Structural Brain Correlates of Mathematical Processing in Bilinguals

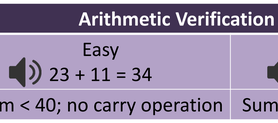
Jennifer Legault*, Kaitlyn A. Litcofsky, Shin-Yi Fang, & Ping Li
Department of Psychology and Center for Brain, Behavior, and Cognition, Pennsylvania State University

Background

- Bilinguals have different mapping systems for their native (L1) and second (L2) languages
- Math processing for bilinguals relies on understanding some concepts that are **language-independent** between L1 and L2 while others that are **language- or culture-specific**[1]

Language-independent

1 + 2 = 3



Language-specific

Symbol	1	2	3
L1	—	=	≡
L2	One	Two	Three

- Various cognitive abilities and training are associated with variability or changes in gray matter volume (GMV)
  - Linguistic[2], non-linguistic[3,4], and math processing[5,6]
  - VBM results are consistent with fMRI findings[2,5,6]

Here, we investigate the structural correlates of math processing in bilinguals.

Research Questions

1. How does variability in neural structure relate to math processing in L1 and L2?
   - Dehaene (2003) posits math processing to rely on:
     - The angular gyrus (AG)
     - The intraparietal sulcus (IPS)
     - The superior parietal lobe (SPL)
   - Together with our fMRI findings (see bottom middle), these regions comprise our VBM ROIs
2. Is structural variability related to cognitive performance consistent with previous studies?
   - L2 Vocabulary: left inferior parietal lobe (IPL)[2]
   - Working Memory: IPL, prefrontal cortex, inferior frontal gyrus, and parahippocampus[7]

Methods

Participants

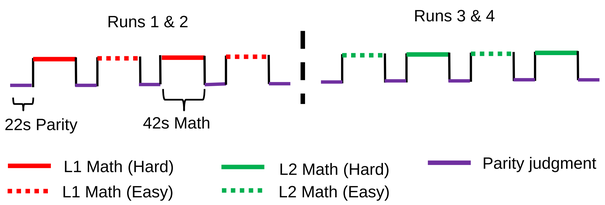
- 24 right-handed Chinese-English adult late bilinguals
  - 16 Female, Age *M* = 25.25 *SD* = 5.1

Math Performance Measures

- fMRI Language-Specific Math tasks
  - Auditory presentation; L1 and L2 completed separately

Arithmetic Verification Judgment		Parity Judgment
Easy 23 + 11 = 34	Hard 23 + 48 = 71	23?
Sum < 40; no carry operation	Sum > 60; carry operation	Odd/Even

fMRI Math runs



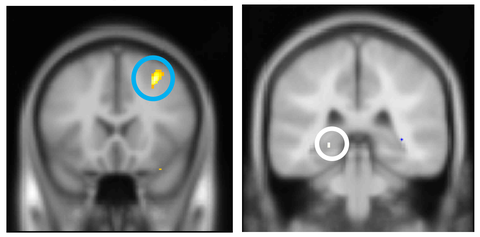
Cognitive Performance Measures

- Brief Mathematics Assessment (BMA)[8]
- Peabody Picture Vocabulary Test (PPVT)[9]
- Letter-Number Sequencing Task (LNS)[10]
- O-Span Task[11]

VBM Results

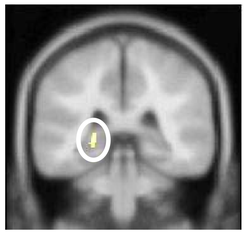
How does variability in neural structure relate to math processing in L1 and L2?

L1 (Chinese) math performance



L1 Hard RT (-) R MFG⁺ (left)
L1 Parity Accuracy (+) L hippocampus⁺ (right)

L2 (English) math performance

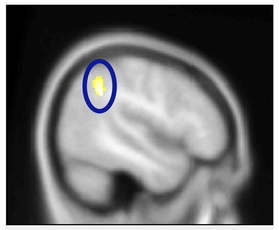


L2 Parity Accuracy (+) L hippocampus⁺

- Parity judgements in both languages were correlated with GMV in the left hippocampus
- L1 math performance was additionally associated with GMV in the right middle frontal gyrus

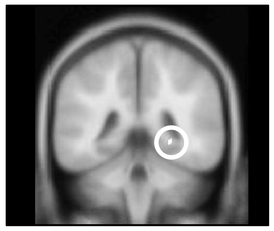
How does variability in neural structure relate to individual differences in cognitive abilities?

Basic math performance



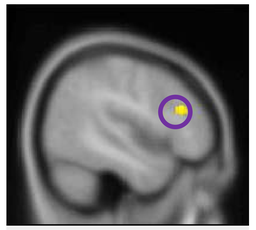
BMA (+) R IPL*
BMA (+) MFG⁺, L fusiform⁺ (not shown here)

Working Memory



LNS (+) R parahippocampus⁺

L2 Vocabulary



PPVT (+) R IFG⁺

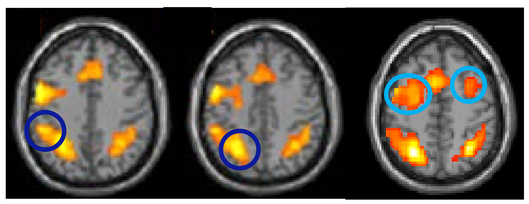
- Math performance was significantly associated with GMV in the right inferior parietal lobe
- Individual differences in working memory and L2 vocabulary correlated with GMV in the right parahippocampus and inferior frontal gyrus, respectively

**FWE corrected p < .05; ⁺uncorrected at p < .05*

fMRI Findings

Is math-related variability in neural structure reflected in our fMRI study?

fMRI findings → VBM ROIs

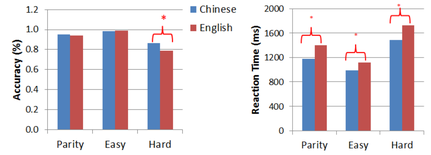


- Areas in the superior and inferior parietal lobe
- Bilateral middle frontal gyrus (MFG)
- Bilateral inferior frontal gyrus (IFG)
- Bilateral precuneus
- Left insula
- Bilateral precentral gyrus
- Bilateral superior frontal gyrus

- Math > parity: bilateral horizontal segment of the intraparietal sulcus (left) and the SPL (middle) and the bilateral MFG (right)
  - Similarly, BMA performance was correlated with GMV in the right IPL, and performance on hard math questions was correlated with GMV in the right MFG (not shown above)
- Math processing in L1 recruited more regions than in L2 (precentral gyrus and SFG)
  - While Parity judgments in L1 and L2 were associated with the left hippocampus, hard math questions were associated with the right MFG only in L1
    - Brain-behavior relationship may be more consistent in L1 than L2

Behavioral Results

fMRI Behavioral Results



Behavioral Correlations

- Math performance was positively correlated in L1 and L2
  - L1 and L2 Hard RT
- Working memory positively correlated with L2 math performance
  - L2 Parity Accuracy and L2 Hard Accuracy
- L2 vocabulary positively correlated with L2 math performance
  - L2 Hard Accuracy
- Math ability (BMA) was negatively correlated with frequency of translating from L1 to L2 for hard questions

Summary

- Basic math performance was significantly correlated with GMV in the right IPL
  - Consistent with previous studies of semantic representation of number quantities, numerical transcoding ability, and general math competence[1,5,6]
- Parity judgments in both languages were correlated with GMV in the left hippocampus
  - May reflect retrieval of fact-based information
- Math performance in L1 was also correlated with GMV in the right MFG
  - Consistent with our fMRI results and studies relating to effortful learning[12]
- Future studies should examine the longitudinal changes that may occur with:
  - Math training to examine if there is transferability of skills in other domains
  - L2 training to examine the effects of L2 proficiency on math processing

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*** Contact: Jennifer Legault (jtl190@psu.edu)**