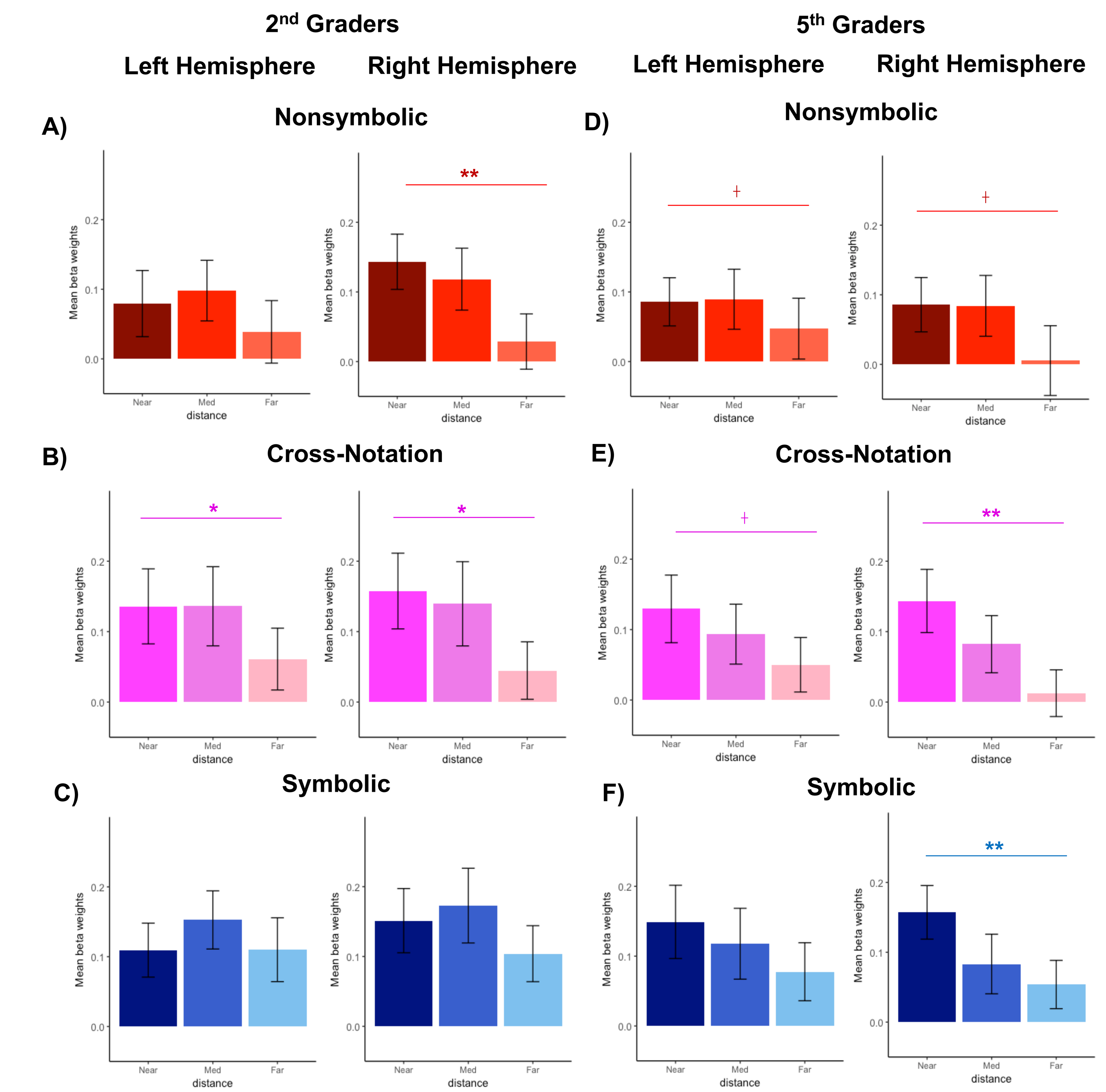

Figure 5: ROI analysis was conducted based on a set of IPS coordinates identified by a previous meta analysis.[4] Both 2nd (p=.005) and 5th graders (p<.0001) showed a significant distance effect. Overall, right hemisphere showed significantly greater distance effect than left hemisphere in both 2nd (p<.01) and 5th (p<.05) graders. 2nd graders showed a distance effect in the nonsymbolic (p<.05) and the cross-notation conditions (p<.02), 5th graders showed a significant effect in the cross-notation (p<.007) and the symbolic (p=.014) conditions.

Discussion

- 5th graders compared ratio magnitudes more rapidly and accurately than 2nd graders.
- Both behavioral and neural distance effects were observed in all children.
- Neural distance effects in each notation show greater overlap in 5th graders than 2nd graders.
- Educational experiences may help build symbolic representations of fractions on foundational neural systems for non-symbolic ratios.

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References

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[2]Matthews, P. G., Lewis, M. R., & Hubbard, E. M. (2016). Individual Differences in Nonsymbolic Ratio Processing Predict Symbolic Math Performance. *Psychological Science*, *27*(2).
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