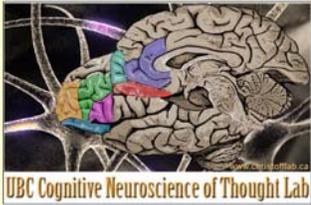


## Human thinking: Lessons from Neuroscience

Kalina Christoff, Ph.D.



## The two sides of human thought

*The critical,  
analytical side...*

*and the intuitive,  
spontaneous side*

**Reasoning**

**Mind-wandering**

**Deduction**

**Daydreaming**

**Induction**

**Intuition**

**Analogy making**

**Creative thinking**

**Convergent thinking**

**Divergent thinking**

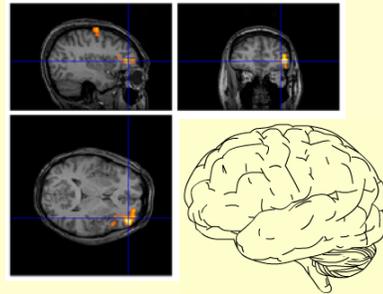
**Logical thought**

**Stream of consciousness**

The optimally thinking mind  
should be trained to

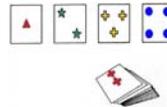
- make use of both sides of thought
- flexibly switch from analytical thinking to mind wandering – and vice versa
- use each kind of thinking in the appropriate circumstances for it

## What has neuroscience taught us about thinking?

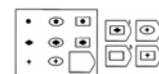


## Patient studies

Card Sorting



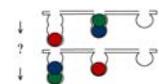
Raven's Progressive Matrices



Inductive Reasoning

*Socrates was a man  
Socrates was mortal  
∴ All men are mortal*

Tower of London



### The prefrontal cortex (PFC)



Damage to PFC leads to impairments in reasoning and problem solving

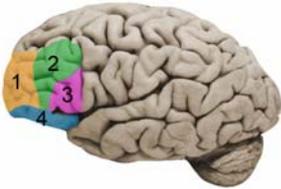
### The prefrontal cortex (PFC)



**Cognitive control**      **Perception and memory**

**PFC biases neural processes occurring in posterior brain regions**

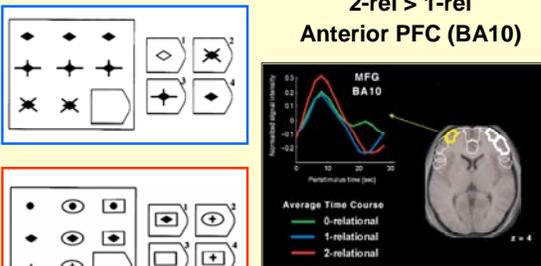
### Neuroimaging and neurophysiology



1. RLPFC (lateral BA10)
2. DLPFC (BA46, BA 9)
3. VLPFC (BA45, BA47)
4. Lateral OFC (BA11)

### Relational reasoning

2-rel > 1-rel  
Anterior PFC (BA10)

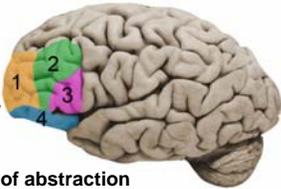


Average Time Course  
 — 0-relational  
 — 1-relational  
 — 2-relational

Christoff et al. (2001) Neuroimage

### Neuroimaging and neurophysiology

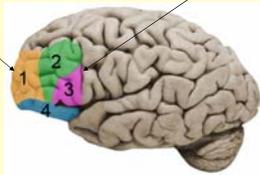
**Complex problem solving**  
**Cognitive introspection**  
**Highly abstract thought**  
*(Christoff et al., 2000, 2003)*



1. RLPFC (lateral BA10)
2. DLPFC (BA46, BA 9)
3. VLPFC (BA45, BA47)
4. Lateral OFC (BA11)

**The highest forms of abstraction**

### Cognitive control at different levels of abstraction



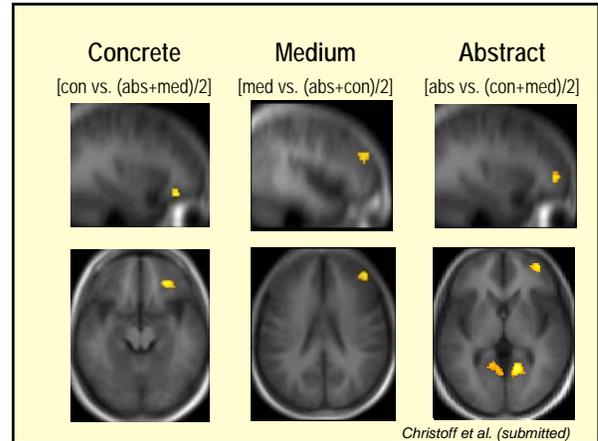
**highly abstract information**      **concrete information**

**Topography of thought within the prefrontal cortex**

### Verbal problem solving task: anagrams

Abstract	Medium	Concrete
A P e a l p	D n c a e	D k e s
H m a r	T p i r	F o d o
G a c r e	S n g o	B O l t e t

*Christoff et al. (submitted)*



### The prefrontal cortex (PFC)

Cognitive control

Organized at different levels of abstraction

### The prefrontal cortex (PFC)

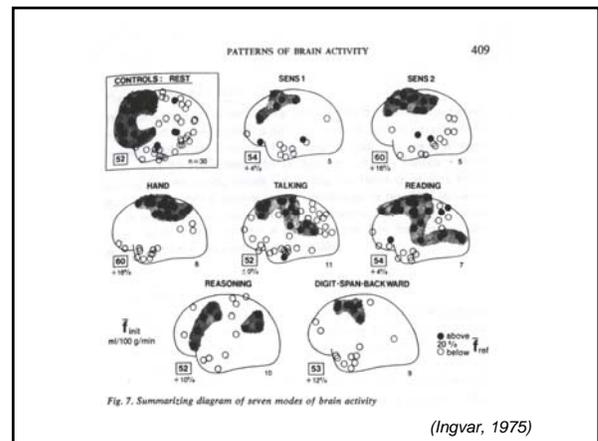
- Reasoning
- Deduction
- Induction
- Analogy making
- Convergent thinking
- Logical thought

*The critical, analytical side...*

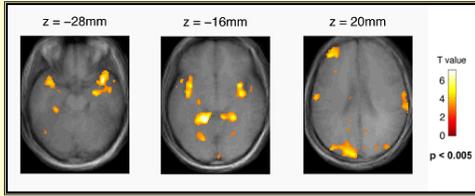
### Posterior cortices and limbic areas

*...the intuitive, spontaneous side*

- Mind-wandering
- Daydreaming
- Intuition
- Creative thinking
- Divergent thinking
- Stream of consciousness



### Brain recruitment during rest



Christoff et al. (2004) Cortex

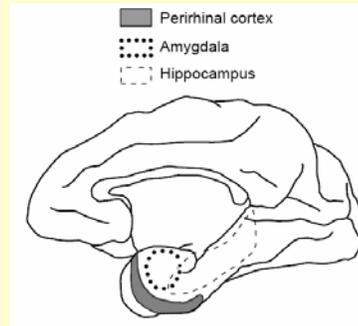
**Temporal cortex (lateral and medial)**

memory processes

**Occipital and parietal cortex**

imagery

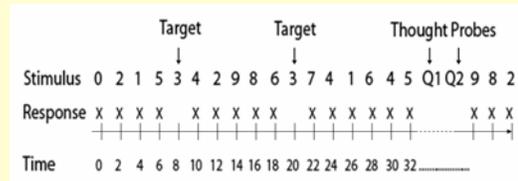
### The medial temporal lobe



### Studying mind wandering directly...

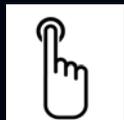
- What brain regions are involved?
- What happens when awareness of mind wandering is present?

### Sustained Attention to Response Task (SART)



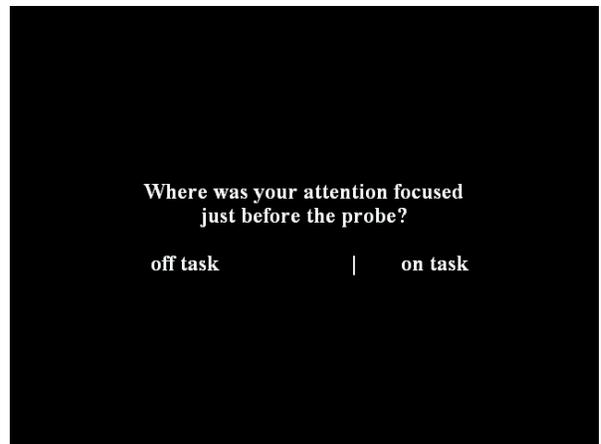
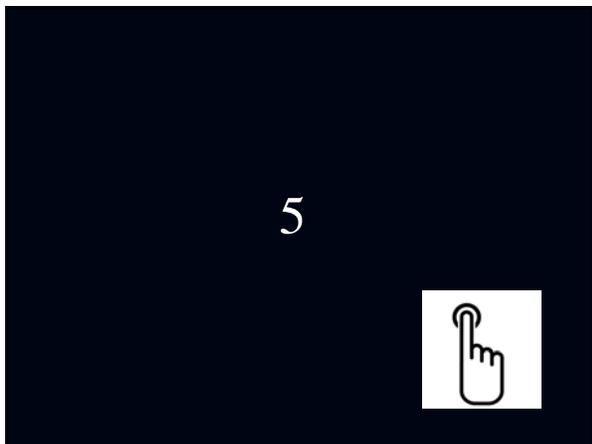
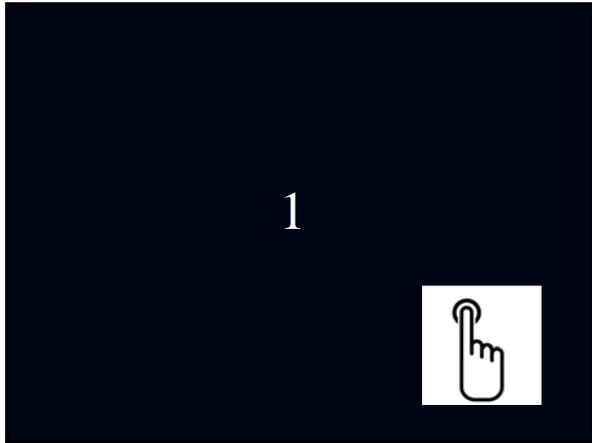
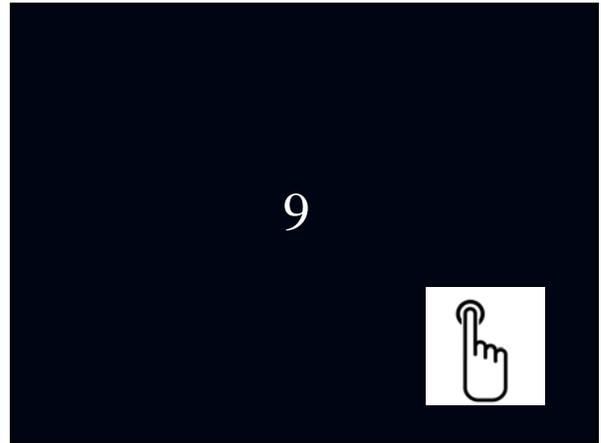
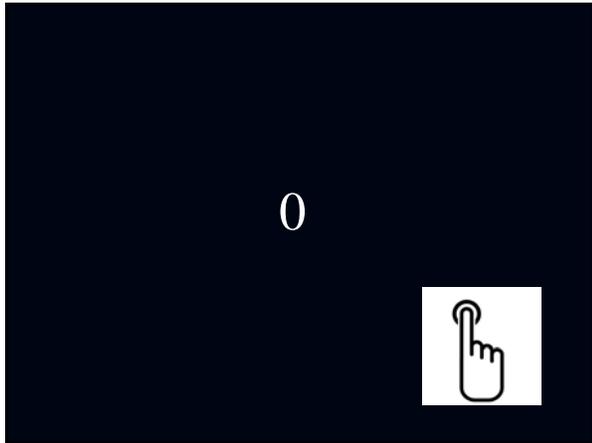
- Continuous go no-go task
- Respond to all non-targets (numbers 0-9)
- Inhibit response to targets (the number 3)

5



2







### Suppression of memories

Hippocampus – decrease in activation  
Lateral prefrontal cortex – increase in activation

Anderson et al. (2004). Science.

### Prefrontal cortex interacts with hippocampus during suppression

Fronto-Hippocampal Correlation

Left BfE suppresses forget - suppresses remember

### Regulating intrusions involves down-regulating hippocampal activation

Levy & Anderson (in progress b)

Hippocampal Activity  
Blue: S<R  
Pink: S2 and S3>S1

15

Reverse spontaneous replay of memories in hippocampus during "off states"

Foster & Wilson (2006) Nature

### Posterior cortices and limbic areas

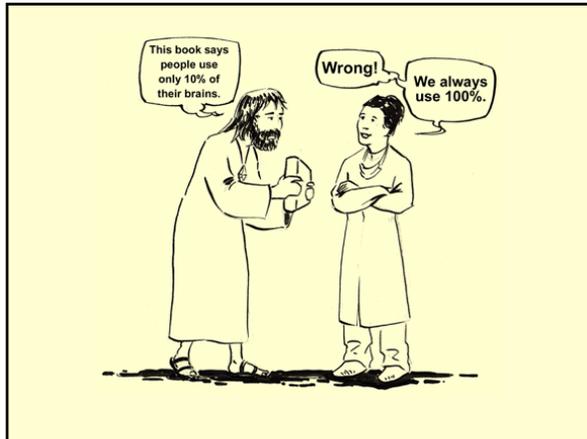
Stream of consciousness

Perception, memory and emotion

Memories, images, and emotions are allowed to "occur" spontaneously

### The two sides of human thought

The critical, analytical side... and the intuitive, spontaneous side



## The two sides of human thought

- The critical, analytical side
  - based on critique and questioning
  - introspection and self-evaluation
  - a sense of effortful control and the self-generation of thoughts
- The intuitive, spontaneous side
  - based on belief and acceptance
  - reduced agency and awareness of self
  - a sense of ease as thoughts occur by themselves

## Topics for discussion

- Science has shown that prefrontal cortex 'down-time' is crucial for thinking and learning
  - during sleep (insights increase afterwards)
  - spaced learning – better results
- The fact that people continue to be drawn to religion even today, in the presence of technological and scientific advances
  - evidence that there is a fundamental need for a different, less controlled, more intuitive kind of thought
  - this need may will most likely never disappear – and is likely to increase with increasing scientific advancement
- We need to revise our own understanding of optimal thinking
  - not just "scientific" (in the strict definition of this term)
  - instead, find ways to make flexible use of both sides
  - knowledge of when each kind of thinking is appropriate

## Thanks to

### *Lab members*

- Kamyar Keramatian
- Rachelle Smith
- Alan Gordon
- Graeme McCaig

### *Collaborators*

- Mario Liotti (SFU)
- Alex MacKay (UBC MRI)
- Burkhard Maedler (UBC MRI)

### *Funding*

- Canadian Institutes of Health Research (CIHR)
- Natural Science and Engineering Council (NSERC)
- Michael Smith Foundation for Health Research (MSFHR)
- Canadian Foundation for Innovation (CFI)

