Gray Matter Correlates of Mathematical Fluency in Children

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Introduction

We conducted a voxel-based morphometry (VBM) analysis on data from 132 children to assess correlation between GMV and performance in the Woodcock-Johnson III math fluency sub-scale.

Arithmetic skill
- Crucial for academic achievement
- Only a few brain structural imaging studies have investigated the relation between gray matter volume (GMV) and arithmetic skill

Gray matter volume (GMV)
- GMV in the intraparietal sulcus (IPS) has been shown to be positively correlated with individual differences in arithmetic scores (Li et al., 2013; Price et al., 2016).

Methods

We used a recently published neuroimaging dataset (Suarez-Pellicioni et al., 2019)
- T1-weighted anatomical scan from 132 typically developing children (62 male, 70 female)
- age: 8-15; mean = 11.3, sd = 1.46

WJ-III (Woodcock-Johnson III)
- Assesses achievement on simple math calculations
- Average Math Fluency score
- M = 94.39, sd= 15.92

Processing
- Image segmentation was conducted in Computational Anatomy Toolbox (CAT) for Statistical Parametric Mapping (SPM 12).
- All structural images were realigned and segmented into GMV, WMV, and CSF.
- Regression analysis was conducted between whole-brain GMV and standardized math performance as the covariate of interest; age, sex, and total intracranial volume were included as covariates of non-interest.
- An absolute threshold mask of 0.1 was used to exclude voxels pertaining to subcortical structures and cerebellum.
- 3dClustSim was used to calculate the whole brain cluster threshold that would be appropriate to control for type I errors for an uncorrected $p < .001$, which corresponds to a $p < .05$ corrected.
- Results were visualized using xjView.

Results

Significant temporal clusters
- Right fusiform gyrus (# of voxels = 224, peak MNI: 30 3 –51) ***(Figure 1a)***
  - Previous number studies associated bilateral fusiform function with processing Arabic numerals (Ischebeck et al., 2007; Dehaene & Cohen, 1997)
  - In previous studies right fusiform activation was associated with visuospatial working memory (Rosenber-Lee et al., 2013)
- Left middle temporal gyrus (# of voxels = 152, peak MNI: -71 –36 -15)***(Figure 1b)***
  - In previous arithmetic processing studies MTG activation was associated with verbal processing during arithmetic fact retrieval (Ischebeck et al., 2007; Prado et al., 2011).
- Left inferior temporal gyrus (# of voxels = 298, peak MNI: -60 –51 -12)***(Figure 1c)***
  - Like left MTG, left ITG was associated with retrieval tasks and trained performance in previous arithmetic studies (Delazer et al., 2003; Pospoel et al., 2017).
  - Found to be more activated when processing Arabic numerals compared to letters (Grotheer et al., 2016) & more active for expert mathematicians when reading mathematical formulas compared to non-experts (Amalric & Dehaene, 2016).
  - GMV in bilateral ITG was found to be higher for musicians, possibly related to ventral visual pathway (Gaser & Schlaug, 2003).
- We conducted further group-analysis, comparing males with females, and low- and high-performers (math fluency) and did not find any group differences.
- Previous studies reported intraparietal sulcus (IPS) (Li et al., 2013; Price et al., 2016) GMV correlating with mathematical performance. The whole-brain analysis, as well as an ROI analysis, using a parietal implicit mask, did not show any significant parietal clusters.

Significant GMV Clusters in Math Fluency

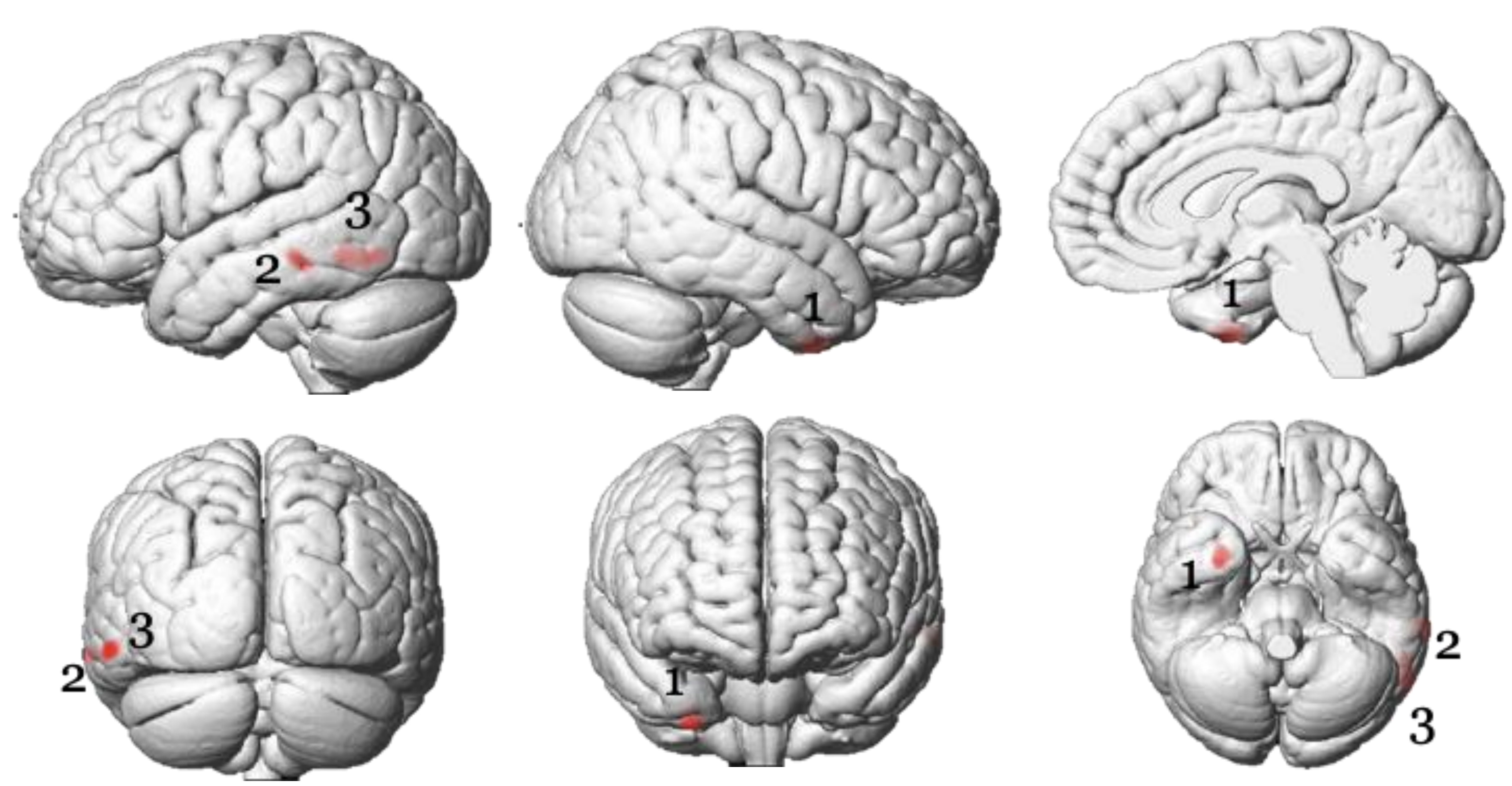

Figure 1. (a) Cluster 1: right fusiform gyrus, (b) Cluster 2: left middle temporal gyrus, and (c) Cluster 3: left inferior temporal gyrus.

Conclusion

- Right fusiform gyrus, left middle temporal gyrus, and the left inferior temporal gyrus had been previously implicated in functional studies of arithmetic operations.
- The regions found seem to suggest GMV correlations for math fluency, with regions associated with retrieval, semantic memory access, Arabic numeral processing, and ventral visual pathway.
- No group effects for gender and math fluency performance.
- Unlike previous studies, no GMV correlation in left or right IPS.

Future Directions

- Connectivity study linking structural and functional neural correlates
- Age-related analysis of GMV and WMV at two different time points to determine the developmental maturation of areas involved in number processing.

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