Meta-Analysis of Neural Networks for Reading, Math, and Working Memory in School-Age Children

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Summary

- We performed coordinate-based meta-analyses to investigate domain-specific and domain-general networks between reading and math.
- Domain-specific areas were related to reading or numerical/arithmetic processes, whereas domain-general areas (left frontoparietal network, right anterior insula) were associated with working memory.

Introduction

Background

- Children demonstrate varying reading and math skills.
- Learning disabilities in reading and math are highly comorbid (e.g., about 40% in dyslexia and dyscalculia [1]).
- This suggests that reading and math may have distinct domain-specific and shared domain-general neurocognitive mechanisms [2].
- While working memory (WM) is strongly correlated with reading and math [3], to elucidate how it supports both skills requires a neural analysis.

Study Aims

- To identify the domain-specific and domain-general neural networks underlying reading and math
- To investigate how the domain-general networks were related to WM

Methods

Literature Search

- Following the PRISMA framework [4]
- Three separate searches of fMRI studies for reading, math, and WM
- Database: PubMed, PsycINFO, ScienceDirect, Scopus, Web of Science

Inclusion Criteria

- Involved typically developing children aged ≤ 13-year-old
- Reported MNI or Talairach coordinates from whole-brain analysis
- fMRI tasks with visually presented stimuli

Activation Likelihood Estimation (ALE) Meta-Analysis

- Coordinate-based, using GingerALE (v3.0.2) [5]
  - *Single dataset analyses: cluster-level family-wise error (FWE) corrected at p < .01 with 1,000 permutations, cluster-forming threshold of p < .001*
  - *Contrast and conjunction analyses: uncorrected p < .01 with 10,000 permutations, cluster size > 200 mm³*
- Contrast Analyses
  1. Contrasts between reading and math to identify domain-specific areas
  2. Conjunction of (reading ∩ math) to identify domain-general areas
  3. Conjunctions of (reading ∩ WM) and (math ∩ WM) to examine WM areas related to reading or math
  4. The result of 2. was compared with the overlap of 3.

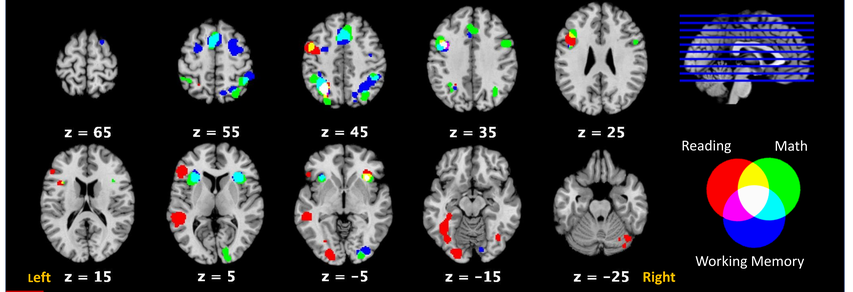
Results

Search Results

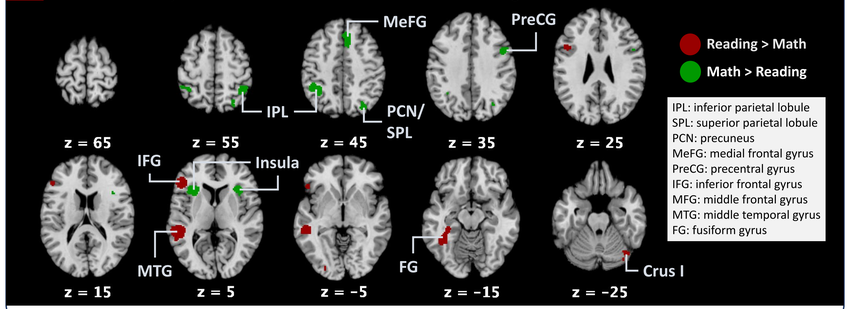
Domain	Contrasts	Foci	Tasks
Reading	39	364	Reading-related, lexical, semantic, or phonological decision
Math	38	371	Numerical or arithmetic
WM	42	438	Complexity: Simple maintenance or complex manipulation Stimuli: verbal, object, or spatial

ALE Results

1 ALE maps of reading, math, and WM



2 Contrast analysis: Domain-specific areas for reading and math



References

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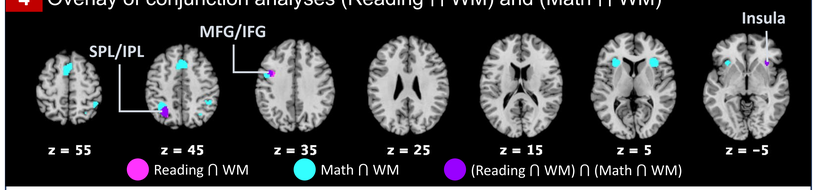
Results

3 Conjunction analysis (Reading ∩ Math): Shared areas between reading and math

4 Overlay of conjunction analyses (Reading ∩ WM) and (Math ∩ WM)



Behavioral Analysis using Mango plug-ins

ROI	Volume (mm³)	Region	Peak MNI (x, y, z)	ALE	Behavioral categories – Cognitive domain (z-score ≥ 3)
1	1432	SPL/IPL/ PCN	(-26, -56, 44)	0.022	Reasoning, language (speech, semantics), attention, memory (explicit, *working z=2.684*)
2	752	Insula	(34, 24, -4)	0.023	Attention, reasoning, memory (explicit, working), language (semantics, phonology)
3	552 512	PreCG/MFG PreCG/IFG	(-46, 0, 42) (-46, 12, 32)	0.020 0.018	Language (speech, semantics, phonology, orthography), memory (working, explicit), attention, reasoning

Conclusions

- Contrast analysis (Fig.2) revealed domain-specific areas including:
  - Left IFG, MTG, FG, right Crus I: phonological, semantic, and orthographic processing for reading [6]
  - Bilateral IPL, PCN, MeFG: numerical and arithmetic processing for math [7]
- Conjunction analysis (Fig.3) identified domain-general areas involving [8]:
  - Left lateral frontoparietal network (MFG/IFG, SPL/IPL): a control system for executive function, including working memory and goal-oriented cognition
  - Right anterior-dorsal insula: integrating task-relevant information in the salience network
- Further conjunction analyses (Fig.4) and behavioral analysis confirmed that domain-general areas were associated with working memory.
- Domain-specific and domain-general networks may account for individual differences in reading and math.
  - Domain-specific networks predict children's abilities in each domain.
  - Domain-general networks underlie shared deficits in dyslexia and dyscalculia.
  - Results provide hypotheses and networks-of-interest for future investigations.