

THE FORMATION OF HABITS

The implicit supervision of the basal ganglia

MEROPI TOPALIDOU

12e Colloque de Société des Neurosciences

Montpellier

May 19-22, 2015



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Goal-Directed Actions VS Habits

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

Goal-Directed Actions

VS

Habits

→ initiation of response is
under direct control of the
**current value of
outcome**

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Goal-Directed Actions

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→ initiation of response is
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→ **sensitive** to devaluation of
the outcome

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

Goal-Directed Actions

VS

Habits

→ initiation of response is under direct control of the **current value of outcome**



→ **sensitive** to devaluation of the outcome

→ direct initiation of responding by **stimulus** and/or **context presentation**

Goal-Directed Actions

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Goal-Directed Actions

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→ initiation of response is under direct control of the **current value of outcome**



→ **sensitive** to devaluation of the outcome

→ direct initiation of responding by **stimulus** and/or **context presentation**



→ **resistant** to devaluation of the outcome

Goal-Directed Actions

VS

Habits

→ initiation of response is under direct control of the **current value of outcome**



→ **sensitive** to devaluation of the outcome

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

→ direct initiation of responding by **stimulus** and/or **context presentation**



→ **resistant** to devaluation of the outcome

Goal-Directed Actions

VS

Habits

→ initiation of response is under direct control of the **current value of outcome**



→ **sensitive** to devaluation of the outcome

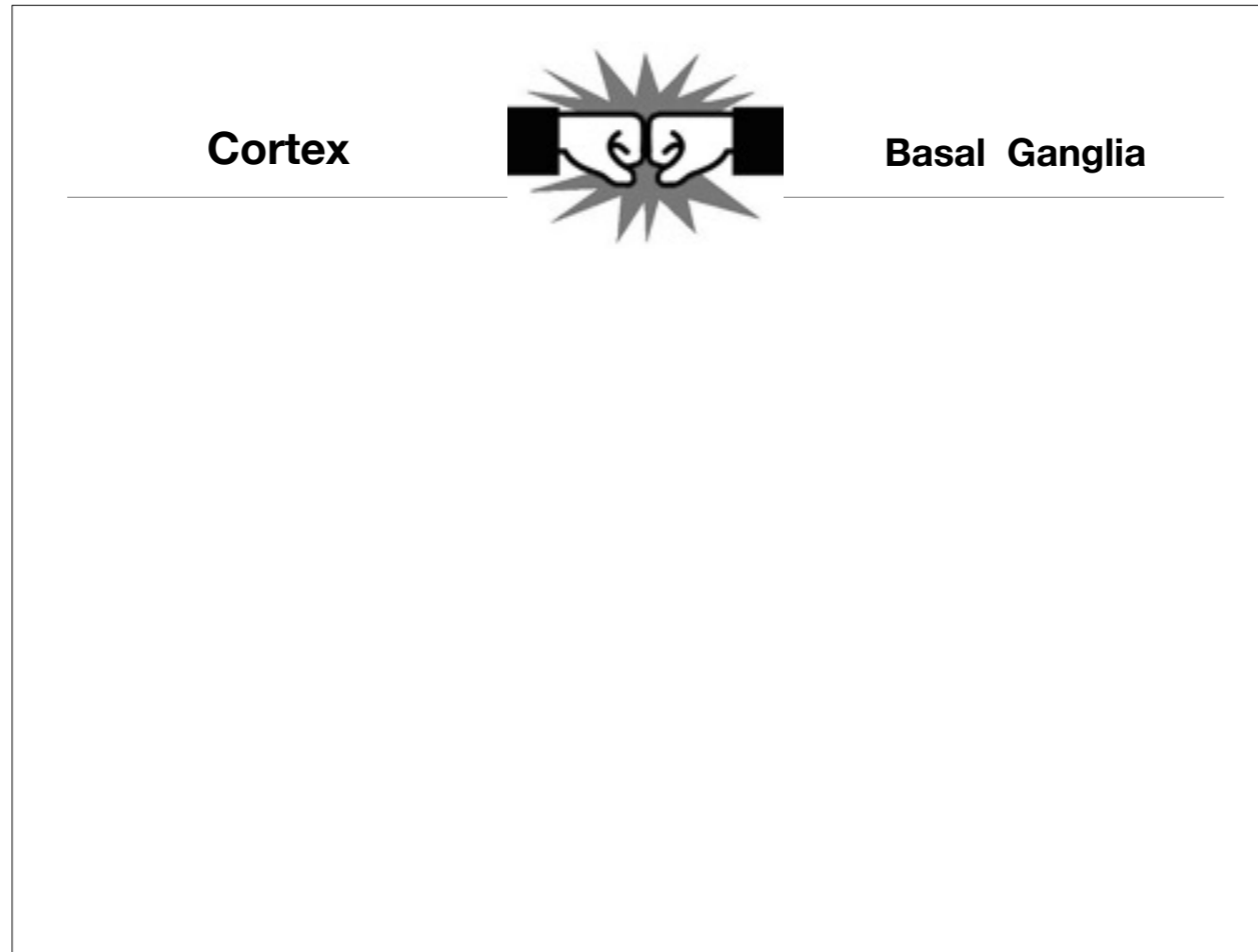
→ behavior adjusts to **reflect** the **new value** of the **outcome** that the action would obtain

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→ **resistant** to devaluation of the outcome

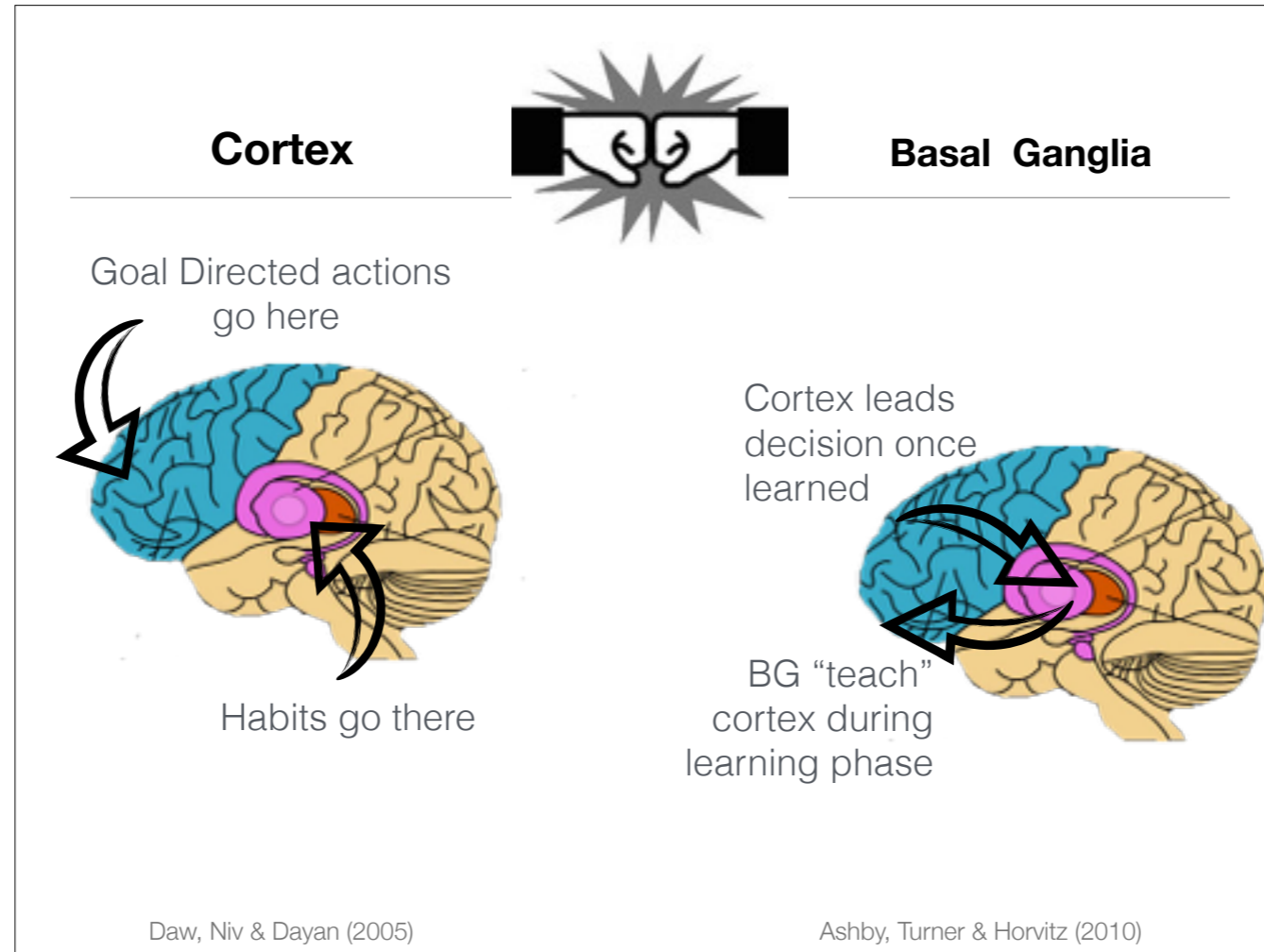
→ habits **persist** even if the **reward** becomes **less attractive** or if the action is not necessary to earn the reward.



Novel behaviors require attention and flexible thinking and therefore are dependent on cortex, whereas automatic behaviors has been assumed to be primarily mediated by subcortical structures.

Much evidence suggests however, that subcortical structures, such as the striatum, make significant contributions to initial learning. More recently, evidence has been accumulating that neurons in the associative striatum are selectively activated during early learning, whereas those in the sensorimotor striatum are more active after automaticity has developed. At the same time, other recent reports suggest that automatic behaviors are striatum- and dopamine-independent, and may be mediated entirely within cortex. Resolving this apparent conflict should be a major goal of future research.

These ideas led to the theory that dominated the 20th century: Novel behaviors require attention and flexible thinking and therefore are dependent on cortex, whereas automatic behaviors require neither of these and so are not mediated primarily by cortex. Instead, it has long been assumed that automatic behaviors are primarily mediated by subcortical structures.



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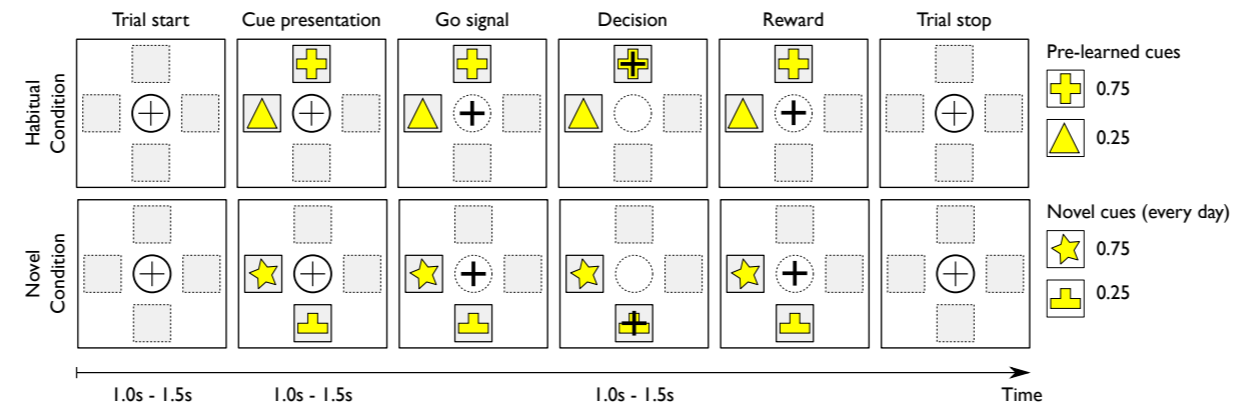
Outline

- Experiment
- Computational model
- Results

Experimental setup

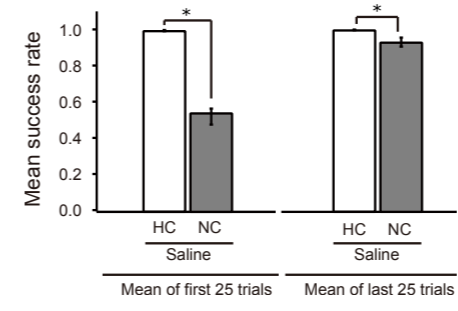
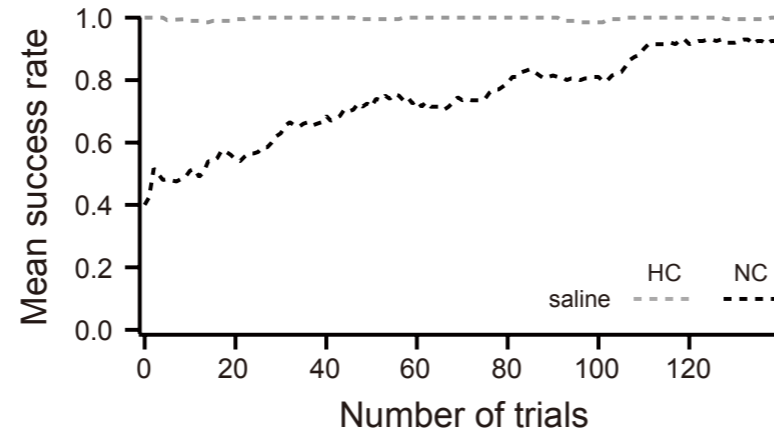
Two monkeys, simple two-armed bandit task with $P=0.75$ and $P=0.25$.

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



Piron et al. (submitted)

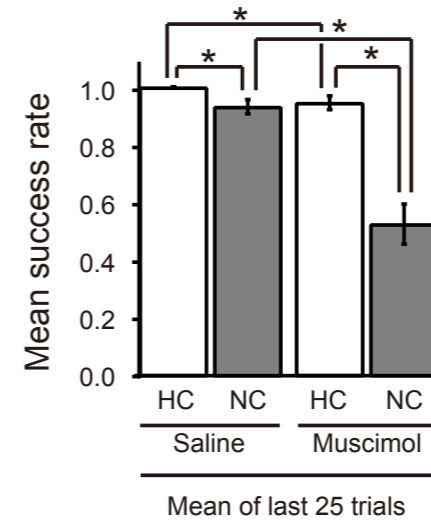
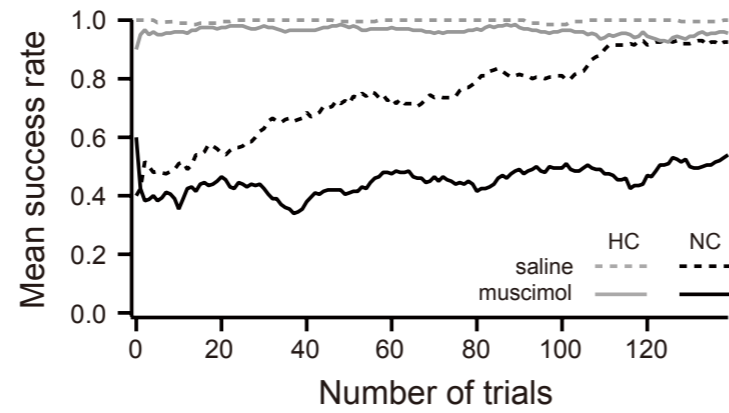
Experimental results



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).

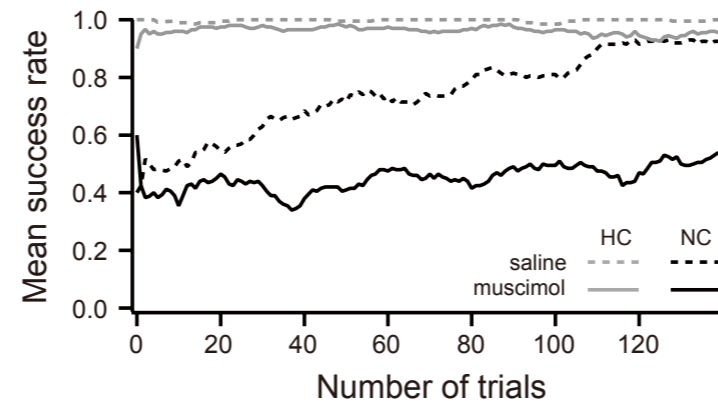


Piron et al. (submitted)

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

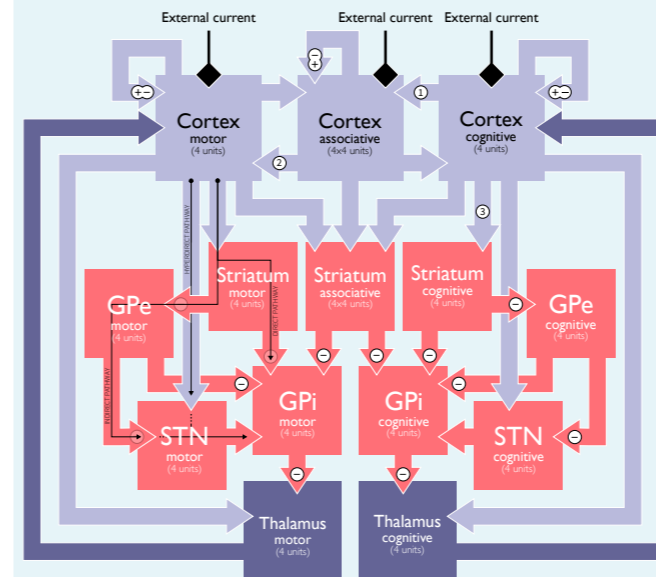
Two segregated loops:

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

Neural Network

Neuron Rate model

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

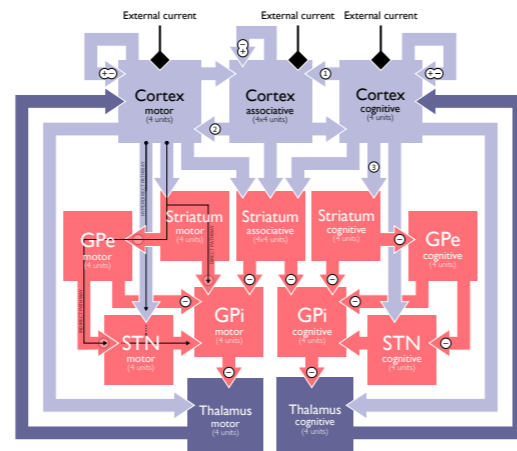


Topalidou et al. (in prep.)

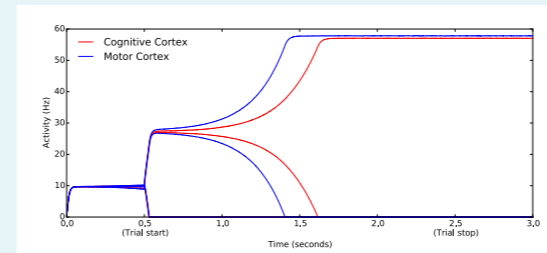
Cortico-basal competition

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

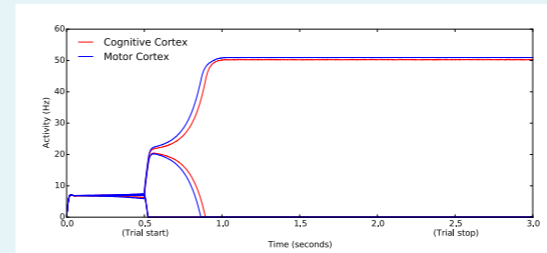
Thanks to lateral competition, cortex can take a decision without interaction with BG.



Cortical decision



Cortico-Basal decision



Topalidou et al. (in prep.)

Acting is learning

Learning occurs at three different places simultaneously.

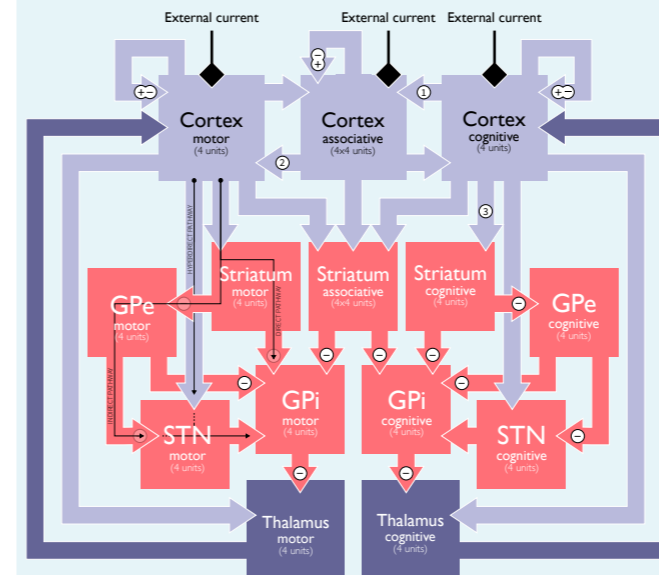
① & ② **Hebbian** learning

③ **Reinforcement** learning

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

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

Hélie et al. (2014)



Topalidou et al. (in prep.)

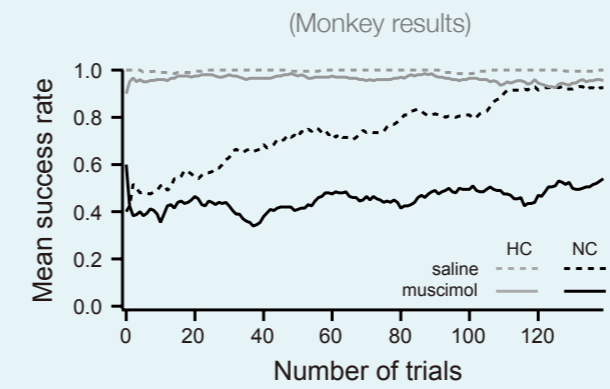
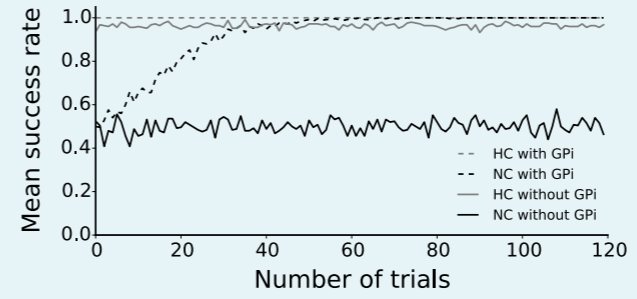
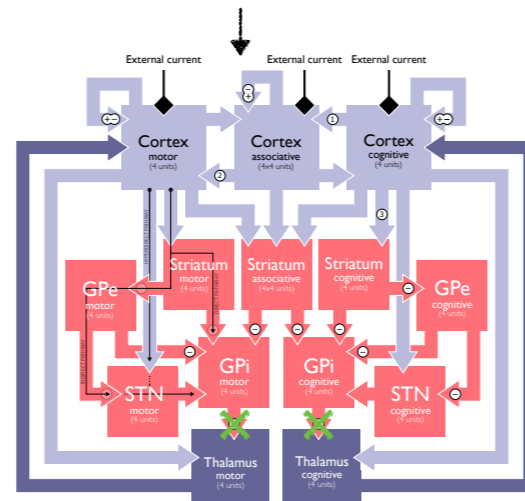
Computational results

Intact model

- peak performances on familiar conditions
- can learn novel conditions

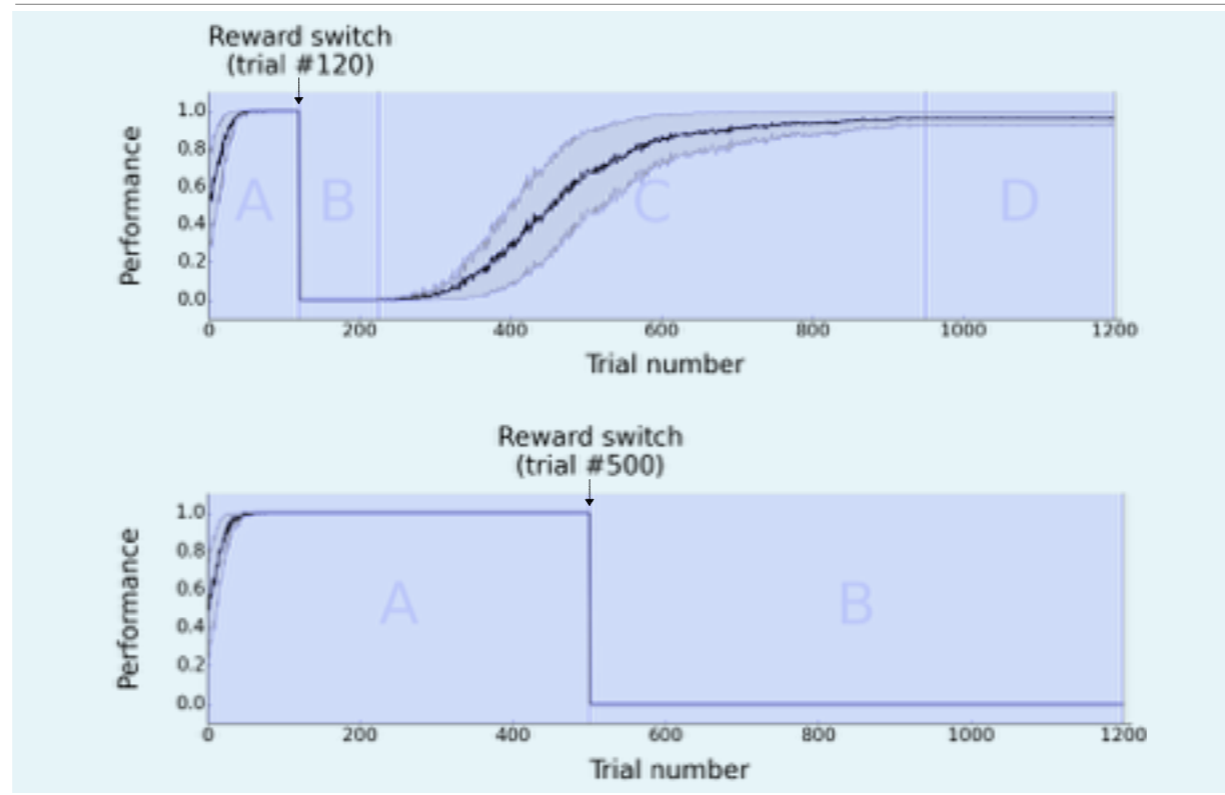
Lesioned model (GPi)

- peak performances on familiar conditions
- **cannot** learn novel conditions



Topalidou et al. (in prep.)

Sensitivity to reward devaluation



Conclusion

The acquisition and the expression of habits are two entangled processes that can be dissociated experimentally.

This experimental dissociation 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 cortex where habits are actually stored, but the cortex cannot learn them on its own.

In the future, the model will be tested in different protocols in order to ensure the accuracy of its predictions.

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