Vatican Talk


TIME
HOW A CHILD'S BRAIN DEVELOPS

Brain-Based Education

- The first 10-12 years of life is a period of elevated synaptic density and brain metabolism.
- This is the critical period in brain development.
- During the critical period, children learn more quickly and efficiently than at any time in development.

Education and the Brain: A Bridge Too Far

(Educ. Researcher, November 1997)

- Too little is known about how developmental synaptogenesis relates to learning.
- Supposed implications of developmental neuroscience do not cohere with what cognitive and educational psychology has revealed about learning.
- Currently, cognitive psychology is the best candidate for a basic science of learning.
- In the future, cognitive neuroscience is the field most likely to develop educationally relevant brain science.
- Cognitive psychology – an intermediate-level theory between brain and behavior – is fundamental both for improving education (immediately) and advancing brain science (and education eventually).

Three Objectives

1. Question the dominant role the development of visual cortex has had on thinking about the neural bases of human learning.
2. Illustrate the importance of cognitive models for educational research and practice.
3. Address how *cognitive* neuroscience can provide converging evidence to refine educationally relevant cognitive models.

Neurobiological Perspectives

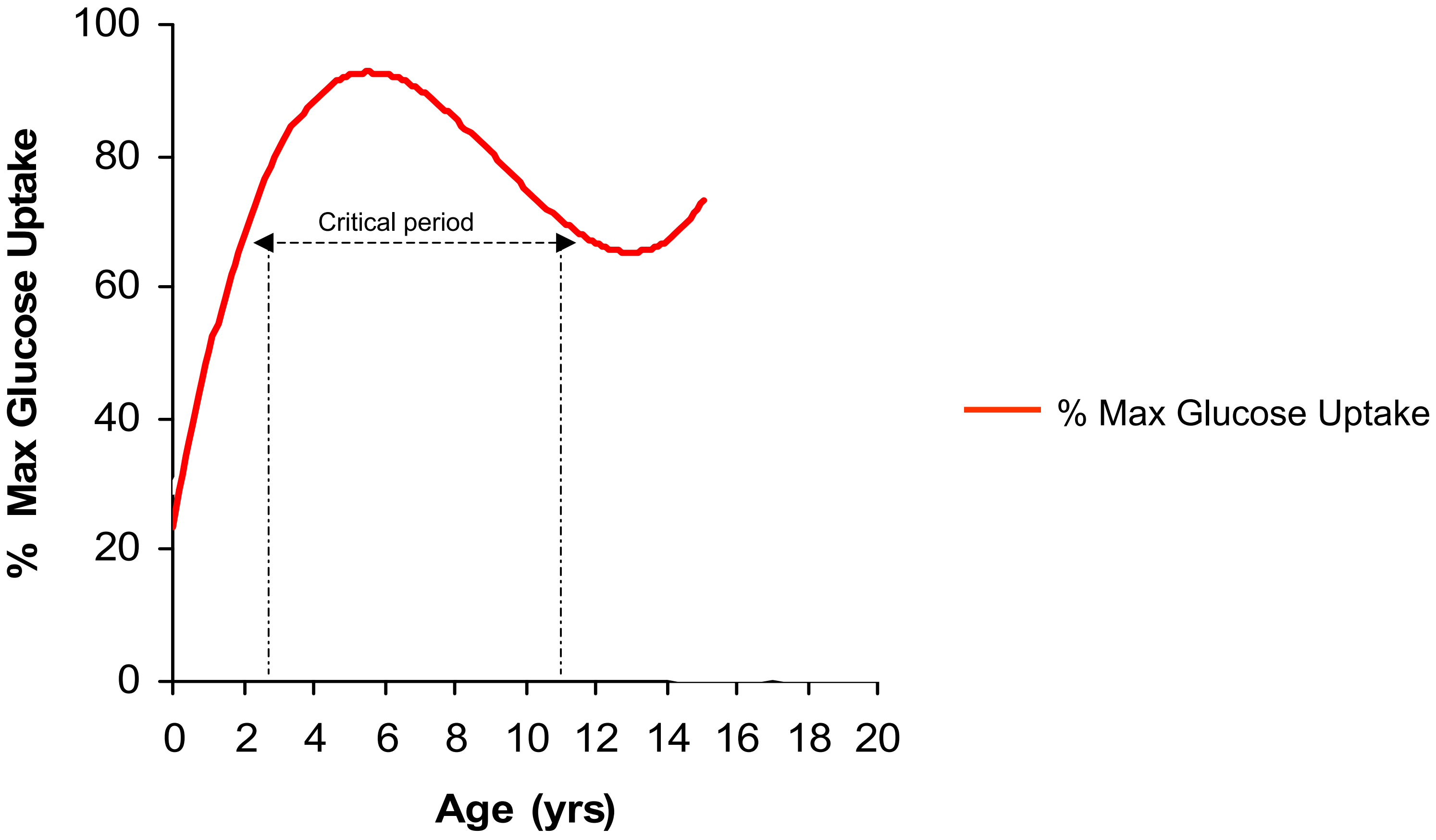
The existence of several discrete stages in the formation of the **ocular dominance columns** is likely to represent a general feature of development. … If this were so it might explain … why certain capabilities -- such as those for language, music, or mathematics -- usually must be developed well before puberty if they are to develop at all … . *(Kandell & Schwartz, 1991, p. 957)*

Data show good correlations between age of synaptic pruning and decline in brain plasticity, especially in more simple systems, such as **visual cortex**. *(Huttenlocher, Nature Neuroscience, 2002)*

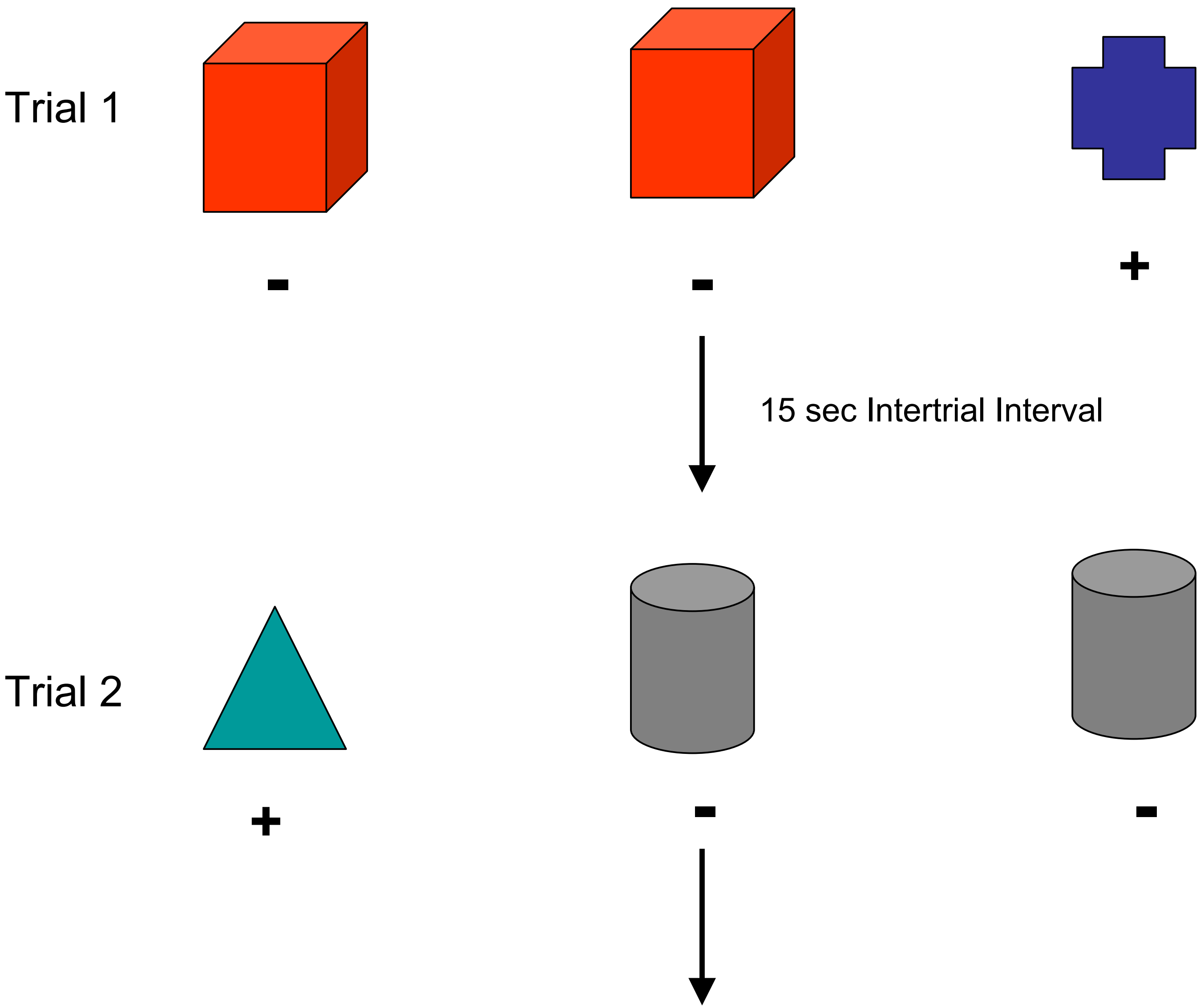
Studies of the plasticity of the visual cortex during the critical period of postnatal development are particularly germane in light of recent controversies about the importance of early childhood experience in determining cortical competency in adults. … ***The visual cortex represents the best model system that we have for understanding how sensory stimulation of the early brain influences brain circuitry and function throughout life.*** *(M. Cynader, Science, 2000)*

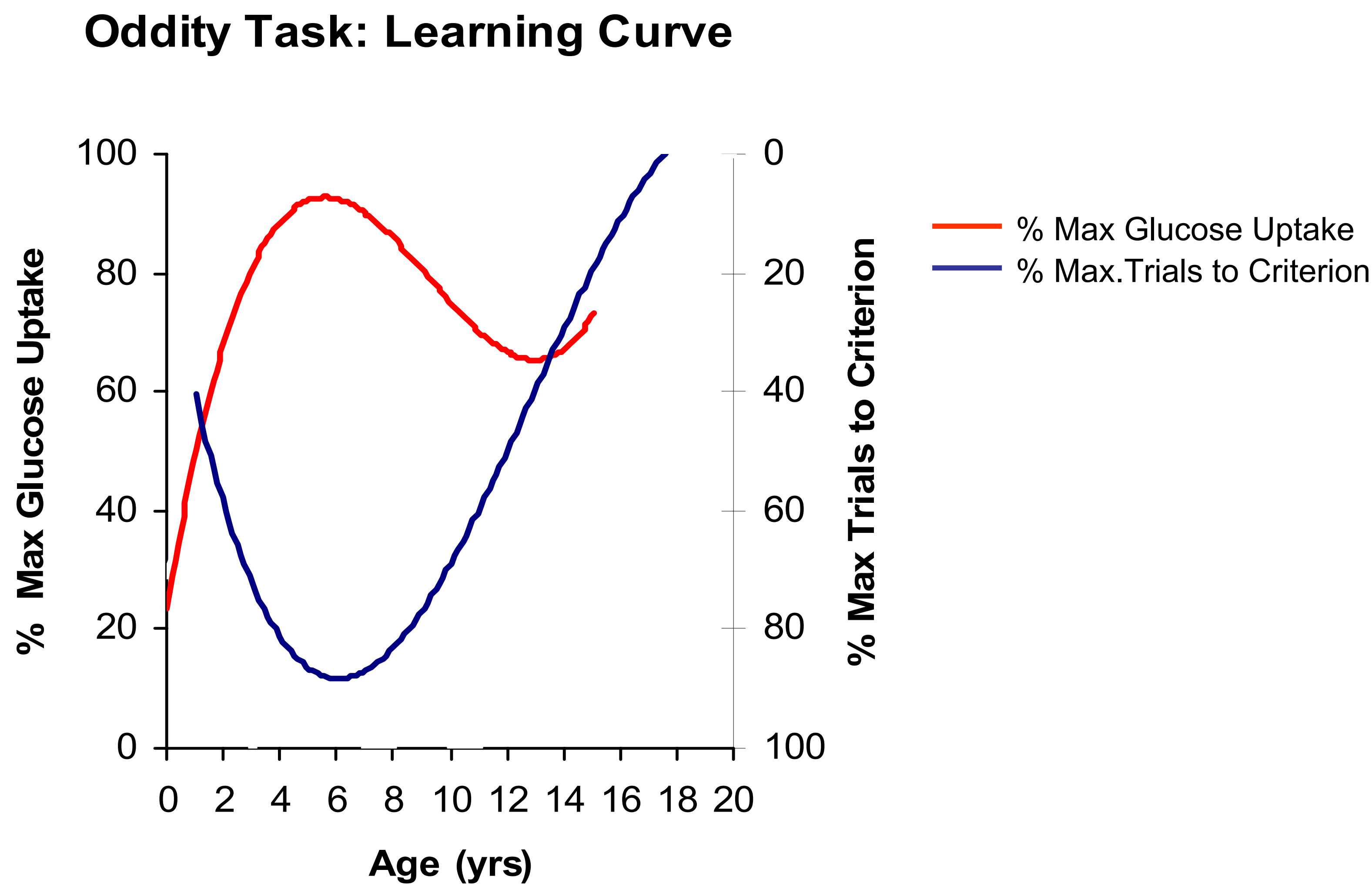
Thus, it is now believed by many (including this author) that the biological "window of opportunity" when learning is efficient and easily retained is perhaps not fully exploited by our educational system. *(H. Chugani, Preventive Medicine 27:184-88, 1998)*

Change in Glucose Uptake (Frontal Cortex)



Oddity with Trial Unique Objects





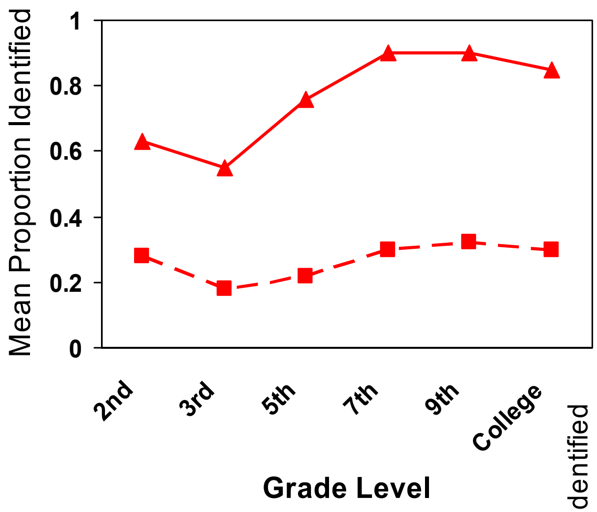
Oddity Task: Learning Curve
100
80
60
40
20
0
0
20
40
60
80
100
0 2 4 6 8 10 12 14 16 18 20
Age (yrs)
% Max Glucose Uptake
% Max Trials to Criterion
% Max Glucose Uptake
% Max.Trials to Criterion

Learning Other Tasks

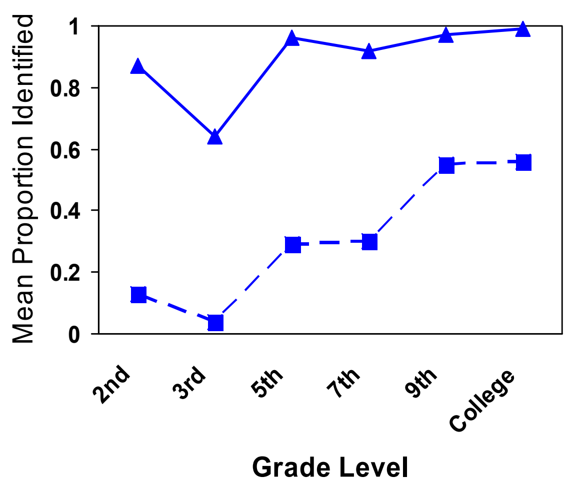
- Adult monkeys and humans learn DNMS more quickly than do immature subjects. (Bachevalier & Mishkin 1984, Overman 1990)
- Adults learn spatial navigation tasks more quickly than young children. (Overman et al.1996)
- Adult humans and monkeys learn discrimination tasks more quickly than do immature subjects. (Overman, Bachevalier, Schumann, & Ryan, 1996)

Development of Expert/Novice Knowledge
(Means & Voss 1985)

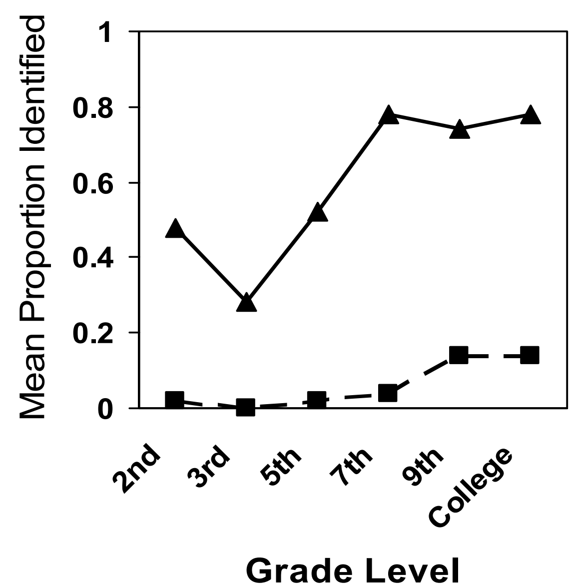
Basic Actions



Subgoal Breadth



High Level Goals



Expert

Novice

Time windows of opportunity (optimum periods) for various functions

Function	Age
Recovery of facial movements after stroke	→ Fetus to neonate
Reversal of strabismic amblyopia	→ 1-5 years
Acquisition of absolute pitch	→ Up to age 10 years
Recovery of language after stroke	→ Up to age 8 years
Accent-free second language learning	→ Up to early adolescence

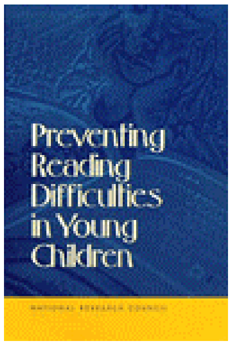
Huttenlocher 2002. p.212

Developmental Neurobiology and Education

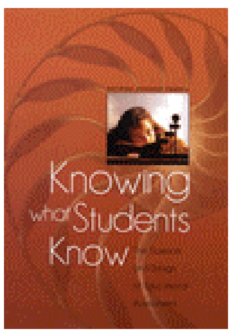
- Implications of brain science for education must be consistent with, and constrained by, decades of research in cognitive and educational psychology.
- “Learning” is shorthand for a vast, varied set of behaviors and cognitive abilities that likely have a vast, varied set of neural correlates.
- A mind-brain-education research program must address strengths and limitations of the visual system as the neural model for development and learning.

National Reading Panel

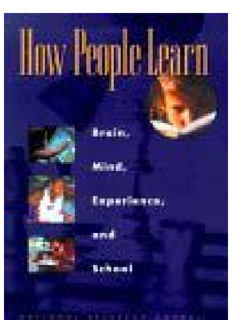
• No brain science mentioned or cited.



• Cites two neuroscientific studies (Shaywitz, 1996, Shaywitz et al. 1998), but “finding anomalous brain systems says little about change, remediation, response to treatment.”

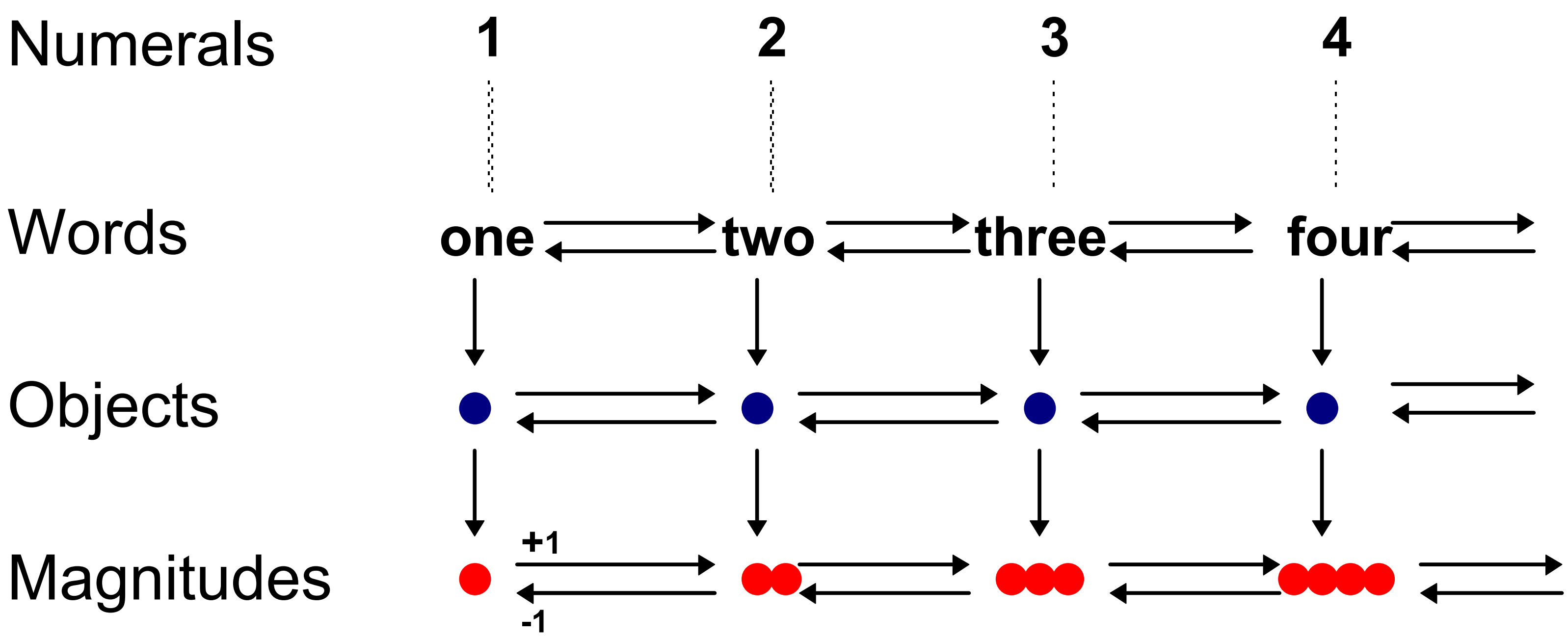


• A six-page appendix, “Cognition and Brain Science, dismisses “brain-based” claims about lateralization, enriched environments, and critical periods, but acknowledges promise of some neuroscientific research on dyslexia (e.g. Shaywitz, Tallal, Merzenich)



• One ten-page chapter concludes:
  • our current understanding of how learning is encoded by structural changes in the brain provides no practical benefit to educators
  • brain scientists should think critically about how their research is presented to educators

Central Conceptual Structure for Elementary Arithmetic



Kindergartner’s Performance on Number Knowledge Test (% Correct)

Item	High SES	Low SES
Here’s a candy. Here are 2 more How many do you have?	100	92
Which pile has more? (Show two piles of chips.)	100	93
How many triangles are there? (Show mixed array of triangles/circle.)	85	79
If you had 4 candies and received 3 more, how many would you have?	72	14
What comes two numbers after 7?	64	28
Which number is bigger/smaller? (Show two Arabic digits.)	96	18

Mean Scores (s.d) on Number Knowledge Test Pre- and Post Number Worlds Instruction

Group	Pre-K	Post-K	Post-Gr. 1
Treatment 1	6.3(2.5)	11.2(2.7)	16.5(3.0)
Treatment 2	5.7(2.5)	12.1(1.9)	17.4(2.0)
Control 1	7.2(2.4)	8.9(2.4)	12.5(2.8)
Control 2	7.2(2.0)	9.3(2.8)	14.3(2.9)
Norm 1	9.8(3.2)	11.4(2.8)	16.9(4.0)
Norm 2	10.6(1.7)	13.5(2.9)	18.8(2.9)

Expected Score: K = 9 - 11; Grade 1 = 16 -18

From S. Griffin and R. Case, Teaching Number Sense, Table 3, Yr. 2 report, August 1993

Learning Multi-Digit Algorithms

Arithmetic Bugs

Smaller from larger:

```
  930
- 653
-----
  433
```

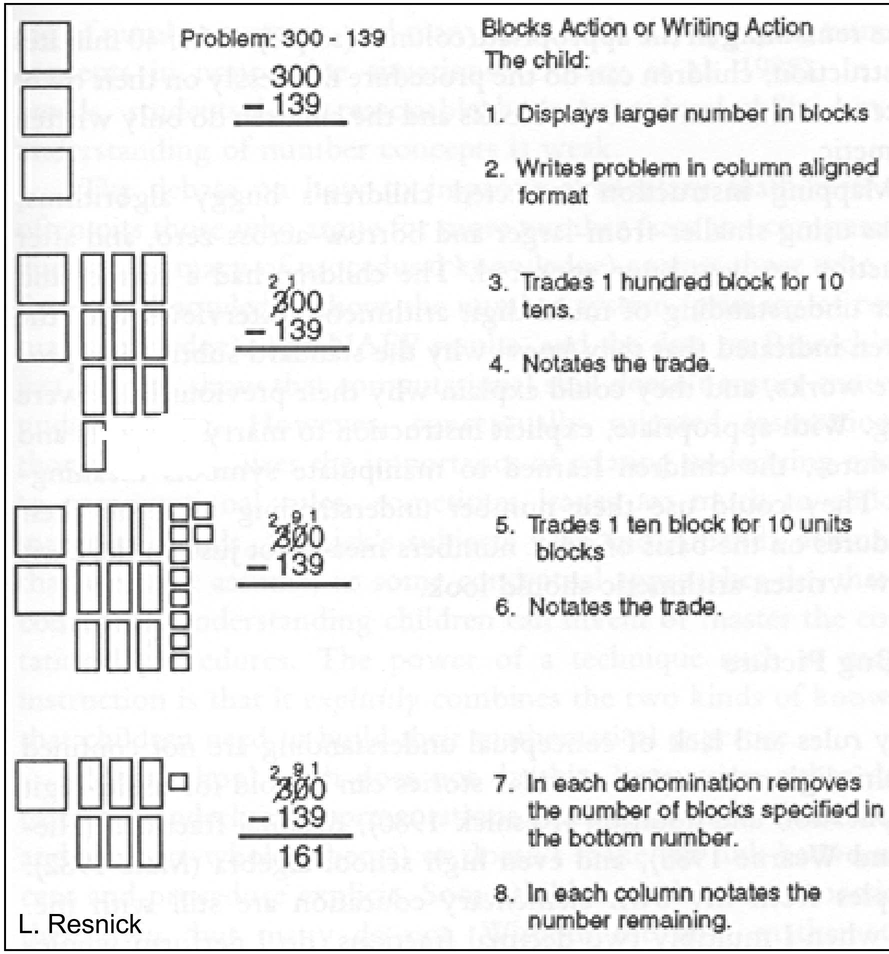
Borrow from zero:

```
  602
- 437
-----
  265
```

Borrow across zero:

```
  602
- 327
-----
  225
```

Brown & VanLehn



L. Resnick

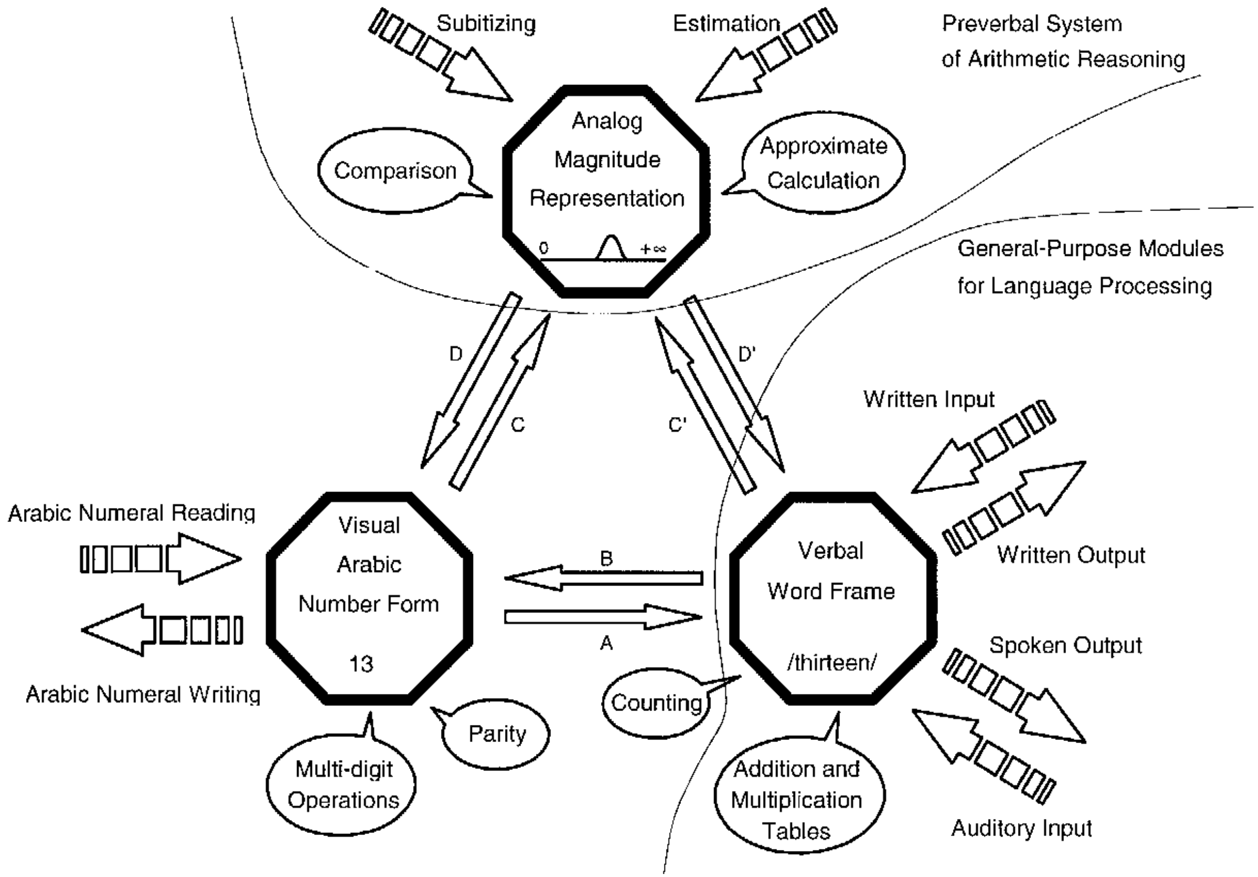
The Transition from Arithmetic to Algebraic Reasoning

Problem Type	Teacher Rank	Student Performance
When Ted got home from work, he took the $81.90 he earned that day and subtracted the $66 received in tips. Then he divided the remaining money by the 6 hours he worked and found his hourly wage. How much per hour does Ted earn?	4	1
Starting with 81.9, if I subtract 66 and then divide by 6, I get a number. What is it?	1	2
Solve: $(81.90 - 66)/6 = y$.	2	5
When Ted got home from work, he multiplied his hourly wage by the 6 hours he worked that day. Then he added the $66 he made in tips and found he earned $81.90. How much per hour does Ted make?	6	3
Starting with some number, if I multiply it by 6 and then add 66, I get 81.9. What number did I start with?	5	4
Solve: $y \times 6 + 66 = 81.90$	3	6

Adapted from Nathan & Koedinger, Cognition and Instruction, 18(2):209-237.

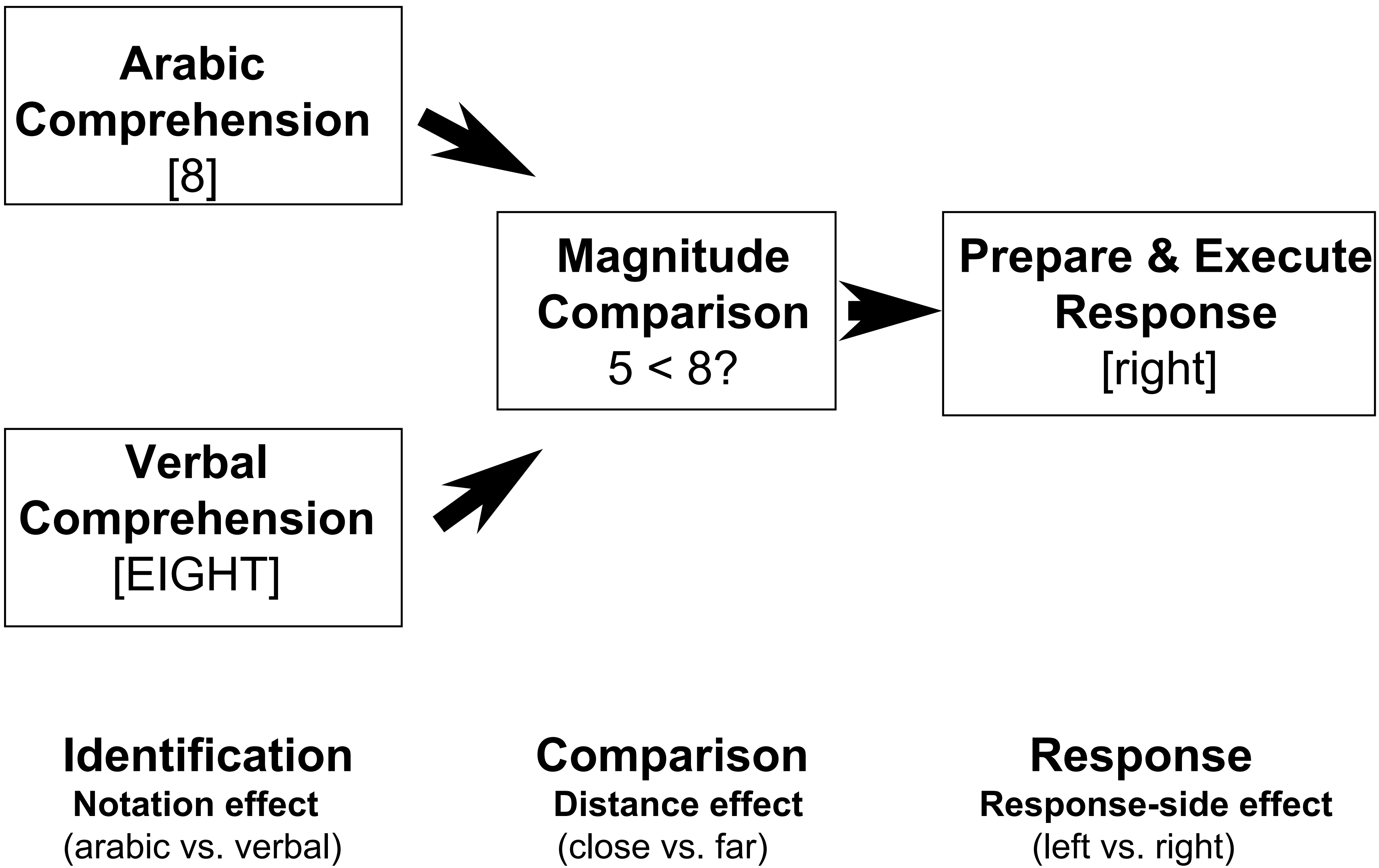
Rank correlation: -.09

Cognitive Models and Learning Problems



What kinds of evidence can support and constrain cognitive models?

- Cognitive psychological studies of mature performance.
- Cognitive developmental studies of children’s performance.
- Animal studies of related or “pre-cursor” skills (e.g. numerosity in animal species).
- Neurological lesion studies that provide behavioral dissociations and insights about localization.
- Imaging studies that seek neural correlates for basic cognitive processes.



(S. Dehaene, J. Cognitive Neuroscience, 8(1), p49, 1996)

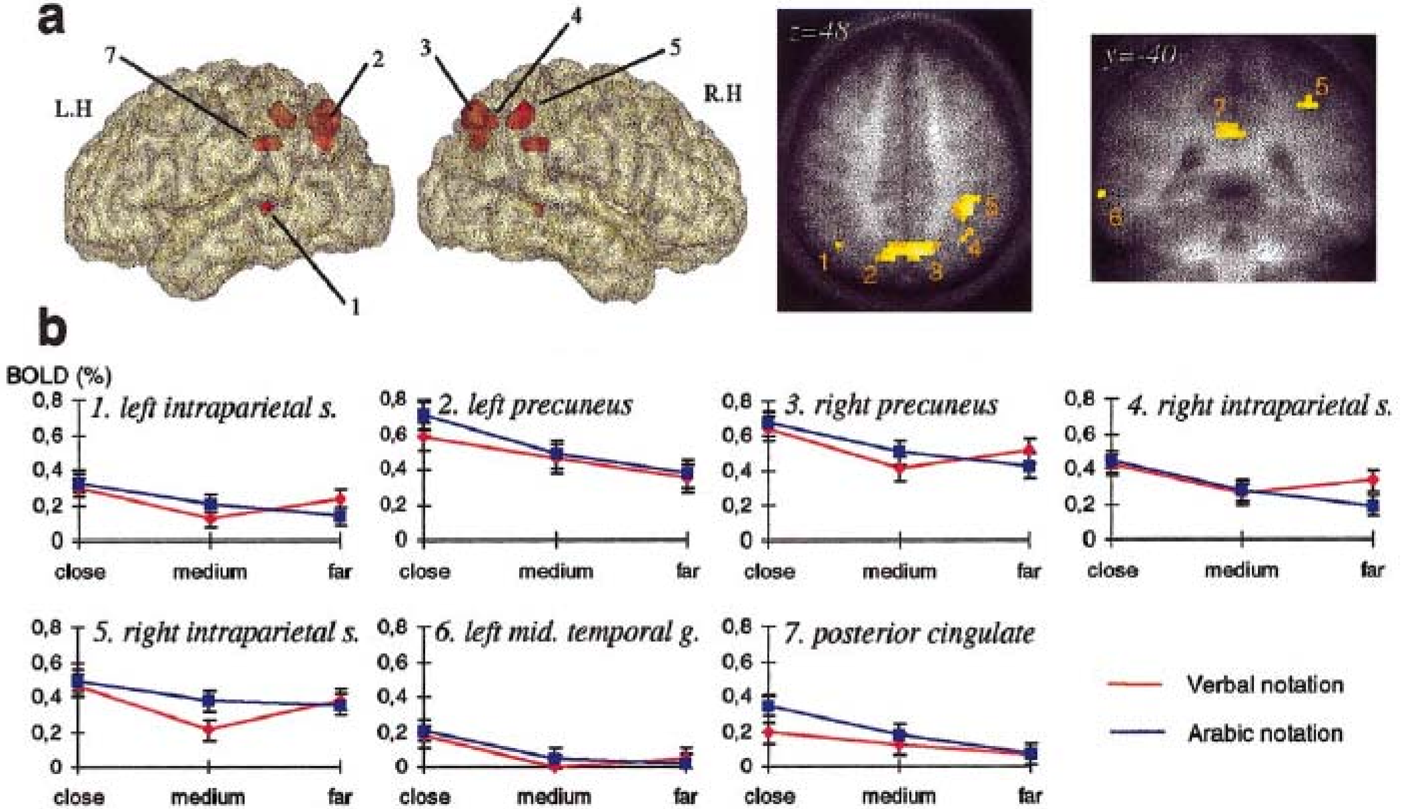
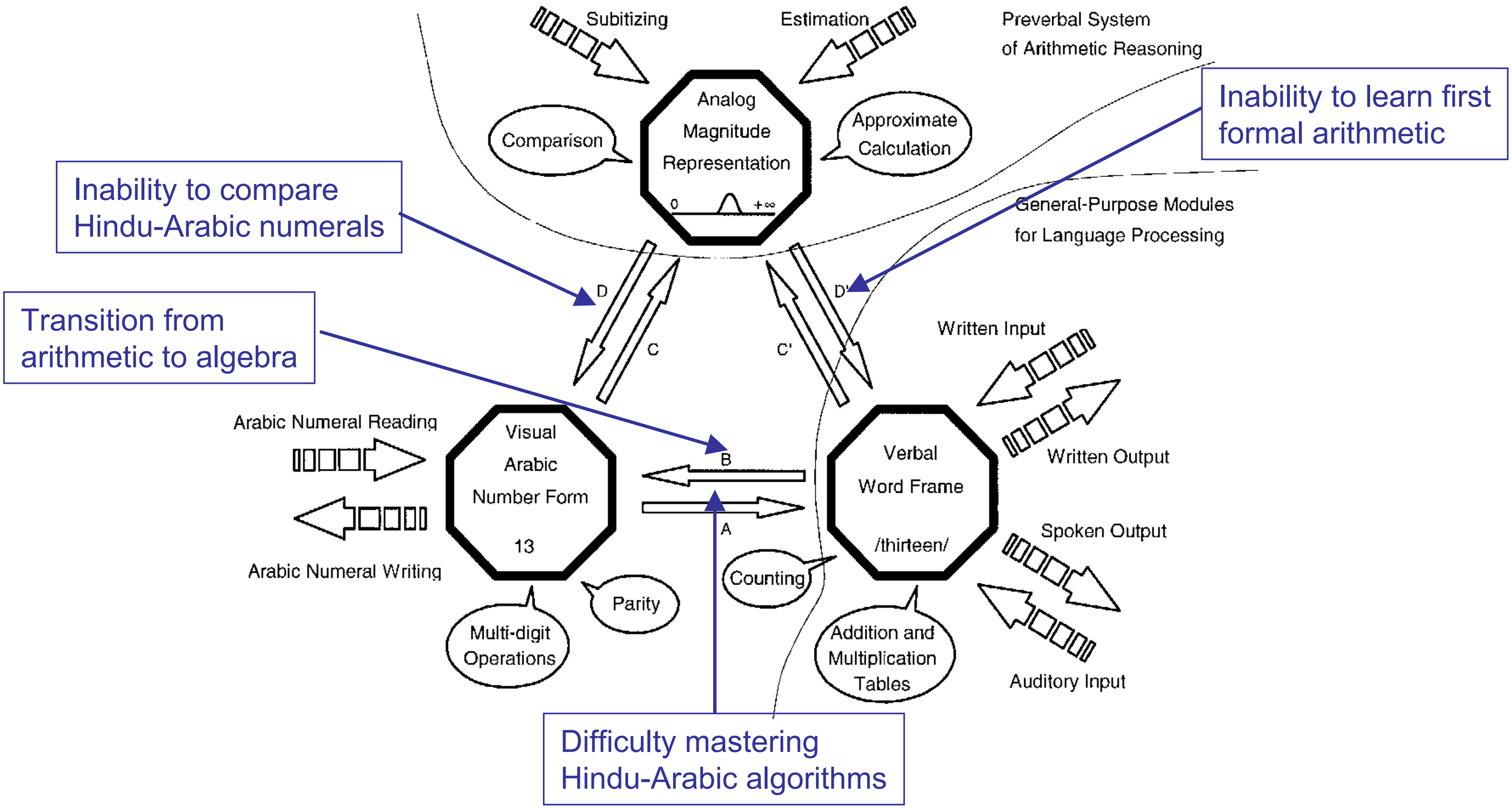


FIG. 2. fMRI of the distance effect in the group analysis. (a) Localization of brain areas affected by numerical distance ($P < 0.05$ corrected). On the left, 3D representation of these regions on a transparent brain (L.H, left hemisphere; R.H, right hemisphere). On the right, detailed position of each region on an axial and a coronal anatomical slice. (b) For each identified region, plots show percentage activation for the most significant voxel as a function of numerical distance in the verbal (red) and Arabic (blue) conditions. Length of statistical significance bars represents $\frac{1}{2}\sqrt{(MSE/n)}$, where MSE is the mean square error associated with the subject $\times$ conditions interaction and n the number of subjects.

Cognitive Models and Learning Problems



- What makes cognitive neuroscience *cognitive* neuroscience?

- *Cognitive* neuroscience seeks mental correlates of cognitive models and analyses, not of unanalyzed behaviors.

Cognitive Neuroscientific Method

- Cognitive Assumptions:
  – Elementary mental operations are at the basis of human behavior.
  – Cognitive models show how elementary operations are orchestrated to regulate behavior.

- Cognitive Neuroscientific Assumption: Although elementary operations are strictly localized in the human brain, cognitive models are implemented in distributed brain areas.

- Neuroscientific models do not provide information about the computations performed at nodes in the theories.

- Cognitive models do not provide information about neural anatomy involved.

- Cognitive neuroscience attempts to relate the specific elementary mental operations as developed from cognitive models to neural anatomical areas.

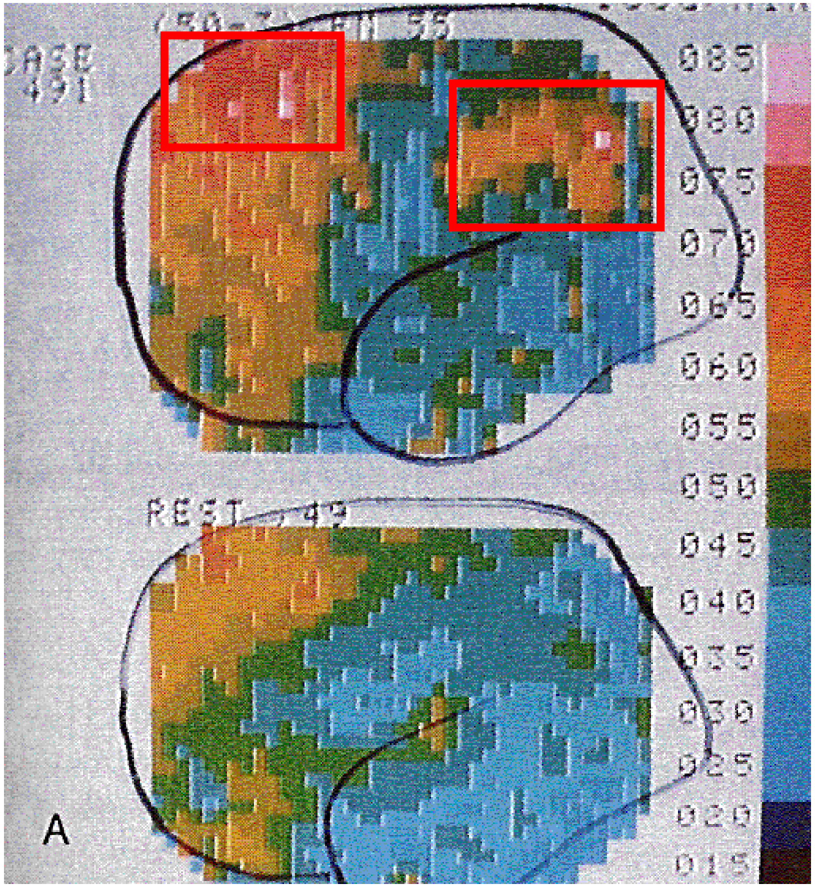
Posner et al, 1988

Analyzing functional imaging studies

- The research should be hypothesis-driven; for imaging studies, this means asking questions like "Is the hippocampus involved in retrieval of episodic memories?" rather than "What happens in the brain when subjects play chess?"
- Well-designed imaging studies allow scientists to ask questions about basic cognitive processes, rather than identifying networks of brain regions activated by a series of tasks.
- Such research relies on the authors' ability to isolate the cognitive process of interest, and so the sophistication of the behavioral design is crucial.
- Imaging studies are strengthened by correlations between behavioral performance and brain activation, particularly when these correlations can be demonstrated on single trials or for individual subjects.

Numerical Cognition: An early functional imaging study

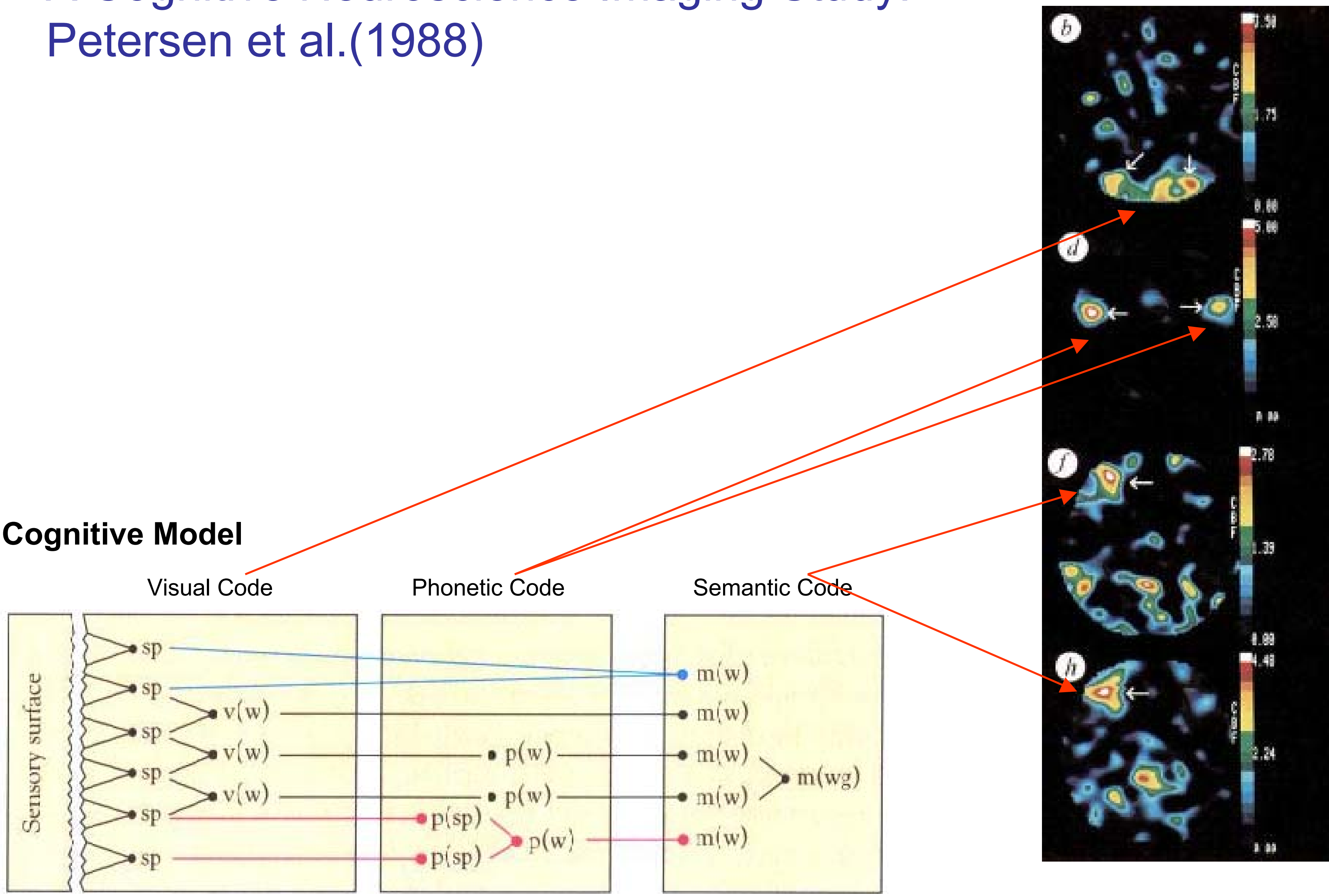
Counting backward from 50 by 3s



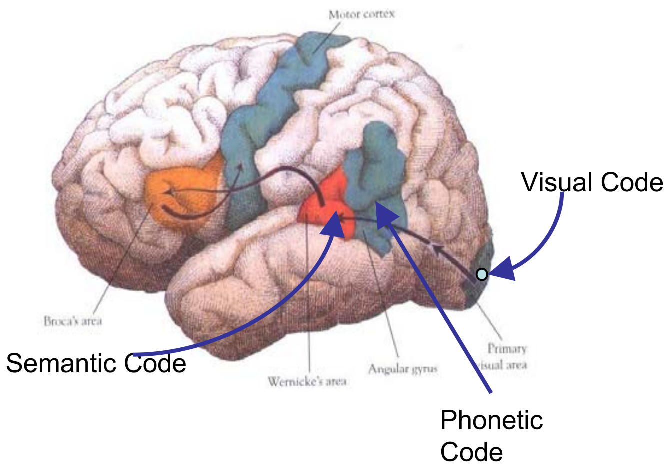
Roland & Friberg (1985) J. of Neurophysiology 53(5):1227

A Cognitive Neuroscience Imaging Study: Petersen et al.(1988)

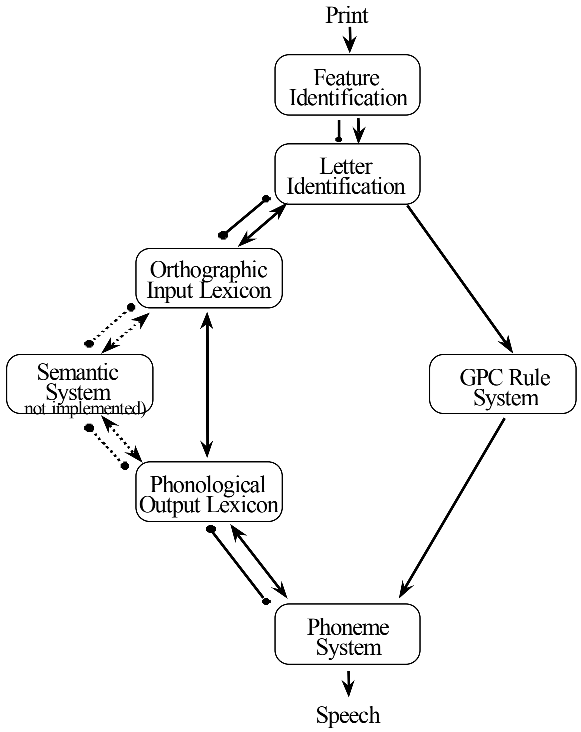
Cognitive Model



Neurological Model



Cognitive Dual Route Model



- Lack of activation in Wernicke's area and angular gyrus is consistent with the claim that the visual code has direct access to output coding without mandatory phonological recoding.
- Semantic processing activates frontal, rather than posterior temporal regions.
- The imaging results are consistent with a multiple-route cognitive model.
- The imaging results are inconsistent with the single-route neurological model.
- Imaging results can provide independent, converging evidence to complements results from both cognitive psychological studies and lesion studies (also independent data sources) that speak to the adequacy of cognitive models.

Fiez et al., Neuron, 1999

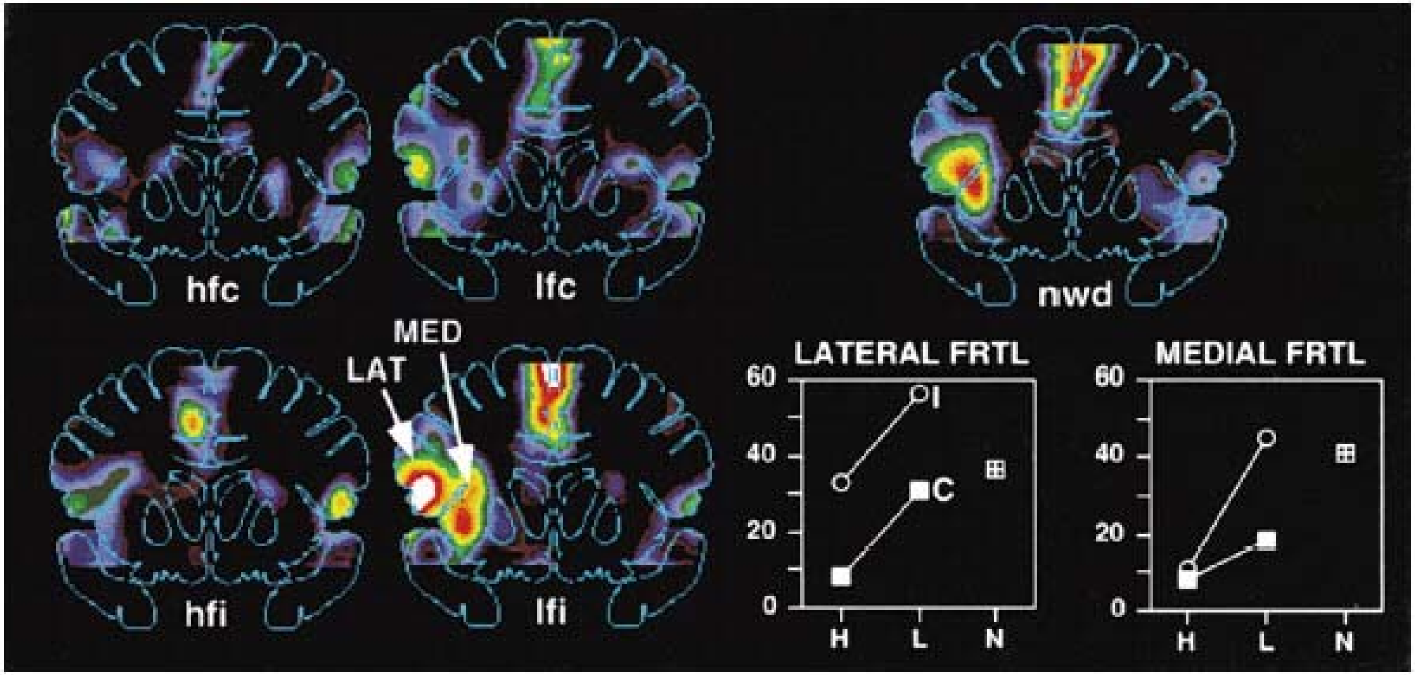
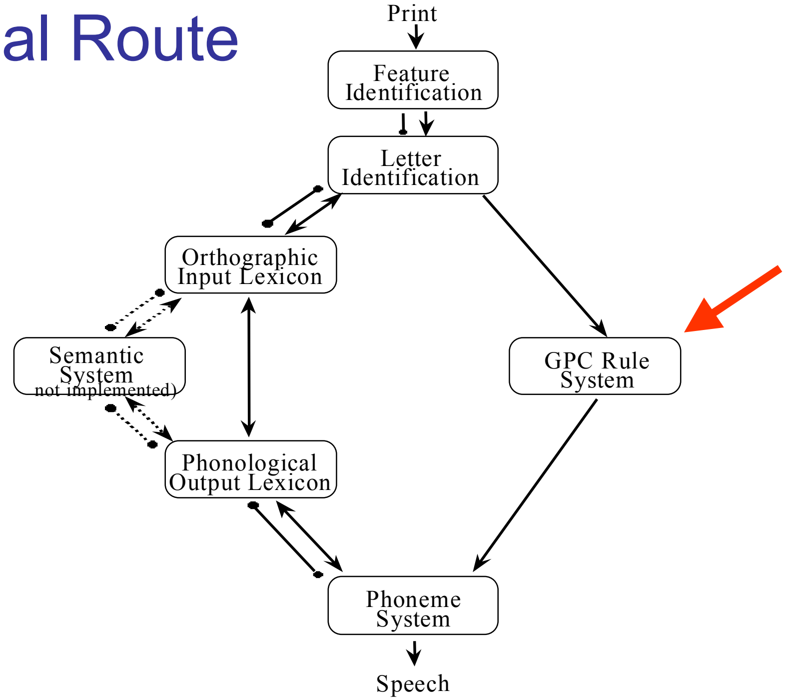


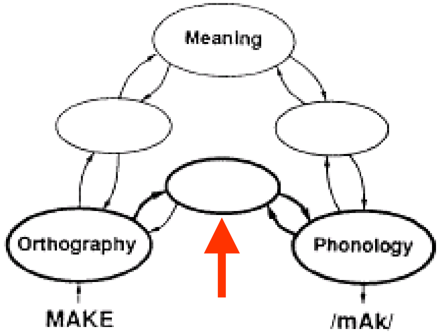
Figure 1. Left Lateral and Medial Frontal Opercular Activation Is Shown across the Four Word Conditions and the Pronounceable Nonword Condition

The images are coronal sections located 13 mm anterior to the anterior commissure, with magnitudes represented by a color scale that ranges from 0 (dark purple) to 60 (white) counts. The graphs show mean regional magnitudes across frequency (H, high; L, low; N, nonword), with inconsistent words indicated by the open circles, consistent words indicated by the closed squares, and nonwords indicated by the patterned square. hfc, high-frequency consistent; lfc, low-frequency consistent; hfi, high-frequency inconsistent; lfi, low-frequency inconsistent; nwd, nonword condition.

Dual Route



Connectionist



- Left frontal activity is consistent with both dual route and connectionist models of lexical processing.
- Imaging and neuropsychological evidence suggest that the left frontal region *contributes to* but is *not limited to* orthographic to phonological transformation.
- Imaging and neuropsychological evidence also suggest the region is not *critical for all types* of phonological processing.
- What types of lexical and sub-lexical processing does phonology posit?

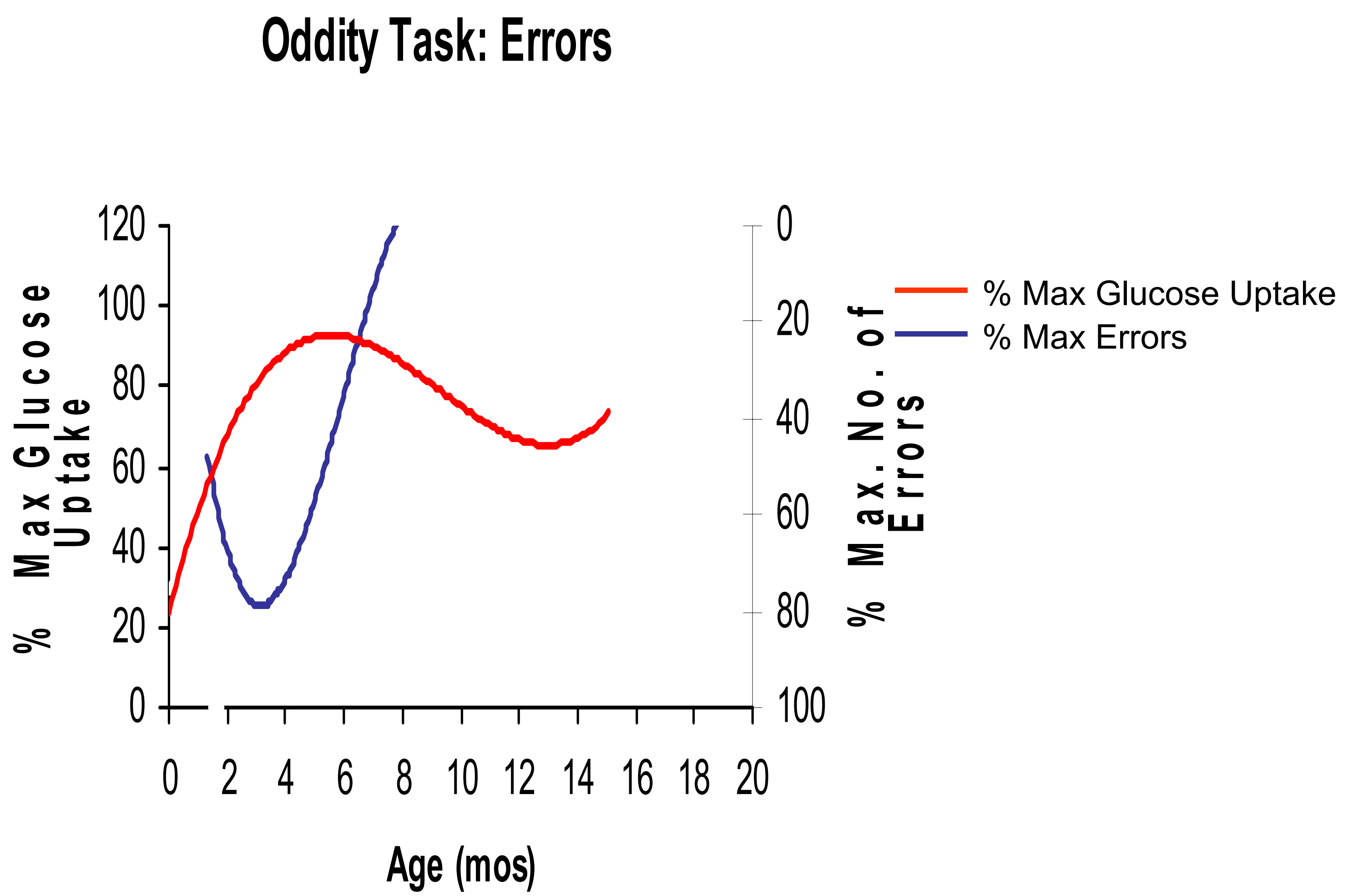
Conclusions

- A mind-brain-education research program must
  - Critically address the implications of developmental neurobiology for learning.
  - Make room for cognitive psychology – an intermediate level theory of the mental -- in this program.
- *Cognitive* neuroscience brings converging behavioral, cognitive, and neural evidence to the development and refinement of cognitive models.
- Cognitive models can have educational implications and applications.

Question

- At the current time, might it be better to encourage research in NeuroLearning (a basic science) rather than NeuroEducation (an applied science)?

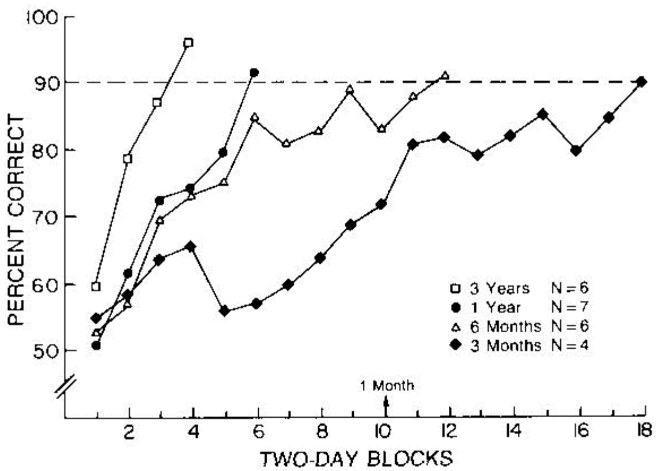
THE END



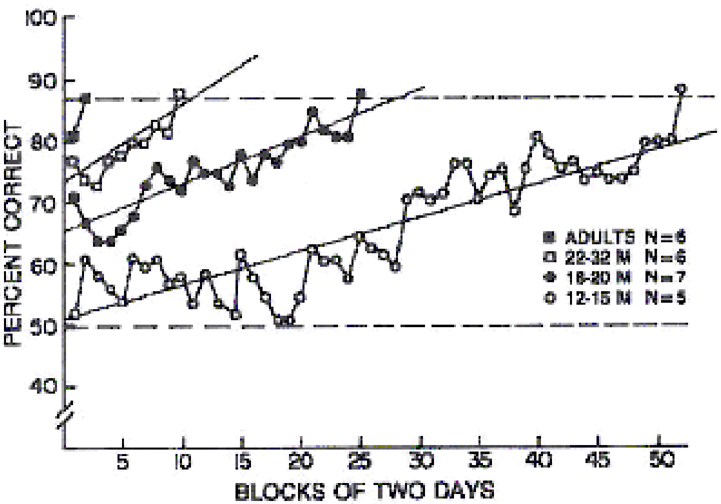
Oddity Task: Errors
% Max Glucose Uptake
120
100
80
60
40
20
0
% Max. No. of Errors
0
20
40
60
80
100
0
2
4
6
8
10
12
14
16
18
20
Age (mos)
% Max Glucose Uptake
% Max Errors

Learning DNMS

Monkeys



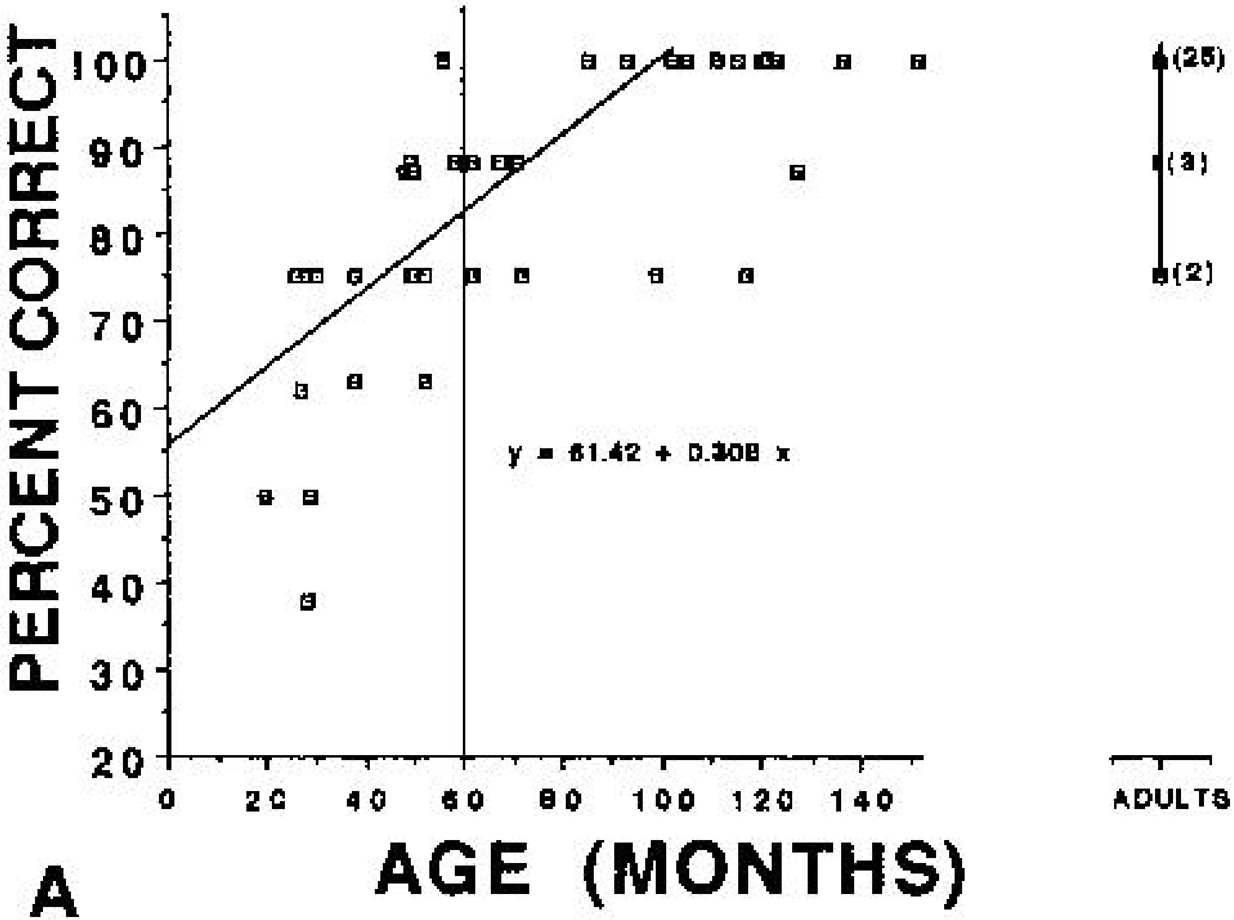
Humans



Bachevalierr & Mishkin, 1984

Overnman, 1990

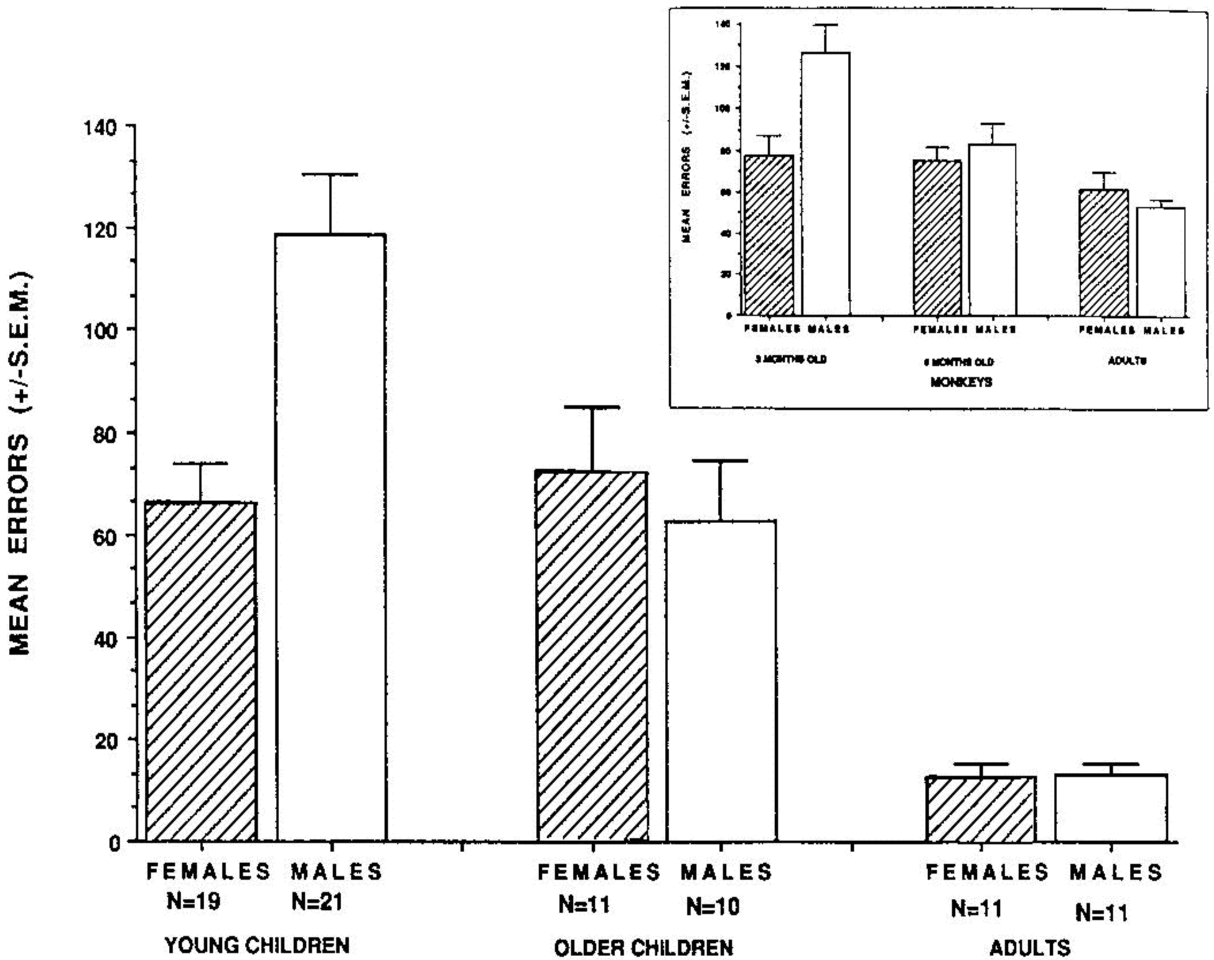
Spatial Learning (Radial Arm Maze)



Free choice of 8 open arms with no proximat cues

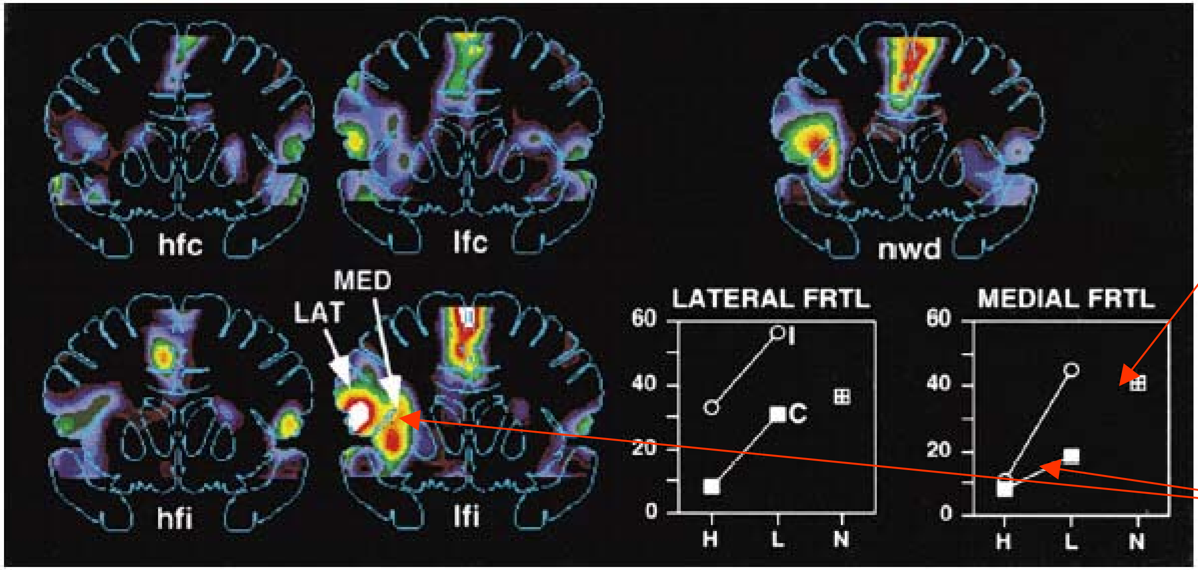
Overman et al. 1996

8-Pair Concurrent Discrimination



Overman, Bachevalier, Schumann, & Ryan, 1996

Mirrors Behavior

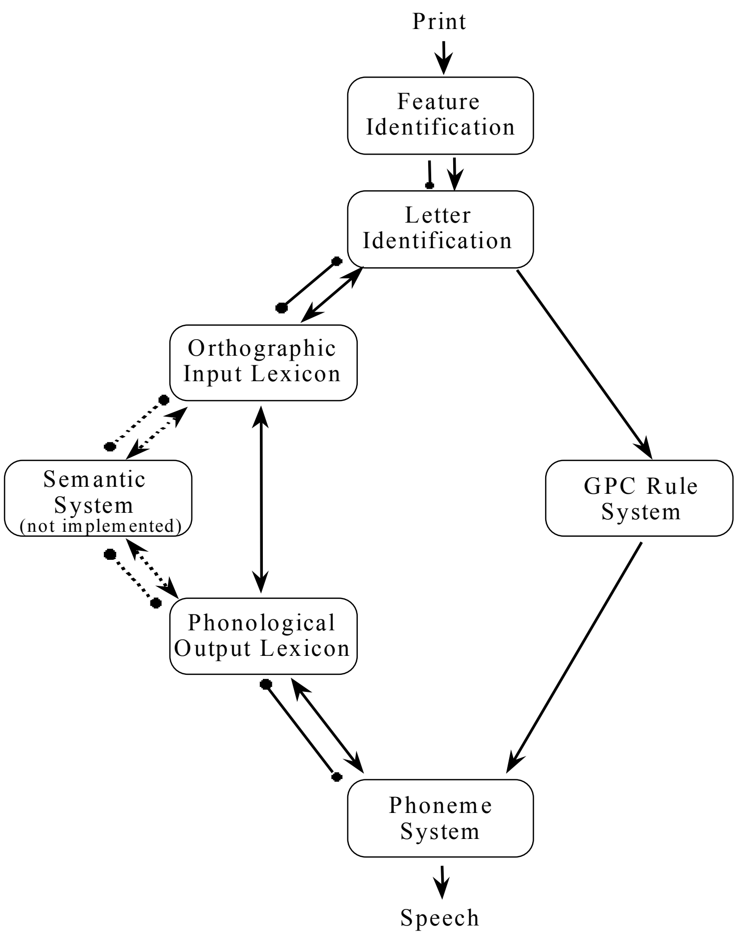


Consistent w// 3 models
Connectionist
DRC
Third option

Figure 1. Left Lateral and Medial Frontal Opercular Activation Is Shown across the Four Word Conditions and the Pronounceable Nonword Condition

The images are coronal sections located 13 mm anterior to the anterior commissure, with magnitudes represented by a color scale that ranges from 0 (dark purple) to 60 (white) counts. The graphs show mean regional magnitudes across frequency (H, high; L, low; N, nonword), with inconsistent words indicated by the open circles, consistent words indicated by the closed squares, and nonwords indicated by the patterned square. hfc, high-frequency consistent; lfc, low-frequency consistent; hfi, high-frequency inconsistent; lfi, low-frequency inconsistent; nwd, nonword condition.

DRC


Print
Feature Identification
Letter Identification
Orthographic Input Lexicon
Semantic System
(not implemented)
GPC Rule System
Phonological Output Lexicon
Phoneme System
Speech

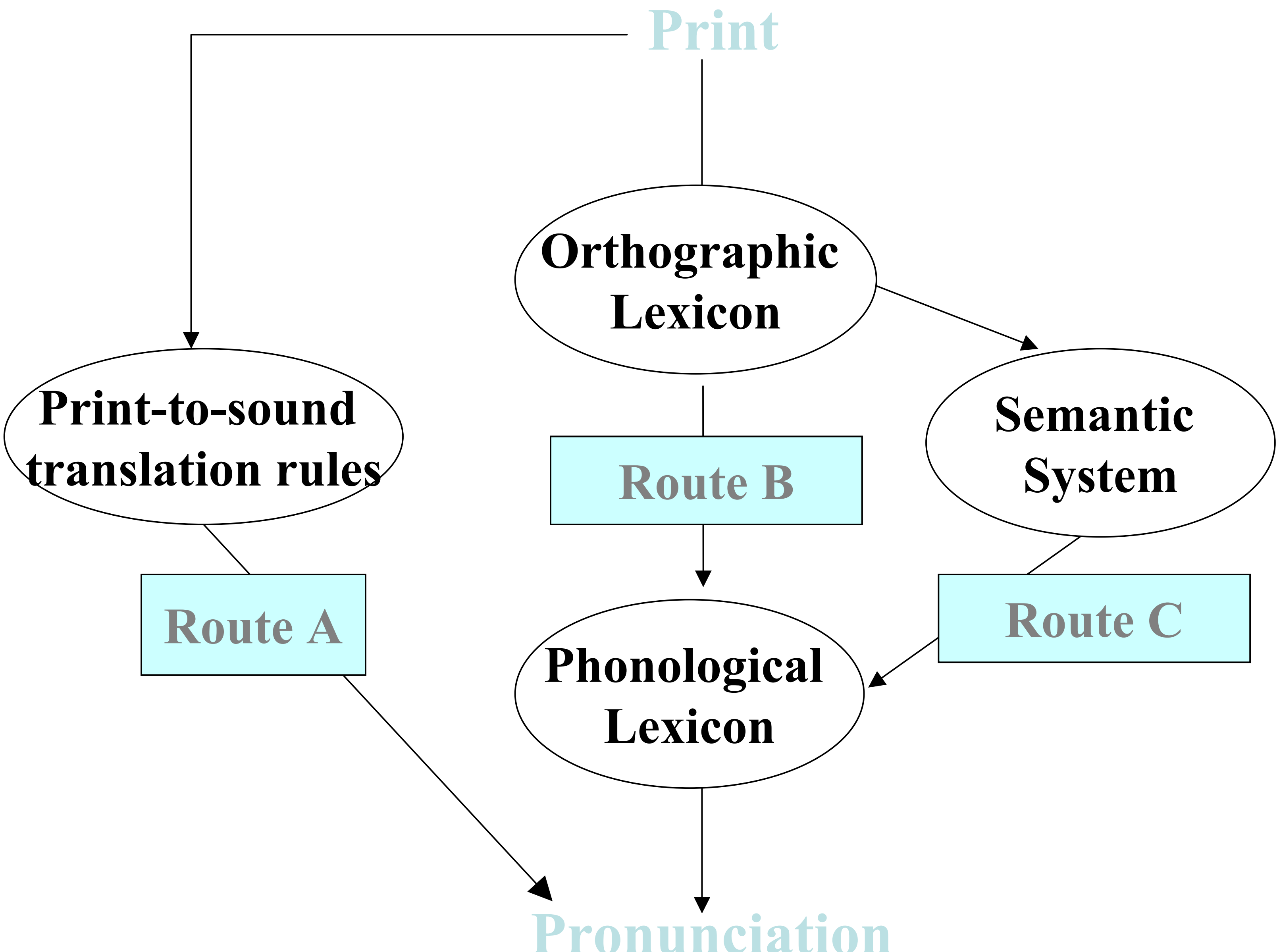
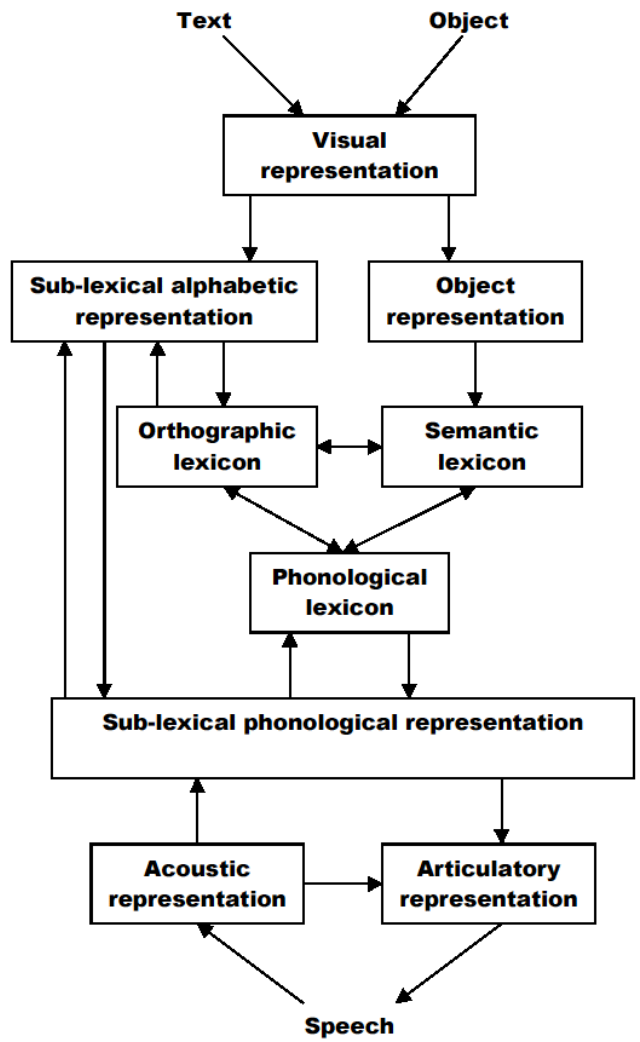


Figure 1: A simplified dual-route model of naming, adapted from Besner (1999)

Figure 2. The final state: orthographic reading stage



Dual-route Model of Reading

- Central to this framework (Coltheart, 1978) is the concept of mental lexicon (Treisman, 1960) where each word's spelling (orthography), sound (phonology) and meaning (semantics) are assumed to be stored as unique entities.
- Two qualitatively different routes are assumed to be in operation in deriving phonology from print:
  - Lexical route operates by addressing information stored in the lexicon (Route B and Route C) .
  - Nonlexical route operates independent of the lexicon by assembling phonology via print-to-sound conversion rules (Route A).

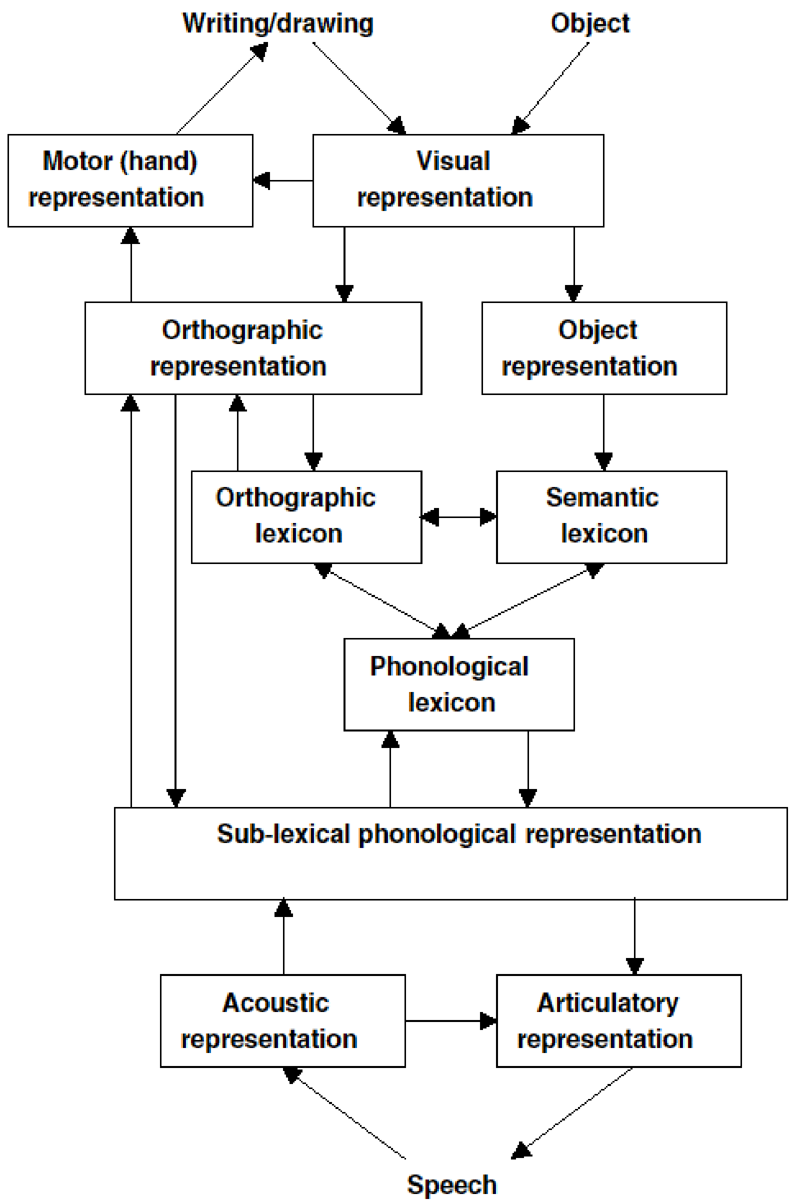


Figure 1. An information processing model of lexical access.

Ramus F. 2001

Table 1. Representations and processes involved in different tasks.

	Motor	Visual	Object	Orthographic	Semantic lexicon	Ortho-graphic lexicon	Ortho-phono route	Phono-ortho route	Phono-logical lexicon	Sub-lexical phon	Acoustic	Articulatory
Reading aloud		X		X		X			X	X		X
		X		X			X			X		X
Free writing	X			X	X	X						
	X			X	X			X	X	X		
Spelling to	X			X				X		X	X	
dictation	X				X		X			X	X	X
Digit span									X	X	X	X
Non-word repetition										X	X	X
Naming		X	X		X				X	X		X
Spoonerisms									X	X	X	X
Speech perception	X									X	X	
Speaking					X				X	X		X

For the first three tasks, two possible routes are shown (see Figure 1 and text)

The Future Challenge for Mind-Brain Science

The challenge for the future is to understand at a deeper level the actual mental operations assigned to the various areas of [brain] activation. Before this goal can be achieved, the experimental strategies used in PET studies must be refined so that more detailed components of the process can be isolated.

- M. Posner & M. Raichle, 1994

Brain and Behavior

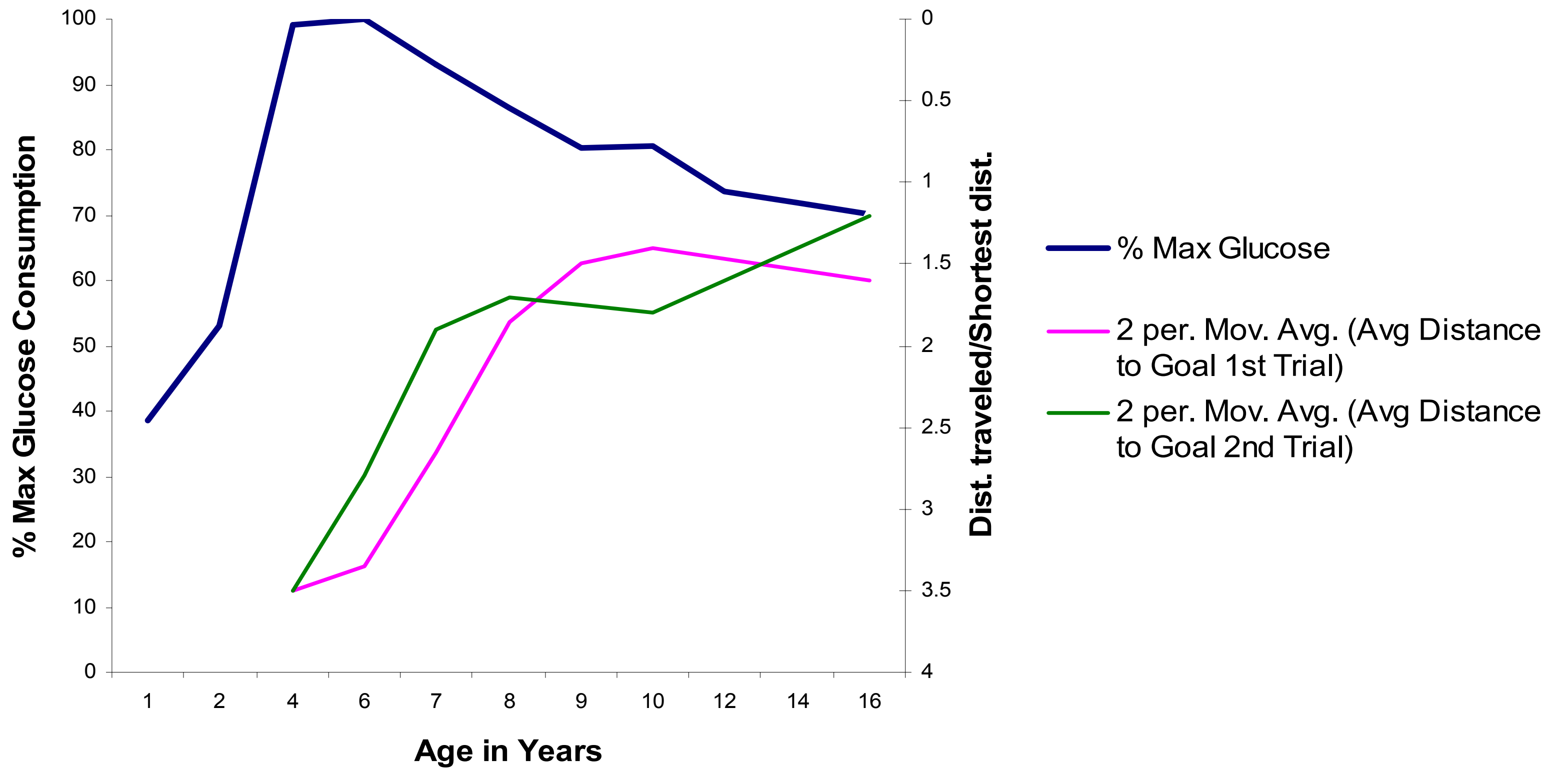
An analysis at the behavioral level lays the foundation for an analysis at the neural level. Without this foundation, there can be no meaningful contribution from the neural level.

- Randy Gallistel

My Claim

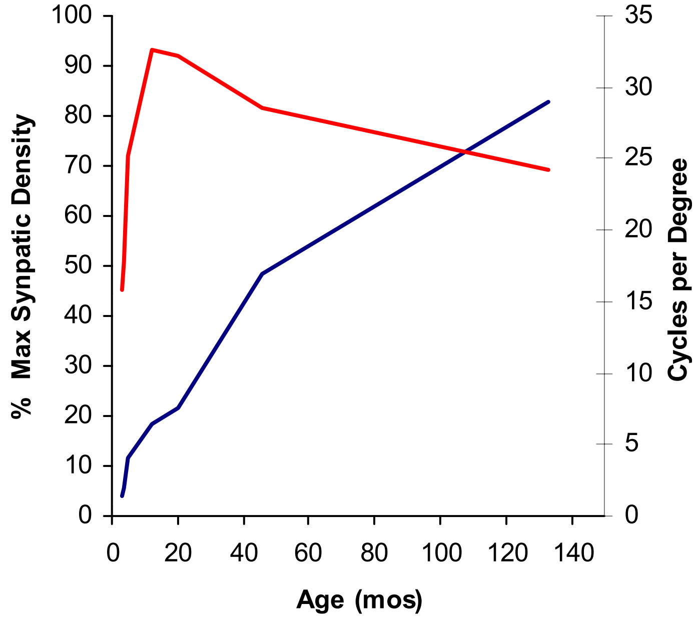
- Cognitive model is enough for education.
- Need cognitive model to understand brain.
- Concentrate there and build bridges.
- Cog neuro maps cognitive functions on to brain structures
- Cognitive model prior
- Can imaging (brain-based evidence contribute) to refining cognitive models

Learning an Open Field Navigation Task



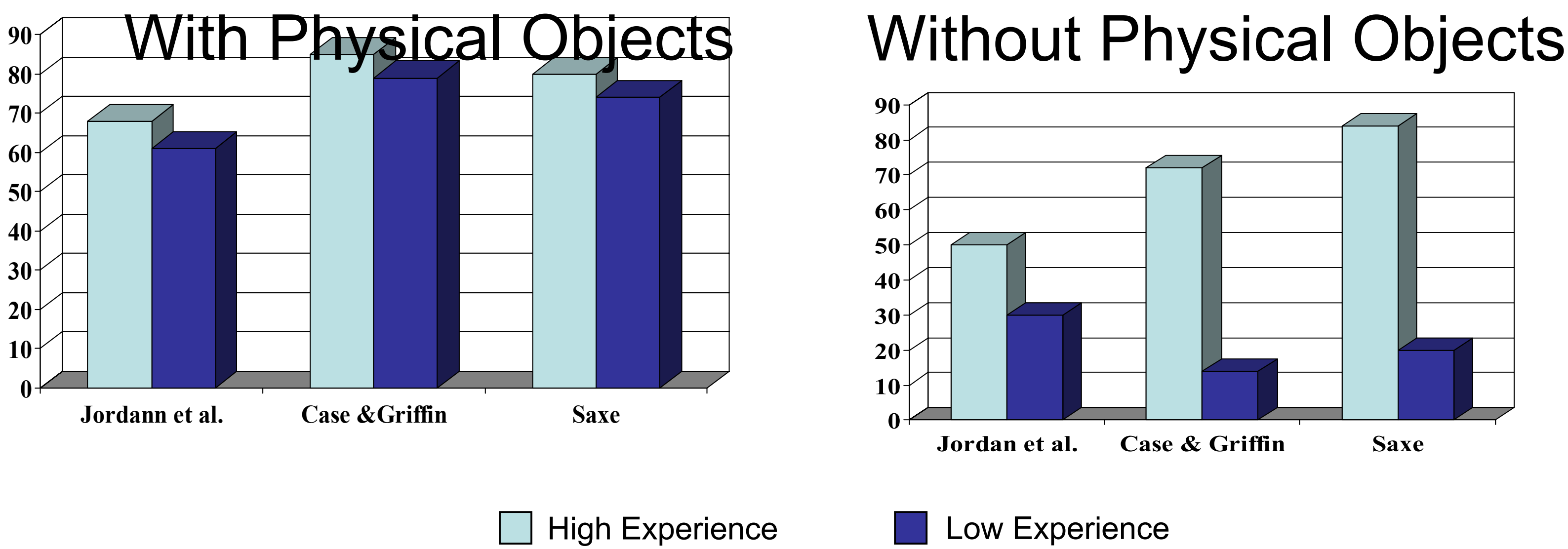
H.T. Chugani; Overman et al.

Synaptic Density vs. Visual Acuity



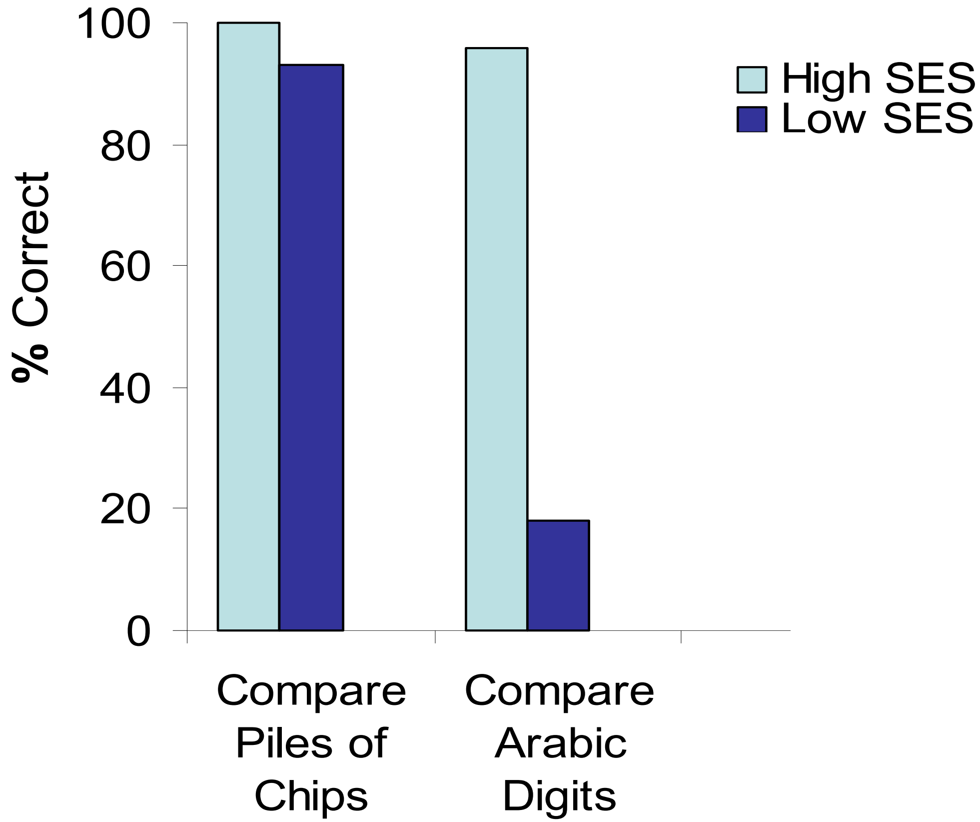
Redrawn from P. Huttenlocher 1987

Solving Addition Problems

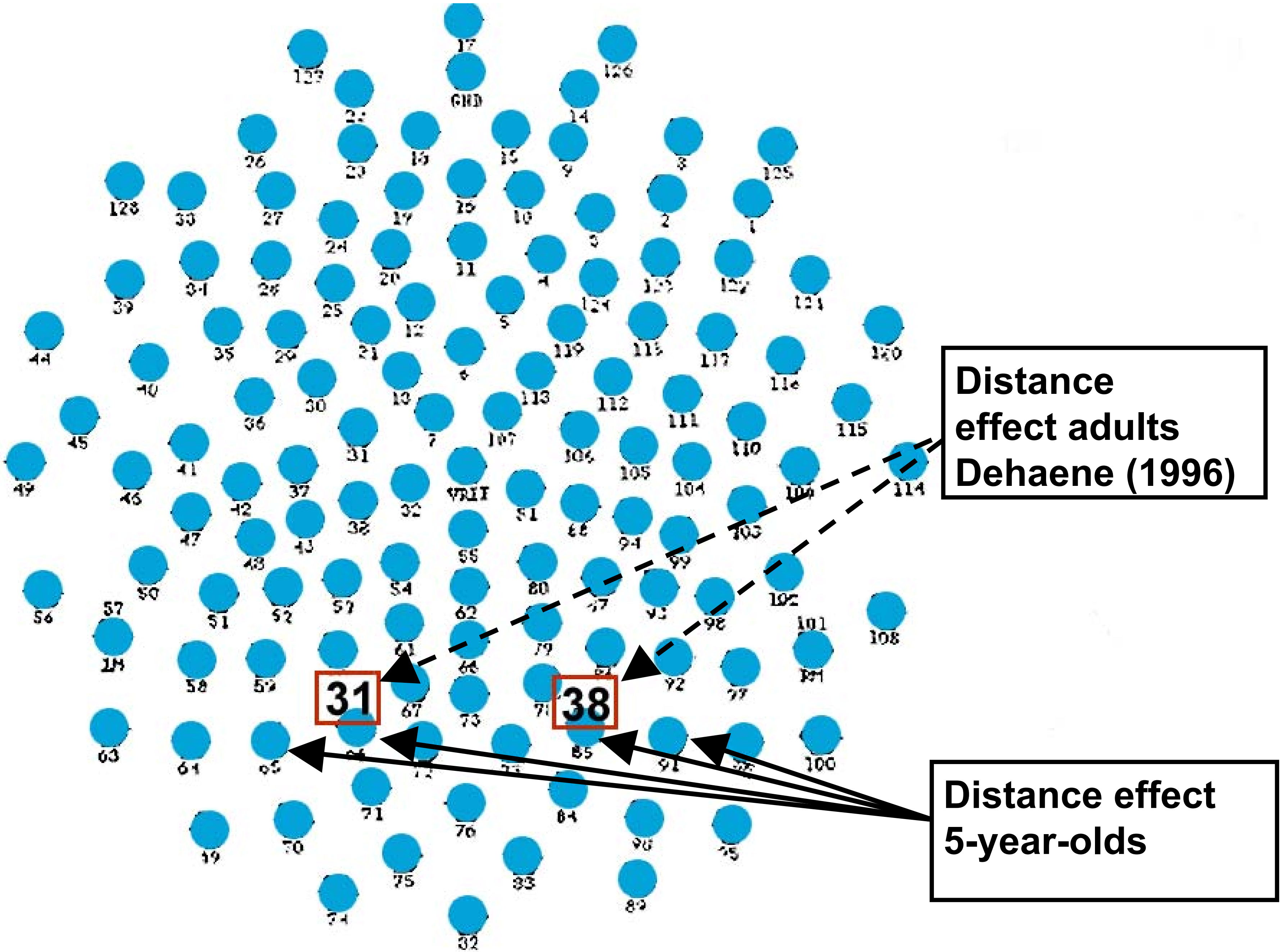


- Jordan et al.: Middle-income vs. low-income kindergarten children
- Case & Griffin: High-SES vs. low-SES kindergarten children
- Saxe: Oksapmin trade store owners vs. Oksapmin adults

Comparison: Which is Bigger?



From Griffin, Case & Siegler 1994



Temple & Posner 1998, PNAS 95: 7837

What has been useful to education? Cognitive Models

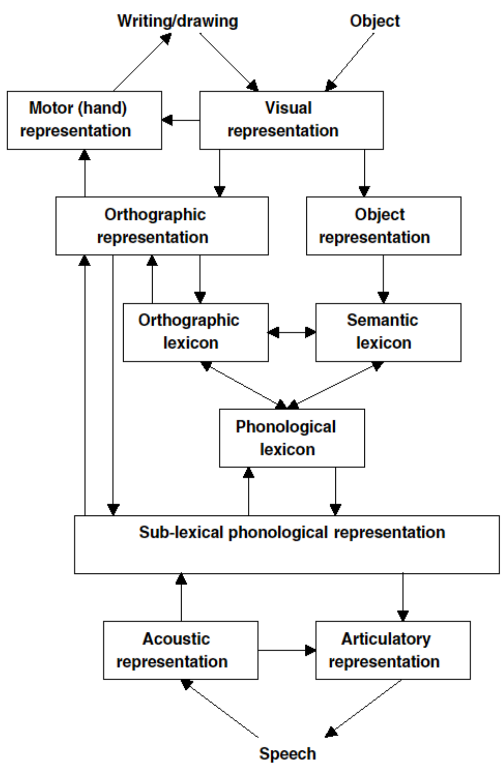
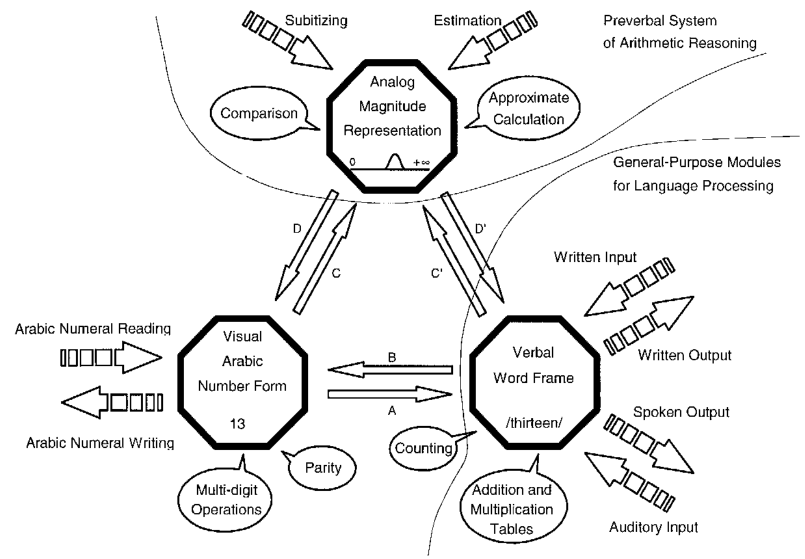
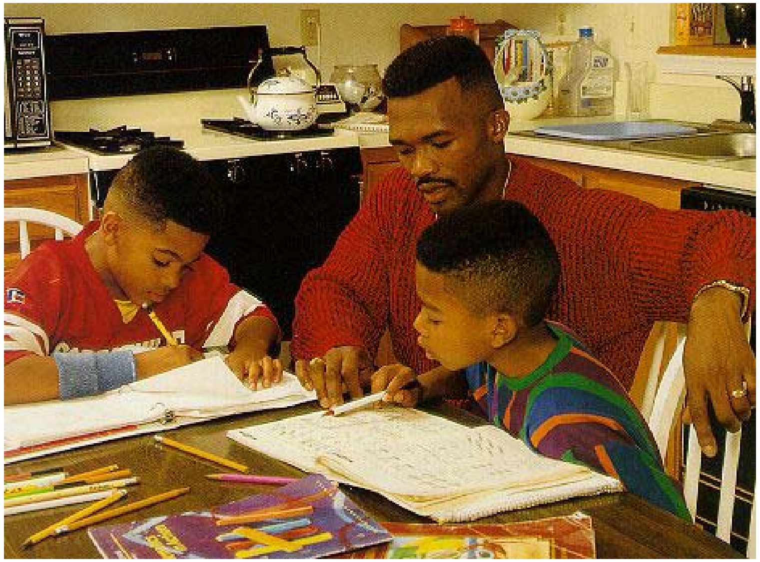


Figure 1. An information processing model of lexical access.



What Children Know About Number



- Three systems: pre-verbal magnitudes, number words, Arabic numerals.
- Most children learn these systems and how they inter-relate prior to school entry. 4.
- Most children arrive at school able to use this understanding to count, compare, and invent strategies for solving simple number problems.

Considerations

- Heuristic: For any set of publications (manuscripts) of size S, the number worth reading (publishing) is $S^{1/3}$.
- Within current cognitive neuroscience this heuristic provides an optimistic threshold.
- Traditionally educational research is weak compared to basic research.
- Applied or interdisciplinary research should remain connected to its related basic sciences.
- Although cognitive neuroscience has implications for cognitive theories, its relation to educational practice is still rather indirect.
- We know little about the brain, learning, and higher cognitive functions.
- A NeuroLearning research program might prove more timely and beneficial than a NeuroEducation research program.

Phonological Hierarchy

- Phoneme discrimination and categorization
- Phonological variation – “the idea-r-is”
- Place assimilation – “sweek girl”
- Phoneme duration (Finnish)
- Syllabic grammar
- Stress – ANcora vs anCORa
- Metrical feet (Eng. troCHAic, thirTEEN MEN vs. THIRteen MEN)
- Prosody

Neurology and Structure-Function Inferences

Neuroscientists err “in drawing conclusions about functional change [*learning*] from data on structural change [*synaptic density*] without considering whether or how the two phenomena are related. (Bruer 2002)

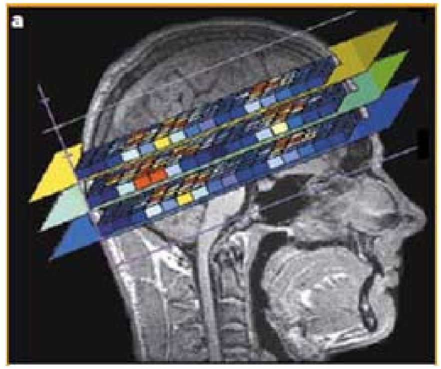
Bruer is critical of structure-function correlations but much of what we know about the functional organization of the human cerebral cortex is based on structure-function correlations, starting with the work of the 19th century anatomists such as Broca and Wernicke. (Huttenlocher 2002)

Neurological Inference

When a particular site is damaged by disease or injury, a well-defined deficiency in behavior sometimes ensues. In many cases on may conclude that some aspects of the behavior are normally dependent on the part of the brain that has been destroyed.

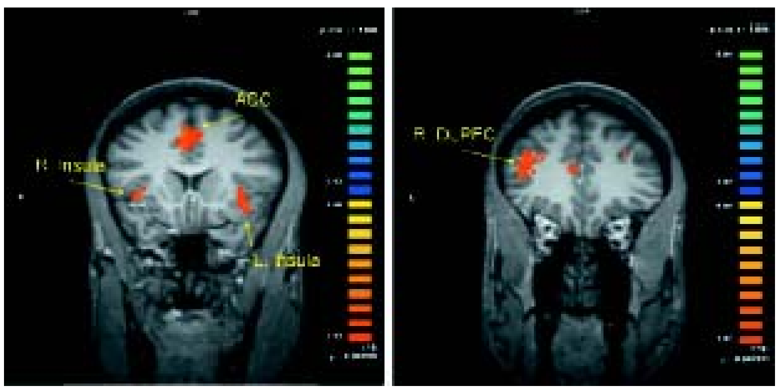
-N. Geschwind 1979

Example: Frontal lobe damage causes impaired learning of DMS but not of other non-delay memory tasks.



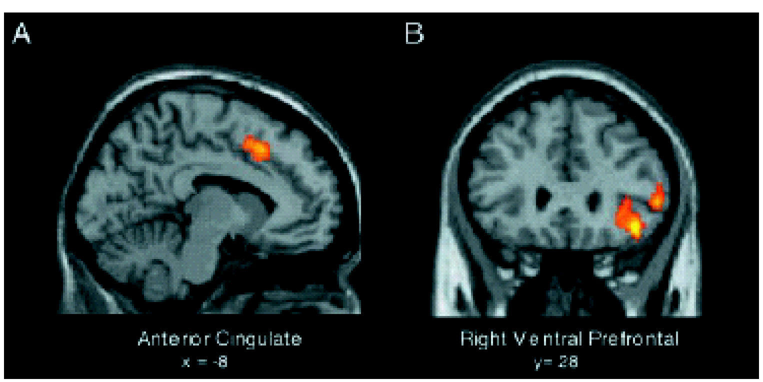
Chess

Amateur players show more focal λ-bursts in the medial temporal lobe than grandmasters, who show more activity in the frontal and parietal cortex



Economic Decision Making

Unfair offers in the Ultimatum Game differentially activated bilateral anterior insula, dorsolateral prefrontal cortex, and anterior cingulate cortex.



Social Pain

Social exclusion compared to inclusion increased activity in anterior cingulate cortex and right ventral prefrontal cortex.

The Future Challenge for Mind-Brain Science

The challenge for the future is to understand at a deeper level the actual mental operations assigned to the various areas of [brain] activation. Before this goal can be achieved, the experimental strategies used in PET studies must be refined so that more detailed components of the process can be isolated.

- M. Posner & M. Raichle, 1994

A Technology for Analyzing Behavior

Cognitive science provides an empirically based technology for determining people's existing knowledge, for specifying the form of likely future knowledge states, and for choosing the types of problems that lead from present to future knowledge.

- D. Klahr & R. Siegler

Value of Cognitive Models to Instruction

- Provide explicit statements of the representations involved in a problem or learning domain.
- Provide explicit statements of how those representations interact in successful learning or task completion.
- Provide diagnostic insights into learning problems.
- Provide bases for training studies.
- Provide guides for instructional design