THE FORMATION OF HABITS

The implicit supervision of the basal ganglia

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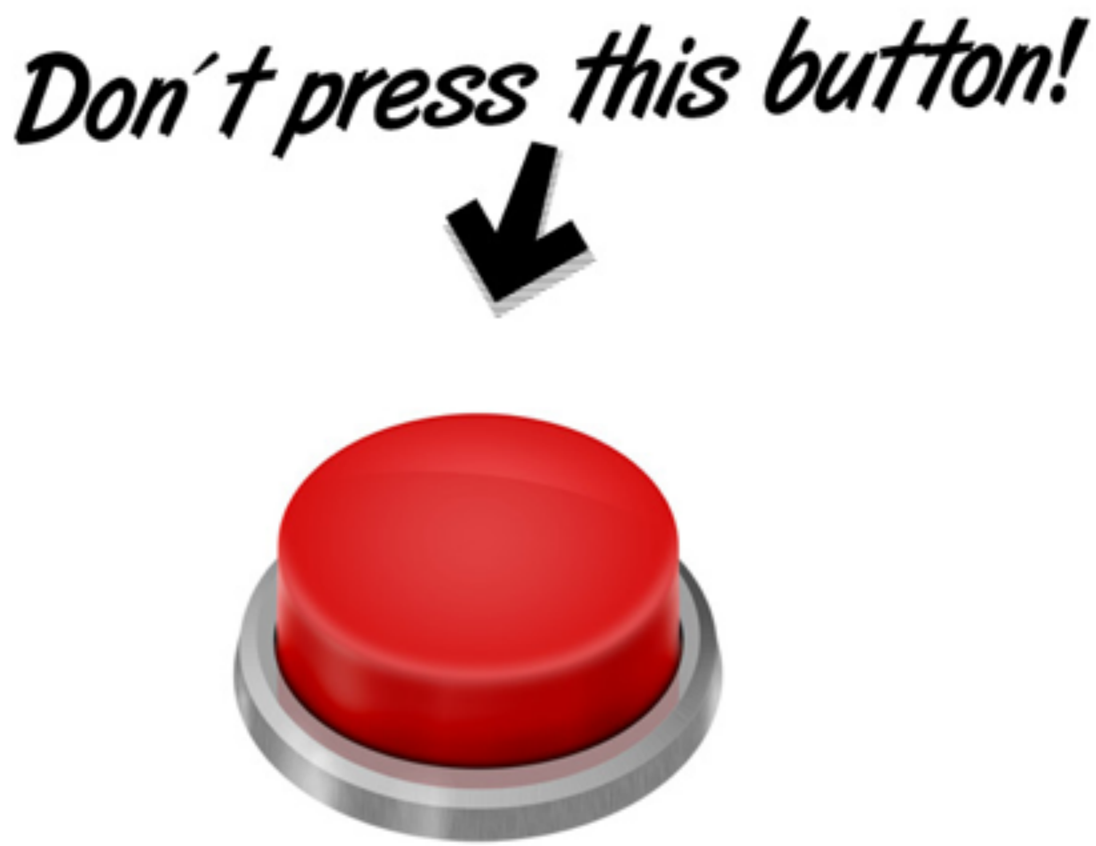

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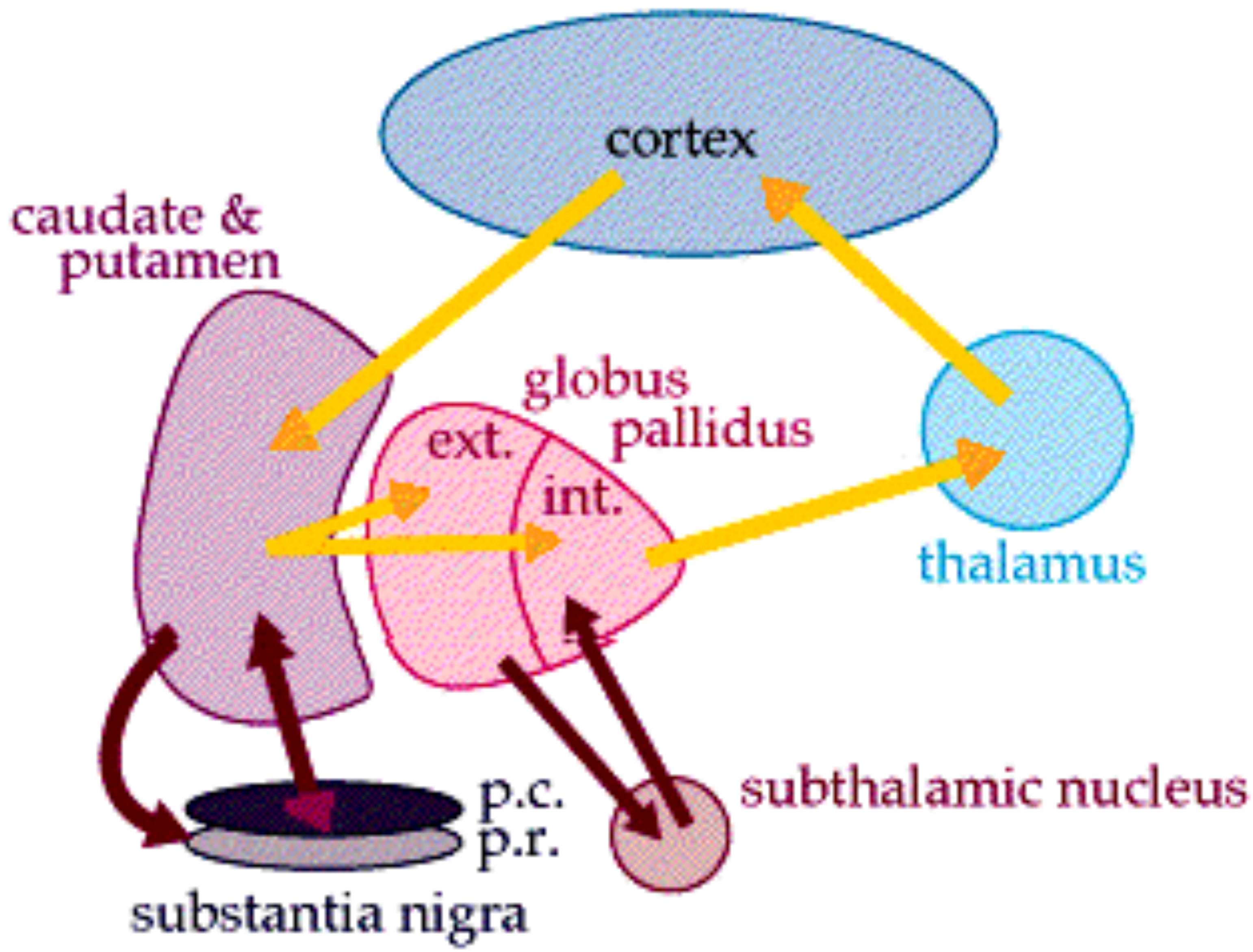
Goal-Directed Actions VS Habits

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

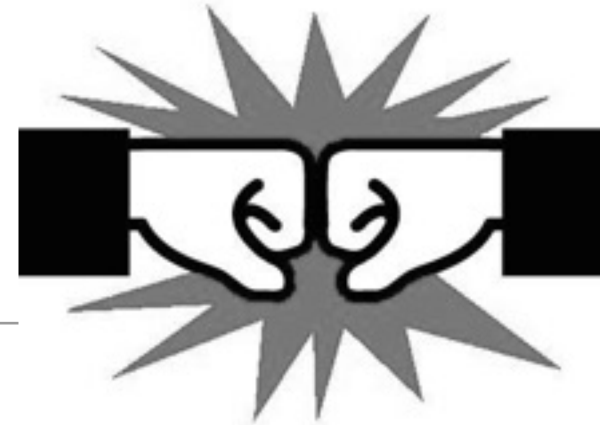
→ habits **persist** even if the **reward** becomes **less attractive** or there is no reward at all.

Belin et al. (2008), Yin (2008), Foerde & Shohamy (2011), Doll et al. (2012)

Basal Ganglia



Cortex

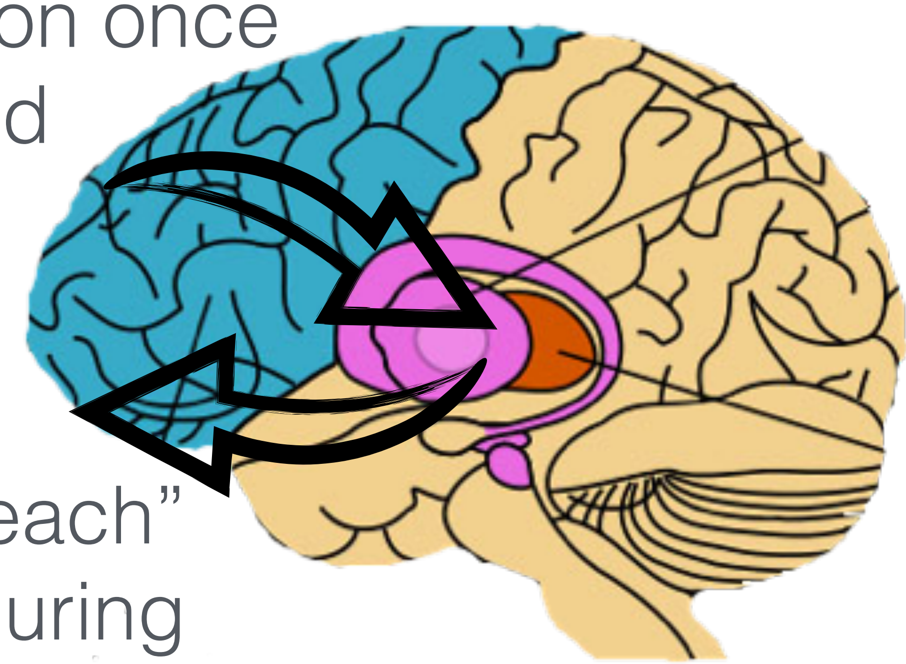


Basal Ganglia

Goal Directed actions go here

Habits go there

Cortex leads decision once learned



BG “teach” cortex during learning phase

Daw, Niv & Dayan (2005)

Ashby, Turner & Horvitz (2010)

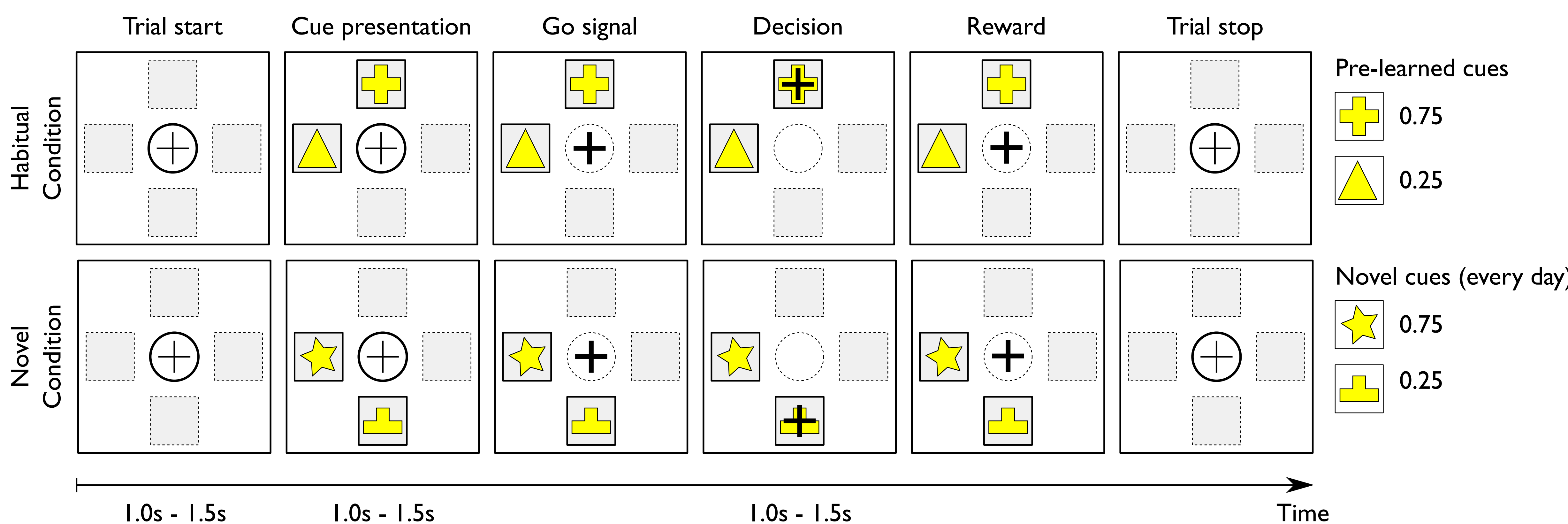
Outline

- Experiment
- Computational model
- Results

Experimental setup

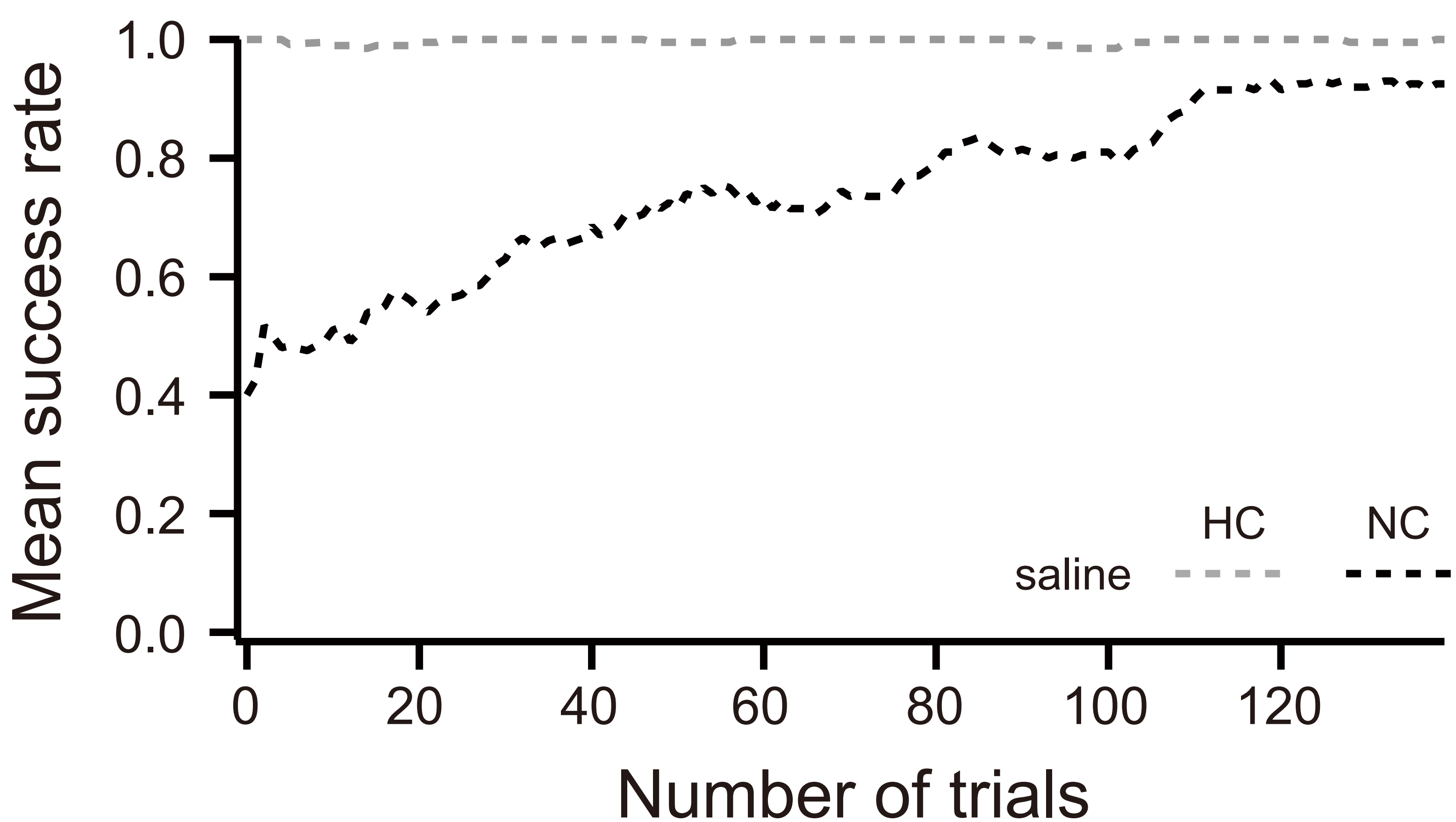
Two monkeys, simple two-armed bandit task with P=0.75 and P=0.25.

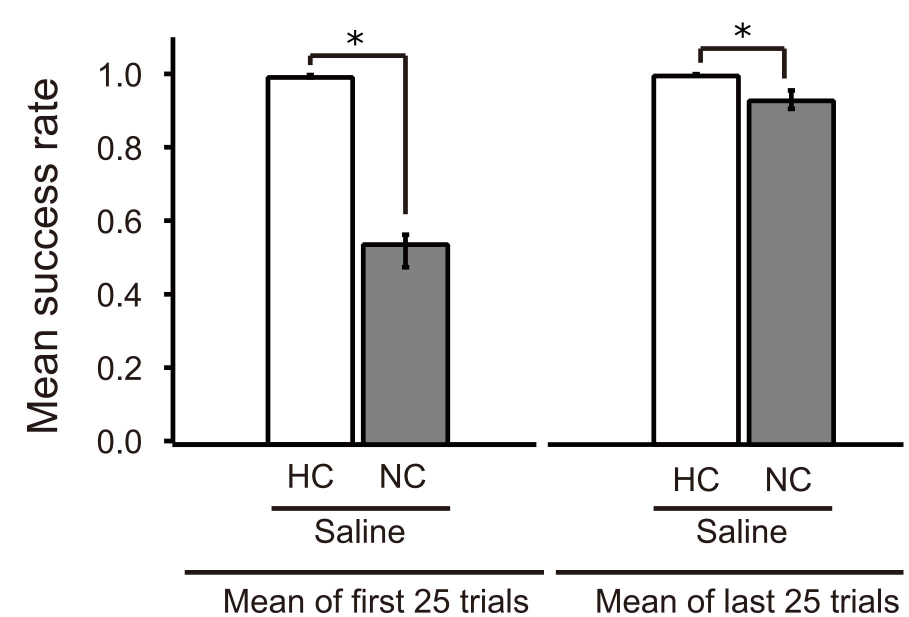
→ Habitual condition (known stimuli pair, same every day)
→ Novel condition (unfamiliar stimuli pair, new every day)



Piron et al. (submitted)

Experimental results

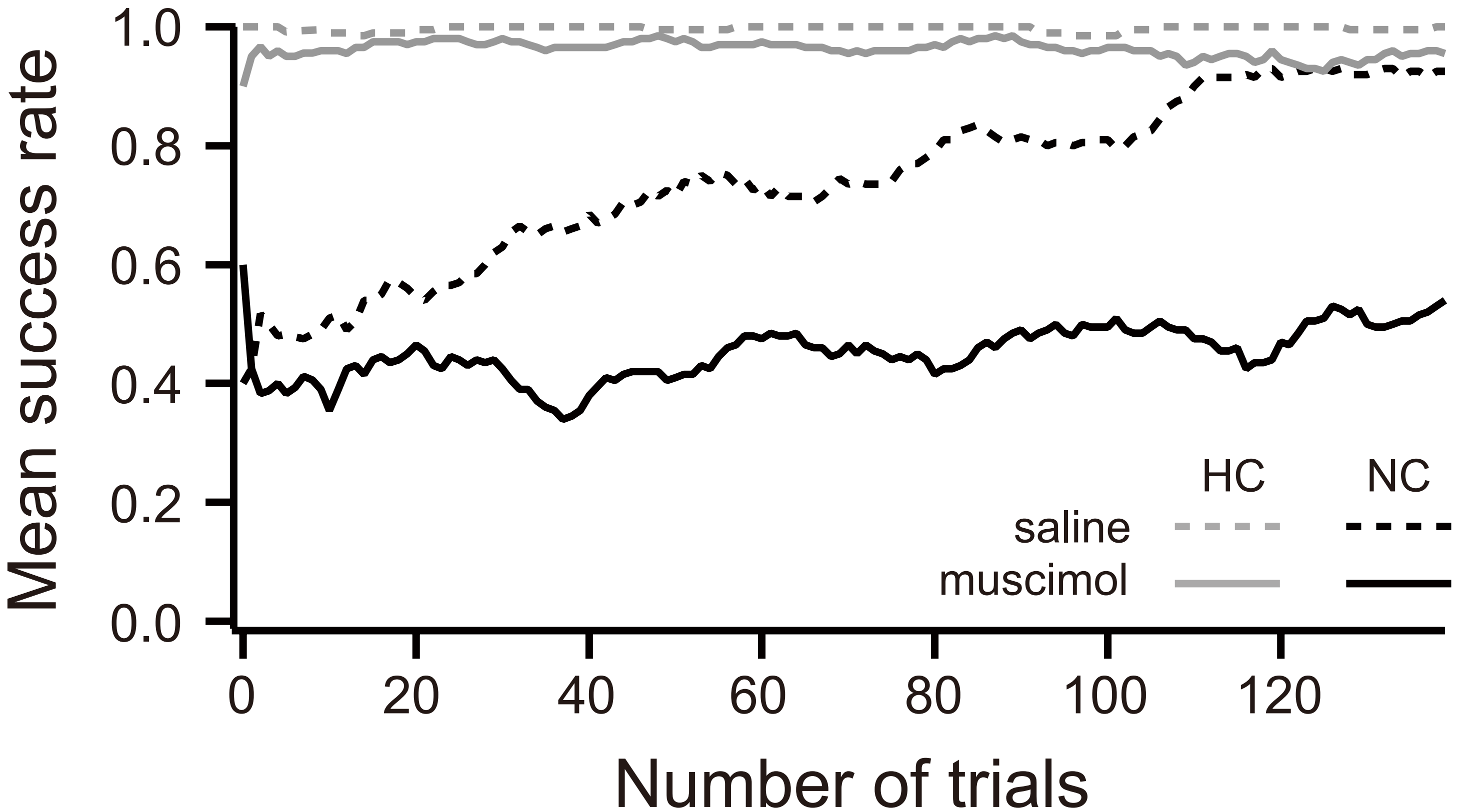


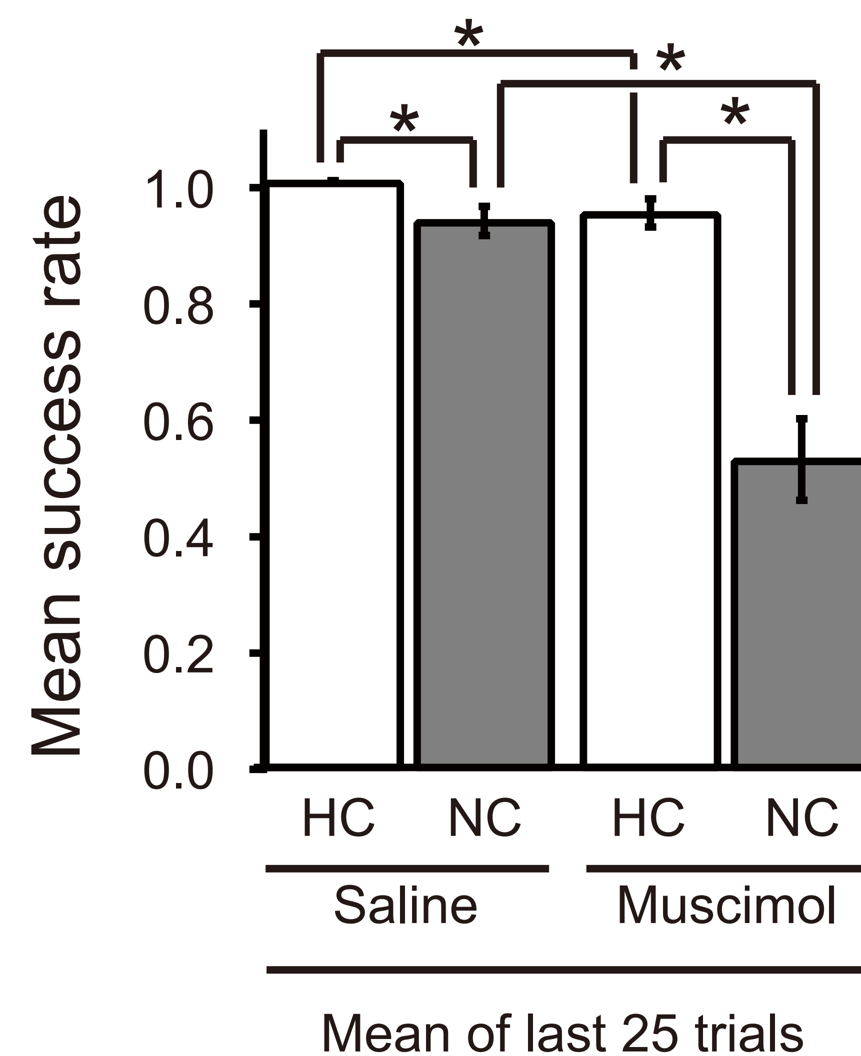


Piron et al. (submitted)

Experimental results

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



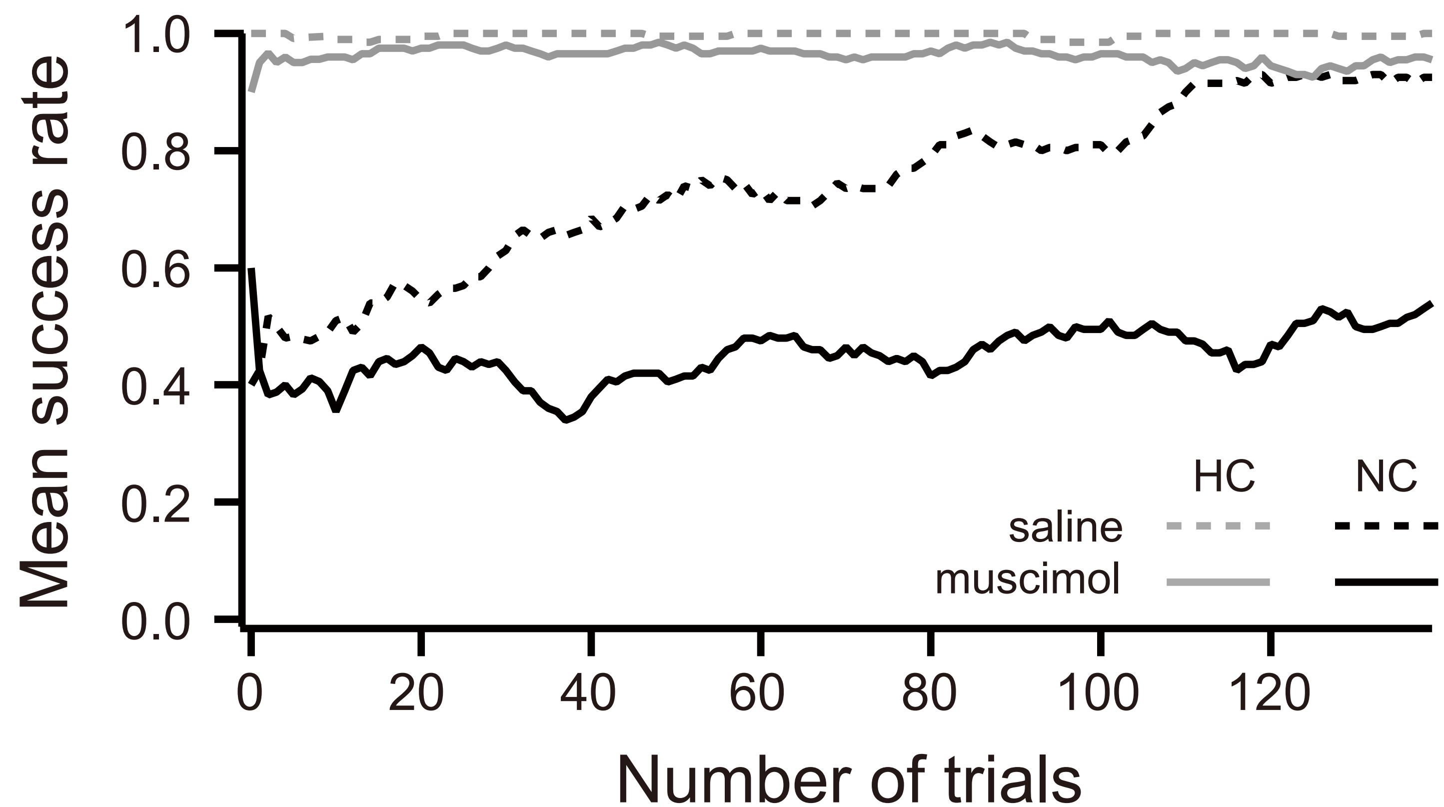


Piron et al. (submitted)

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.



Piron et al. (submitted)

Computational model

Two segregated loops:

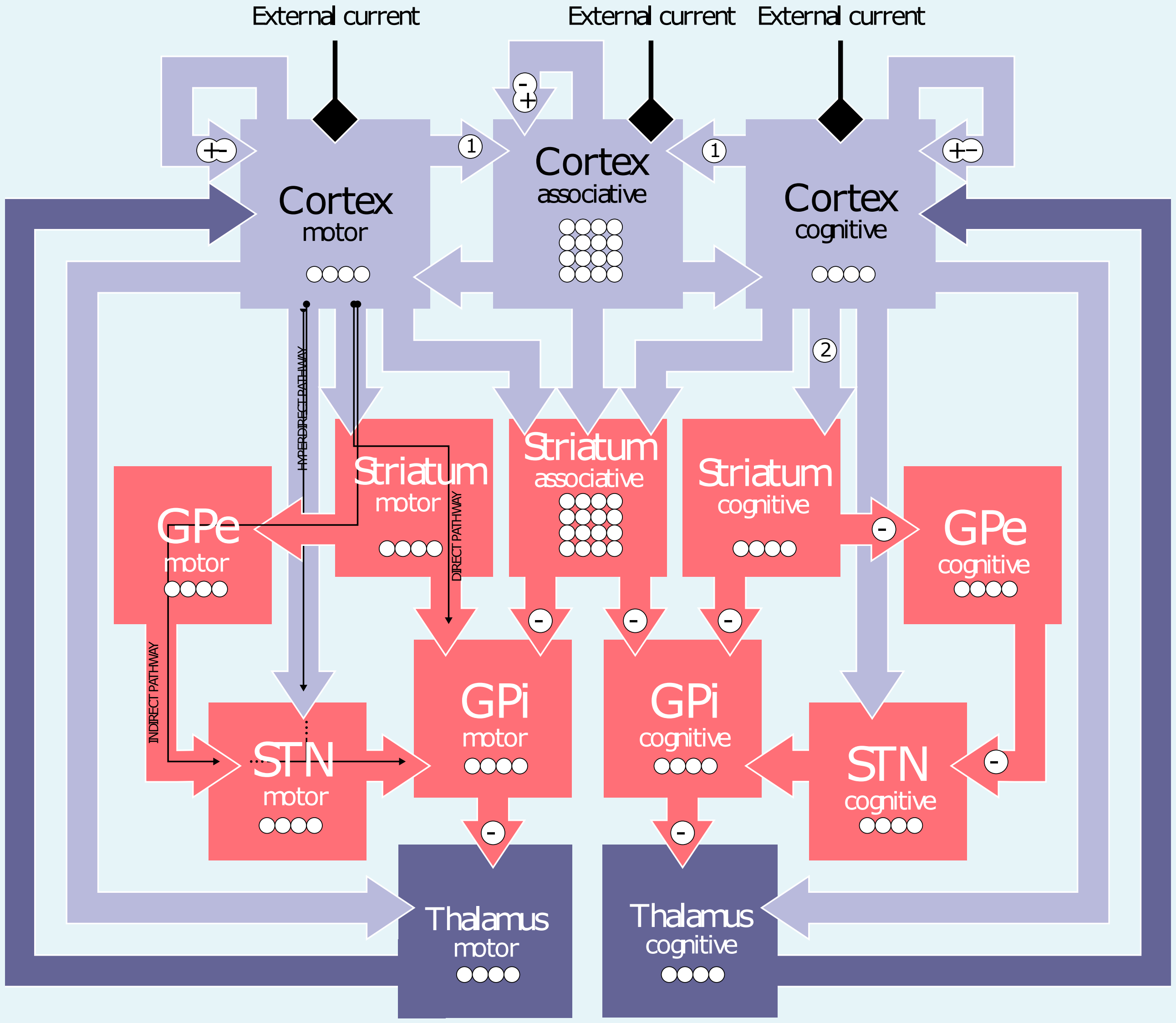
→ Cognitive loop allows to **choose** a shape
→ Motor loop allows to **reach** a shape

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

Neural Network

Neuron Rate model

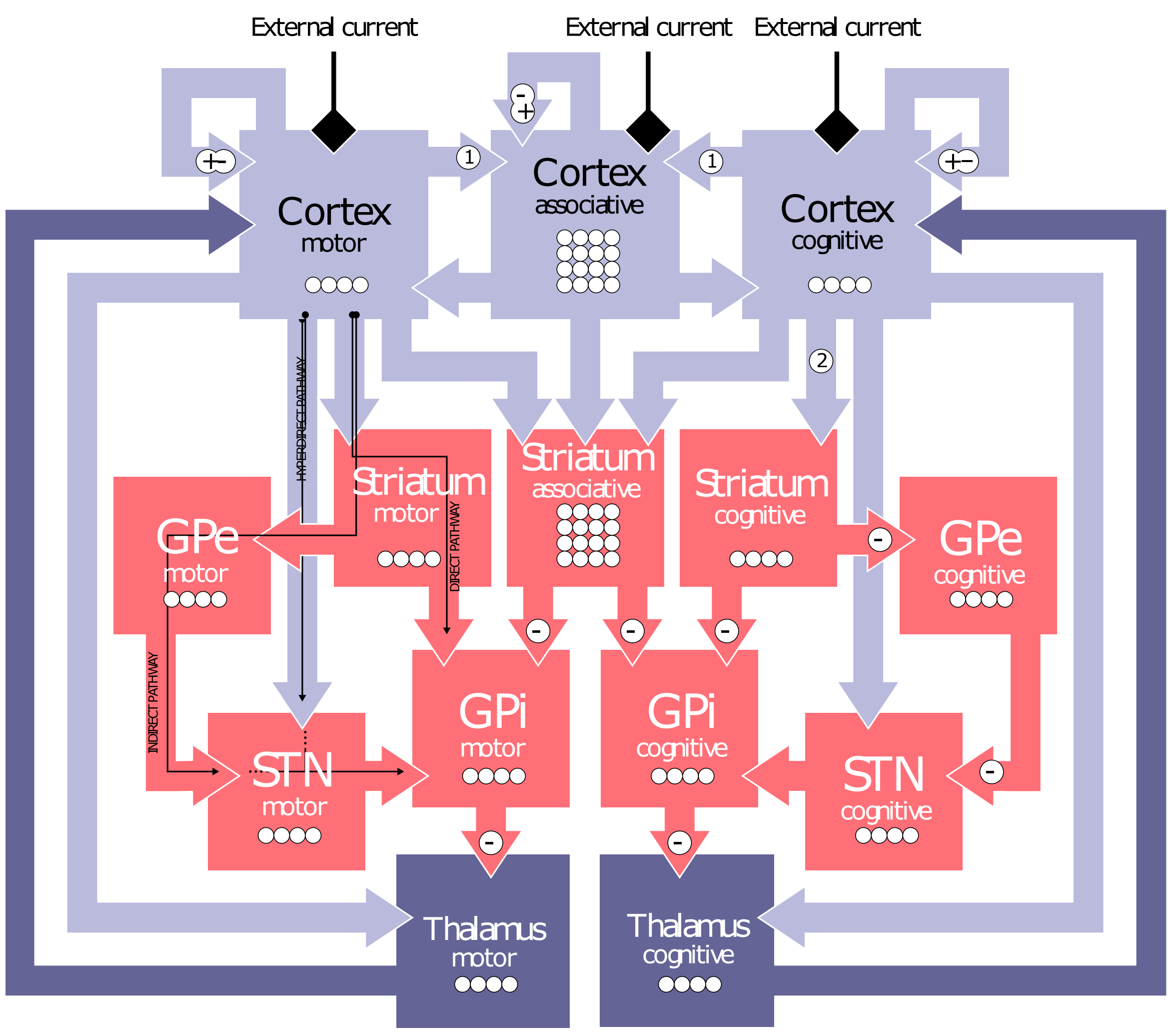
$$\tau \frac{dm}{dt} = - m + I_s - T$$



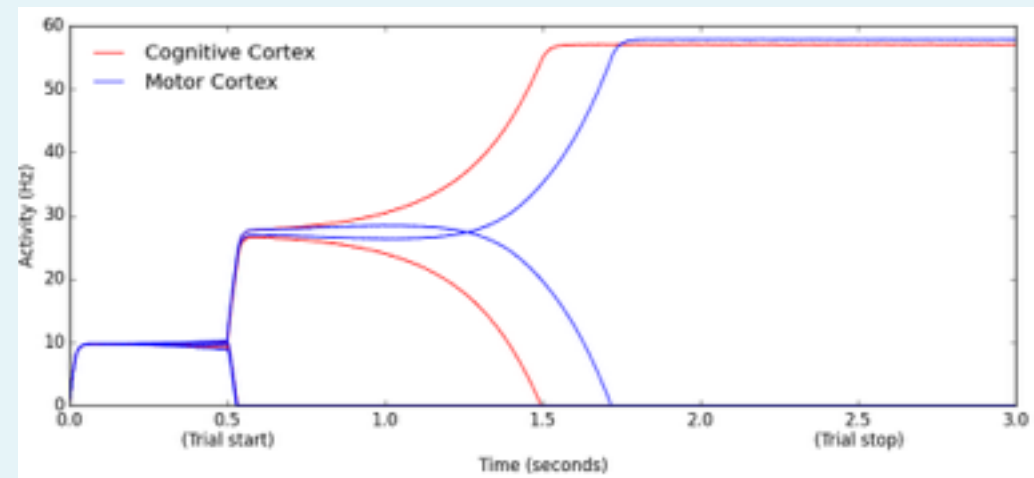
Topalidou et al. (in prep.)

Cortico-basal competition

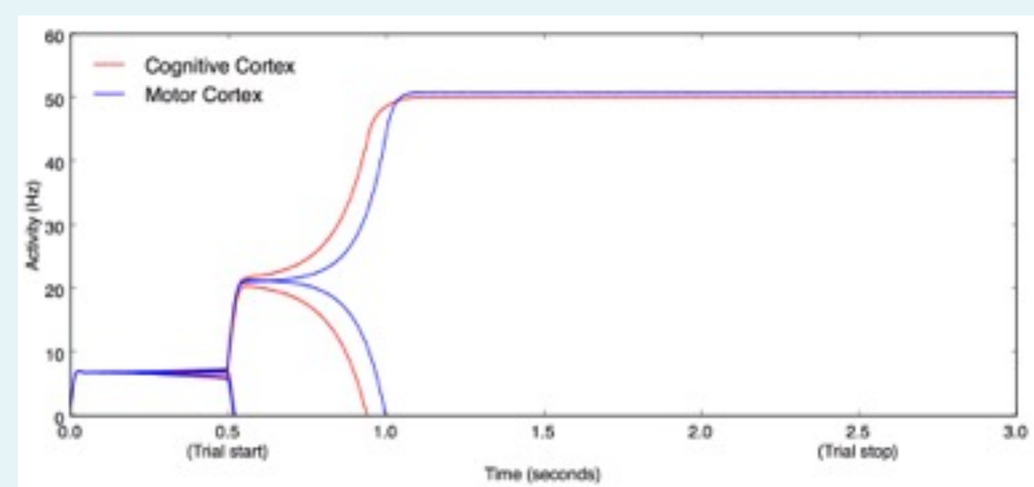
Thanks to lateral competition, cortex can make a decision without interaction with BG.



Cortical decision



Cortico-Basal decision



Topalidou et al. (in prep.)

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.

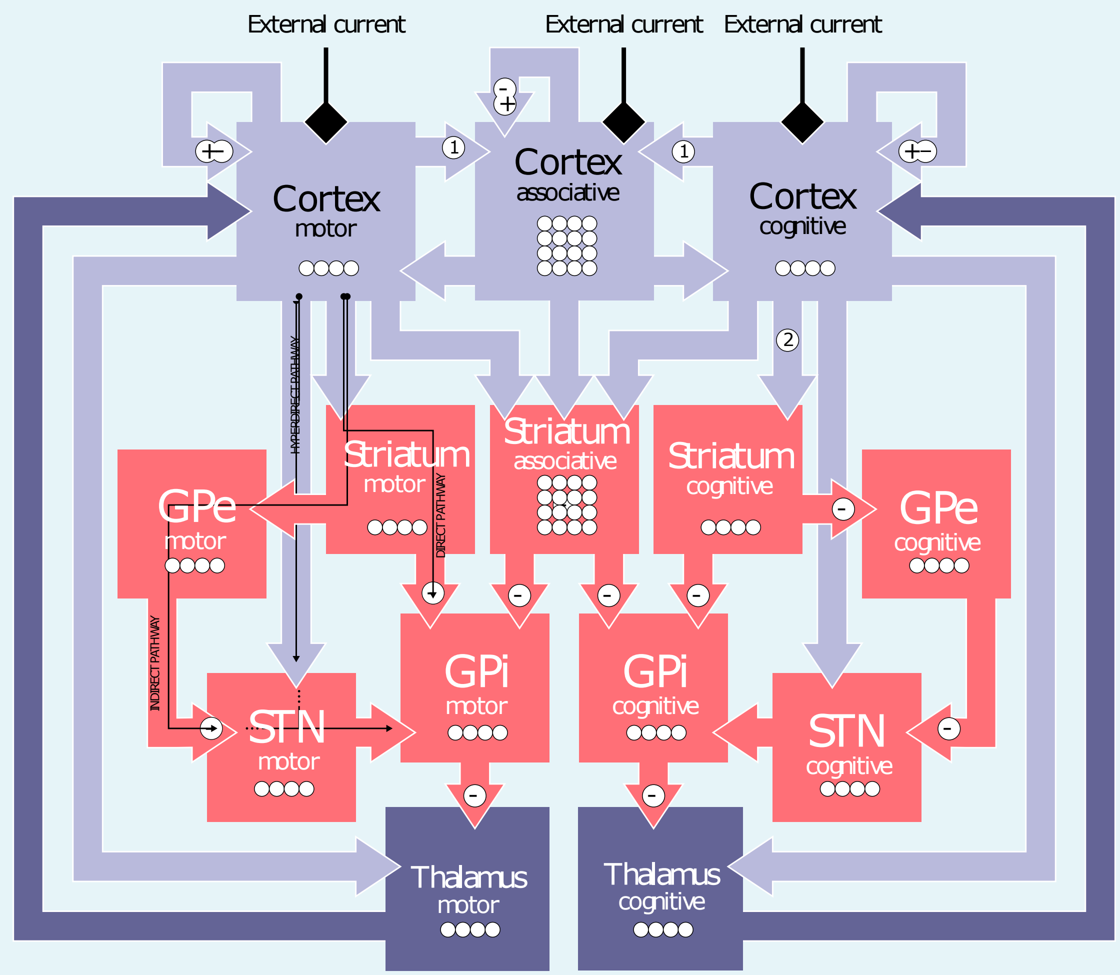
$$\tau \frac{dV}{dt} = -V + I_{ext} + I_{syn}, U = f(V)$$

$$I_{syn}^{A \to B} = \text{gain} \sum \times W_{A \to B} \times U_A$$

$$\text{Hebbian (1)}: \Delta W_{A \to B} = U_A \times U_B \times (W_{A \to B} - W_{min}) \times (W_{max} - W_{A \to B})$$

$$\text{Reinforcement (2)}: \Delta W_{A \to B} = \alpha \times PE \times U_B$$

$$PE = \text{Reward} - V_i$$

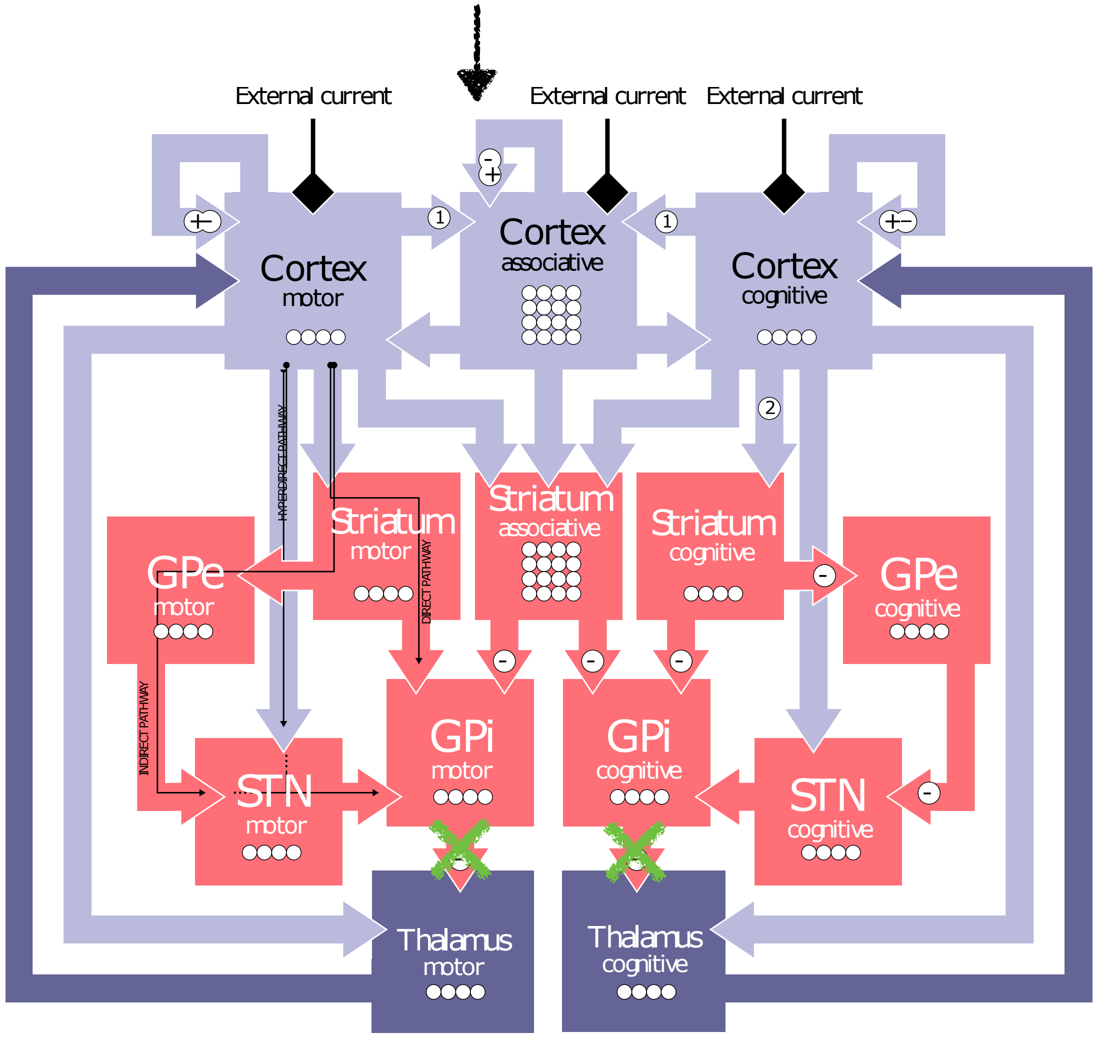


Barto (1995), Hélie et al. (2014), Topalidou et al. (in prep.)

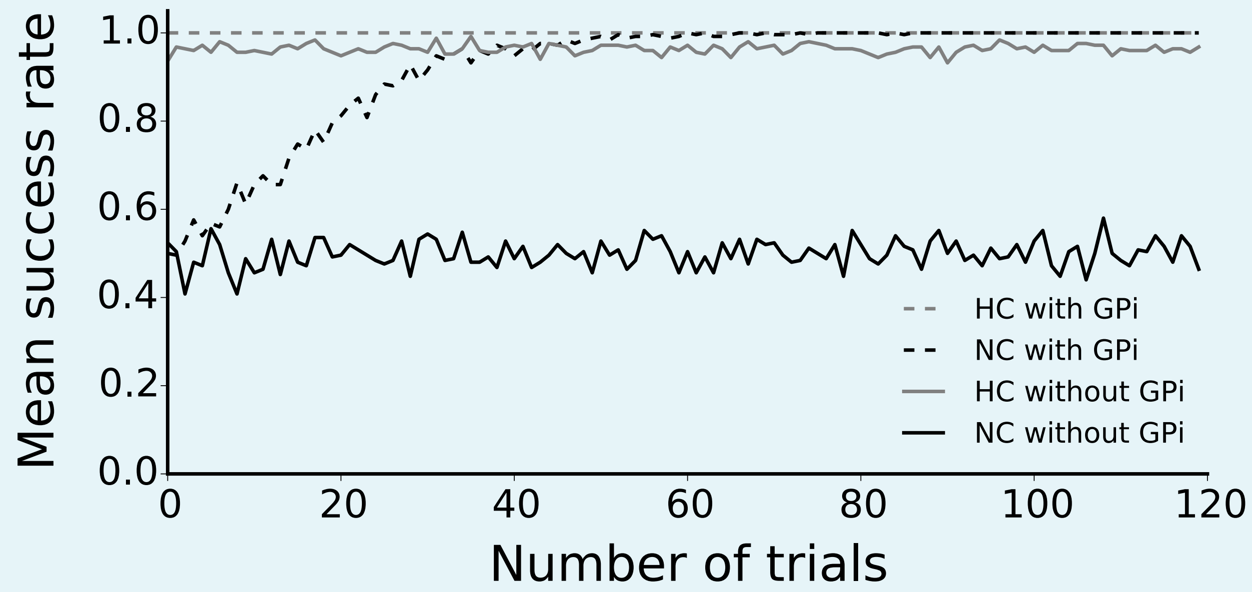
Computational results

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

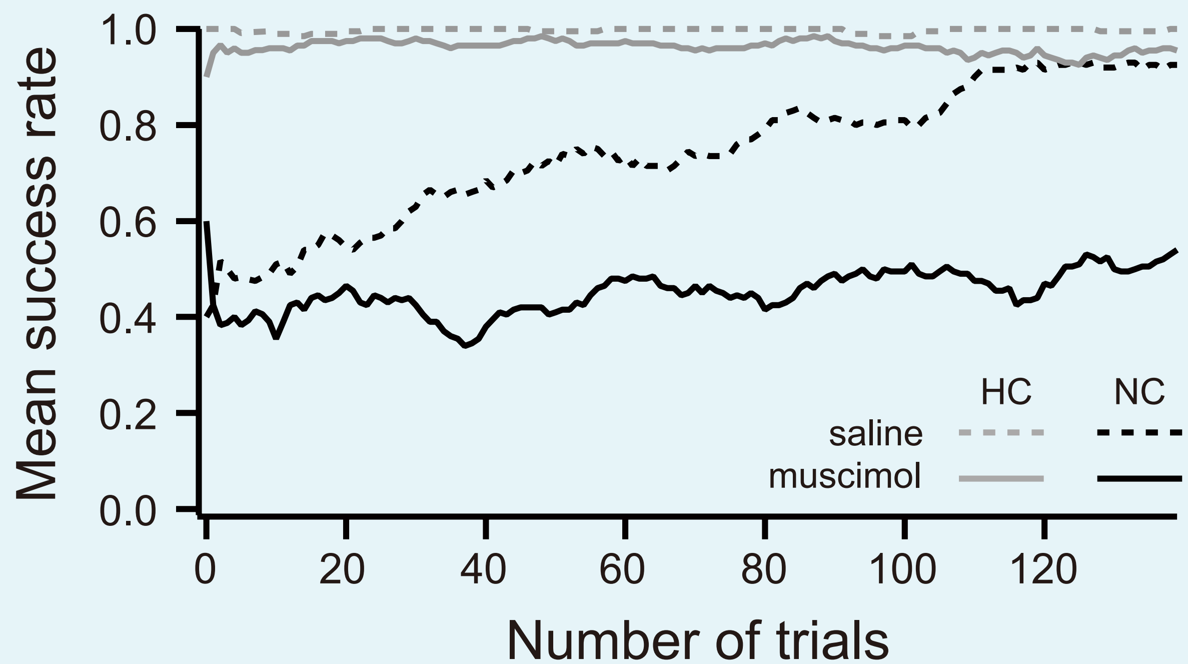
Lesioned model (GPi)
→ peak performances on familiar conditions
→ **cannot** learn novel conditions



(Model results)

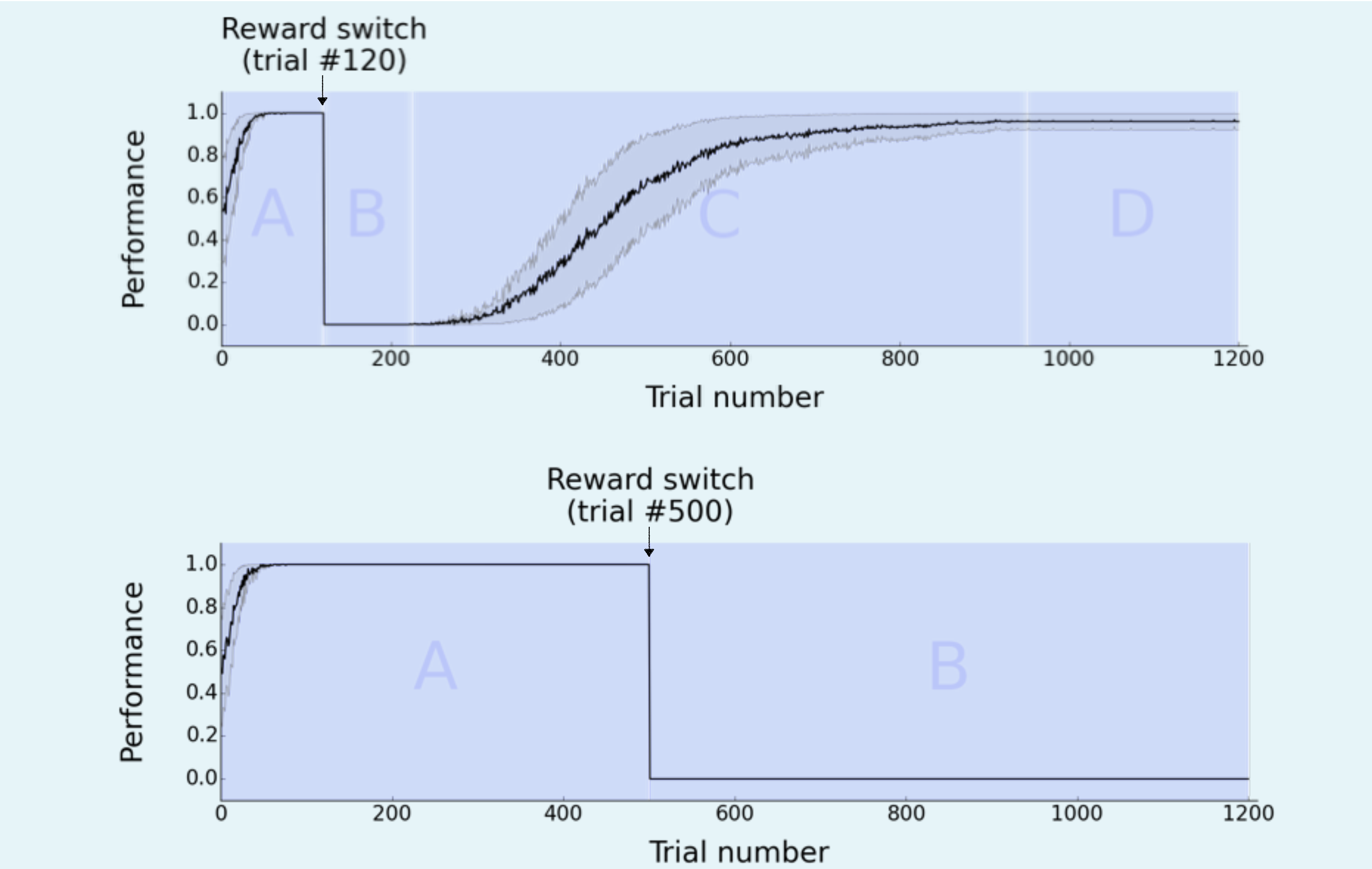


(Monkey results)



Topalidou et al. (in prep.)

Sensitivity to reward devaluation

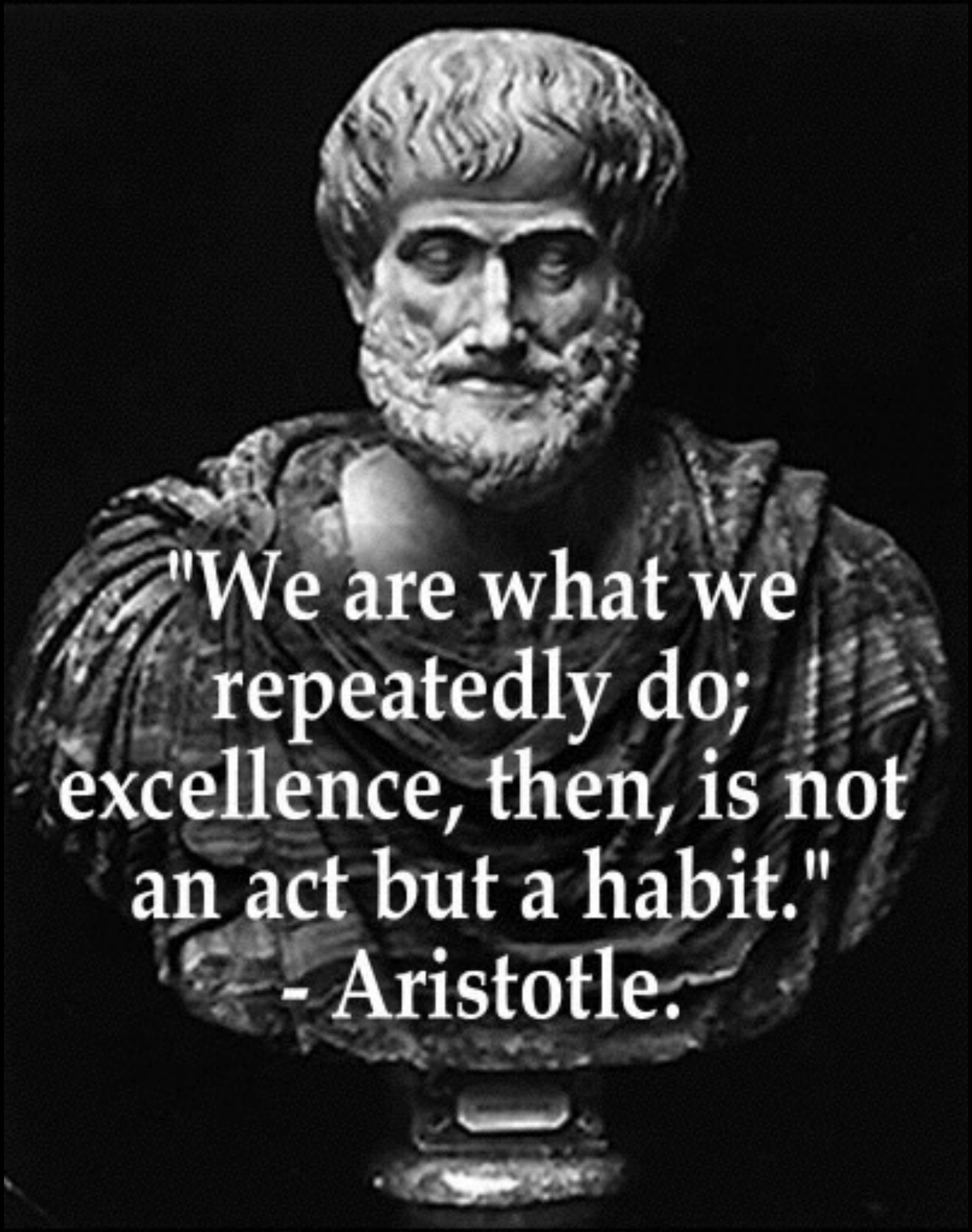


Conclusion

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.

Acknowledgments

- N. Rougier
- Th. Boraud
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For more details: Poster M23