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Using Cognitive Modeling to Understand the Roles of Prefrontal and Posterior Parietal Cortex in Algebra Problem Solving

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Introduction

• *Retrieval* and *transformation* are highly correlated in algebra problem solving:

• The current instantiation of the ACT-R theory (Anderson, 2005) associates *retrieval* and *transformation* with activity in *prefrontal* and *posterior parietal cortex*, respectively

• Activity in these regions are likewise correlated during naturalistic problem solving (Anderson et al., 2003)

• Can we isolate the processes of transformation and retrieval in algebra problem solving and manipulate them independently?

• If so, can we also isolate activity in their neural correlates?

Method

• 20 participants run in a BOLD fMRI study

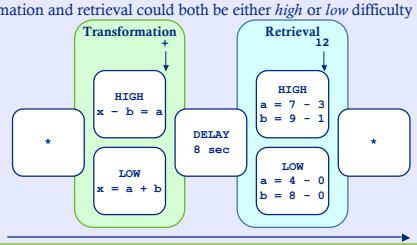
• Algebra equations were created that needed to be solved in 2 phases:

  • *Transformation phase*: isolate x from a and b

    •Retrievals are delayed until numerical values of a and b are given

  • *Retrieval phase*: calculate the value of x given the numerical values of a and b

• The transformation and retrieval could both be either *high* or *low* difficulty

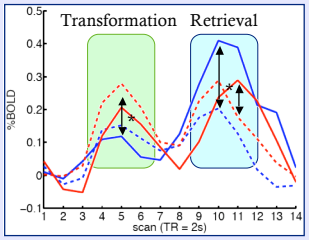


Results and Modeling

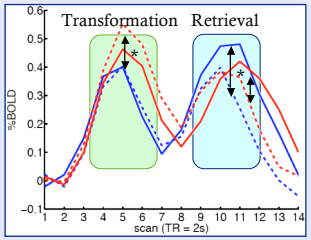
• Manipulating *retrieval load* of algebra problems results in differential activity in both *prefrontal* and *posterior parietal* cortex

• Manipulating *transformational requirements* of algebra problems results in differential activity in both *prefrontal* and *posterior parietal* cortex

Prefrontal Cortex



Posterior Parietal Cortex



Low Trans, Low Ret — Low Trans, High Ret — High Trans, Low Ret — High Trans, High Ret

• Why did our manipulations fail to isolate the activity in these regions?

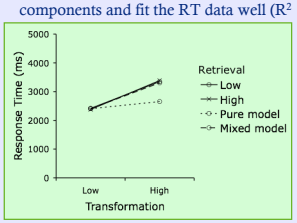
  • **Explanation 1:** These regions are not functionally distinct as characterized by ACT-R

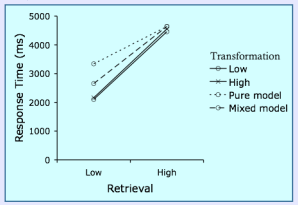
  • **Explanation 2:** Our task manipulations failed to properly isolate retrieval and transformation

• We designed two ACT-R models to determine the plausibility of Explanation 2

  • **Pure Model:** Encompassed our initial assumptions about the design but failed to fit the RT data (R^2 = .50)

  • **Mixed Model:** Assumed that both manipulations had retrieval and transformation components and fit the RT data well (R^2 = .94)





Pure Model

Low Transformation		High Transformation	
Low Retrieval	High Retrieval	Low Retrieval	High Retrieval
Encode x + a = b	Encode x + a = b	Encode x - b = a	Encode x + a = b
Retrieve key for +	Retrieve key for +	Transform	Transform
Respond +	Respond +	Retrieve key for +	Retrieve key for +
Encode a = 4 - 0	Encode a = 7 - 3	Respond +	Respond +
Encode b = 8 - 0	Retrieve 7 - 3 = 4	Encode a = 4 - 0	Encode a = 7 - 3
Retrieve 4 + 8 = 12	Encode b = 9 - 1	Encode b = 8 - 0	Retrieve 7 - 3 = 4
Retrieve key for 2	Retrieve 9 - 1 = 8	Retrieve 4 + 8 = 12	Encode b = 9 - 1
Respond 2	Retrieve 4 + 8 = 12	Retrieve key for 2	Retrieve 9 - 1 = 8
	Retrieve key for 2	Respond 2	Retrieve 4 + 8 = 12
	Respond 2		Retrieve key for 2
			Respond 2

Mixed Model

Low Transformation		High Transformation	
Low Retrieval	High Retrieval	Low Retrieval	High Retrieval
Encode x + a = b	Encode x + a = b	Encode x - b = a	Encode x + a = b
Retrieve key for +	Retrieve key for +	Retrieve Operator	Retrieve Operator
Respond +	Respond +	Transform	Transform
Encode a = 4 - 0	Encode a = 7 - 3	Retrieve key for +	Retrieve key for +
Encode b = 8	Retrieve 7 - 3 = 4	Respond +	Respond +
Retrieve 4 + 8 = 12	Encode b = 9 - 1	Encode a = 4 - 0	Encode a = 7 - 3
Retrieve key for 2	Retrieve 9 - 1 = 8	Encode b = 8	Retrieve 7 - 3 = 4
Respond 2	Retrieve 4 + 8 = 12	Retrieve 4 + 8 = 12	Encode b = 9 - 1
	Retrieve key for 2	Retrieve key for 2	Retrieve 9 - 1 = 8
	Respond 2	Respond 2	Retrieve 4 + 8 = 12
			Retrieve key for 2
			Respond 2

Conclusions

• There is a lot of difficulty isolating the basic cognitive processes characterized by ACT-R

• The difference between the roles of prefrontal and posterior parietal cortices in algebra problem solving remains unclear

• Using cognitive modeling can help in the interpretation of behavioral and neuroimaging data

References

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