Reasoning in the Brain

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What is Reasoning?

- Mental activities that are involved when individuals attempt to make discoveries about the world… to increase knowledge
- Occurs either (1) through deduction, or (2) observation, abstraction and generalisation
- Same cognitive operations that humans used in many domains, such as science and math, but also text comprehension, history and everyday problem solving

The Classic View: Piaget & Logic

- Piaget focussed on the development of reasoning (i.e., logic) and the origins of knowledge
- He proposed the quintessential stage theory: Qualitative changes, concurrence, abruptness
- Sensori-motor stage (0-2 years)
- Preoperational stage (2-6)
- Concrete operational stage (7-11)
- Formal operational stage (12 onwards)
- Often opposed direct perception with reasoning

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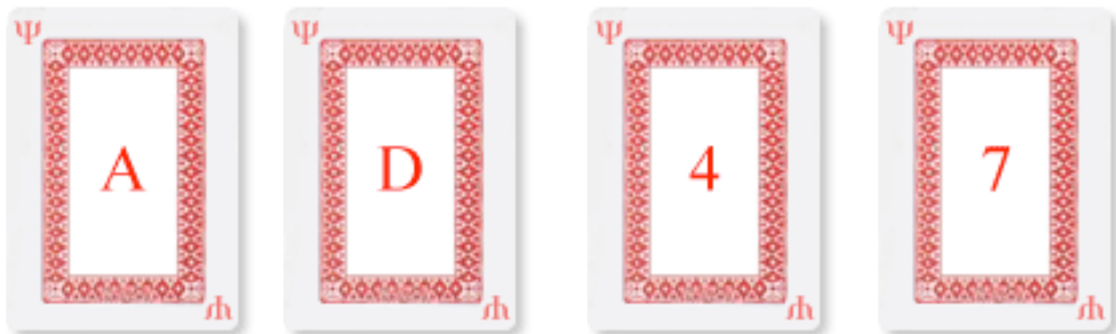
BUT HOW LOGICAL ARE WE REALLY?

Knowledge-Based Inference

1. The Wason Card Task



"If a card has a vowel on one side, then it has an even number on the other side"

Which cards do you turn over to verify this?

Knowledge-Based Inference

1. The Wason Card Task

Beer	Soda	25	17

"If you are drinking alcohol, then you must be over 21"

Which cards do you turn over to verify this?

Knowledge-Based Inference

2. Syllogistic Reasoning

All mammals have fur
Wombats have fur
therefore…

Wombats are mammals

Do you find this compelling?

Knowledge-Based Inference

2. Syllogistic Reasoning

All mammals have fur
Wombats have fur
therefore…

Wombats are mammals

Do you find this compelling?

Well it is wrong! There may be other kinds of animals with fur.

Knowledge-Based Inference

3. Non-computable inferences

Some dogs are brown

Some dogs have stripes

THEREFORE……???

Knowledge-Based Inference

3. Non computable inferences

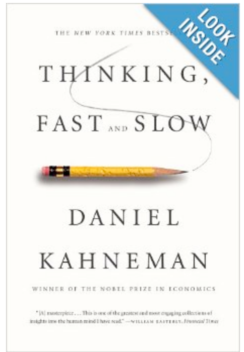
Some dogs are brown

Some dogs have stripes

THEREFORE……???

Many people would conclude that some dogs are brown with stripes, but this is not deductively valid!

Knowledge-Based Inference



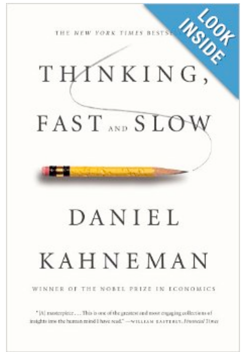
YES… we CAN use logic but this is hard

•Most reasoning is quick and dirty (Kahneman)

•Relies on extensive use of knowledge and short-cuts (heuristics)

•Statistical inference underlies reasoning (we guess what is most "likely" given past experience; Chater & Oaksford):
Statistics is the "language of the brain"

Knowledge Based Inference



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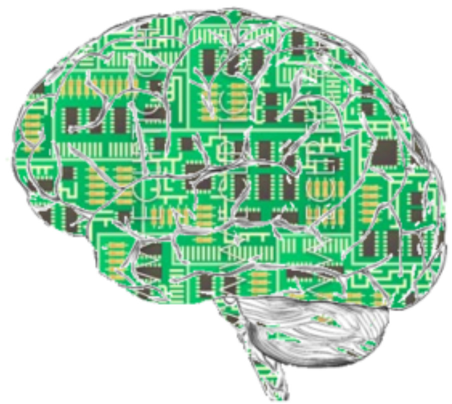
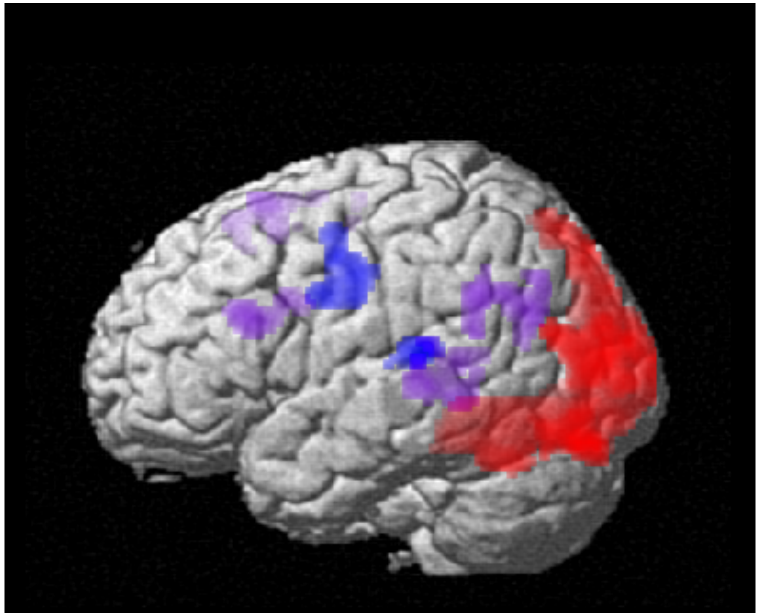


THE KEY TO GAINING NEW KNOWLEDGE IS HARNESSING AND USING PRIOR KNOWLEDGE APPROPRIATELY!

Exploring Reasoning in the Brain

Functional imaging (e.g. fMRI) measures "current processing" *within an individual*

Structural images appear to reflect: "learning" "ability" possibly "potential" differences ***across individuals***



Exploring Reasoning in the Brain

- Almost all work carried out with adolescents and young adults
- Difficulties of working with children include noise, motion artefacts, lack of structural templates.
- Lowest ages typically 6 years of age

Three Examples....

- **Deductive inference**

E.g., all mammals have fur. Wombats are mammals, therefore wombats have fur

- **Causal inference**

Increased atmospheric CO2 output causes global warming

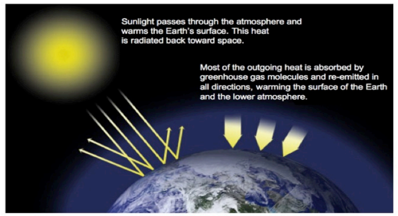


Figure 1 (source: http://climate.nasa.gov/causes)

- **Analogical inference**

E.g., Rutherford Atom ⇔ Solar System

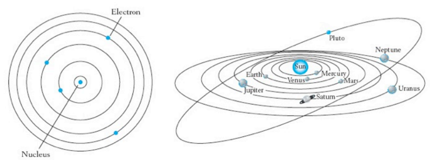
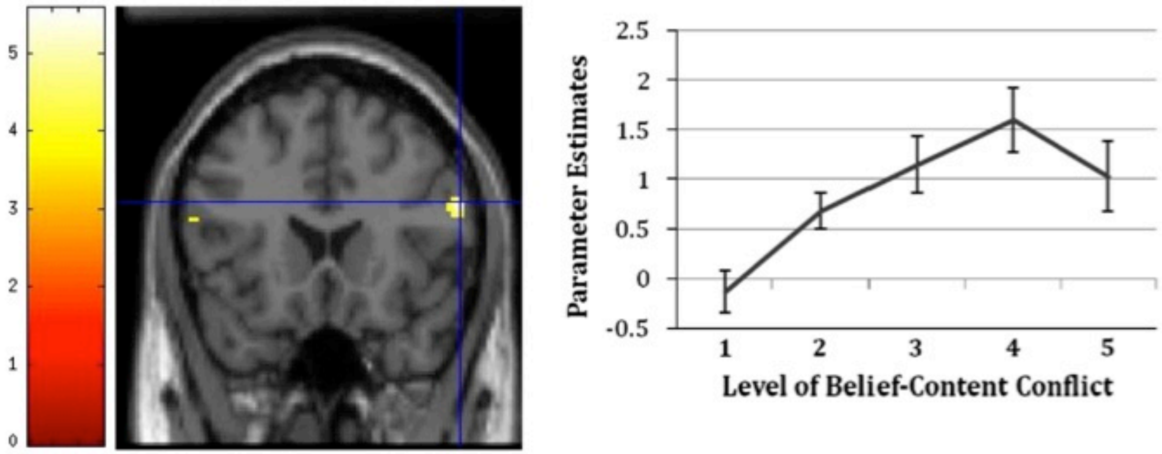


Figure 5 (Source: Galotti, Fernandes, Fugelsang, & Stolz, 2010; *Nelson Publishing*)

Deductive Inference in the Brain



Greater activation of DLPFC with greater level knowledge conflict

Figure 4 (Source: Stollstorf, Vartanian, & Goel, 2012; *Brain Research*)

Deductive Inference in the Brain

- Imaging studies suggest that both language-based and visual spatial modes are engaged during deductive reasoning (Goel, 2007, 2003)
- A fractionated system that can be dynamically reconfigured in response to the familiarity of the task
- Implication of DLPFC (Dorsal Lateral Prefrontal Cortex) … especially in tasks involving the integration of prior knowledge

Causal Inference in the Brain

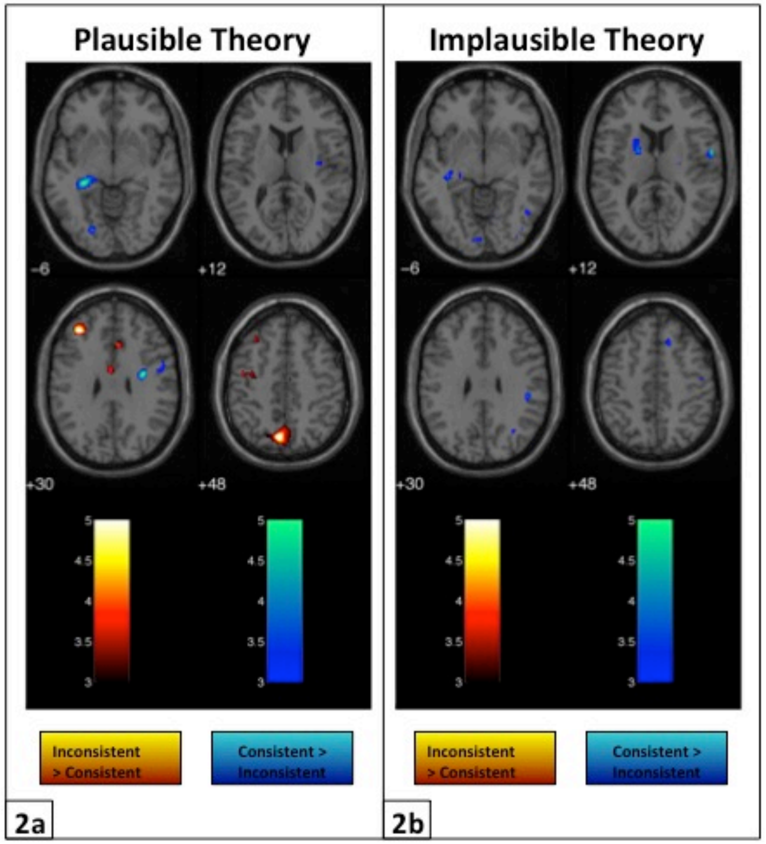


Figure 2 (Source: Fugelsang & Dunbar, 2005; *Neuropsychologia*)

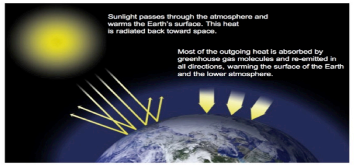


Figure 1 (source: http://climate.nasa.gov/causes)

Different patterns of activation when making consistent vs. inconsistent inference

Causal Inference in the Brain

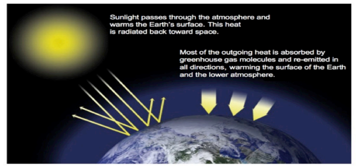


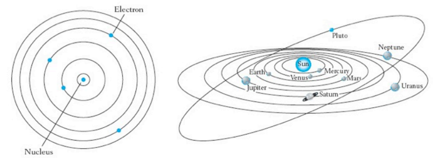
Figure 1 (source: http://climate.nasa.gov/causes)

- Few studies of causal reasoning (Fugelsang & Dunbar, 2005)
- Different systems underlie causal perception from causal reasoning
- Evaluating causal explanations recruited :

(1) parts of the parahippocampal cortex (associated with semantic knowledge) when the explanation was consistent with prior beliefs

(2) the DLFPC (Dorsal Lateral Prefrontal Cortex) and Anterior Cingulate (AC) when hypothesis was inconsistent with prior beliefs

Analogical Inference in the Brain



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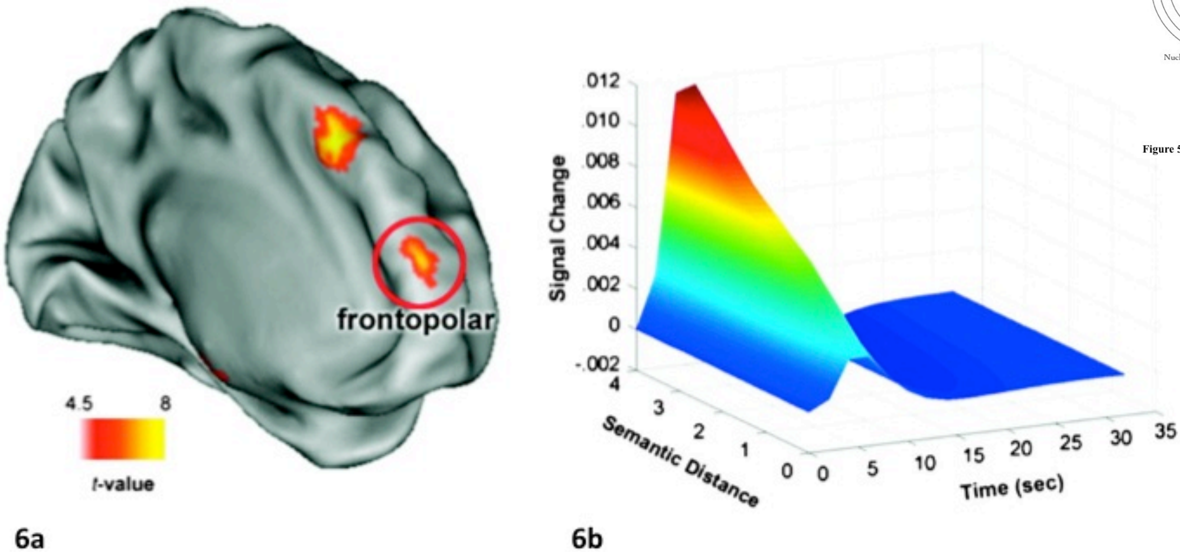

kitten:cat::puppy:dog
kitten:cat::spark:fire

Figure 6 (Source: Green, Kraemer, Fugelsang, Gray, & Dunbar, 2010; *Cerebral Cortex*)

Greater semantic distance implied greater activation

Analogical Inference in the Brain

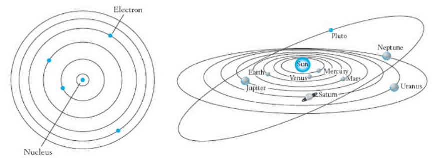

Figure 5 (Source: Galotti, Fernandes, Fugelsang, & Stolz, 2010; *Nelson Publishing*)

- Some studies with children from age 8 years.
- Need to differentiate perceptual from verbal analogies
- Evaluating or producing analogies revealed that:

(1) Frontopolar cortex (part of the PFC) and right lateral PFC are sensitive to integration of multiple systems of relations (either abstract or concrete)

(2) Children engage similar systems but *do so too late to influence their initial response*, or not at all if there is too much relational complexity.

Key ideas…

- Findings are consistent with the idea that executive functions can be dissociated into *Evaluative* and *Executive* components involving the AC and DLPFC respectively

- AC identifies conflict and DLPFC resolves conflict

- Few developmental fMRI studies
- BUT findings are consistent with the suggestion of the importance of conflict monitoring in classic theories of reasoning (e.g., Piaget's reflective abstraction)

Putative Implications for Education

- Participants engage different reasoning systems when presented with hypotheses consistent or inconsistent with prior beliefs or knowledge

(1) So… increasing domain knowledge should be a pre-cursor to teaching inferential techniques (e.g., hypothesis testing)

(2) Improving "conflict monitoring" will have knock-on effects on reasoning in the brain

More developmental research needed!

Latest News….

MIND, BRAIN, AND EDUCATION

Differences in Brain Activation Between Novices and Experts in Science During a Task Involving a Common Misconception in Electricity

Steve Masson[1], Patrice Potvin[1], Martin Riopel[1], and Lorie-Marlène Brault Foisy[1]

ABSTRACT— Science education studies have revealed that students often have misconceptions about how nature works, but what happens to misconceptions after a conceptual change remains poorly understood. Are misconceptions rejected and replaced by scientific conceptions, or are they still present in students' minds, coexisting with newly acquired scientific conceptions? In this study, we use functional magnetic resonance imaging (fMRI) to compare brain activation between novices and experts in science when they evaluate the correctness of simple electric circuits. Results show that experts, more than novices, activate brain areas involved in inhibition when they evaluate electric circuits in which a bulb lights up, even though there is only one wire connecting it to the battery. These findings suggest that experts may still have a misconception encoded in the neural networks of their brains that must be inhibited in order to answer scientifically.

For at least 30 years, researchers in science education have studied people's spontaneous conceptions about how nature works (Duit & Treagust, 2012). These studies have shown that these intuitive conceptions are often opposed to the scientific knowledge taught in schools (Liu, 2001). For example, many people believe that heavier objects fall faster (even in the absence of air resistance, which is false), or that it is warmer in summer because the Sun is closer to the Earth (which is also false). If these misconceptions were not so difficult to change, they would not be a problem. However, one of the most robust findings of science education research about misconceptions is that they are particularly hard to change (Duit & Treagust, 2012; Periago & Bohigas, 2005; diSessa, 2006; Vosniadou, 2012; Wandersee, Mintzes, & Novak, 1994), which poses a serious challenge for science teachers who try to change their students' misconceptions into scientifically valid knowledge.

The problem of the persistence of nonscientific conceptions during science education has led to a field of research called "conceptual change" (for a review, see Duit & Treagust, 2012; diSessa, 2006; Vosniadou, 2008, 2012). This field tries to understand why students' misconceptions are hard to change, what changes during conceptual change, and how to facilitate the learning of unintuitive scientific concepts. Over the years, researchers in this field have proposed several theoretical models to answer these questions (Carey, 2009; Chi, 1994; Giordan & DeVecchi, 1987; Mortimer, 1995; Nussbaum & Novick, 1982; Posner, Strike, Hewson, & Gertzog, 1982; diSessa, 1993; Smith, 2007; Stavy et al., 2006; Vosniadou, 1994).

Most of these models (Carey, 2009; Chi, 1994; Duit & Treagust, 2003; Giordan & DeVecchi, 1987; Nussbaum & Novick, 1982; Posner et al., 1982; Smith, 2007; Vosniadou, 1994) share a common postulate according to which conceptual change is hard to achieve not only because students must abandon their initial misconceptions, but also because they must radically restructure their knowledge structure in order to accommodate new scientific concepts and theories. For example, according to Duit and Treagust

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Towards an Intervention…

- Science and maths learning require *inhibiting prior beliefs and direct perceptual solutions*
- DLPFC & ACC implicated in scientific reasoning
- Improved inhibitory control is a key factor in cognitive development– *and is impaired in low SES children*
- Previous domain-general executive control interventions have had mitigated success and limited transfer… so focus on within domain control.

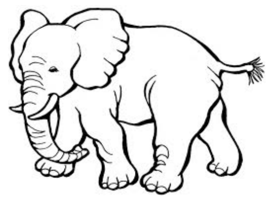
The Project Outline

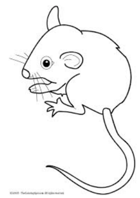
- Funded by Wellcome Trust & Education Endowment Foundation
- Target Years 3 & 5 [8-, & 10-year-olds]
- 9000 children in full intervention over 100 schools
- 15 minutes of training 3 times weekly for one term
- Computer-based control (Hawthorne effect)

The Project Outline

- **Examples Science judgements**:

(i) Are elephant cells BIGGER/SMALLER/THE SAME SIZE *as mouse cells*?





(ii) When a candle melts, does the resulting wax weigh MORE/LESS/THE SAME *as before*?

The Project Outline

- **Examples Maths judgements**:

(i) Does the red arc bend MORE/LESS/THE SAME *as the clear arc*?

(ii) Is 2/3 MORE/LESS/THE SAME *as* 4/6?

General Conclusions…

- Fractionated generalist systems made from basic cognitive building blocks
- Both *executive control* and *semantic knowledge* systems play an important role in reasoning
- Reasoning that is consistent with prior knowledge recruits different a neural system than reasoning that is inconsistent with prior knowledge
- The late maturing of the DLPFC may partially underlie prolonged development of reasoning skills

Thank you for your attention!