Math and Psychology (and Neuroscience)

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Introduction

- ★ Why psychology?
  - The prevailing idea of the “math brain”
  - The people I know who study and teach math

DISCLAIMER: I don’t study psychology or neuroscience

Outline - Research Questions of Interest

- ★ Is there such a thing as a “math brain”?
- ★ Can anyone have a “math brain”?
- ★ Psychology/neuroscience and math education: what changes could we make to the education system?

DISCLAIMER: generally, there are not concrete answers to these research questions

Do we have math brains?

GABA and Glutamate

- ★ Neurotransmitters (chemical messengers) often associated with learning and “school-based skills”
  - We don’t have a lot of concrete information about this association in people
  - Both neurotransmitters are naturally occurring
    - It’s possible for a person’s level of either GABA or glutamate to be irregular; measures can be taken to regulate these levels
- ★ GABA
  - Inhibitory neurotransmitter
    - Calming effect on the brain
- ★ Glutamate
  - Excitatory neurotransmitter
  - Needed to make GABA

A Study

Roi Cohen Kadosh and colleagues conducted a study to analyze the concentration of GABA/glutamate and mathematical ability over time.

- ★ Procedure
  - Researchers administered math tests to 255 participants ranging in age (six years old - college students) while monitoring their brain activity
  - This process was repeated 1.5 years later
- ★ Results
  - Different associations found for younger v. older participants
  - For younger and older participants, GABA and glutamate levels were good predictors of their performance on the later math test

Interpreting these Results

- ★ Why the difference in correlations found between younger/older age groups?
  - GABA and glutamate may have different roles at different stages of development
- ★ Are these results useful?
  - Sort of!
    - A starting point for understanding why people at different ages/levels struggle with mathematical cognition
    - The better we understand this, the better we can work on the mechanisms involved, and potentially improve learning and mathematical cognition
  - Suggest the usefulness of learning interventions to regulate GABA/glutamate

A Framework for Mathematical Cognition

Camilla Gilmore and colleagues formulated a framework for how different components of mathematical cognition fit together

- ★ Their argument
  - Previous frameworks for mathematical cognition have utilized too broad a view of what constitutes mathematics and failed to categorize mathematical cognition
- ★ Their goal
  - Improve upon previous frameworks in order to help us:
    - Make sense of existing empirical evidence
    - Identify important unanswered questions
  - Although the framework is not intended to be a model of mathematical processing, implications about mathematical processing arise from the framework

Gilmore's Categorization

- ★ Gilmore's categorization of mathematical cognition: three levels
  1. (1) Overall mathematics achievement
  2. (2) Proficiency with specific components of mathematics
  3. (3) Basic mathematical processes
- ★ Further influences
  - General cognitive skills
  - Learning experiences

Previous/Alternative Approaches - Potential Issues

- ★ Vague (or nonexistent) categorization of mathematical cognition under alternative frameworks (and why this is an issue)
  - Use of broad measures of mathematics achievement
    - Makes it difficult to determine what factors play a role in learning/performing mathematics
  - Conflating broad achievement in mathematics with proficiency with specific components of mathematics
    - Makes it difficult to compare and combine findings across studies

Existing Evidence within Gilmore's Framework

How do basic mathematical processes connect to proficiency with specific components of mathematics?

- ★ Studies suggest a reliable relationship between several basic mathematical processes and proficiency with specific mathematical components
  - Magnitude comparison skills → mental/written arithmetic
- ★ Do basic mathematical processes = general cognitive skills?
  - In a word, no
  - General cognitive skills also do not explain the relationship between basic math processes and proficiency with specific components in general

Existing Evidence within Gilmore's Framework

How does proficiency with specific components of mathematics connect to overall mathematics achievement?

- ★ What specific components of math are associated with high overall achievement?
  - Early years of schooling: number fact retrieval, arithmetical skills, understanding of arithmetical principles, understanding of fractions
    - Variation in different years/stages of schooling
    - Lack of research on conceptual understanding

Existing Evidence within Gilmore's Framework

How does each level connect to general cognitive abilities?

- ★ Evidence suggests executive function skills are important for overall math achievement and proficiency with specific components of math
  - Potential shortcoming: studies focus mainly on arithmetic
- ★ Importance of working memory
  - Relationships found between working memory and whole-number calculation, word-problem solving, and more
- ★ Linguistic Influences?

Side Tangent

Language, Psychology, and Mathematical Cognition

How might your native language influence how you think?

- ★ A 2003 study investigated the acquisition of the base-ten system among children who spoke different languages
  - They observed differences in how children who spoke Chinese/Japanese/Korean compared to children who spoke French/Swedish/English represented numbers
    - One glaring potential issue here
- ★ A 2008 study attempted to distinguish between language and cultural effects
  - Tested Chinese and British primary school childrens' proficiency with specific components of mathematics (domain: arithmetic)
    - Found that language has a specific rather than all-pervasive influence on differences in arithmetic performance

How might your native language influence your brain?

- ★ A 2023 study compared brain connectivity in native German and Arabic speakers
  - German native speakers exhibited stronger connectivity in an intra-hemispheric frontal to parietal/temporal dorsal language network
    - Known to be associated with complex syntax processing
  - Arabic native speakers showed stronger connectivity in the connections between semantic language regions, including the left temporo-parietal network, and stronger inter-hemispheric connections via the posterior corpus callosum connecting bilateral superior temporal and inferior parietal regions
    - As far as I could find, associated with structural processing
      - Might be meaningful for mathematical cognition, might not be

Existing Evidence within Gilmore's Framework

What is the impact of mathematical learning experiences?

- ★ Most research investigating this question has only considered the connection between learning experience and overall mathematical achievement!
  - Very disappointing to me
- ★ Children's understanding of mathematical equivalence
- ★ Influences on basic mathematical processes
  - Informal learning experience may be important, but this is underexplored

Do we have math brains?

Can we all have math brains?

The Brain of a Mathematician

- ★ A 2016 study compared the brain activity of mathematicians and nonmathematicians of the same academic standing
  - While in an MRI scanner, the subjects listened to 72 high-level math statements, and 18 high-level nonmathematical statements
- ★ Results
  - For mathematicians only, a network of the brain was activated when they listened to the math-related statements
  - Co-author Marie Amalric, “our results show that high-level mathematical reflection recycles brain regions associated with an evolutionarily ancient knowledge of number and space.”
    - Previous research has found that these nonlinguistic areas are active when performing basic arithmetic or even simply seeing numbers on a page

Interpreting the Results

- ★ Suggests a link between advanced and basic mathematical thinking
- ★ Stanislas Dehaene
  - Has conducted research suggesting humans are born with some intuitive sense of numbers
    - However, we don't know how the connection between this intuitive "number sense" and higher-level math is formed
- ★ An interesting question
  - Is an innate capability to recognize different quantities (an intuitive "number sense") the biological foundation on which the capacity to master group theory can be built?

The Knowledge

https://www.youtube.com/watch?v=sU4W36_5oiM

The Brain's Capacity for Growth

- ★ "The Knowledge" London black cab driver test
  - Neuroscientists decided to study their brains
  - Important breakthrough in understanding brain plasticity
- ★ Numerous studies since have shown extensive brain growth in people of all ages
- ★ How can we train our brains to be better at math?
  - The power of struggle
  - Making connections!
  - "Open focus"
    - https://www.youtube.com/watch?v=_7gu1PKg7oM

Can we all have math brains?

What about math education?

Back to the Math Brain Conundrum

- ★ Fixed-ability language and “gifted” programs
  - Detrimental for children who are not “gifted”
  - Also! Detrimental for children who are “gifted”
    - Children told they are gifted or have a math brain struggle to struggle
- ★ Should we be grouping students by ability?

Math Drills and Timed Tests: A Touchy Subject

- ★ Are math drills and timed tests helpful for learning math?
  - For: free up working memory to handle more complicated math problems by making basic arithmetic automatic
  - Against: produce so much anxiety that it overwhelms working memory and prevents learning
- ★ Lack of empirical evidence that timed math tests cause anxiety
  - This can't be right
    - And it would seem it isn't, really
- ★ First person accounts
  - People get stressed and forget things
  - People decide they aren't a math person and lose interest
- ★ Argument for timed activities and games (instead of tests)

The End

Thank you for listening! :)

Discussion Questions:

1) What do you make of these research questions in light of the evidence presented?
2) Were you ever told you had a “math brain”? Did your school have a “gifted” program?
    a) How do you think your education was impacted by this, if at all?
3) What other experiences have you had while learning math? What’s worked for you? What should change?
    ~~a)~~ Does all this research make you think differently about any of this?