Master of Integrative Biology
Neuroscience Specialization - UE5BIN04

INFORMATION PROCESSING IN THE PREFRONTAL CORTEX FOR DECISION MAKING

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Dec 01, 2021

Decision making

choosing among alternative courses of action (or inaction)

Decision making is the cornerstone of any goal-driven behavior

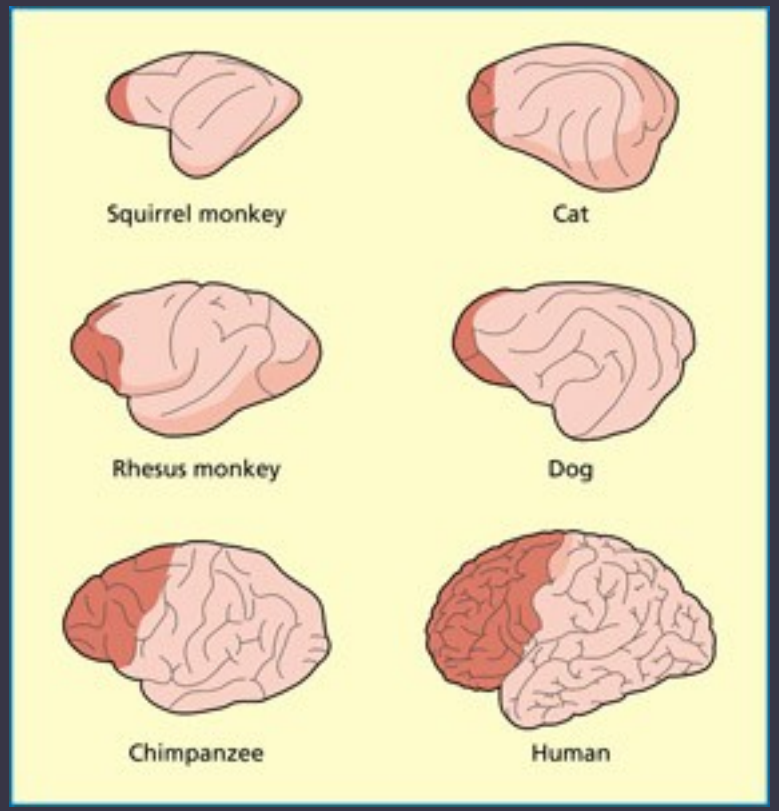
- Daily activities and routines
- Social interactions and relationship
- Profesional activities and performance
- Economics and purchase decisions
- Learning and memory
- Mental health and behavioral dysfunctions

If you decide to stay till the end of the lecture, then you will know why you decided to stay.

The role of the prefrontal cortex

THE BRAIN CENTRAL SYSTEM FOR DECISION MAKING

What makes human PFC unique ?



- **PFC grey matter :** up to 1.9-fold greater than in macaques
- **Subcortical white matter: up to** 2.4-fold greater than in macaques

Human cognitive uniqueness depends on:

- Functions of the frontal lobes
- distributed neural networks.

Donahue et al., 2018; Barton & Venditti, 2013

Two approches of PFC functions

MODULAR APPROACH	CIRCUIT-BASED APPROACH
Localization of functional modules	Distribution of lange-range networks

Goal of the modular approach

- Map cognitive processes in PFC to understand :
  - PFC functional organization
  - How decision making emerge from this organization

Decision making according to the modular approach

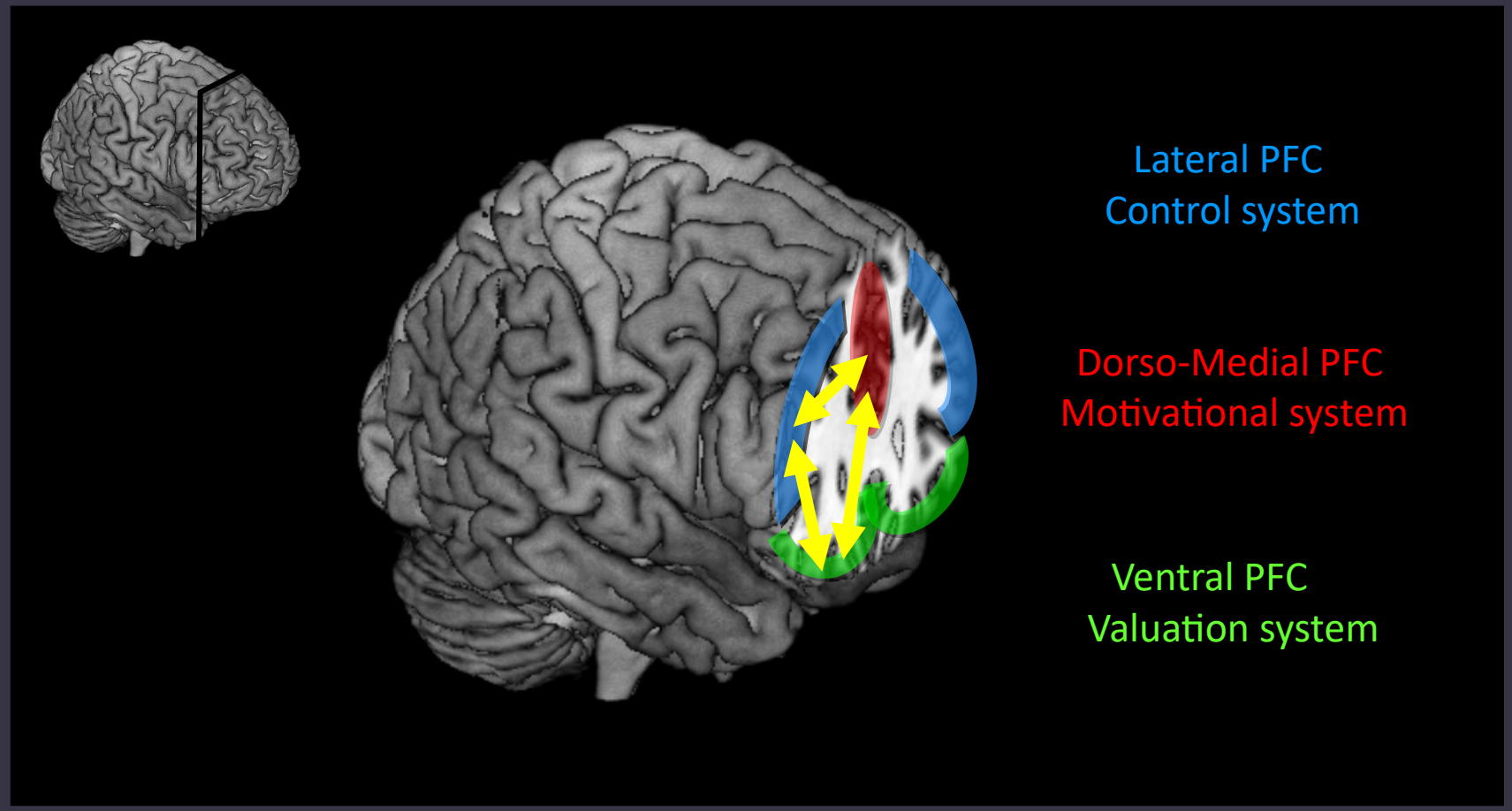
Decision making involves a series of cognitive processes that are implemented in distinct neural modules

A series of component processes :

1. **evaluation** of options
2. **comparison** of option values
3. **selection** of an appropriate action plan
4. **monitoring** of the outcome of the choice

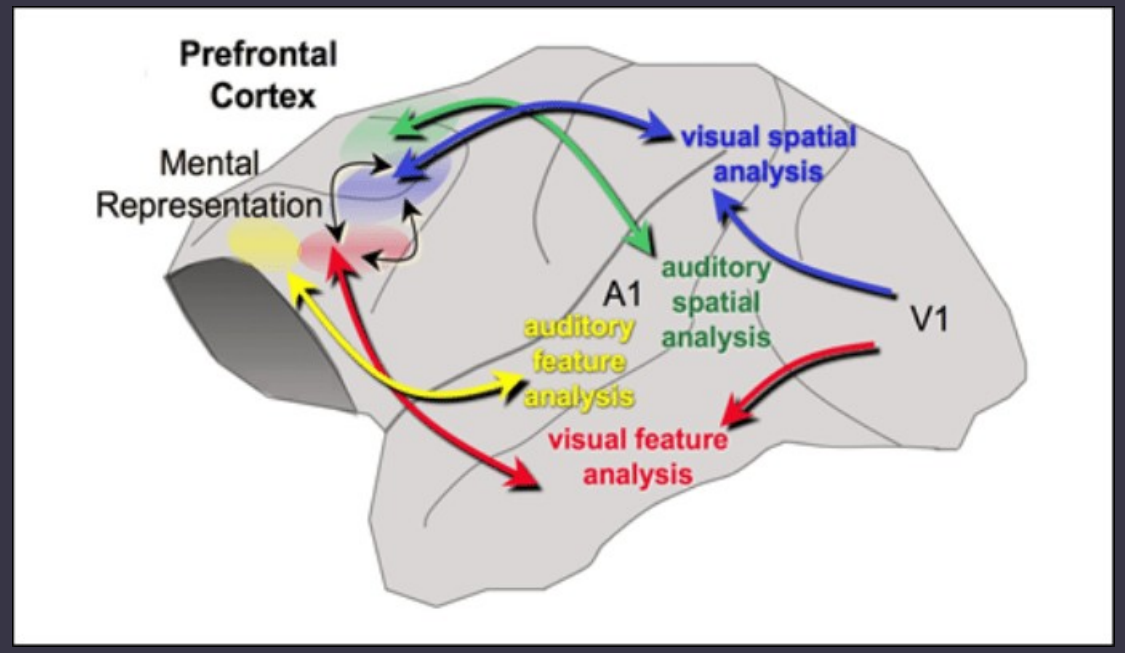
Hunt & Hayden, Nature Rev Neurosci, 2017

Three main functional PFC axes operates along distinct dimensions of information processing



Goal of the circuit-based approach

- Identify which computations are performed recurrently in distinct brain regions to understand :
- Whole-brain functional dynamic
- How decision making emerge from this dynamic



Decision making according to the circuit-based approach

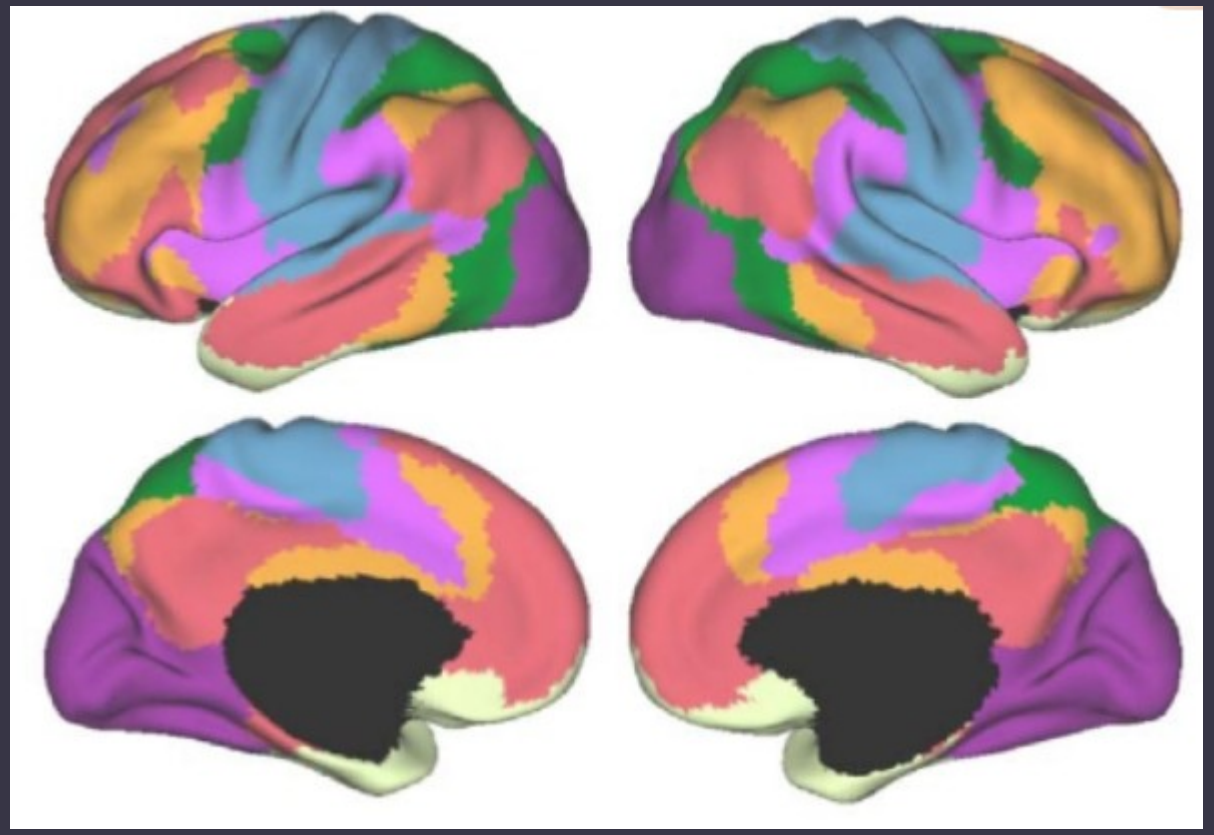
Choices are formed in a distributed fashion across many brain regions that act in concert and perform similar computations.

Three overarching principles :

- Decisions are formed in a **distributed** fashion across many brain regions.
- The distributed networks are highly **recurrent** in nature.
- The networks are organized into **functional and temporal hierarchies**.

Hunt & Hayden, Nature Rev Neurosci, 2017

Large-scale functionnal circuits

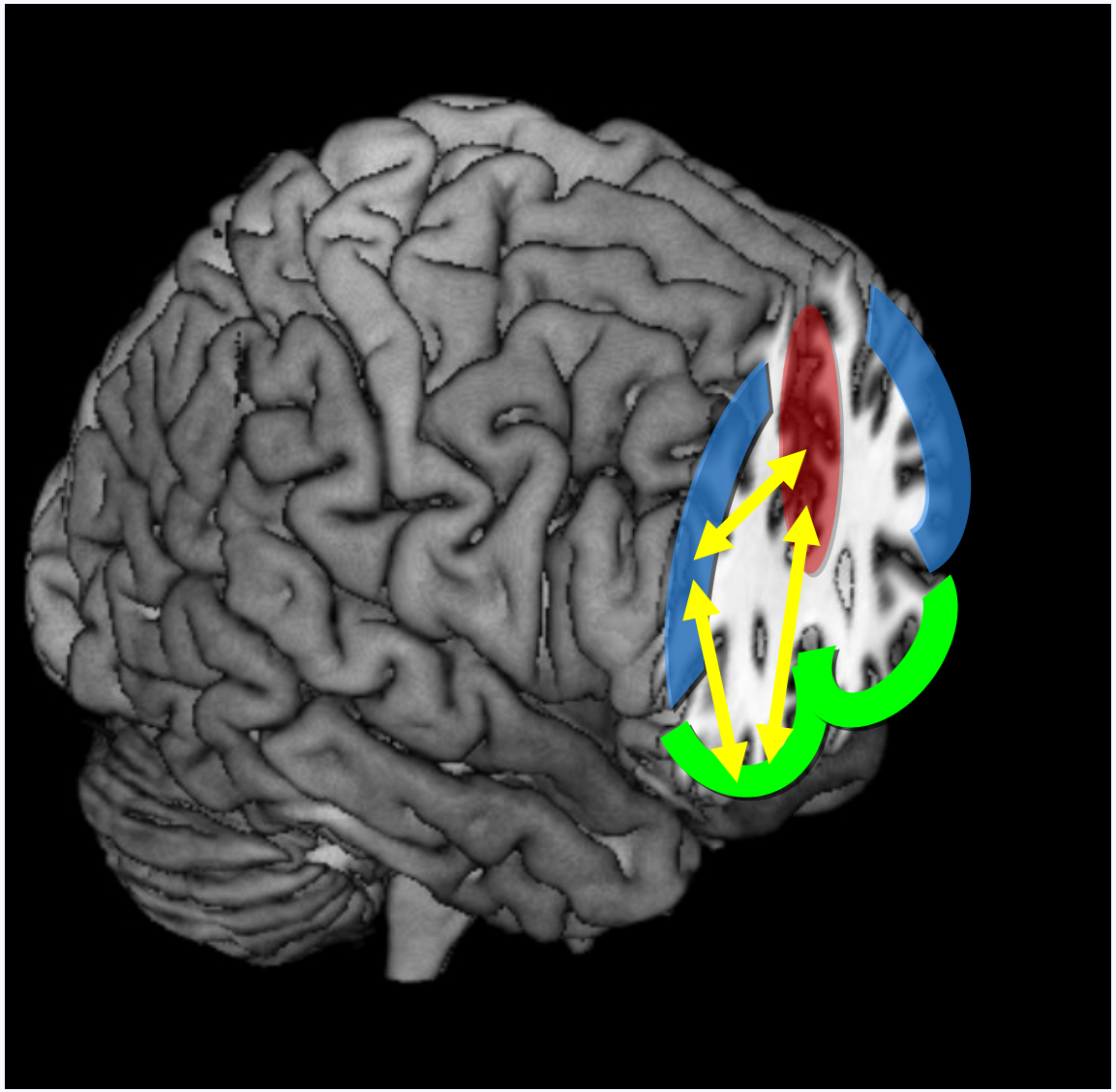


Yeo et al., J Neurophysiol 2011

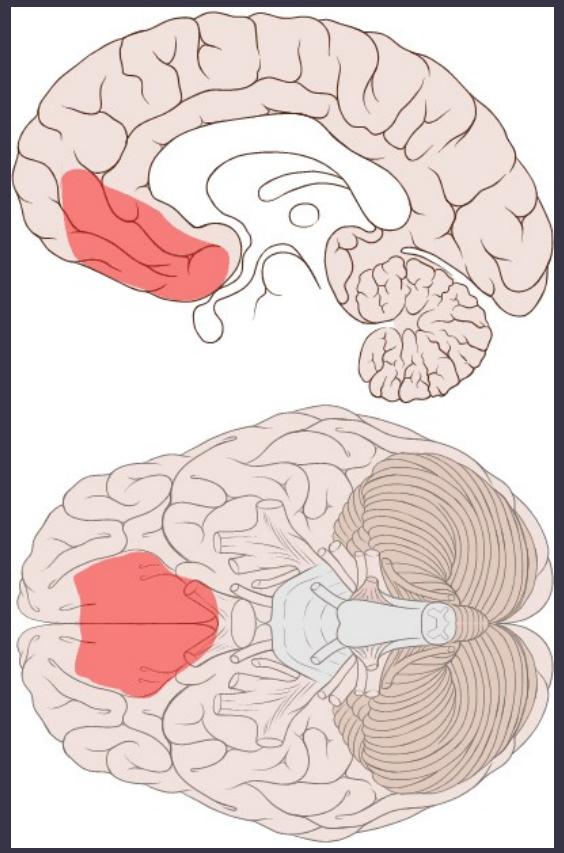
- **Distributed**: embedded within largely parallel circuits.
- **Hierarchical**: serve as a bridge between sensory and motor networks

VALUATION SYSTEM IN VENTRAL PFC

How to choose the best option ?



Ventro-medial PFC



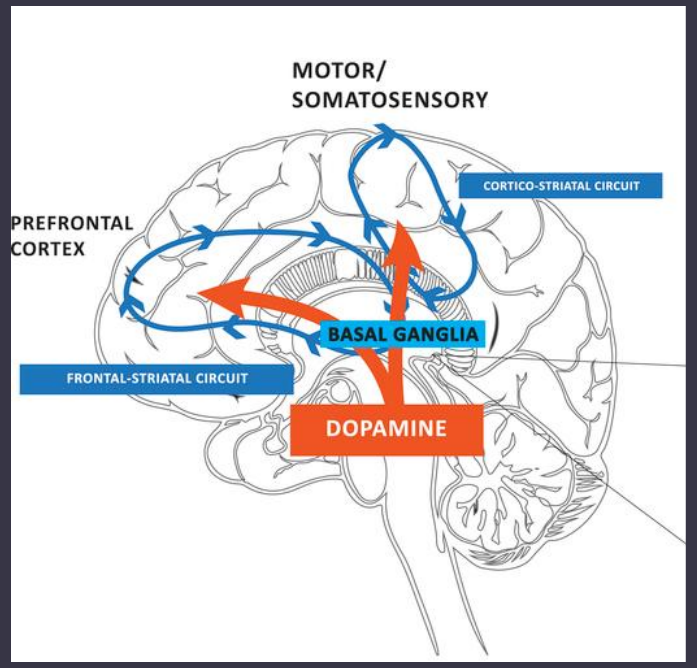
- Also known as **orbitofrontal cortex**

- KEY ROLE IN :
  - **value-based decision making:** part of the dopaminergic reinforcement-learning system:
  - **emotion regulation:** addictions, depression, delusion
  - **social cognition**: self-referential, theory of mind

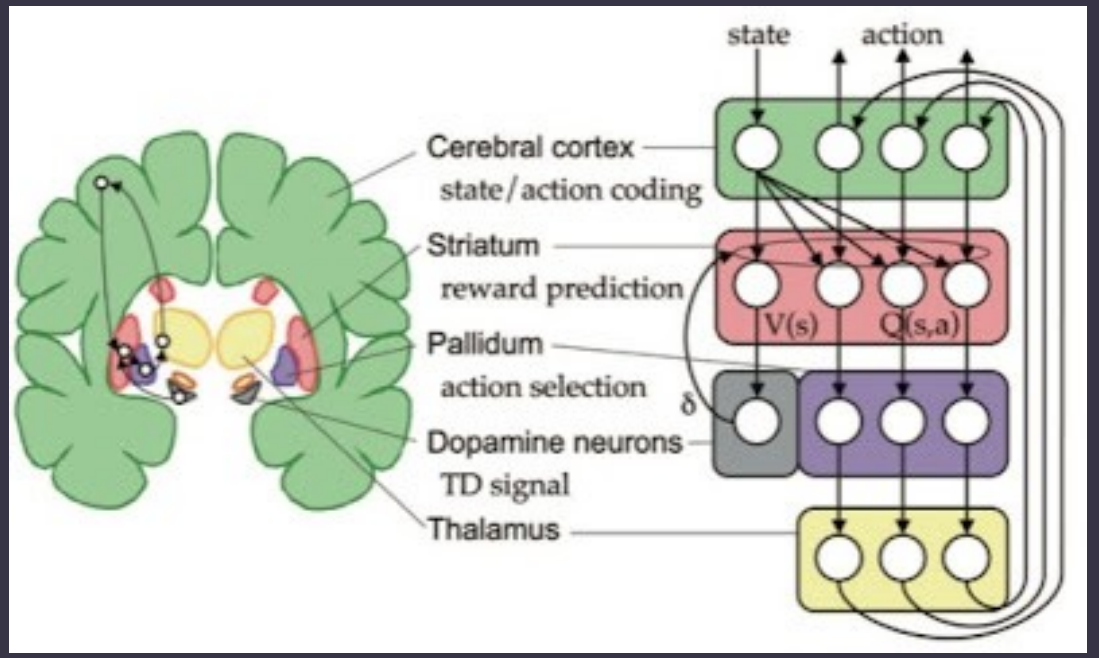
Dopaminergic system and reinforcement learning

Doya, HFSPJ 2007

Dopaminergic loops



Reinforcement learning and dopaminergic loops



Model-free vs model-based decision making

Daw et al, Nature Neurosci 2005

MODEL-FREE DECISION MAKING IN STRIATUM

- based on direct **stimulus-response associations**
- **Estimates cache values** with temporal-difference learning
- **Updates estimated values** directly from experience and feedbacks

MODEL-BASED DECISION MAKING IN PFC

- Leverages internal representations of **task structure**
- Estimates the state and reward **transitions**
- anticipates **long-run consequences** of candidate actions

Ventro-medial PFC in value-based decision making

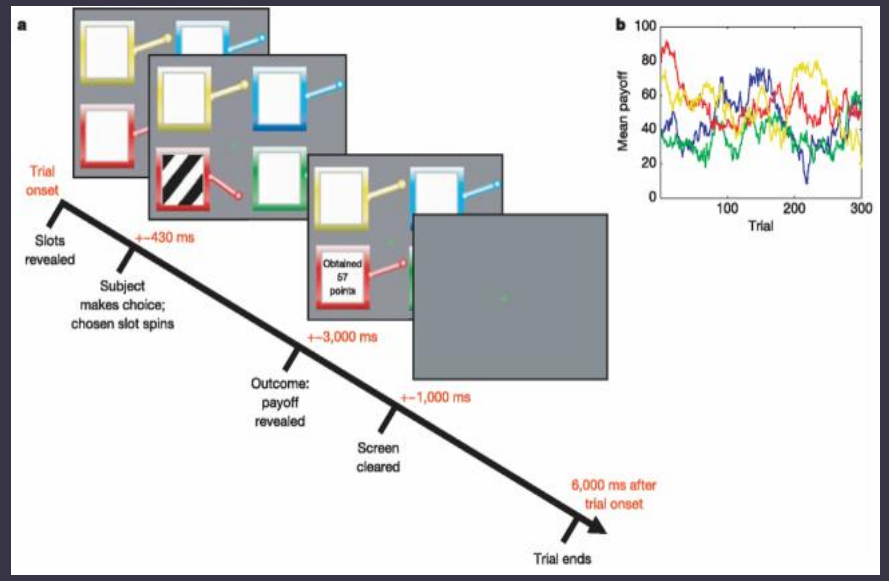
• **VmPFC codes the value of chosen option**	• Activations increased with the reward magnitude and/or reward probability associated with the chosen option
• **VmPFC codes subjective values for intertemporal choices**	• Activations support decisions involving immediately available rewards
• **VmPFC contributes to economic choices**	• Activations are correlated with the value of offered and chosen goods and anticipate losses
• **VmPFC codes goal values**	• Activations increase with goal values and decrease with self-control
• **VmPFC converts rewards into common currency**	• Activations vary for any type of reward (money, food, beverage, sexual appeal)

vmPFC in value-based choices

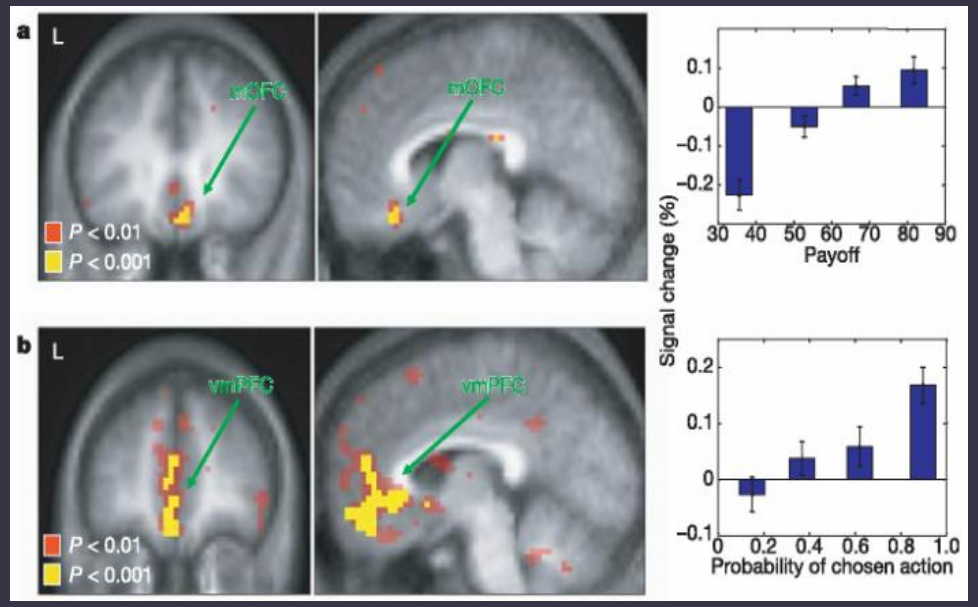
Daw et al., Nature 2006

Experimental protocol

4-arm bandit choice task : competing options associated with stockastic reward magnitude



VmPFC activations increase with rewards magnitude and the value of chosen option

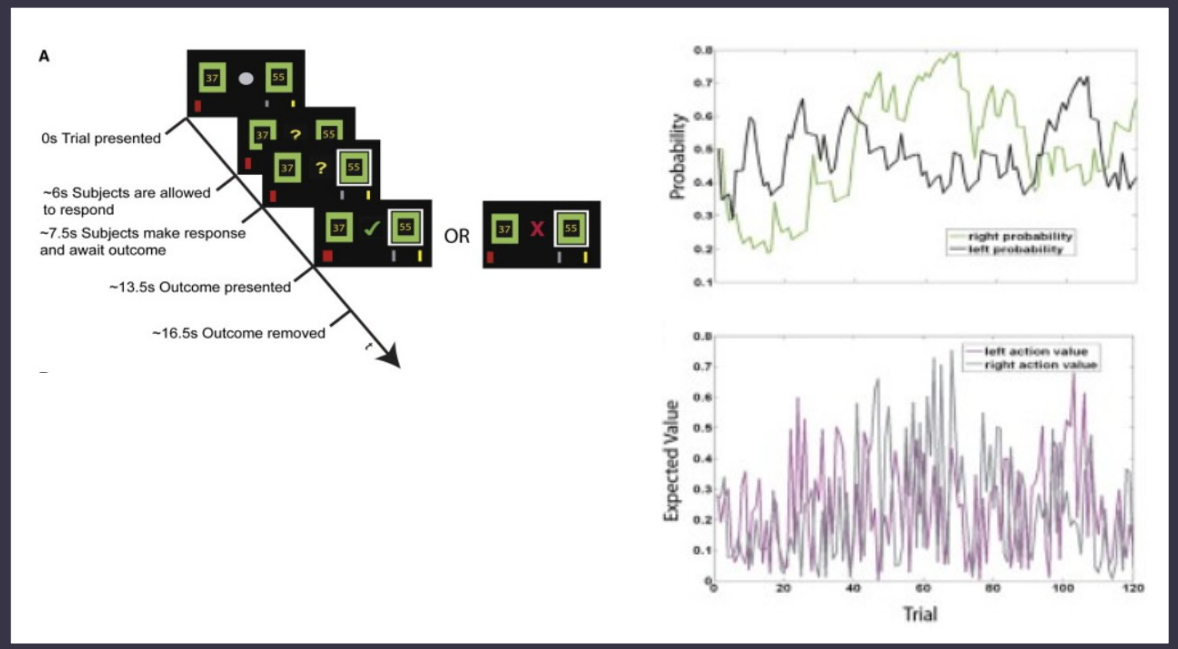


vmPFC codes the evidence in favor of the current decision

Boorman et al., Neuron 2009

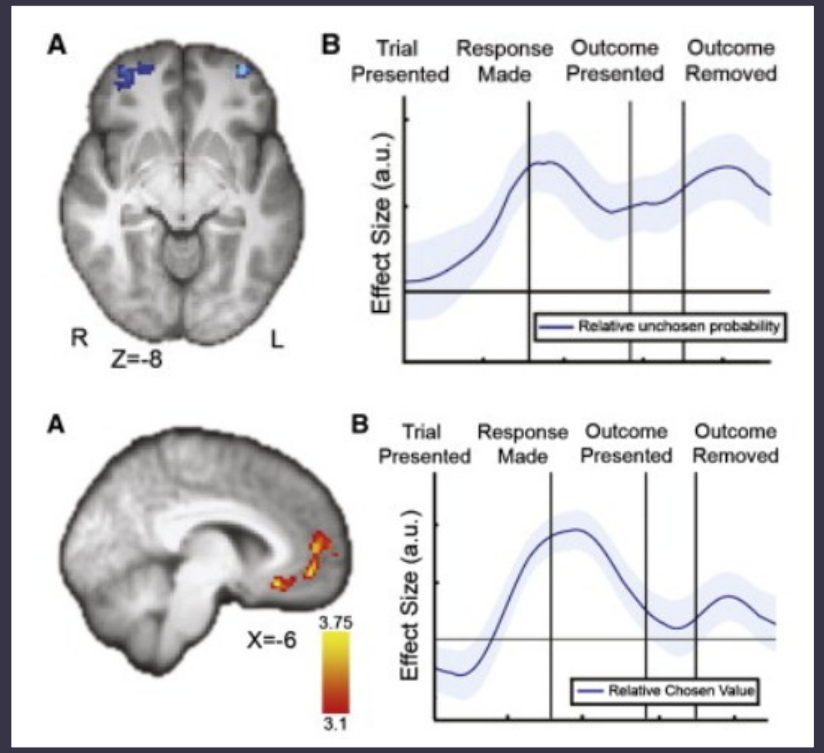
Experimental protocol

2-arm bandit choice task : competing options associated with varying reward magnitude and probability



VmPFC code the value of the chosen option

While anterior lateral PFC tracks the probability of switching to the alternative course of action



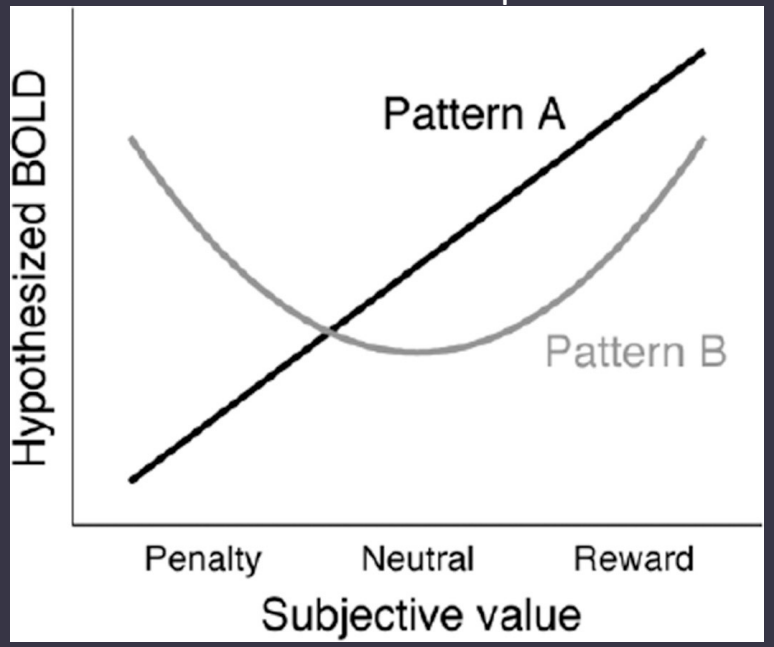
vmPFC codes the evidence in favor of the current decision

Bartra et al, Neuroimage 2013

Hypotheses

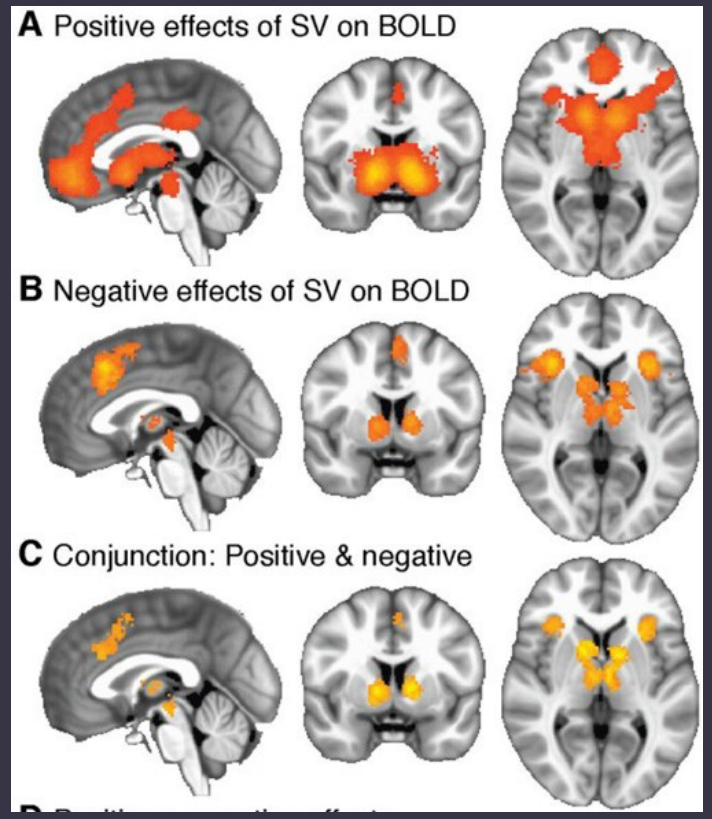
VmPFC activity may vary with subjective values in 2 ways:

- monotonically increasing for more valuable outcomes
- quadraticcally increasing for more extreme outcomes, either rewards or penalties.



VmPFC activations increase monotically with subjective values

While anterior dorsal ACC and striatum activations increase quadrtically



So far you're still attending the lecture, because:

- VmPFC predicts that attending the lecture is going to be rewarding

- VmPFC signals that it is **the best option** at the moment

PRACTICE TIME #1

LOG AT

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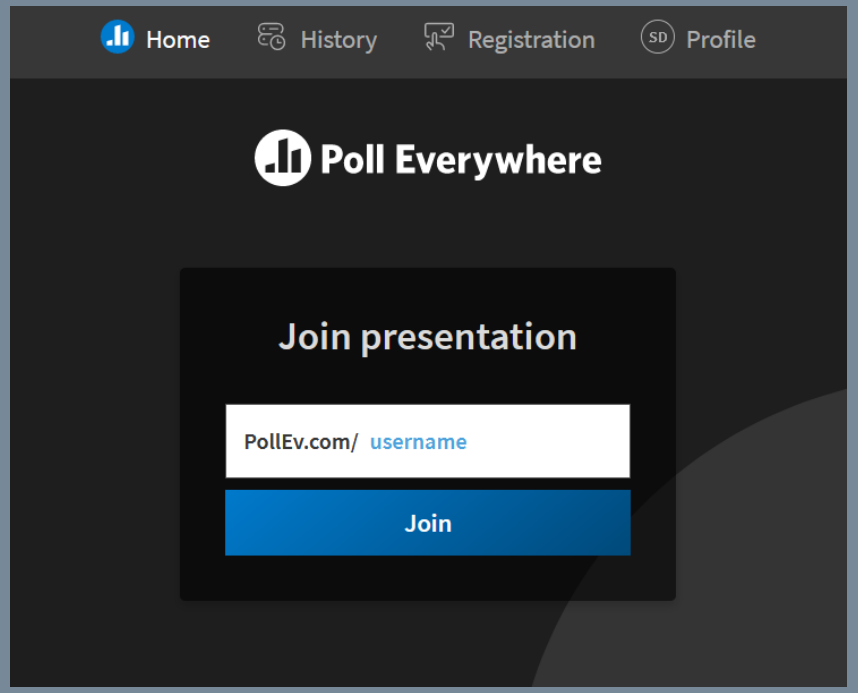
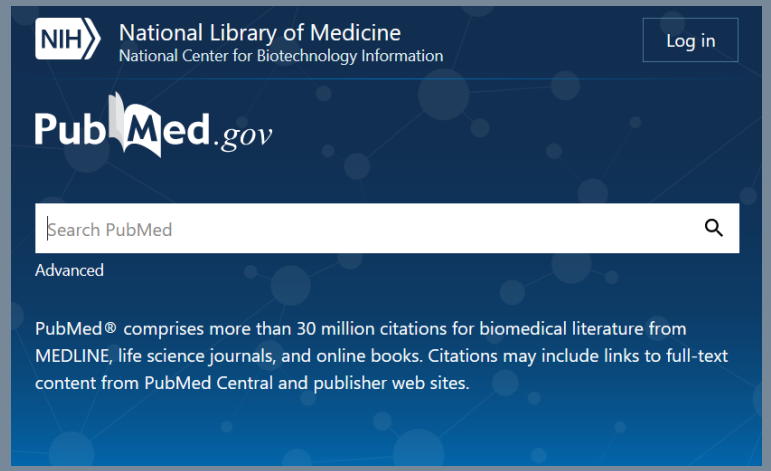


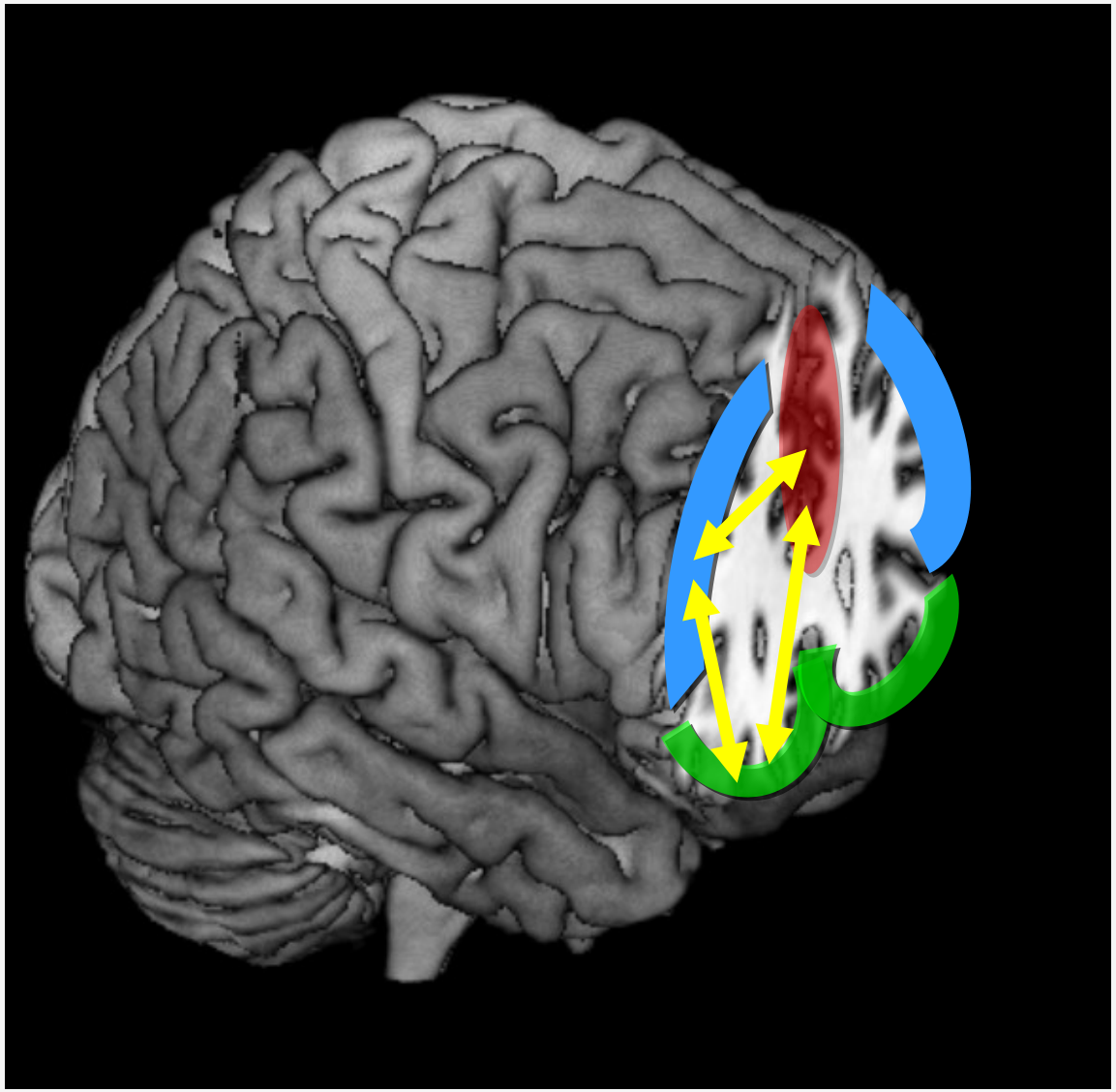
Use one of these search platforms to find the reference of seminal research studies



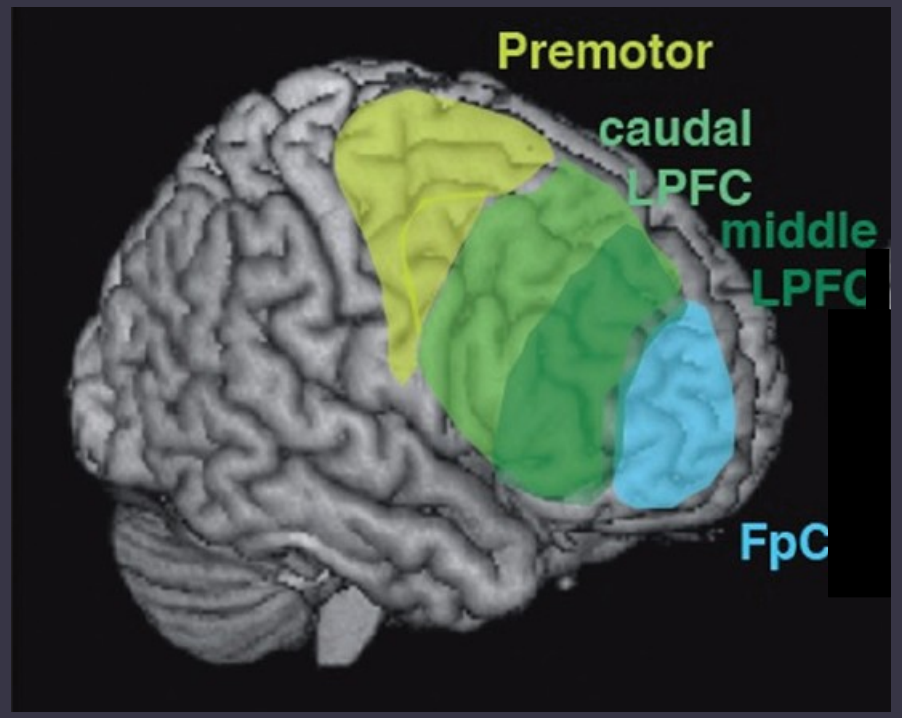
10 MINUTES

COGNITIVE CONTROL IN LATERAL PFC

How to adapt the ongoing course of action or how to change the course of action ?



Lateral PFC



- Neural architecture
  - premotor cortex (BA 6/8)
  - dorsolateral PFC = caudal and middle PFC (BA 46/45/9)
  - Frontopolar cortex or anterior PFC (BA 10)

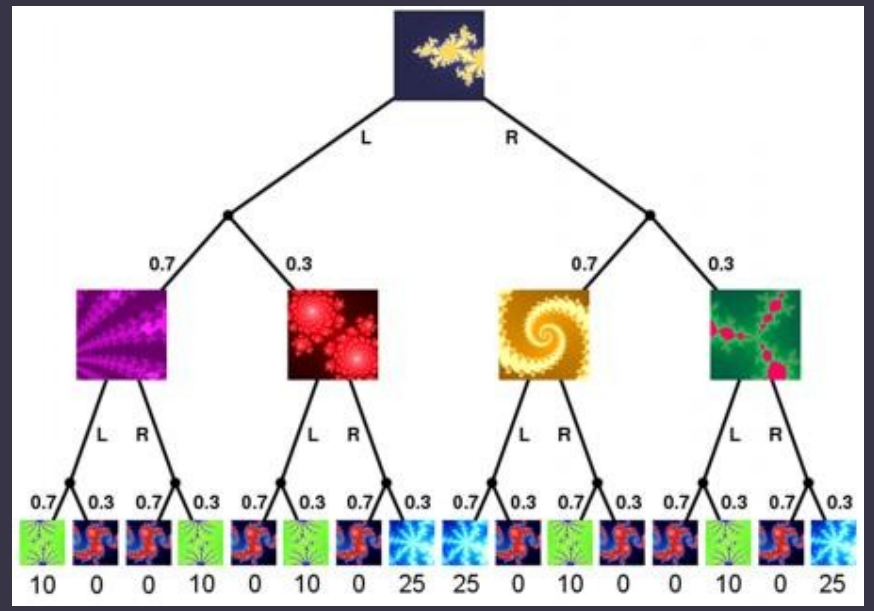
- KEY ROLE IN:
  - **Model-based decision making** : encode task structure, state and reward transitions, long-run consequences
  - **Cognitive control:** adaptation of behavioral responses to environmental constrains

Lateral PFC in model-based choices and state transition

Glascher et al., Neuron 2010

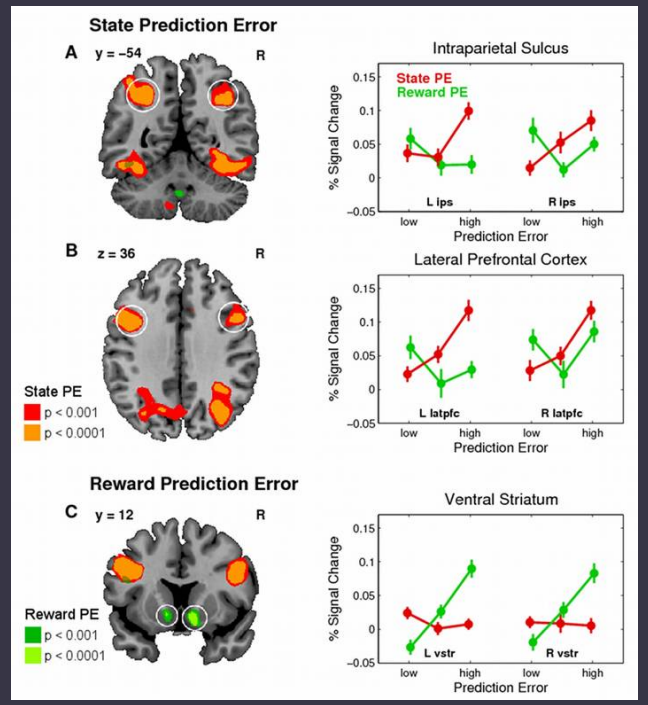
Decision tree paradigm

sequential two-choice Markov decision with varying reward and state transition



PFC codes state prediction error

while striatum codes reward PE



Cognitive control in lateral PFC

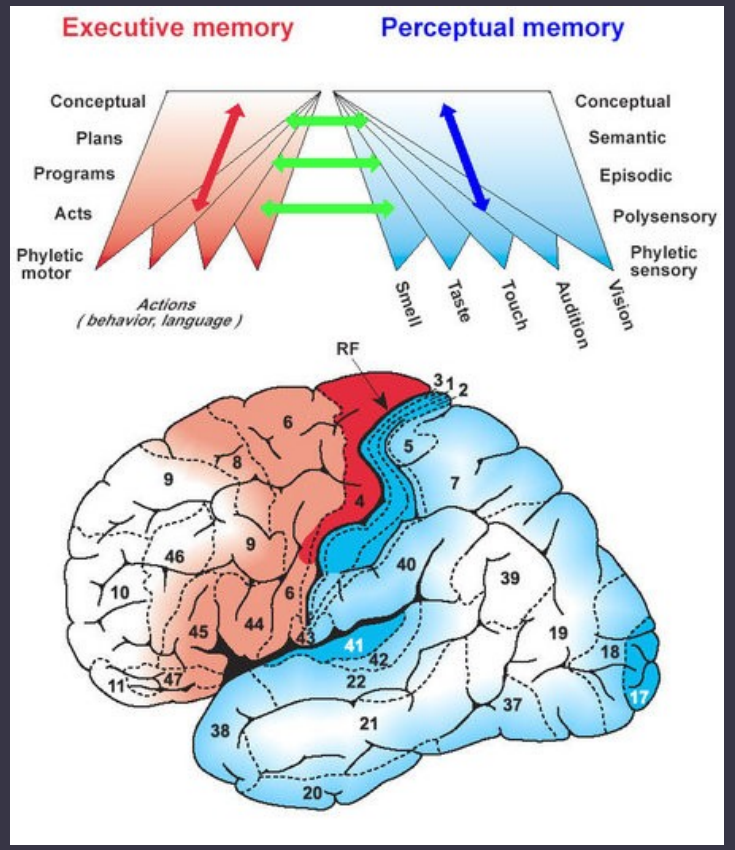
A set of processes that enable behavioral adaptation according to environmental constrains

Key role in high-level cognitive functions:

- **Attention:** selectively orient and shift attention, inhibit irrelevant information
- **Memory**: working memory, long-term and prospective memory
- **Action selection**: switching, planing, problem solving, exploration of alternative solutions

Hierarchical organization of PFC functions

Fuster, *Trends NeuroSci*, 1997



Frontal and posterior lobes are hierarchically organized to support high level cognitive functions:

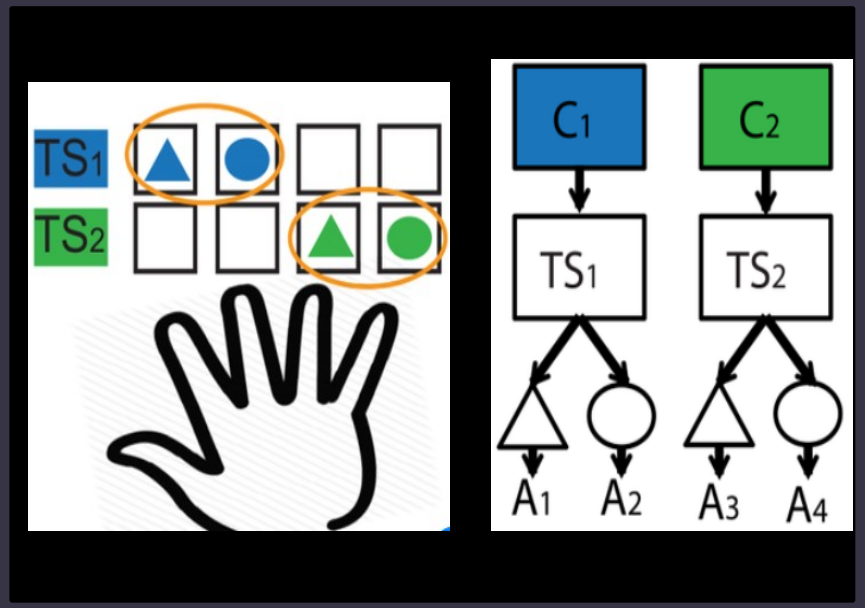
- Frontal system = motor memory
- Posterior system = perceptual memory

PFC functions are hierarchically organized in an anterior-posterior axis to process abstract to more concrete information.

The notion of task set in action selection

Sakai, *Ann Rev Neurosci* 2003

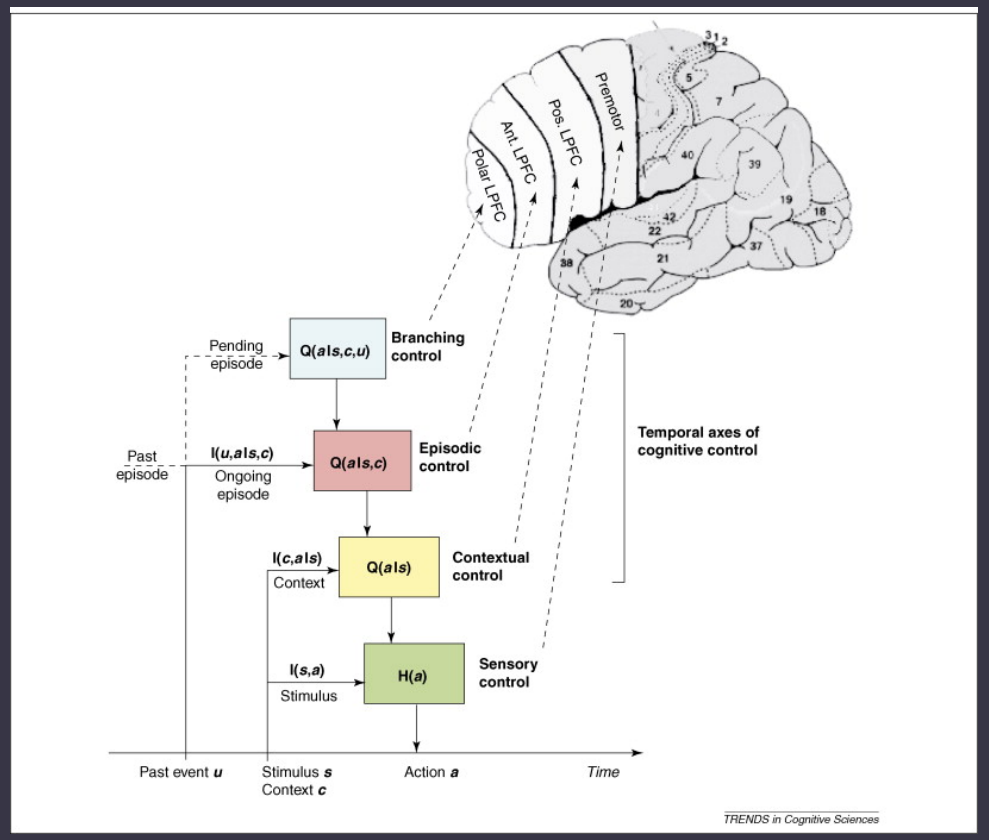
- Abstract rules that are context-dependent
- Abstract rules are actively maintained across an episode to perform a task
- dlPFC functions are organized to selectively represent, update and implement specific task set
- Competition between neural representations of task sets during task switching



Collins & Frank, *PLoS Comput Biol* 2016

Cascade of cognitive control processing

Koechlin & Summerfield, *Trends Cog Sci*, 2007



- **Sensory control** : select actions based on stimulus-response associations
  - **Contextual control** : represent abstract task sets and allow to switch between task sets based on contextual cues
  - **Episodic control :** maintain ensembles of task set and allow to switch between these ensembles based on temporal episode
  - **Branching control** : monitor alternative task sets and instantly resume to

So far you're still attending the lecture, because:

- Dorsolateral PFC allows you getting back and forth between well-known task sets
- Middle lateral lPFC manages to maintain your attention focused on the ongoing task set till the end of the lecture
- Frontopolar cortex helps you getting back on track if you've temporally switched to another task

PRACTICE TIME #2

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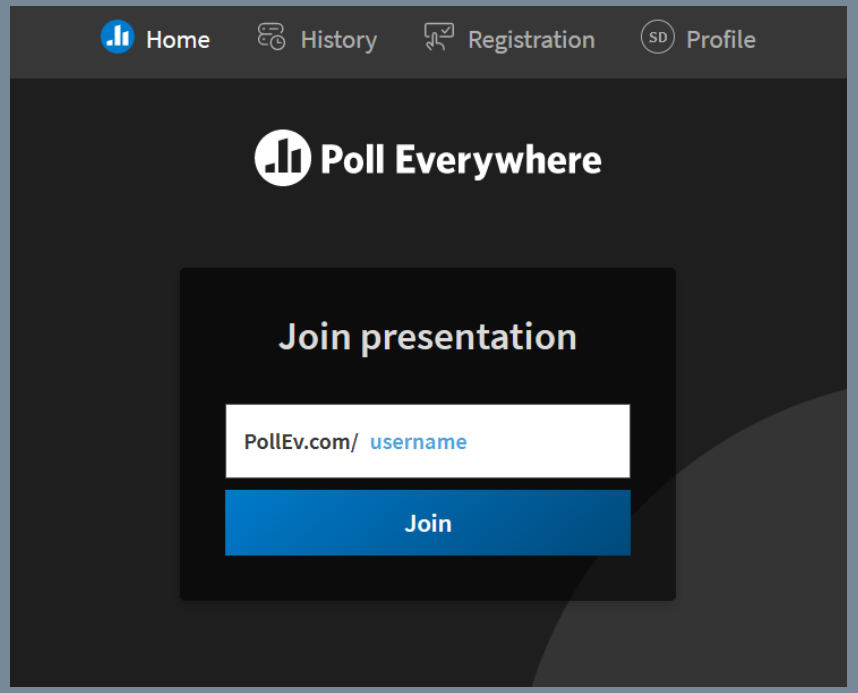


Use David Badre's review in Trends in Cognitive Sciences (2008) to answer the questions

Review

Cell PRESS

Cognitive control, hierarchy, and the rostro–caudal organization of the frontal lobes

David Badre

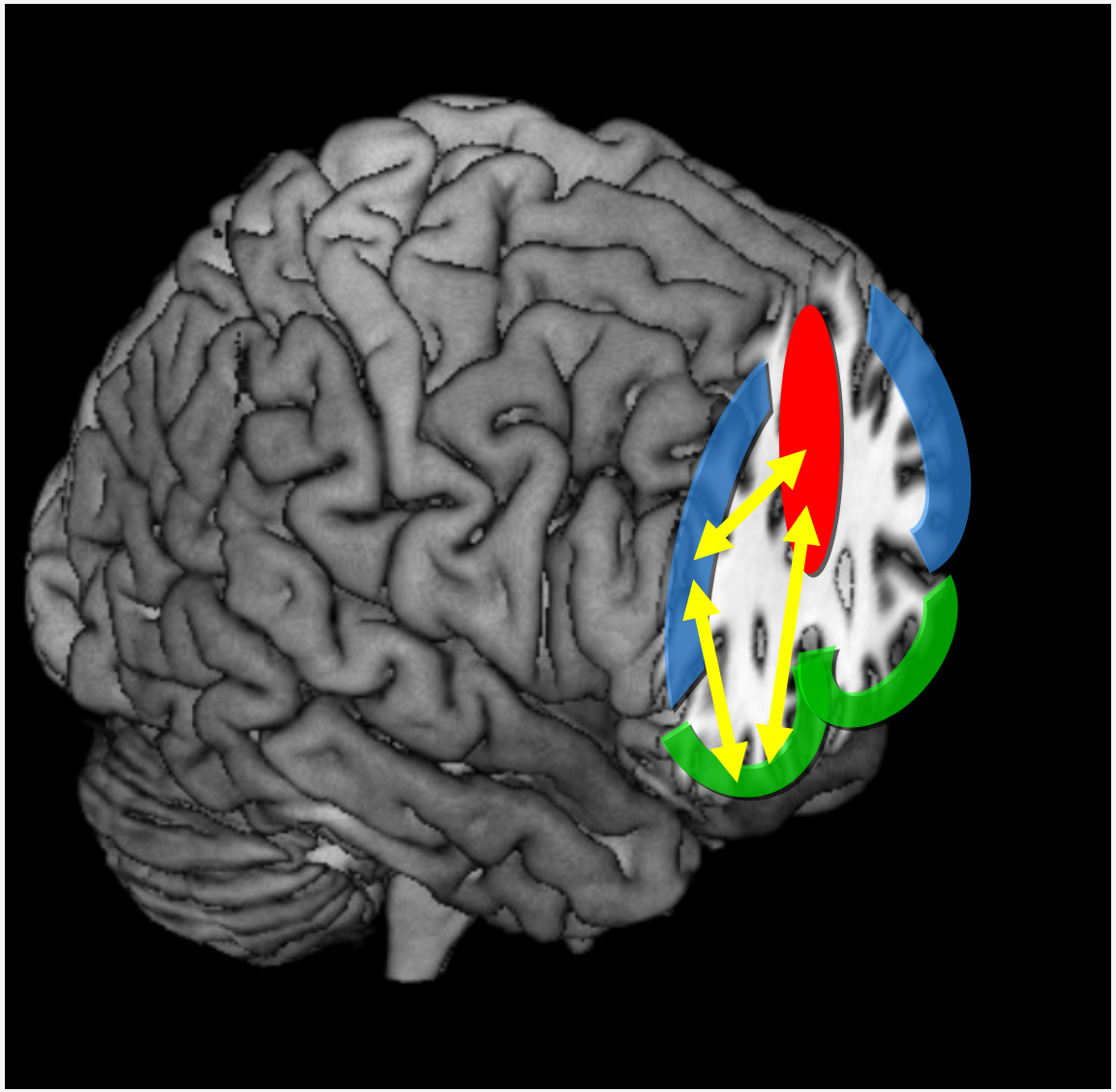
Department of Cognitive and Linguistic Sciences and Department of Psychology, Brown University, Box 1978, Providence, RI 02912-1978, USA

http://titan.cog.brown.edu/research/badrelab/papers/BADRE_TICS08.pdf

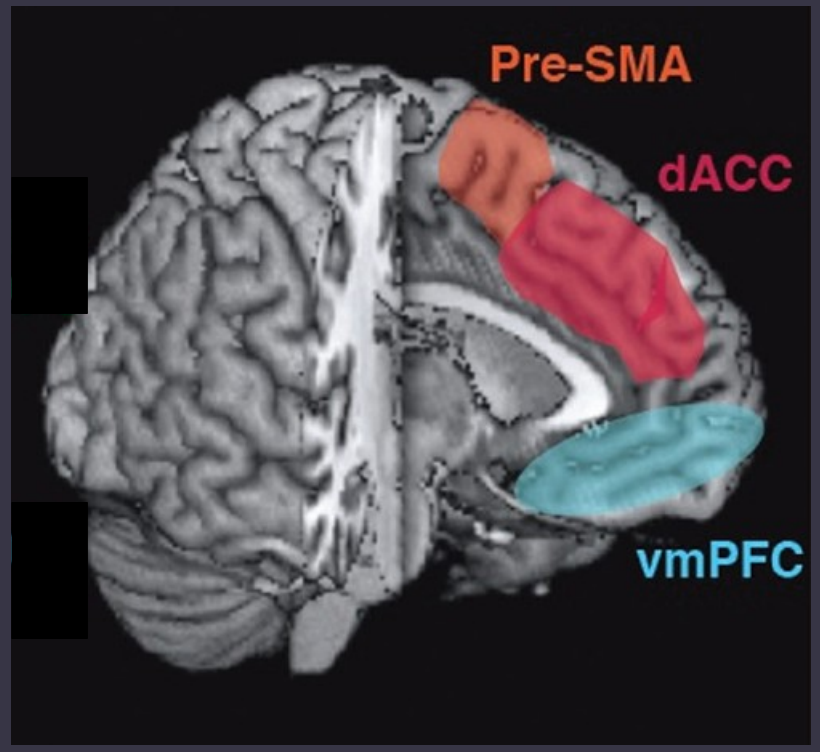
10 MINUTES

MOTIVATIONAL CONTROL IN DORSO-MEDIAL PFC

How to decide to depart from the ongoing course of action and switch to another one?



Dorso-medial PFC

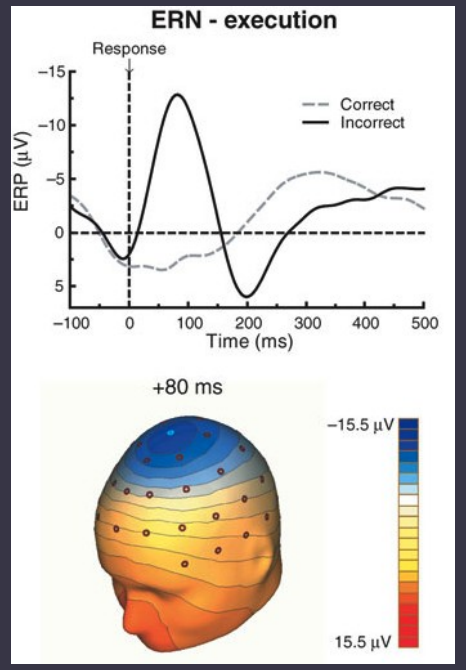


- Neural architecture
  - Dorsal Anterior cingulate cortex (BA 32)
  - pre-supplementary motor area (BA 6)
- Key role in
  - cognitive control
  - value-based decision
  - effort and pain processing

Dorsal ACC in Cognitive control

Error monitoring

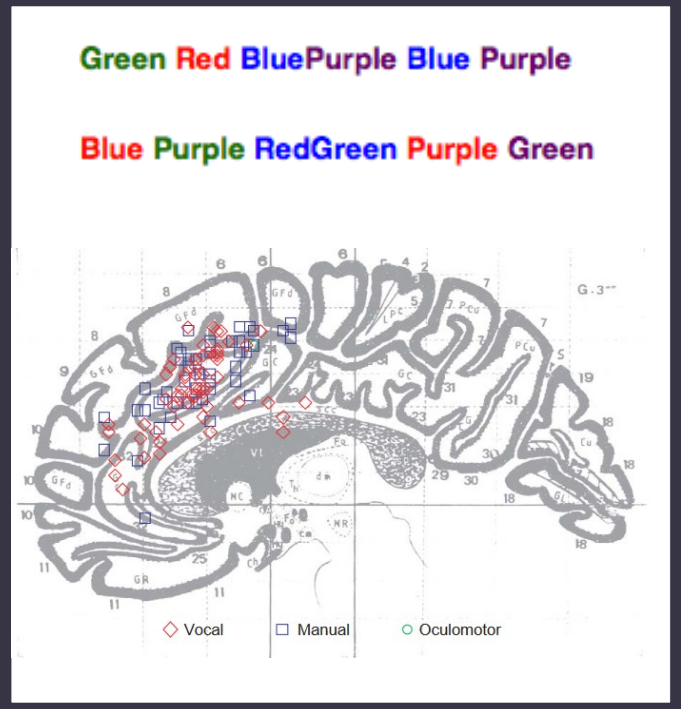
Holroyd & Coles, Psychol Rev 2002



van Schie et al, 2004

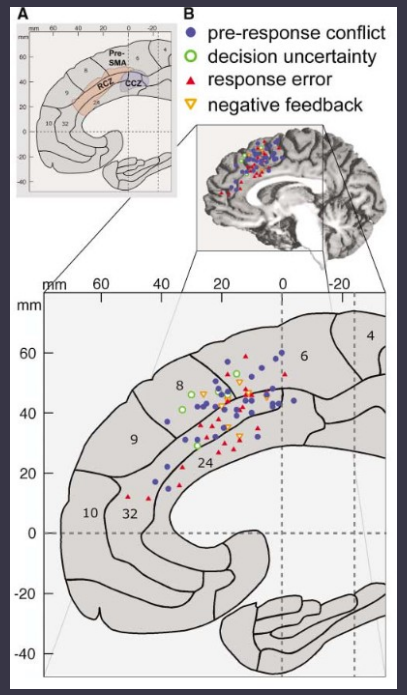
Conflict detection

Botvinick et al, TiCS 2004



Regulatory processes for performance adjustment

Ridderinkhof et al, Science 2004

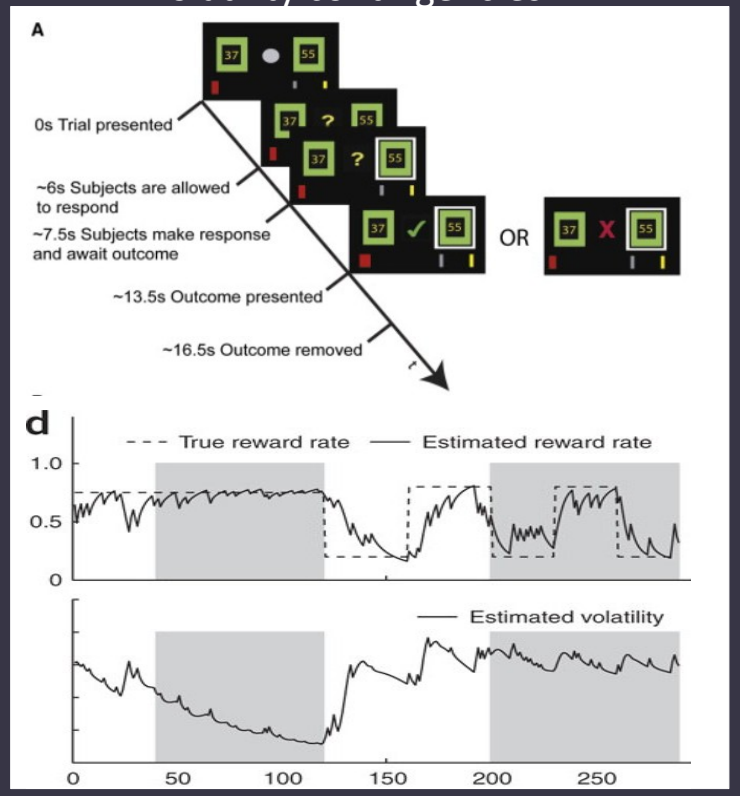


Dorsal ACC & value-based choices

Behrens et al., *Nature Neurosci* 2007

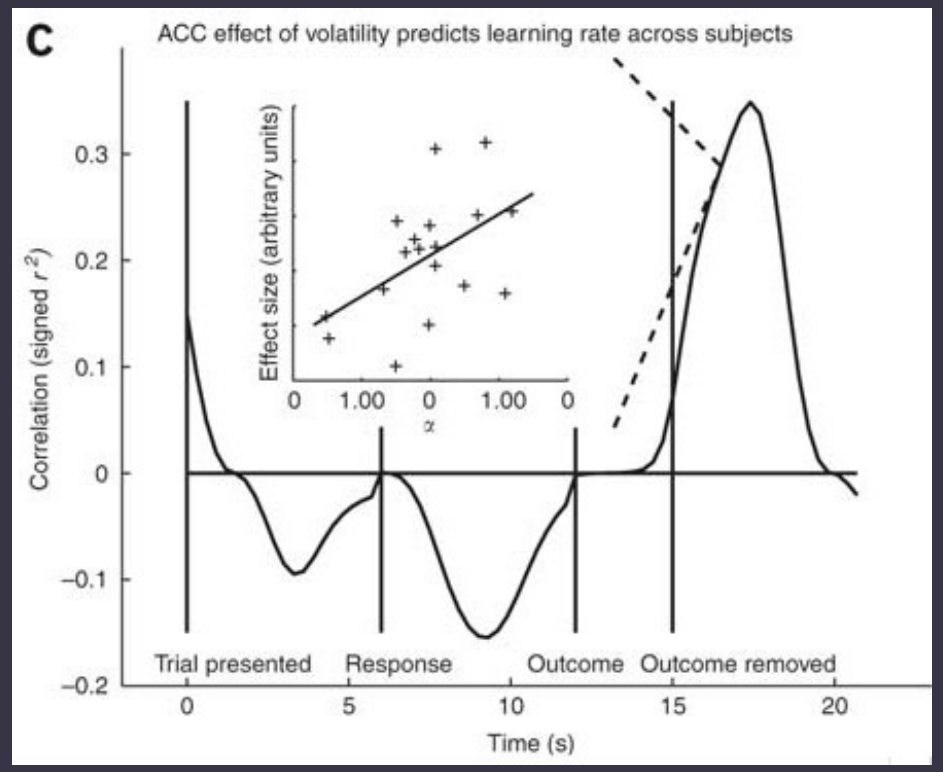
Experimental protocol

2-arm bandit choice task with volatility contingencies



dACC predicts reward volatility

ACC activations vary with estimated volatility after outcome and correlates with subject's learning rate

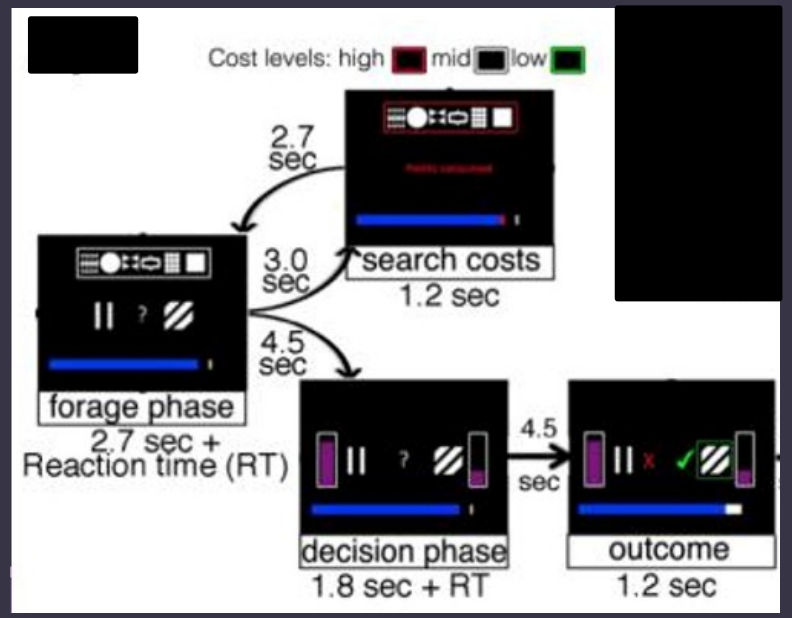


Dorsal ACC & value-based choices

Kolling et al., *Science* 2012

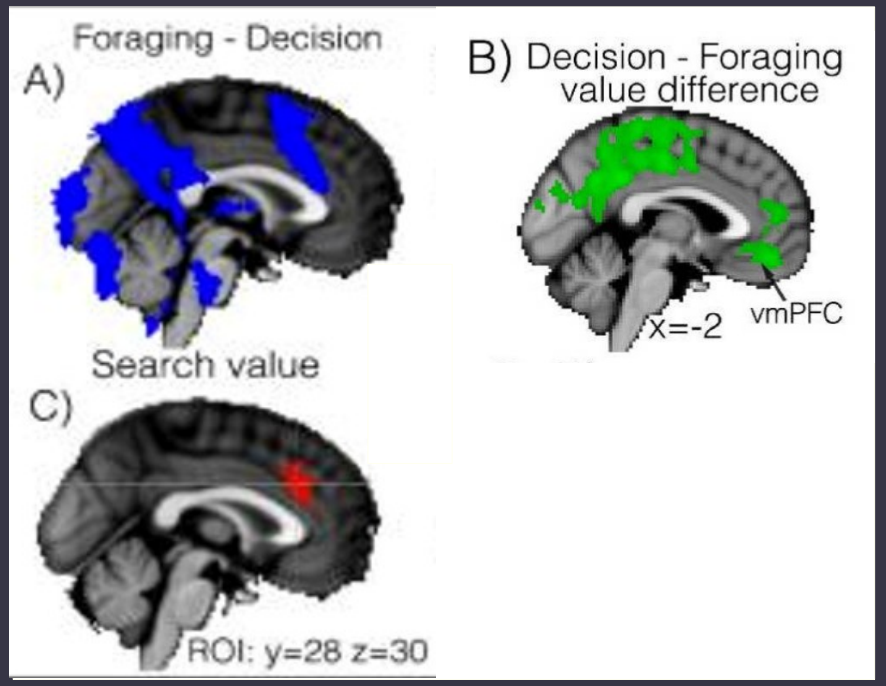
Foraging task

Choose between the default option and an alternative search options



DACC codes the value and the cost of foraging

While vmPFC codes the values of well-defined options

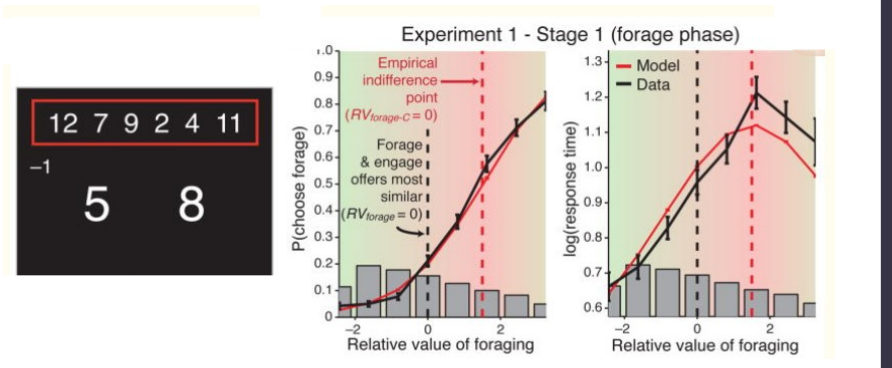


dACC activations during foraging choice

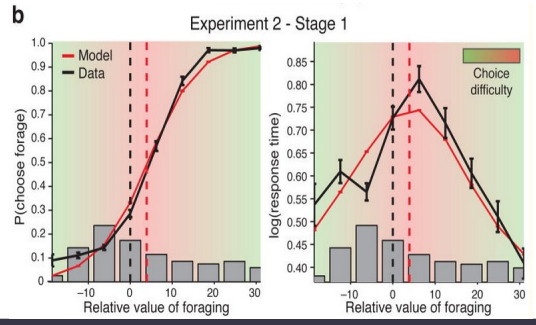
Shenhav et al., Nature Neurosci 2014

Choice difficulty vs foraging value

Control for shift in indifference point between foraging and default option

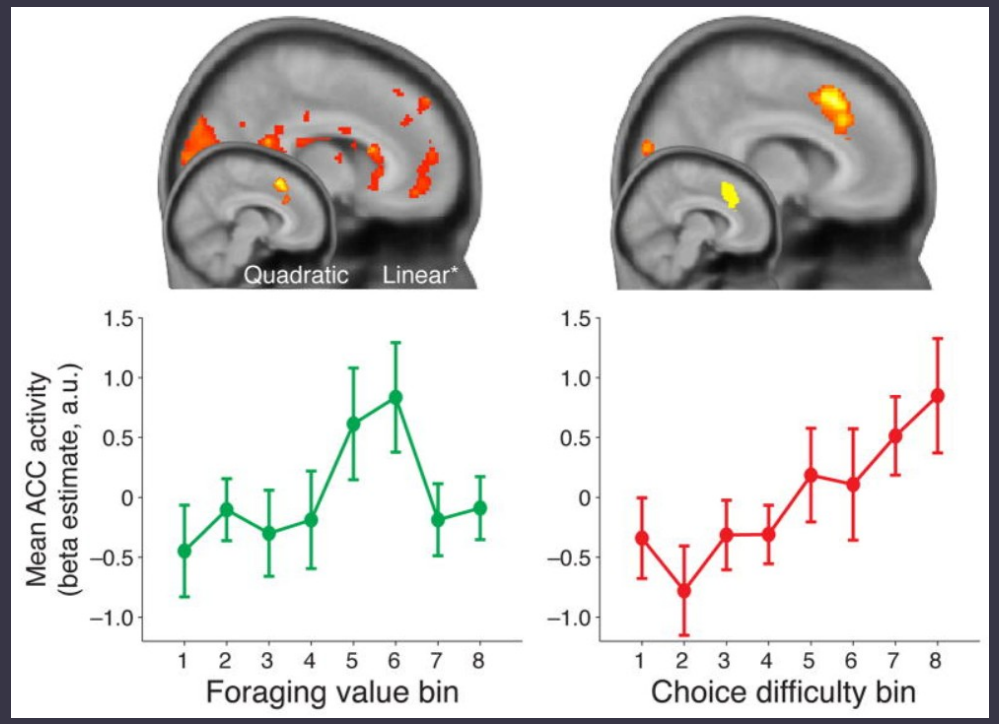


Use larger relative foraging values in Experiment 2



dACC activations scale with choice difficulty

But not with foraging value in experiment that allow to control for



So far you're still attending the lecture, because:

- dACC monitors your study performance
- dACC evaluates that the alternative options are not worthy
- dACC evaluates that the cost of leaving the lecture is too high

PRACTICE TIME #3

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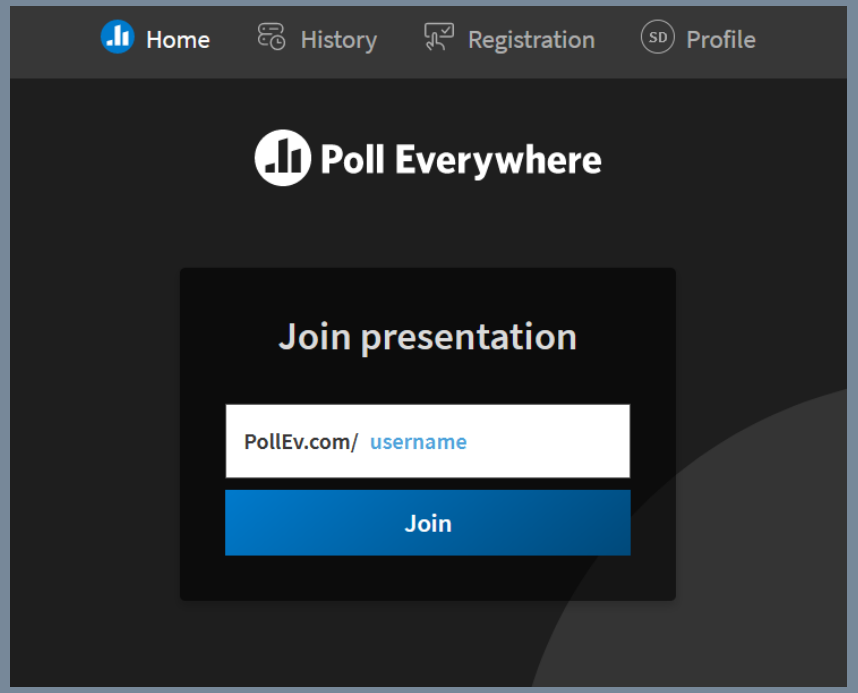
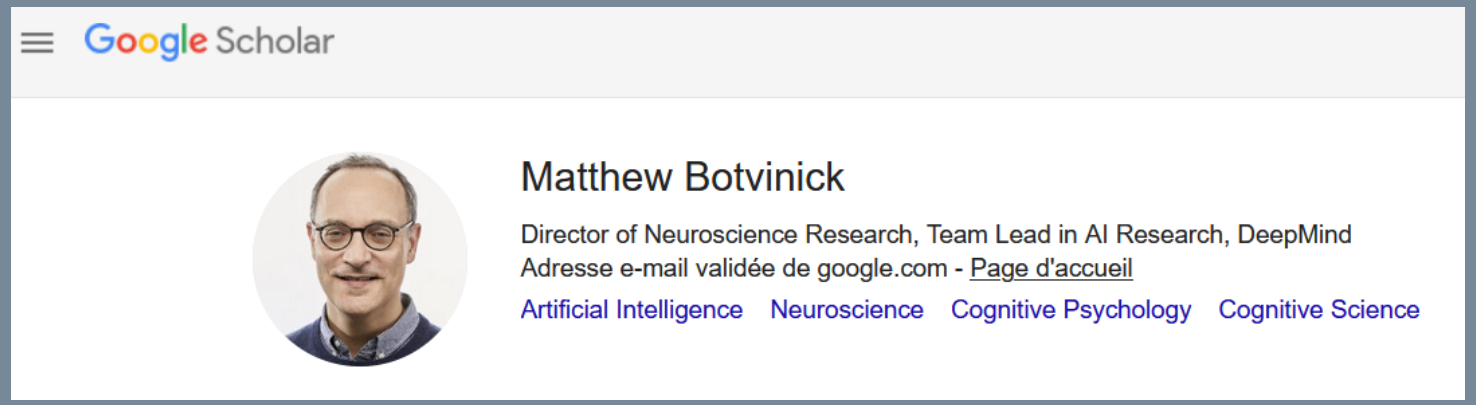
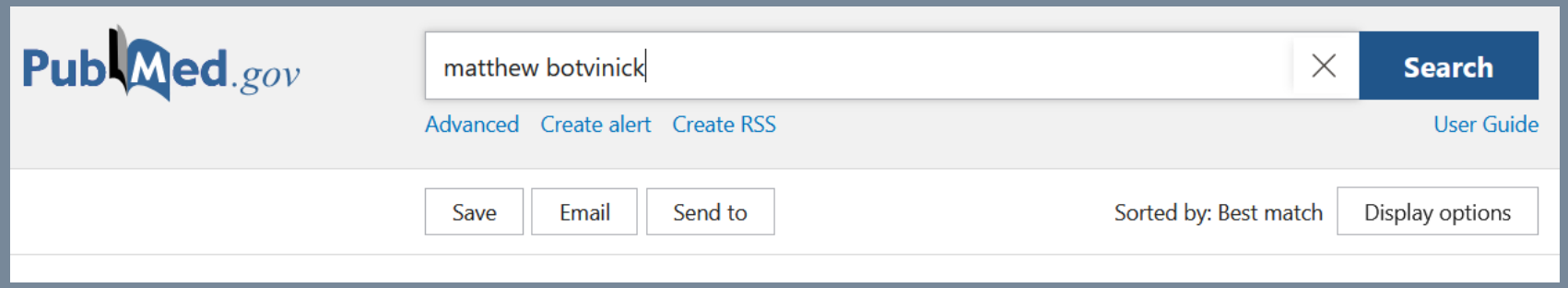


Use one of these search platforms to find key research studies of Matthew Botvinick





10 MINUTES

Thanks for your attention!

PLEASE PROVIDE YOUR FEEDBACK ON THE LECTURE

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