Resolving the credit assignment problem in cortico-basal ganglia pathways

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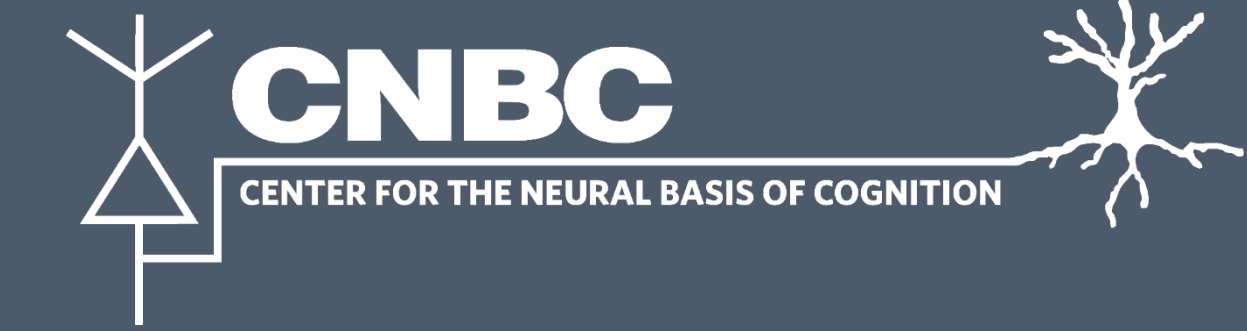
BACKGROUND & MOTIVATION

The cortico-basal ganglia-thalamus (CBGT) network is thought to serve a critical role in learning- and decision-related behaviors.
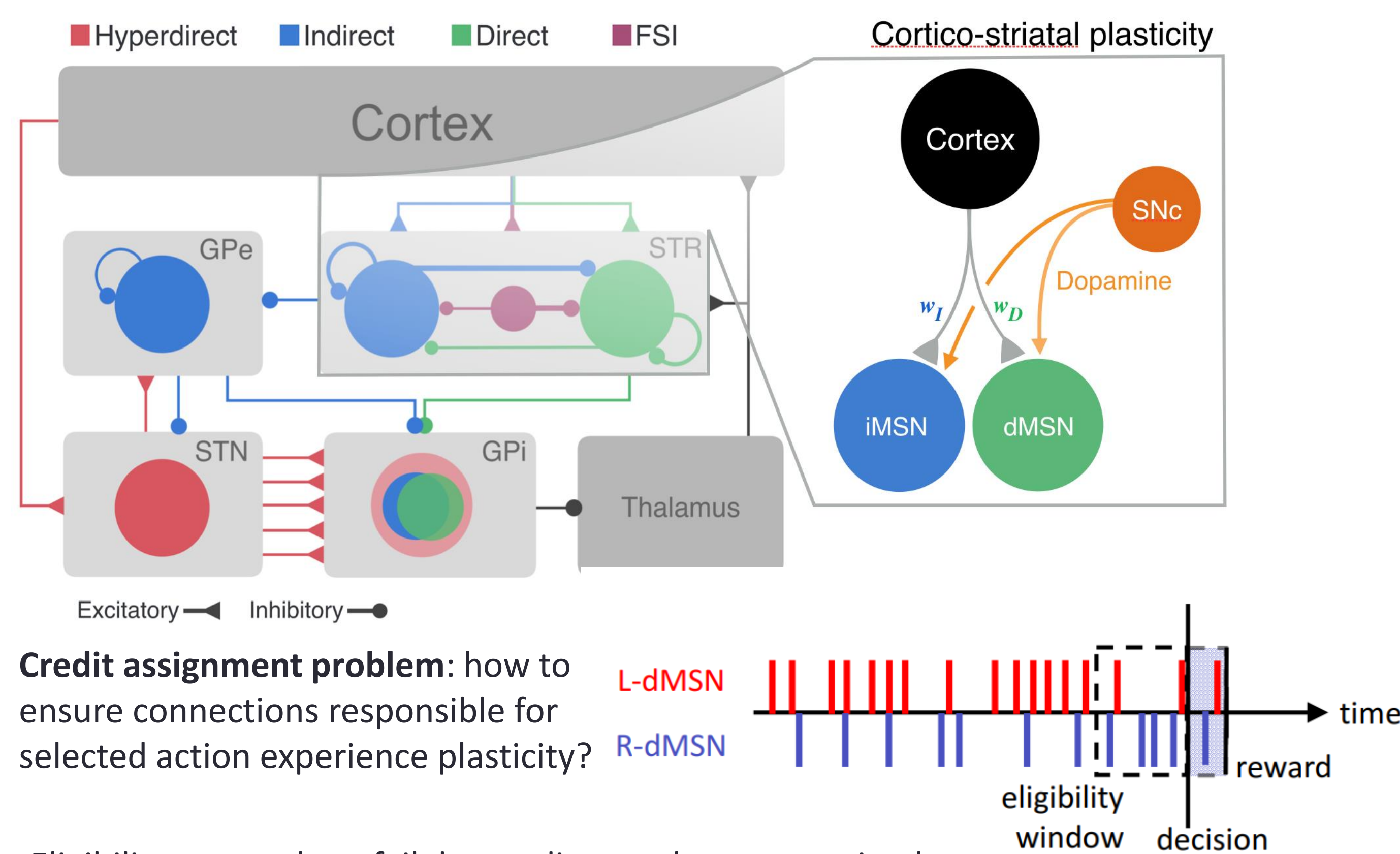
Striatal subpopulations serve as branchpoint between two pathways.
• D1 MSNs form action-facilitating direct pathway
• D2 MSNs form action-suppressing indirect pathway

Cortico-striatal connections, which exhibit dopamine (DA) induced plasticity, strongly influence balance of these pathways and thus overall CBGT network dynamics.

Prediction errors are encoded as phasic dopamine bursts (+PE) or pauses (−PE)
• Cortico-D1 connections potentiated by +PE, depressed by −PE
• Cortico-D2 connections depressed by +PE, potentiated by −PE

Credit assignment problem: how to ensure connections responsible for selected action experience plasticity?

Eligibility traces alone fail due to distance between striatal dynamics, action selection, and reward.

METHODS

Possible resolution: Sustained cortical activity in selected cortical population acts to increase and maintain eligibility in corresponding striatal populations.

Cortical activity known to be sustained in motor planning tasks[7].

Fully spiking basal ganglia network model:
• Two action channels, one per alternative, each containing cortical, basal ganglia, and thalamic populations
• Two striatal populations (D1 and D2) per channel

Sensory input represented by excitatory input to cortical populations

Ramping of thalamic activity to a cut-off (30 spikes / sec) was interpreted as a decision made by the network.

DECISION TIMECOURSE

Start of trial: Equal cortical stimulation applied to both channels

Between decision and reward:
• Cortical stimulation for selected action is maintained
• Unselected action has stimulation removed

Dopaminergic feedback according to Q-value prediction error
D1 and D2 connections undergo spike-timing-dependent plasticity
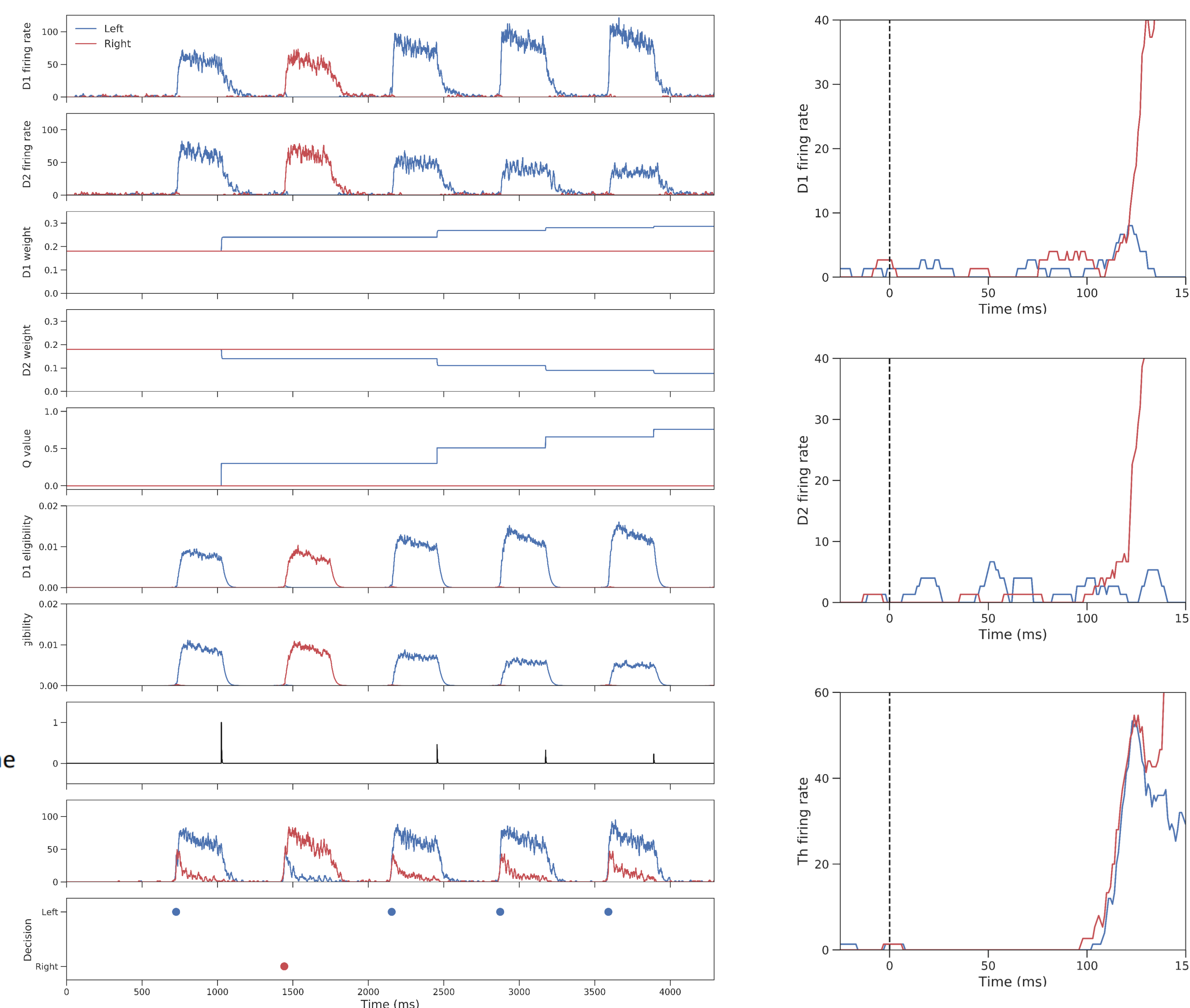
Key results:
• Striatum and thalamus experience ramping with competition
• Large divergence in D1 and D2 weights in correct directions
• Network behavior influenced by weight balance

Dopaminergic Learning Rule (STDP model)

At each time step [1,2]:

$$\frac{dA_{PRE}}{dt} = (-A_{PRE} + \Delta_{PRE} * X_{PRE}(t))/\tau_{PRE},$$

$$\frac{dA_{POST}}{dt} = (-A_{POST} + \Delta_{POST} * X_{POST}(t))/\tau_{POST},$$

$$\frac{dE}{dt} = (-E - X_{PRE}(t) A_{POST} + X_{POST}(t) A_{PRE})/\tau_E,$$

$$\frac{dw}{dt} = \alpha_w E f(K_{DA})(w_{max} - w),$$

$$f(K_{DA}) = \begin{cases} K_{DA}, & \text{if the target neuron is a dMSN,} \\ \dfrac{K_{DA}}{c + |K_{DA}|}, & \text{if the target neuron is an iMSN,} \end{cases}$$

If the action is given [3]:

$$DA_{inc}(t) = r_i(t) - \max_i \{Q_i(t)\},$$

$$Q_i(t+1) = Q_i(t) + \alpha (r_i(t) - Q_i(t)),$$

$$\frac{dK_{DA}}{dt} = \Sigma_i(DA_{inc}(t_i) - K_{DA})\delta(t_i) - K_{DA}/\tau_{DOP},$$

$$\frac{dg_{syn}}{dt} = \Sigma_{i,j} w_i(t_{i,j})\delta(t - t_j) - g_{syn}/\tau_g,$$

SWITCHPOINT TASK

Switch point task:
• 20 trials in which 'Left' action is rewarded
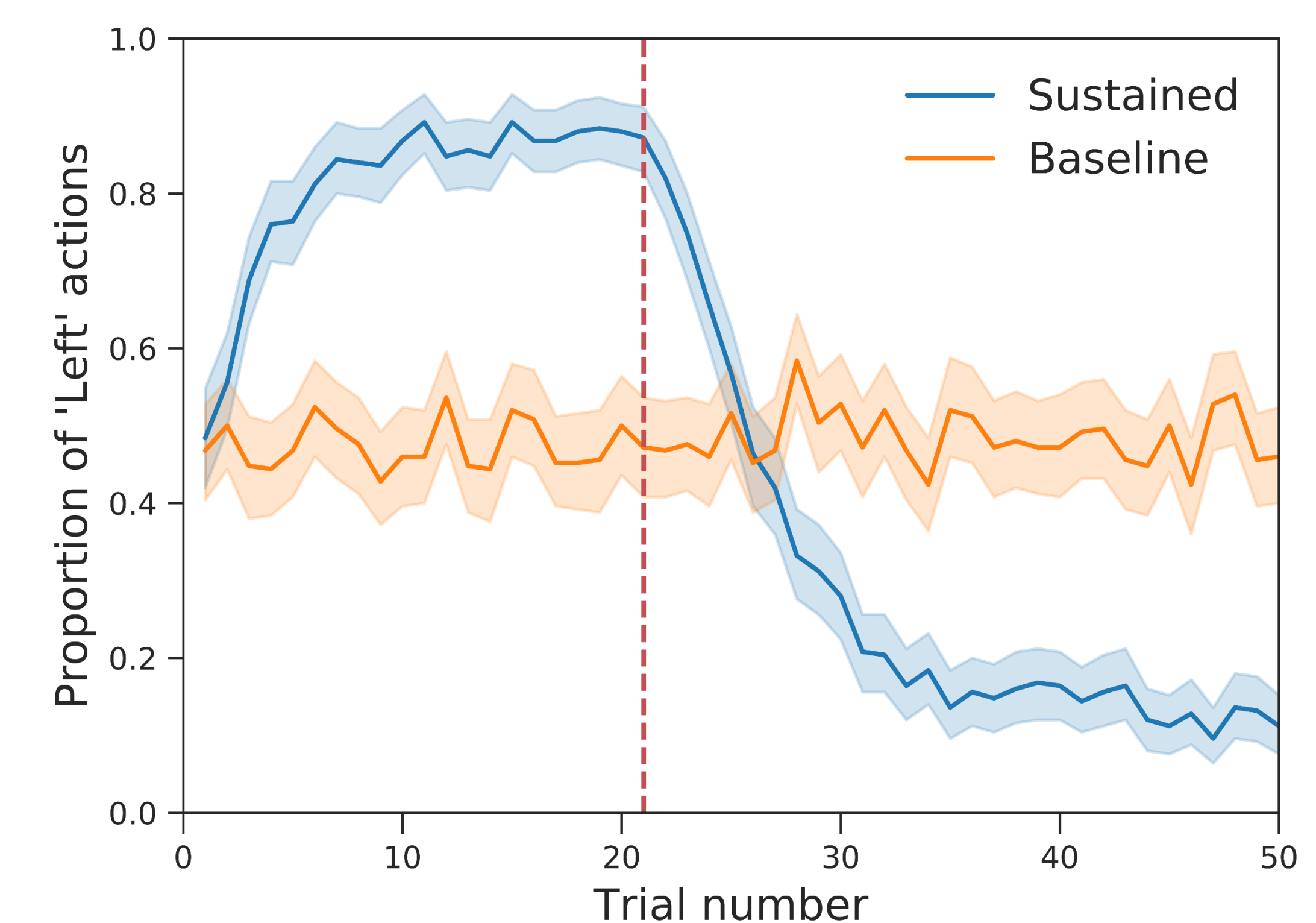• 30 trials in which 'Right' action is reward

250 simulations run, time-course of selection probabilities plotted

Key results:
• Successful learning before switch
• Successful relearning of correct action (same asymptotic accuracy)

Lesion study:
• Baseline network without sustained cortical activity shows no learning

SUMMARY & DISCUSSION

Introduction of sustained cortical activity enables effective credit assignment in full cortico-basal-ganglia-thalamic network model, without requiring a change in synaptic-level plasticity mechanisms.
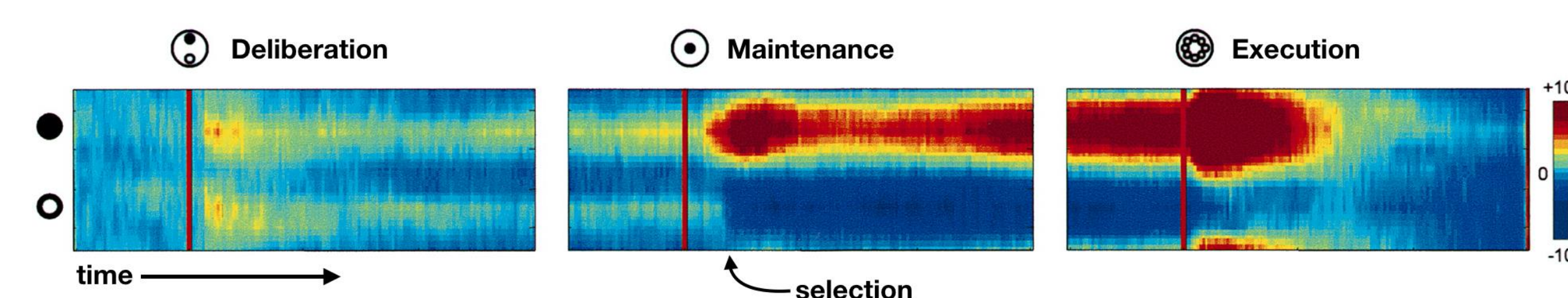
Future directions:
• Explore performance and limitations of model in more complex environments
• Use model to predict physiological activity patterns

REFERENCES & ACKNOWLEDGEMENTS

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