A System-Level Neural Model of the Brain Mechanisms Underlying Instrumental Devaluation in Rats

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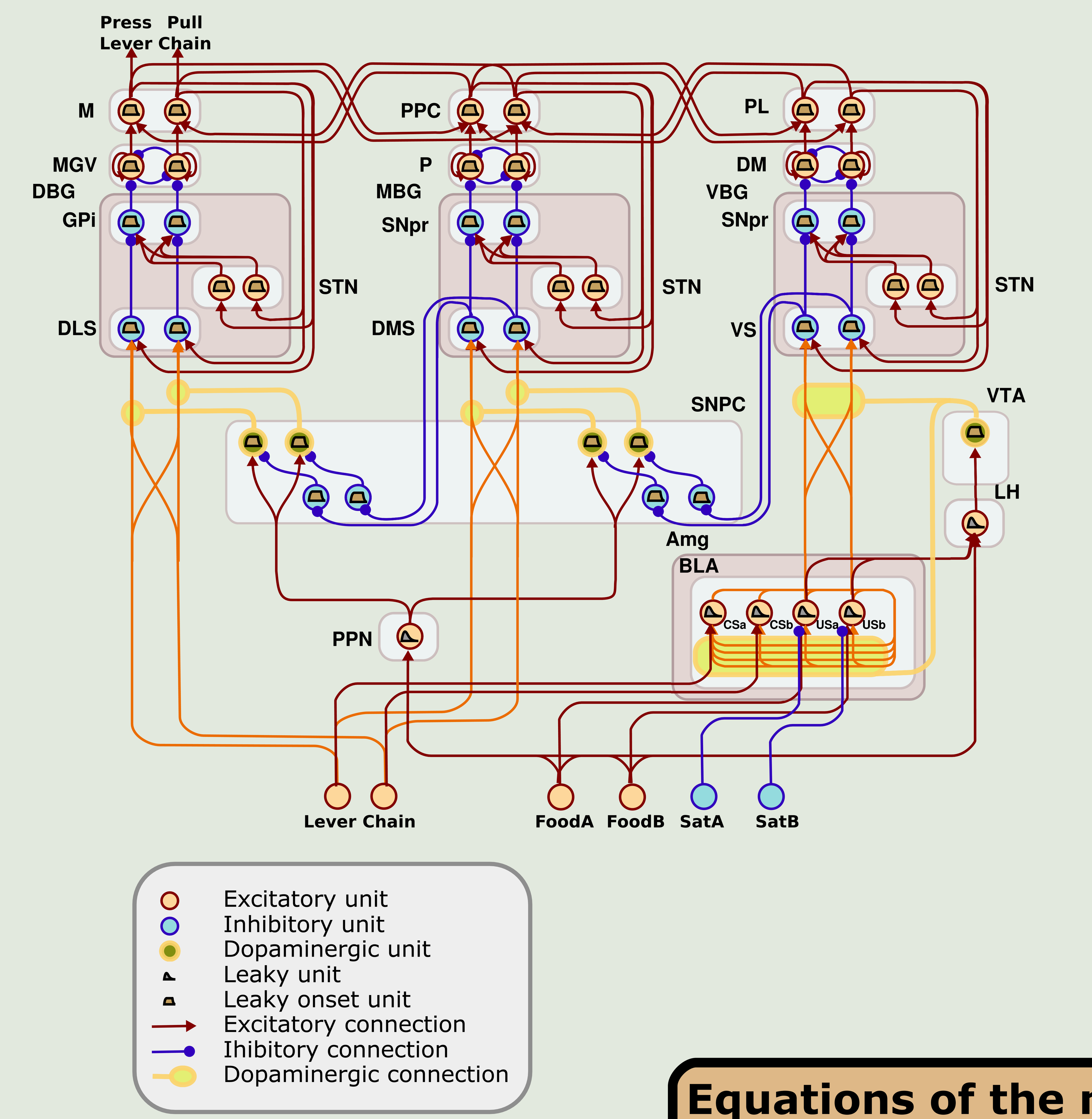
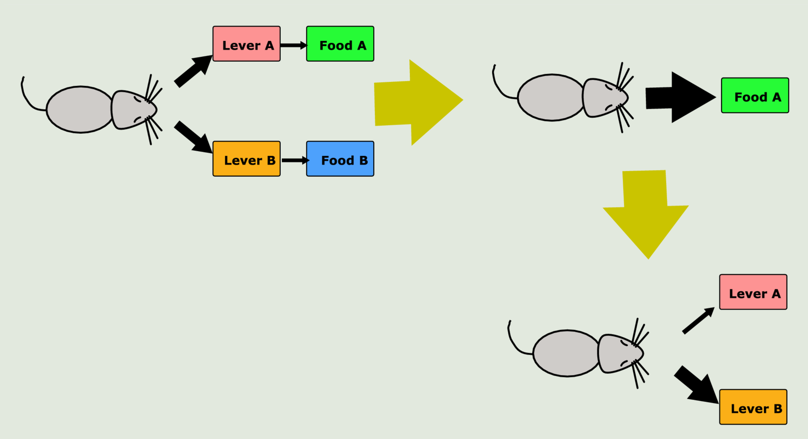
We present a computational model of the neural processes underlying instrumental devaluation in rats. The model reproduces the interaction between the basolateral complex of the amygdala (BLA) and the limbic, associative and somatosensory striato-cortical loops. The central hypothesis implemented in the model is that Pavlovian associations learned within the BLA between manipulanda and rewards modulate goal selection through the activation of the nucleus accumbens core (NaccCo). The model is tested as part of the control system of a simulated rat.

Architecture of the model



Instrumental devaluation



Assumptions behind the model: (1) Pavlovian associations learned within the BLA between manipulanda and rewards modulate goal selection through the activation of the NaccCo. **(2)** Selection processes happening in the limbic basal ganglia, based on the activation of the NaccCo, decide which outcome is chosen as a goal within the Prelimbic cortex (PL). **(3)** Connections between the BLA and the NaccCo are learned through Hebbian associations mediated by feedbacks from the PL to the NaccCo. **(4)** Information about goals selected within the limbic striato-cortical loop influences action selection in the sensorimotor loop both through cortico-cortical projections and through a striato-nigro-striatal dopaminergic pathway passing through the associative striato-cortical loop.

Approach: All components of the model have been built through the use of firing-rate units abstracting population activations. Basal ganglia components are modelled through a simplified version of the GPR model [1]. BLA internal learning of Pavlovian associations is obtained through an Hebbian rule that depends on both dopamine and the timing of pre- and post-synaptic activations of the units. Learning processes happen at the level of all striatal components. Throughout the model dopamine has a role of amplification of the activations of the target units, and causes learning when it overcomes a certain threshold.

Equations of the model

$$[x]^+ = \begin{cases} 0 & \text{if } x \leq 0 \\ x & \text{if } x > 0 \end{cases}$$

$$[x]^- = \begin{cases} x & \text{if } x \leq 0 \\ 0 & \text{if } x > 0 \end{cases}$$

Firing rate

$$\tau \dot{p}_i = -p_i + I + \sum_j w_{ij} \cdot [\tanh(p_j)]^+$$

Hebbian learning

$$\Delta w_{post,pre} = [da - th_{da}]^+ \cdot pre \cdot post$$

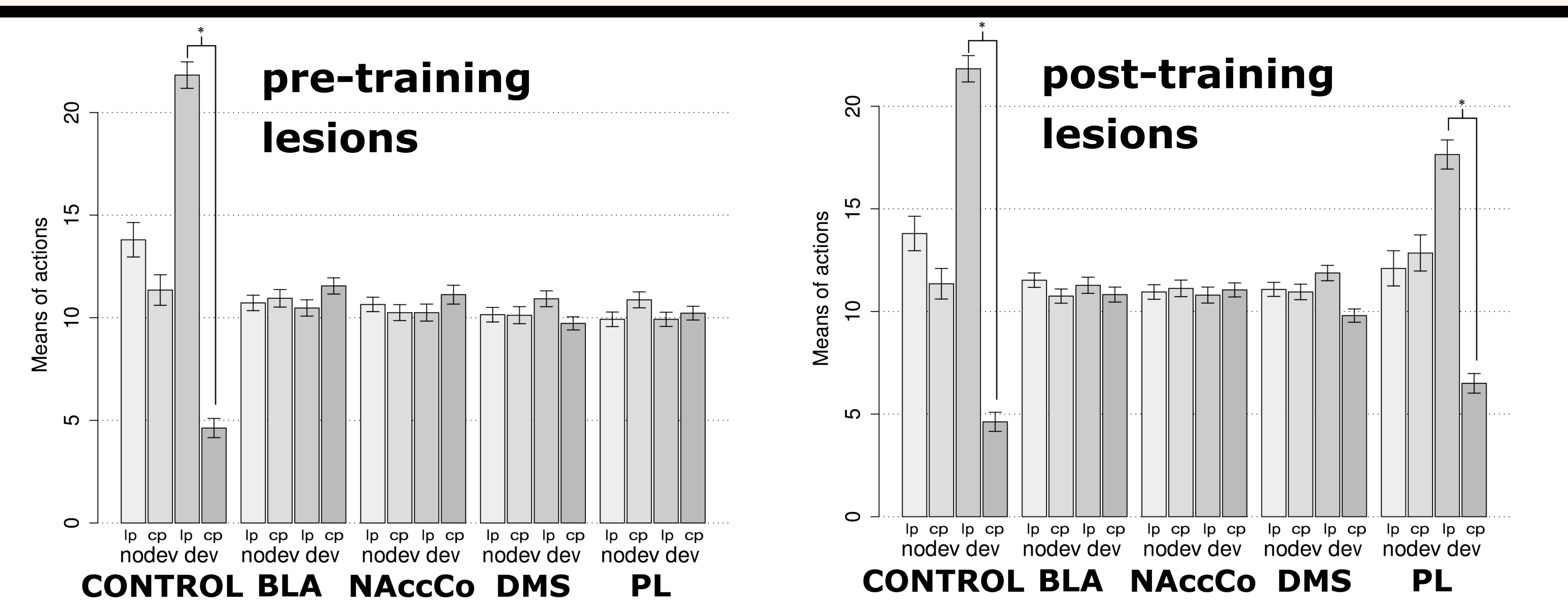
Onset firing rate

$$\tau \dot{v} = -v + I$$
$$\tau \dot{u} = -u + [-v + I]^+$$

Differential Hebbian learning

$$\Delta w_{post,pre} = \sigma \, [u_{pre}']^- \, [u_{post}']^+$$

Results and conclusions: The model shows how Pavlovian associations between manipulanda and rewards may underlie the effects of devaluation in instrumental behaviours. The model reproduces the documented effects on behaviour of both pre- and post-training lesions to the BLA [2], the NaccCo [3], the PL [4], and the dorsomedial striatum (DMS) [5]. In particular the model is able to explain why PL is needed for the acquisition but not for the expression of devaluation. Finally, the model provides predictions about the effects of undocumented post-training lesions to the DLS as well as on the effects of the inactivation of the striato-nigro-striatal pathway.



References

[1] **Gurney, K., Prescott, T. J., and Redgrave, P.** (2001) Biol Cybern 84, 411–423. [2] **Balleine, B. W., Killcross, S. A., and Dickinson, A.** (2003) J Neurosci 23(2), 666–675. [3] **Corbit, L. H., Muir, J. L., and Balleine, B. W.** (2001) J Neurosci 21(9), 3251–3260. [4] **Corbit, L. H. and Balleine, B. W.** (2003) Behav Brain Res 146(1-2), 145–157. [5] **Yin, H. H., Ostlund, S. B., Knowlton, B. J., and Balleine, B. W.** (2005) Eur J Neurosci 22(2), 513–523.

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