THE FORMATION OF HABITS
The implicit supervision of the basal ganglia
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Don’t press this button!
Goal-Directed Actions  VS  Habits

→ behavior adjusts to reflect the new value of the outcome that the action would obtain

→ habits persist even if the reward becomes less attractive or there is no reward at all.

Basal Ganglia
Cortex

Goal Directed actions go here

Habits go there

Basal Ganglia

Cortex leads decision once learned

BG “teach” cortex during learning phase

Ashby, Turner & Horvitz (2010)

Daw, Niv & Dayan (2005)
Outline

• Experiment
• Computational model
• Results
Experimental setup

Two monkeys, simple two-armed bandit task with P=0.75 and P=0.25.

→ Habitual condition (known stimuli pair, same every day)
→ Novel condition (unfamiliar stimuli pair, new every day)
Experimental results

[Graph showing mean success rate over number of trials for saline, HC, and NC groups.]

- Mean success rate: 1.0, 0.8, 0.6, 0.4, 0.2, 0.0
- Number of trials: 0, 20, 40, 60, 80, 100, 120

[Bar graphs showing mean of first 25 trials and mean of last 25 trials for HC and NC groups with Saline.]

Piron et al. (submitted)
Experimental results

Muscimol injection in GPi disrupts learning in novel conditions (NC) but performances remains intact (but slower) in habitual conditions (HC).
Experimental conclusion

If habits were stored in basal ganglia, monkeys would not achieve peak performances in muscimol conditions for familiar stimuli.

If habits were learned in cortex, monkeys would be able to reach peak performances in muscimol conditions for unfamiliar stimuli.
**Computational model**

Two segregated loops:

→ Cognitive loop allows to **choose** a shape
→ Motor loop allows to **reach** a shape

Cognitive decision has to **intervene** in motor decision.

\[ \tau \frac{dm}{dt} = -m + I_s - T \]

Neural Network

Neuron Rate model

Topalidou et al. (in prep.)
Cortico-basal competition

Thanks to lateral competition, cortex can make a decision without interaction with BG.
Acting is learning

Learning occurs at three different places simultaneously.

1. **Hebbian** learning

2. **Reinforcement** learning

Cortex learns to reproduce previous repertories, regardless of whether are appropriate or not (HL).

**Fast** basal ganglia trial-and-error learning (RL) biases **slow** cortical one (HL) ensuring that the correct behavior is produced.

Barto (1995), Hélie et al. (2014), Topalidou et al. (in prep.)
Computational results

Intact model
→ peak performances on familiar conditions
→ can learn novel conditions

Lesioned model (GPI)
→ peak performances on familiar conditions
→ cannot learn novel conditions

(Model results)

(Monkey results)

Topalidou et al. (in prep.)
Sensitivity to reward devaluation
Conclusion

Piron experiment sheds light on the nature of the interaction between the basal ganglia and the cortex and their respective role in the initial formation and the later expression of habits.

The model suggests that the basal ganglia implicitly supervises the learning in cortex where habits are actually stored, but the cortex cannot learn them on its own.

In the future, add more neurons per population, more complex motor cortex in order to include motor skill learning and test the model in a robot through Piron experiment and more complex tasks.
"We are what we repeatedly do; excellence, then, is not an act but a habit."
- Aristotle.
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