Deep Brain Stimulation in the Globus Pallidus internus Promotes Habitual Behavior by Modulating Cortico-Thalamic Shortcuts and Basal Ganglia Plasticity

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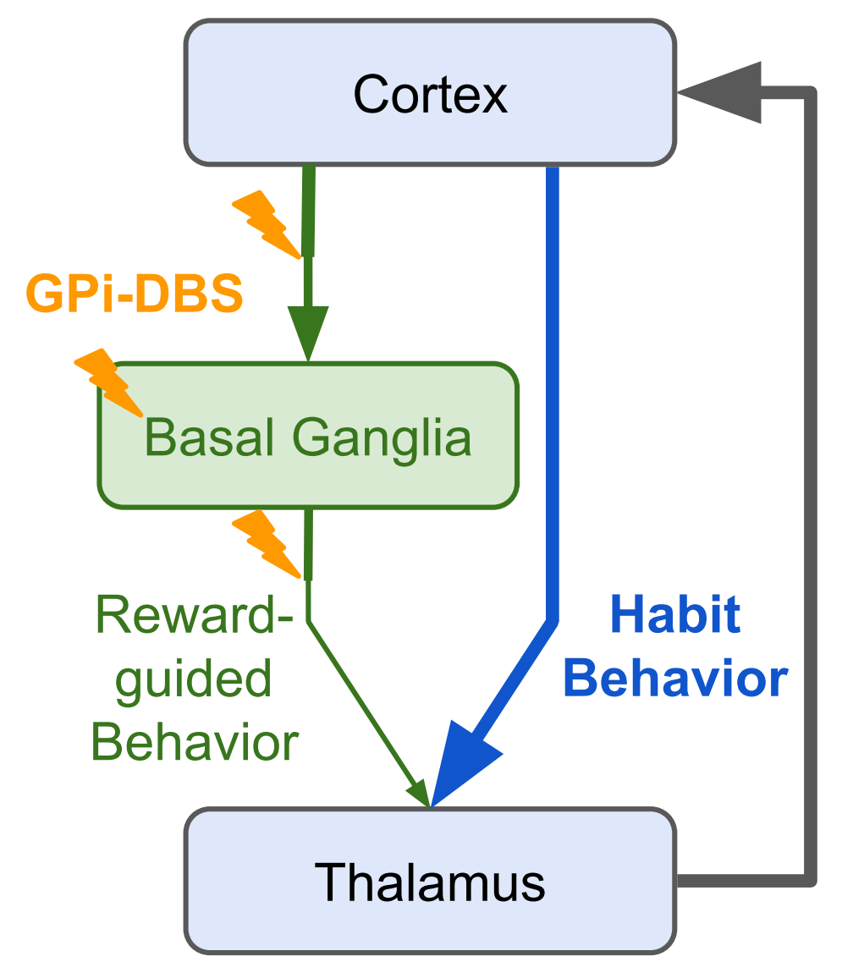
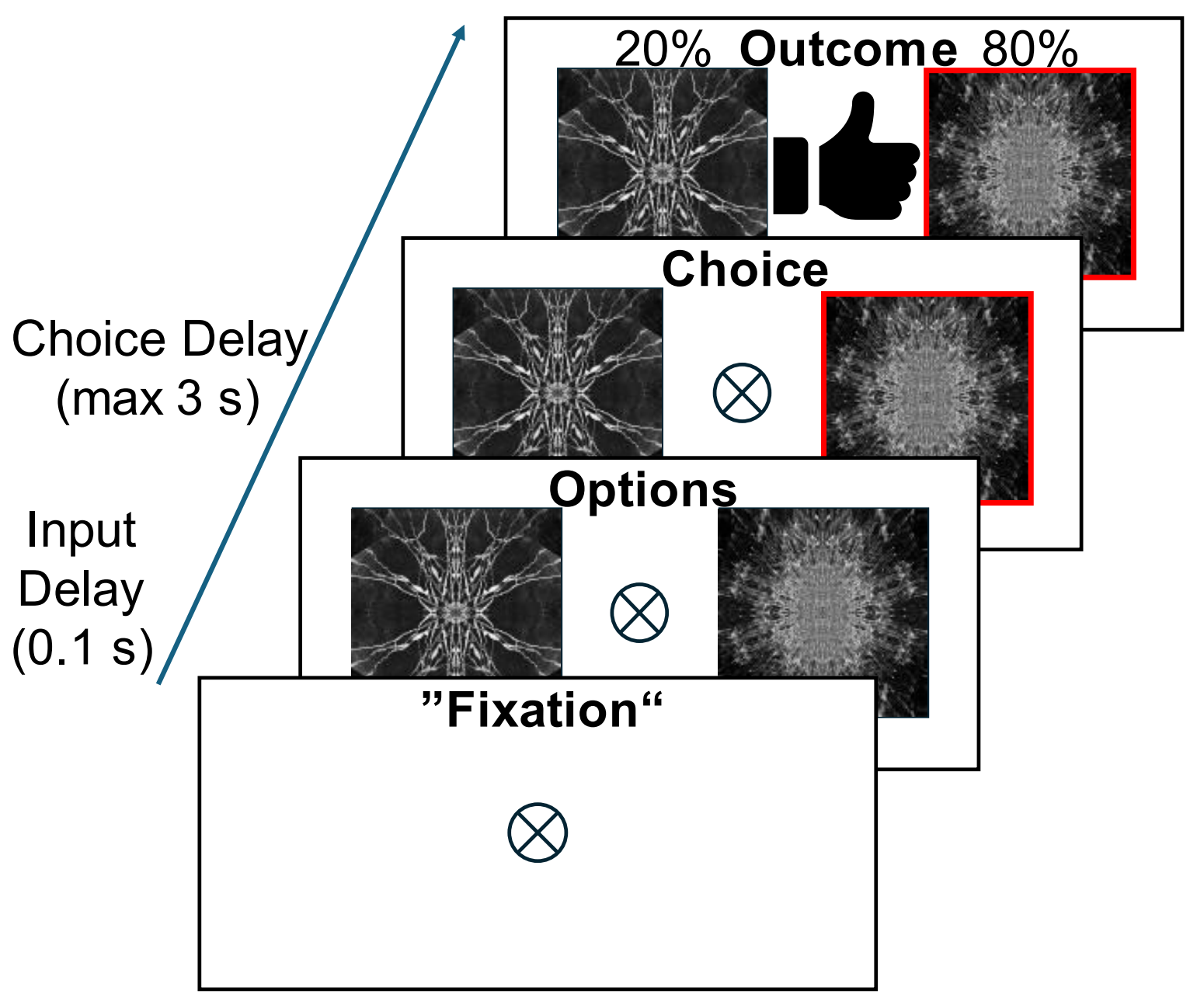
DBS Promoting Habitual Behavior



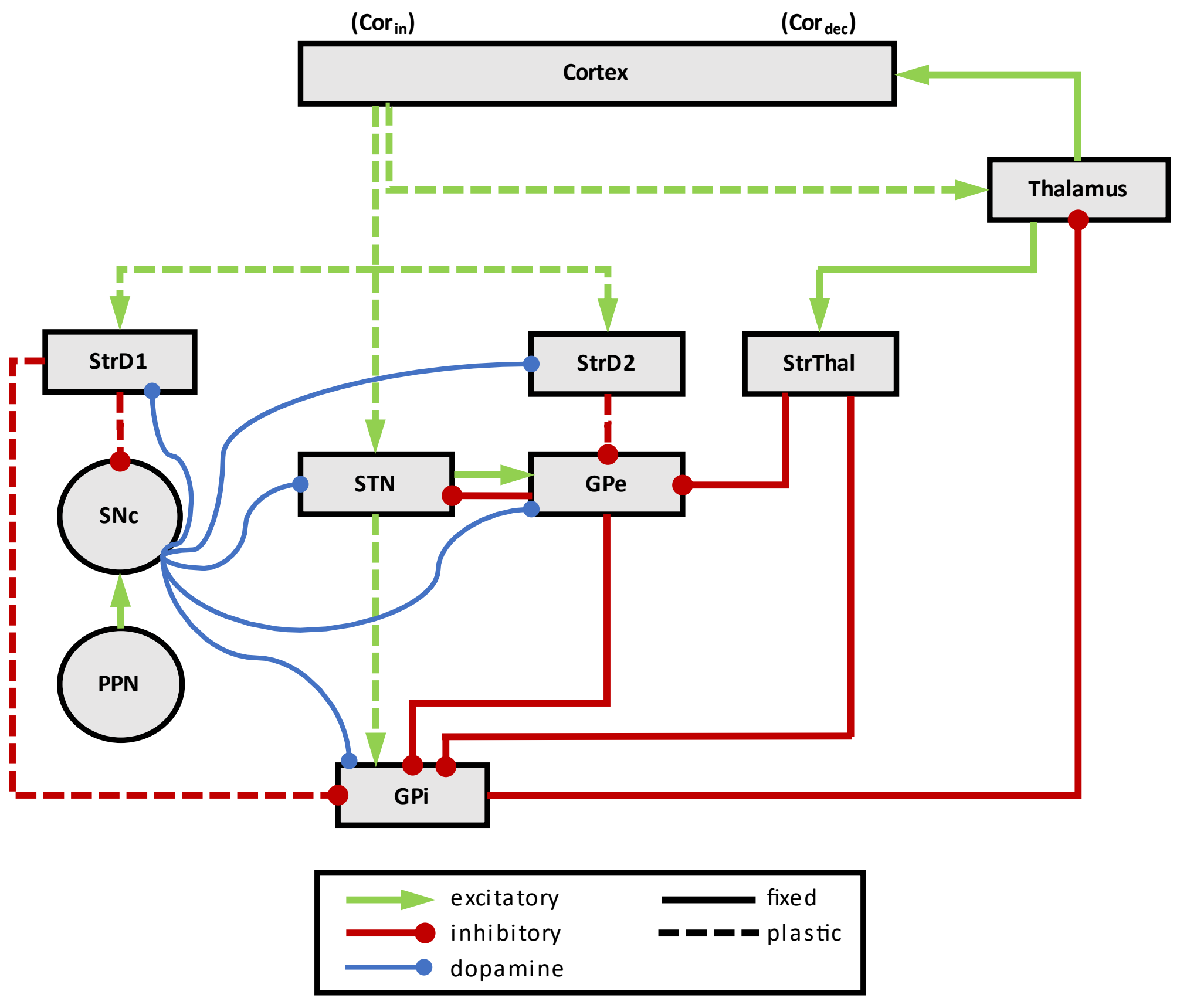
Although deep brain stimulation (DBS) is a widely used treatment with several known effects on stimulated tissue [1], the precise mechanisms by which it influences basal ganglia function remain unclear. In our recent studies [2-5], we explored how the basal ganglia guide learning in slower cortico-thalamic or cortico-cortical connections via reward-based learning, contributing to habitual behavior. Both the basal ganglia and these connections influence decision-making, raising questions about their balance. We propose that deep brain stimulation (DBS) in the basal ganglia regulates this balance, reducing basal ganglia influence and amplifying cortico-thalamic shortcuts’. This aligns with the informational lesion hypothesis of DBS effects [6]. We propose that DBS in the GPi promotes habitual behavior by diminishing reward-guided behavior.

Experimental Procedure



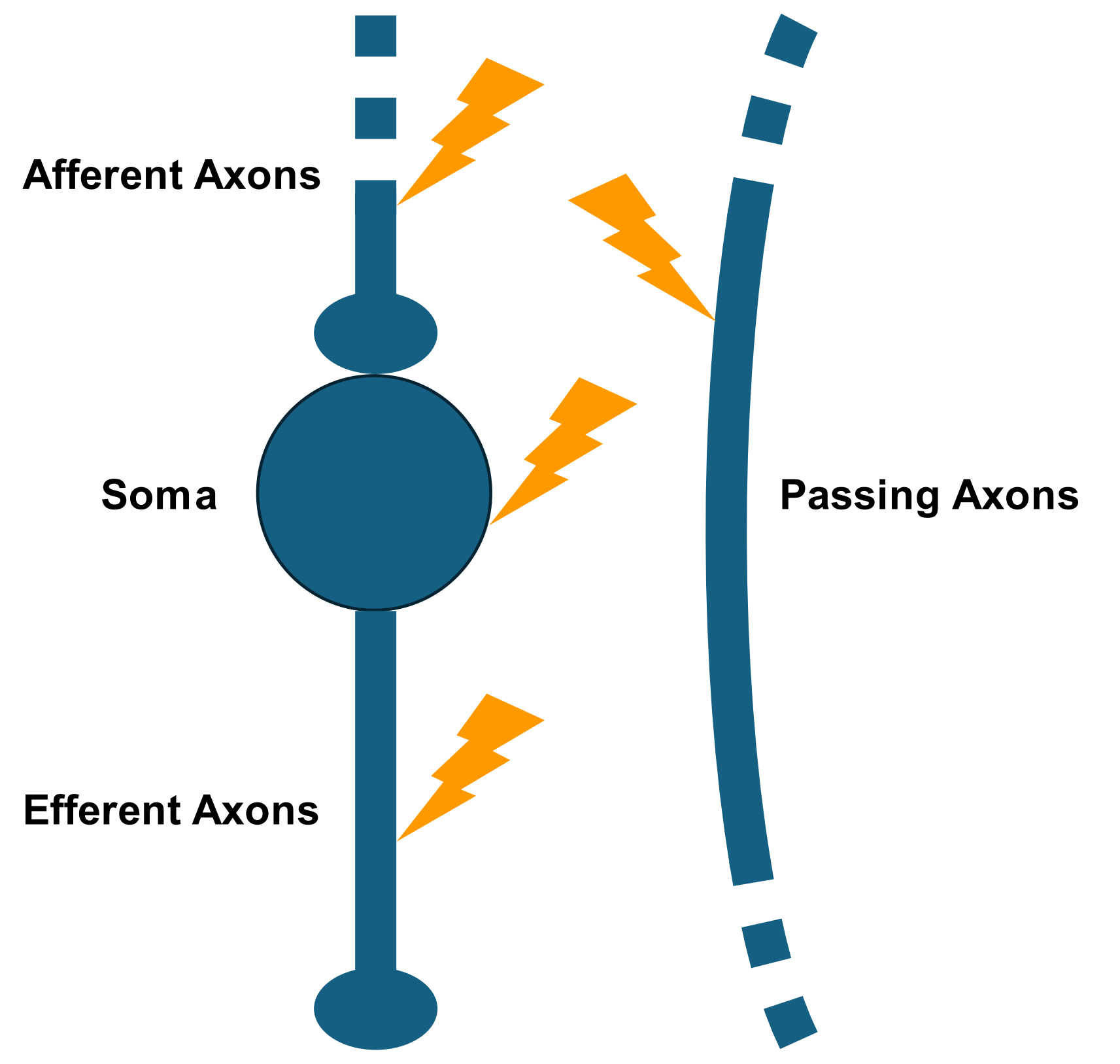
We simulated a two-choice reward reversal-learning task based on De A Marcelino et al. (2023)[7] to replicate patients behavior [8]. Each simulation had 120 trials, divided into three sessions of 40 trials. At the start of each trial, a 100 ms period without input is followed by inputs to the cortex, simulating the presentation of two fractals (**Options**). The model selects a fractal when a cortical neuron's firing rate exceeds a threshold or after 3000 ms (**Choice**). The **Outcome** is instantaneous and reward probabilities start at 80:20 and reverse to 20:80 after 60 trials, prompting the model to adapt.

Model



- rate-coded neurons
- neurosimulator ANNarchy [9]
- Cor_{in} population encodes presentation of fractals
- Cor_{dec} population encodes choice
- reward-guided (i.e., dopamine-modulated) plasticity within basal ganglia
    - learning rewarded associations
- bypassing cortico-thalamic shortcut with simple Hebbian learning
    - trained by basal ganglia choices

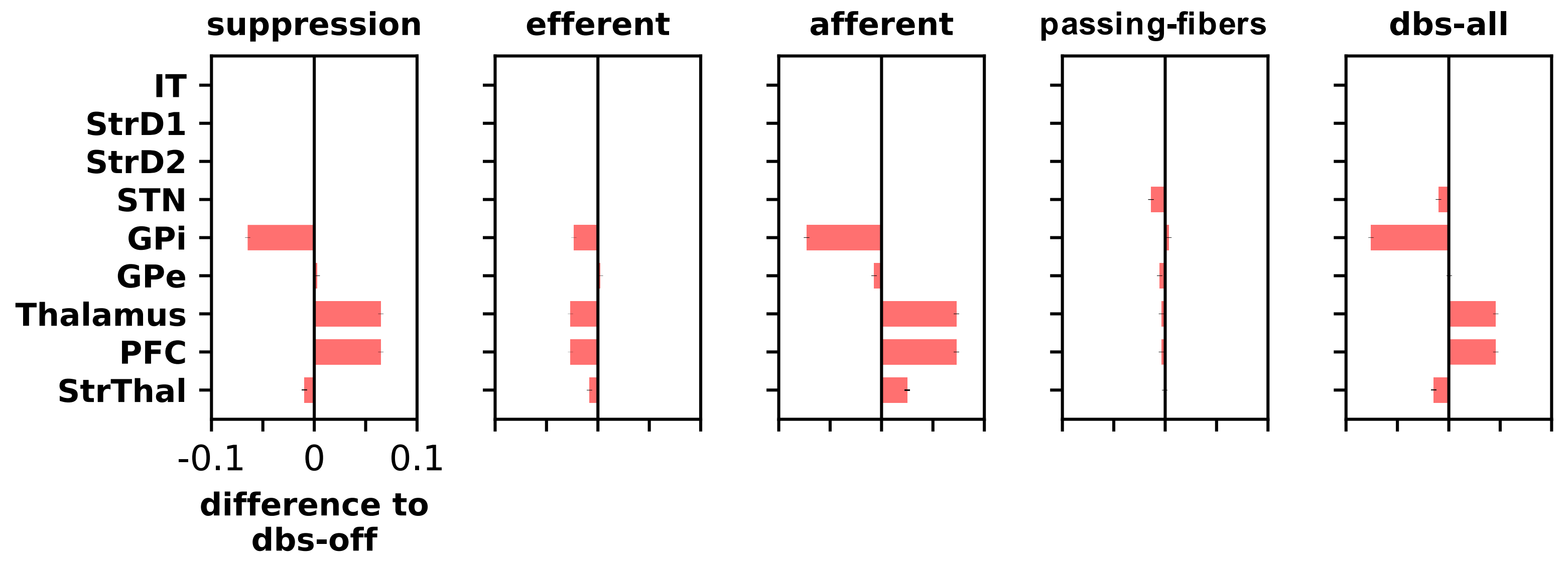
Different DBS Variants



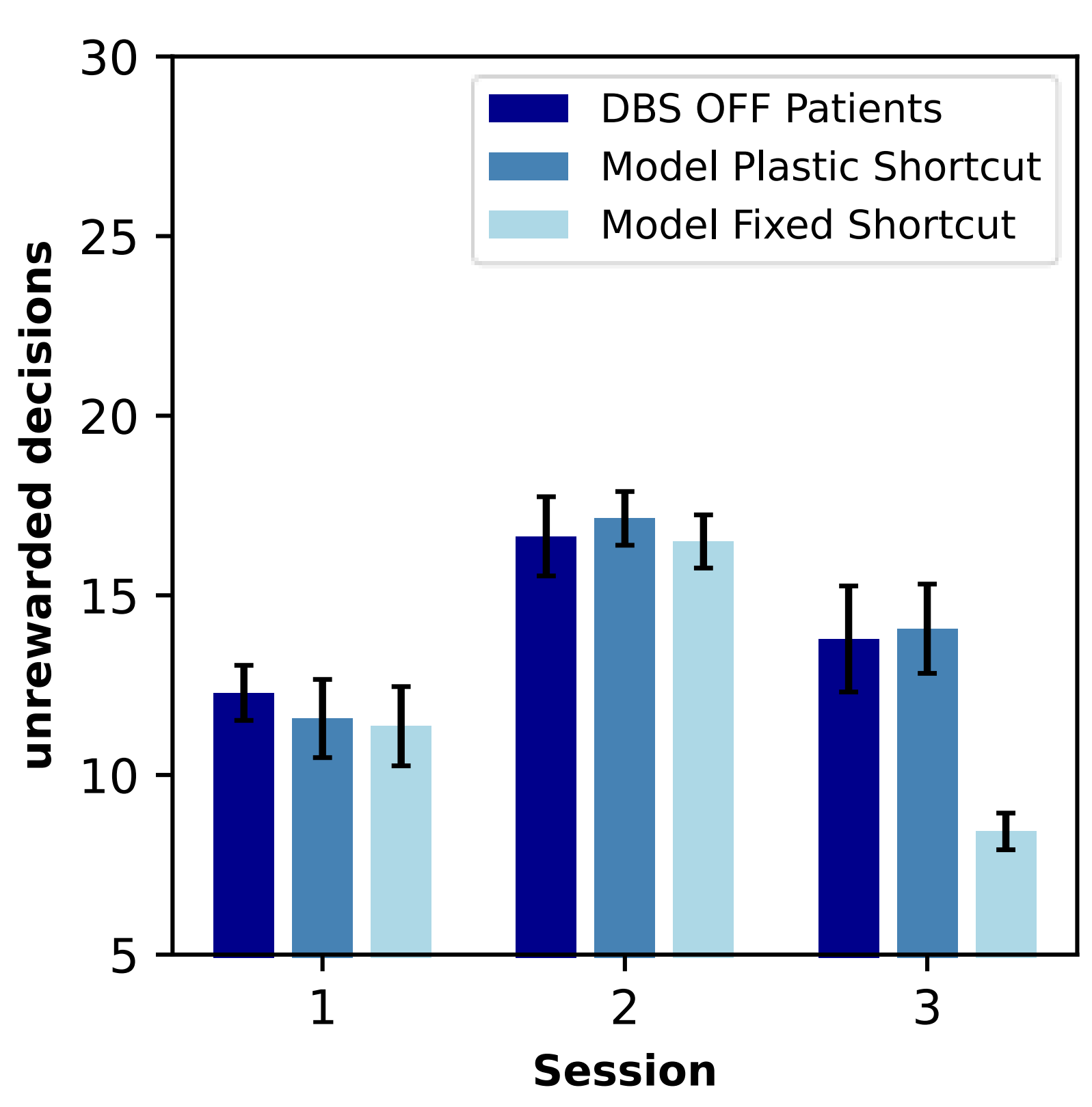
The target for DBS was the GPi. We implemented four distinct effects of DBS, each of which can be activated or deactivated independently:

- stimulation of all afferent axons,
- stimulation of all eferent axons,
- stimulation of passing fibers (from GPe to STN),
- suppression of soma firing rates.

Each variant of DBS produces unique changes in the network's firing rates.

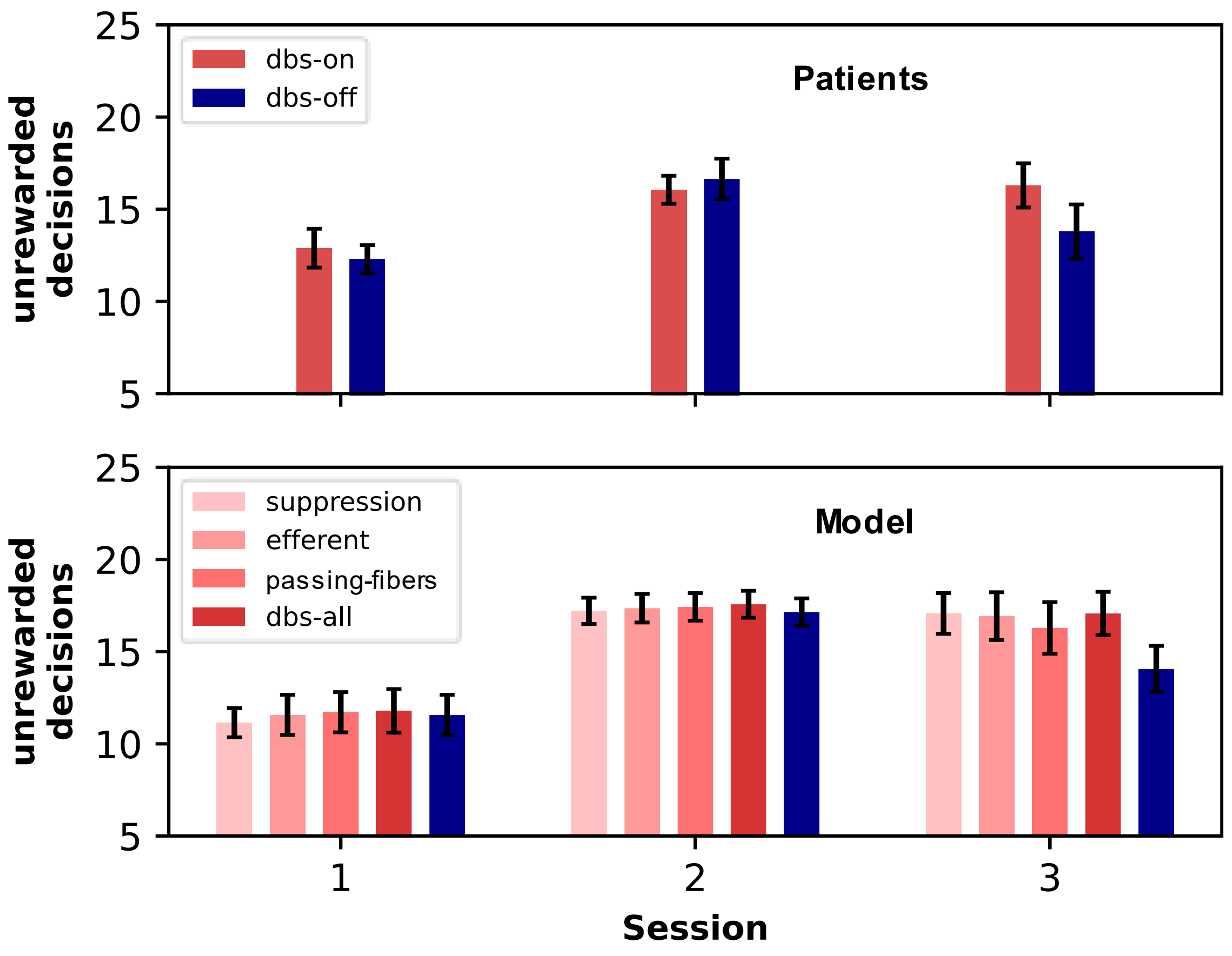


Synaptic Plasticity in Cortico – Thalamic Shortcut



Deactivating the plasticity of the cortico-thalamic shortcut while keeping other conditions identical led to fewer unrewarded decisions in the third session. This shows that a plastic shortcut promotes habitual behavior, i.e., persistence in previously favored choices. This could also clarify why patients made more unrewarded decisions in the third than in the first session, despite the first session involving the uncertainty of initial learning. In contrast, by the start of the third session, 20 trials had already been completed since the reversal, allowing the reward contingencies prevalent in session 3 to be learned.

DBS ON vs. OFF



Patients tend to make more unrewarded decisions during the third session when DBS is ON. Similarly, our model reflects this tendency across most DBS variants. After increasing the number of simulations, the 'suppression,' 'eferent,' and 'dbs-all' variants show a significant difference between DBS ON and OFF for the third session. Our model suggests that DBS shifts the balance between reward-guided and habitual behavior, leading to more unrewarded decisions following the reversal.

References

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Acknowledgements

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