

Attention for learning:

The striatal cholinergic system in reward-based learning

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Real world learning



Outline

Reward-based learning in the brain

- Reinforcement learning in the striatum

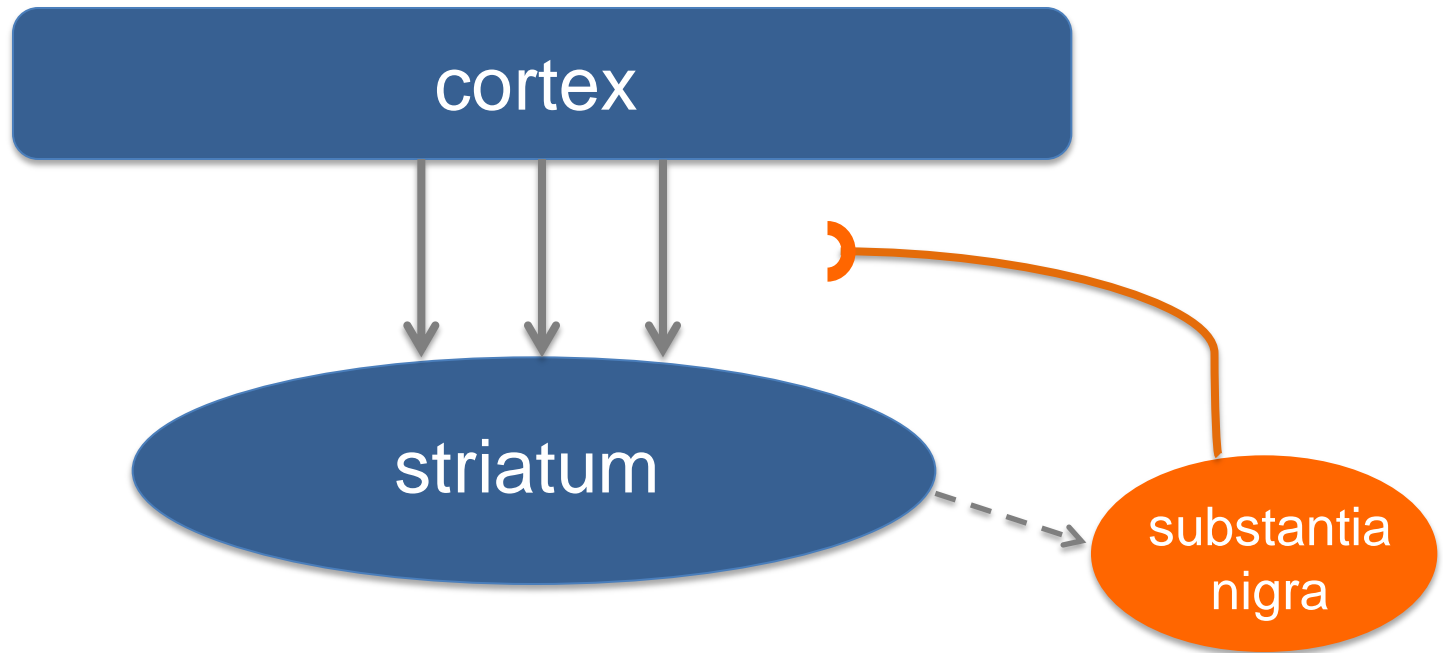
Attention in the striatum?

- Cholinergic interneurons
- Cholinergic gating of RL in the striatum

Attention for learning

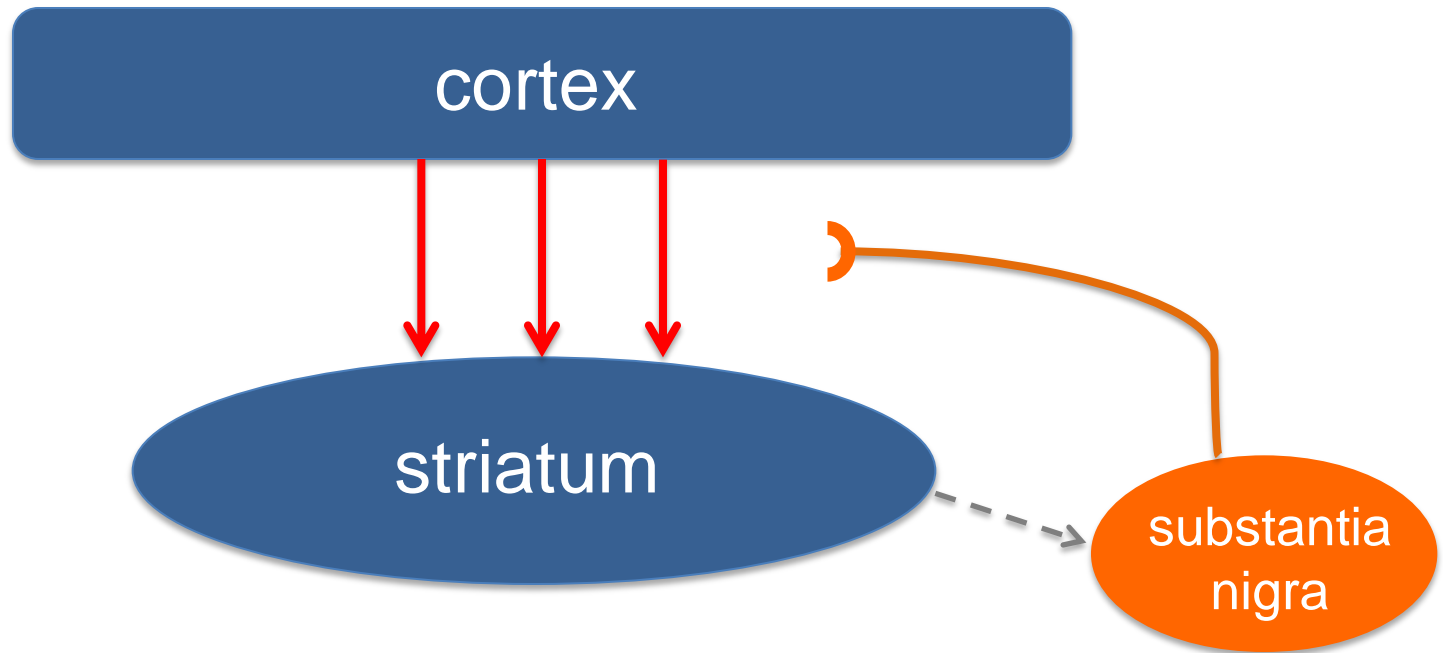
- Cholinergic-gated RL with multiple stimuli

Reinforcement learning

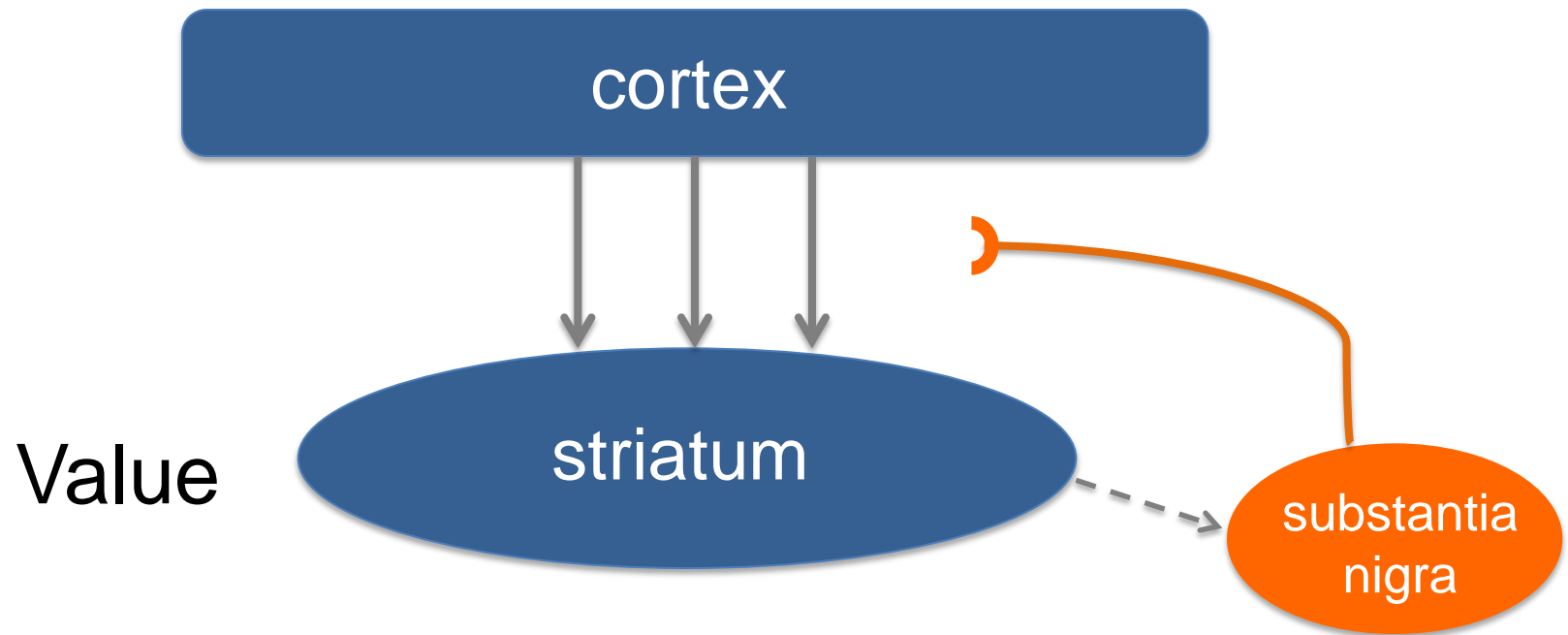


Houk, Adams & Barto 1995
Suri & Schultz 1998
Joel et al., 2002

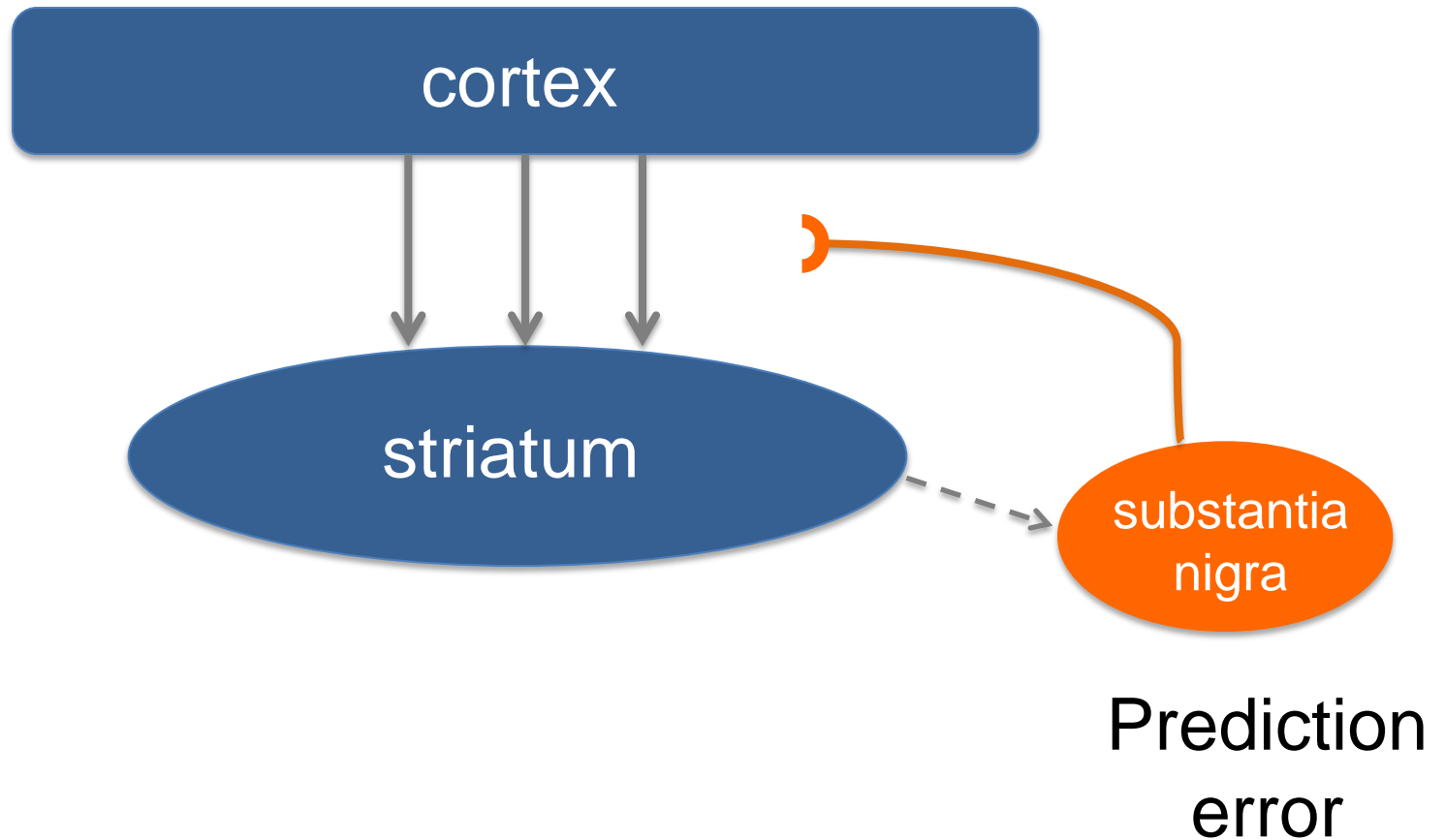
Reinforcement learning



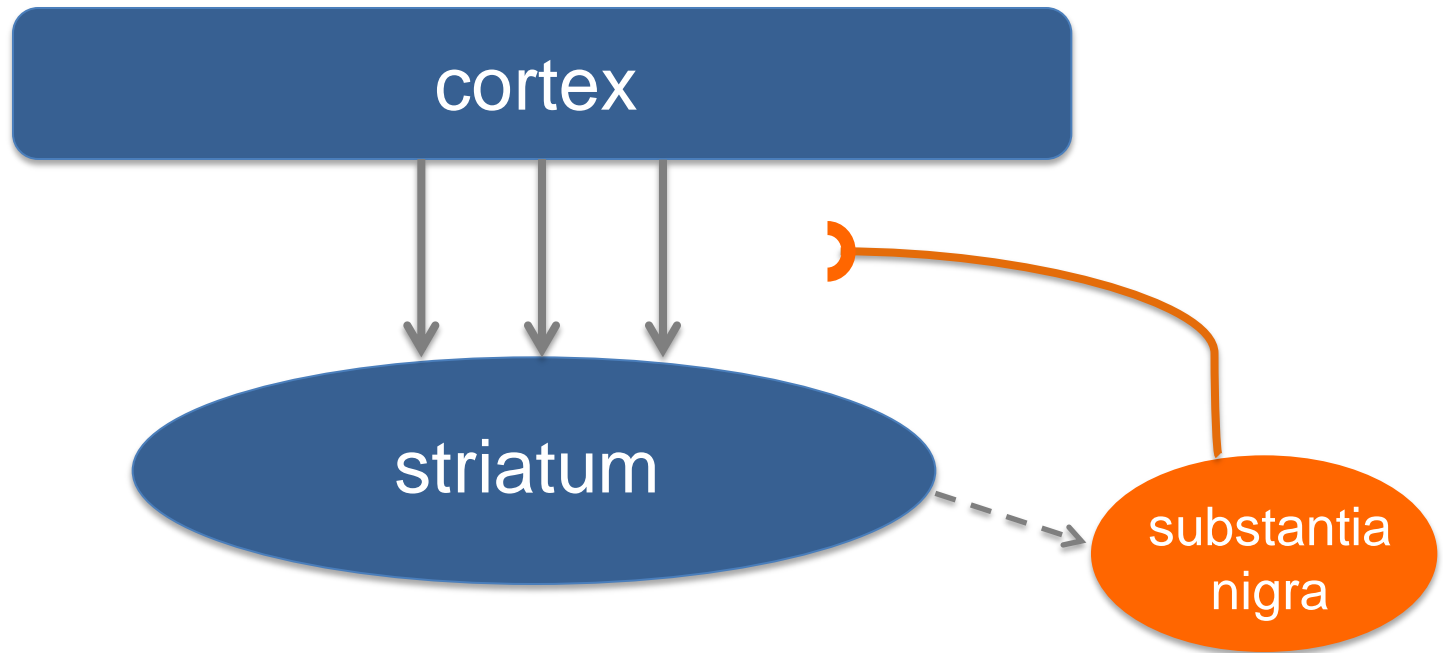
Reinforcement learning



Reinforcement learning



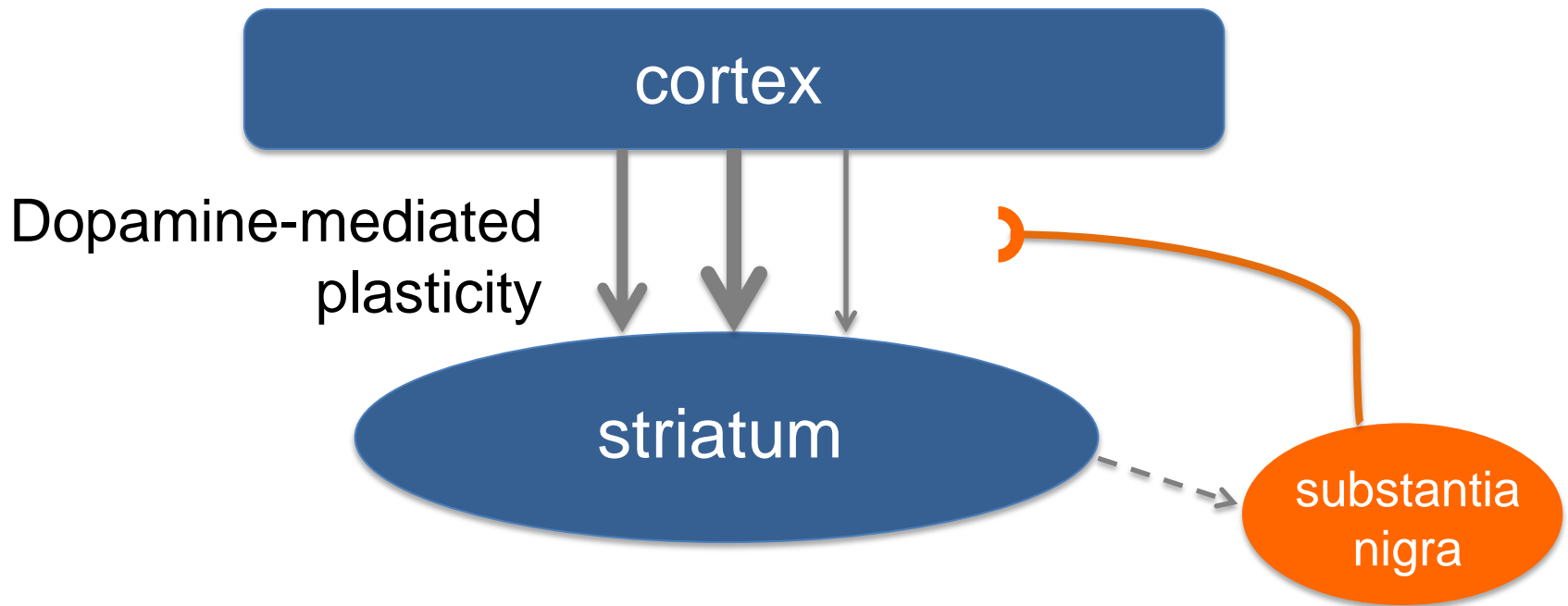
Reinforcement learning



$$\delta(t) = R(t) + \gamma V(t) - V(t-1)$$

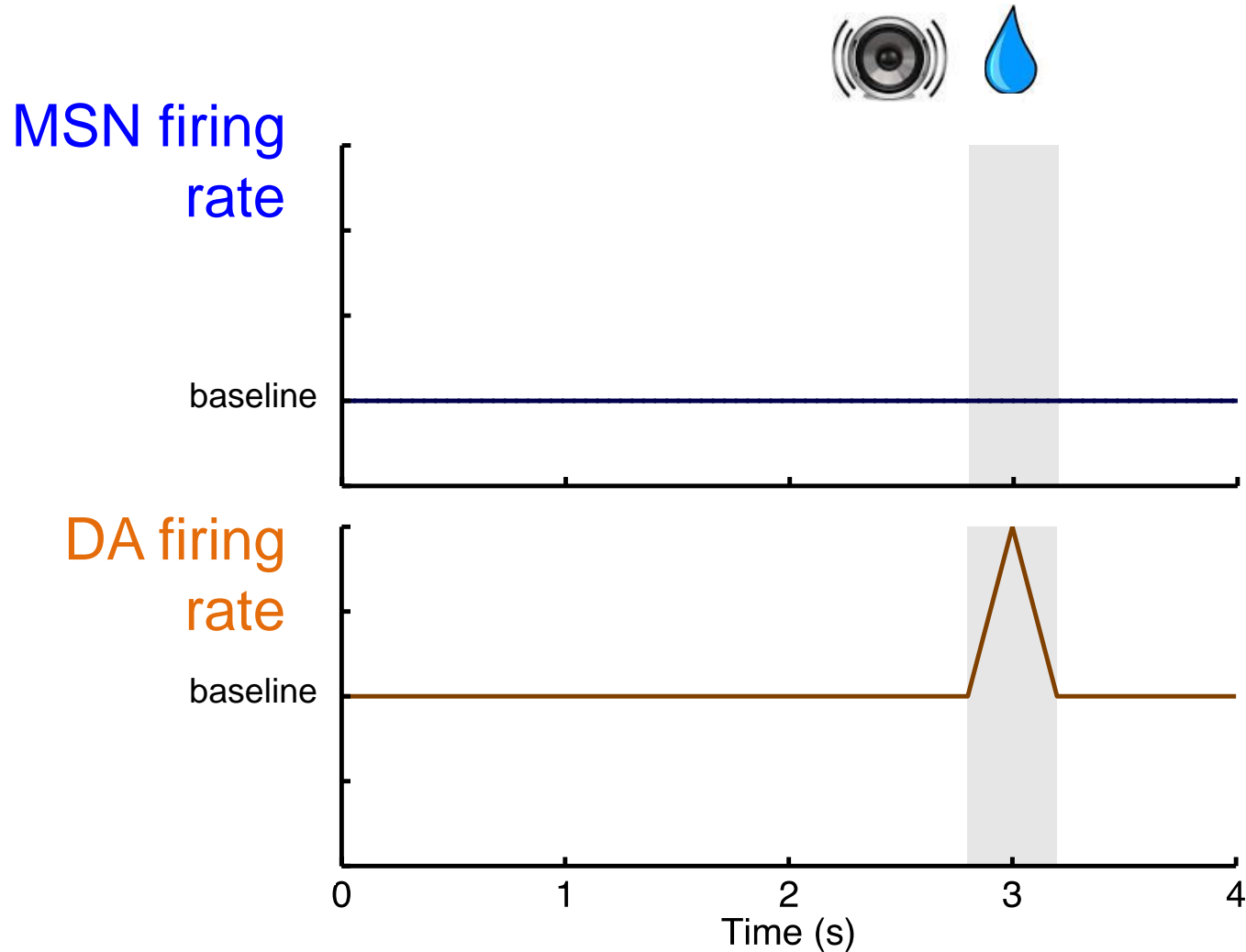
Prediction
error

Reinforcement learning



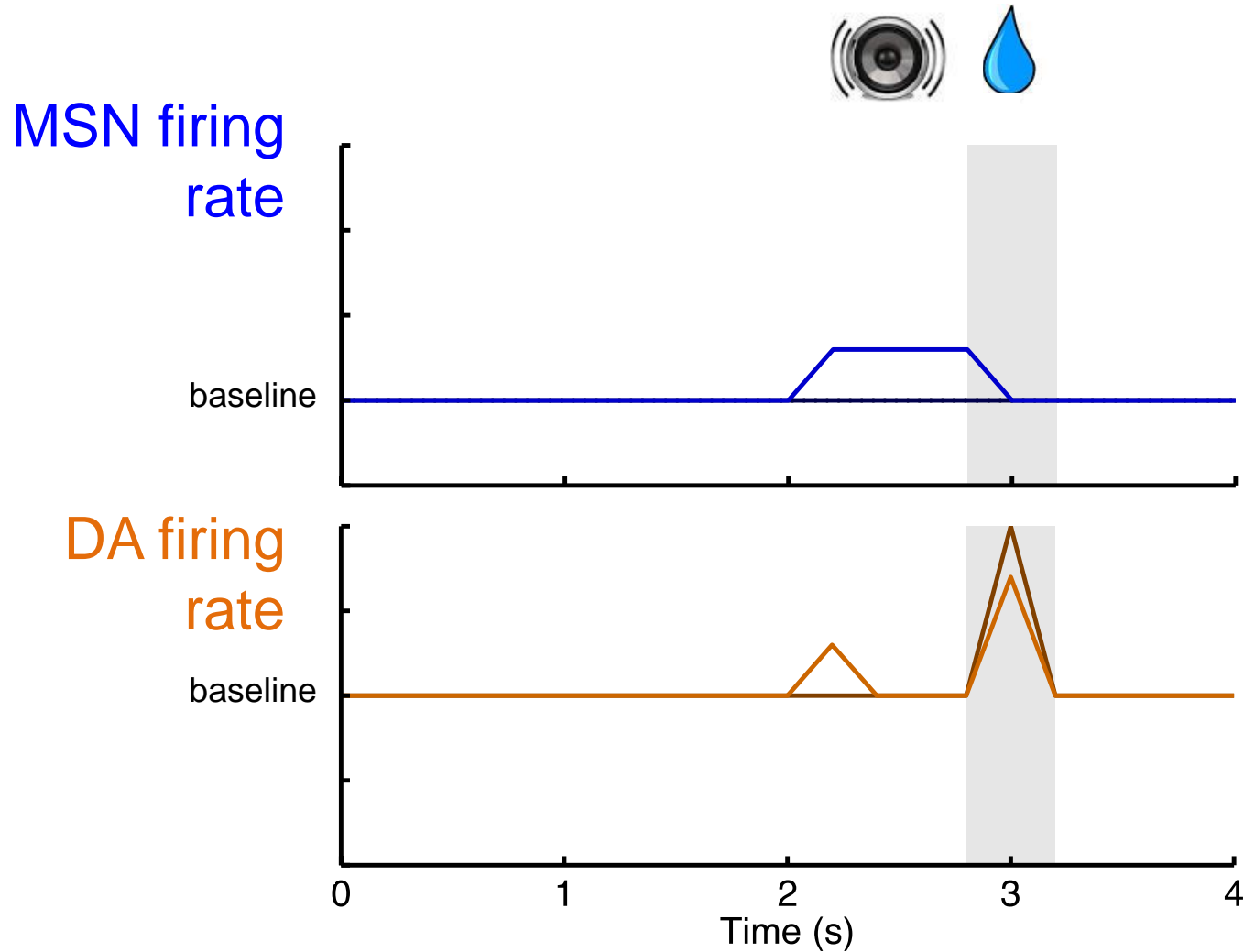
Classical conditioning

Trial 1



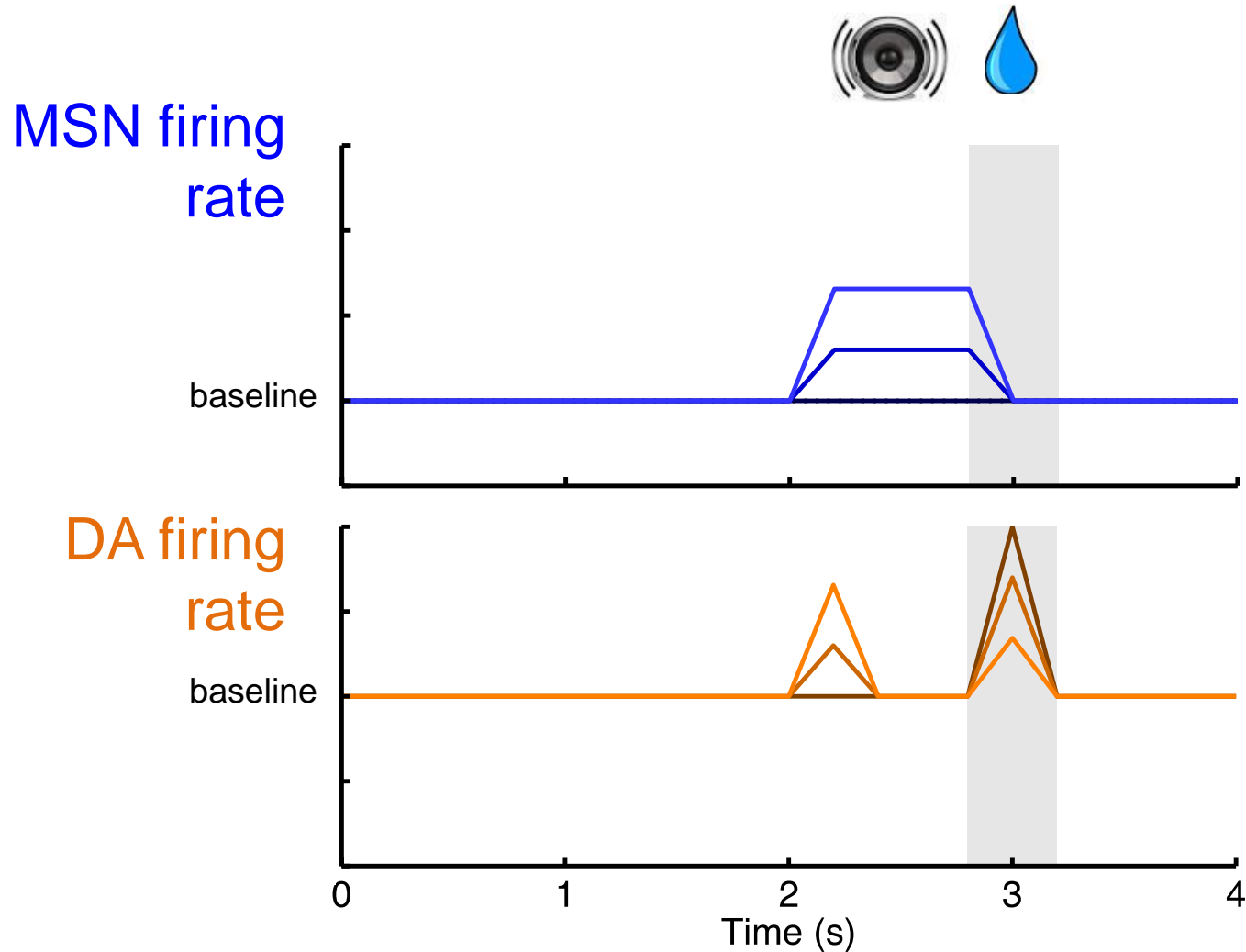
Classical conditioning

Trial 2



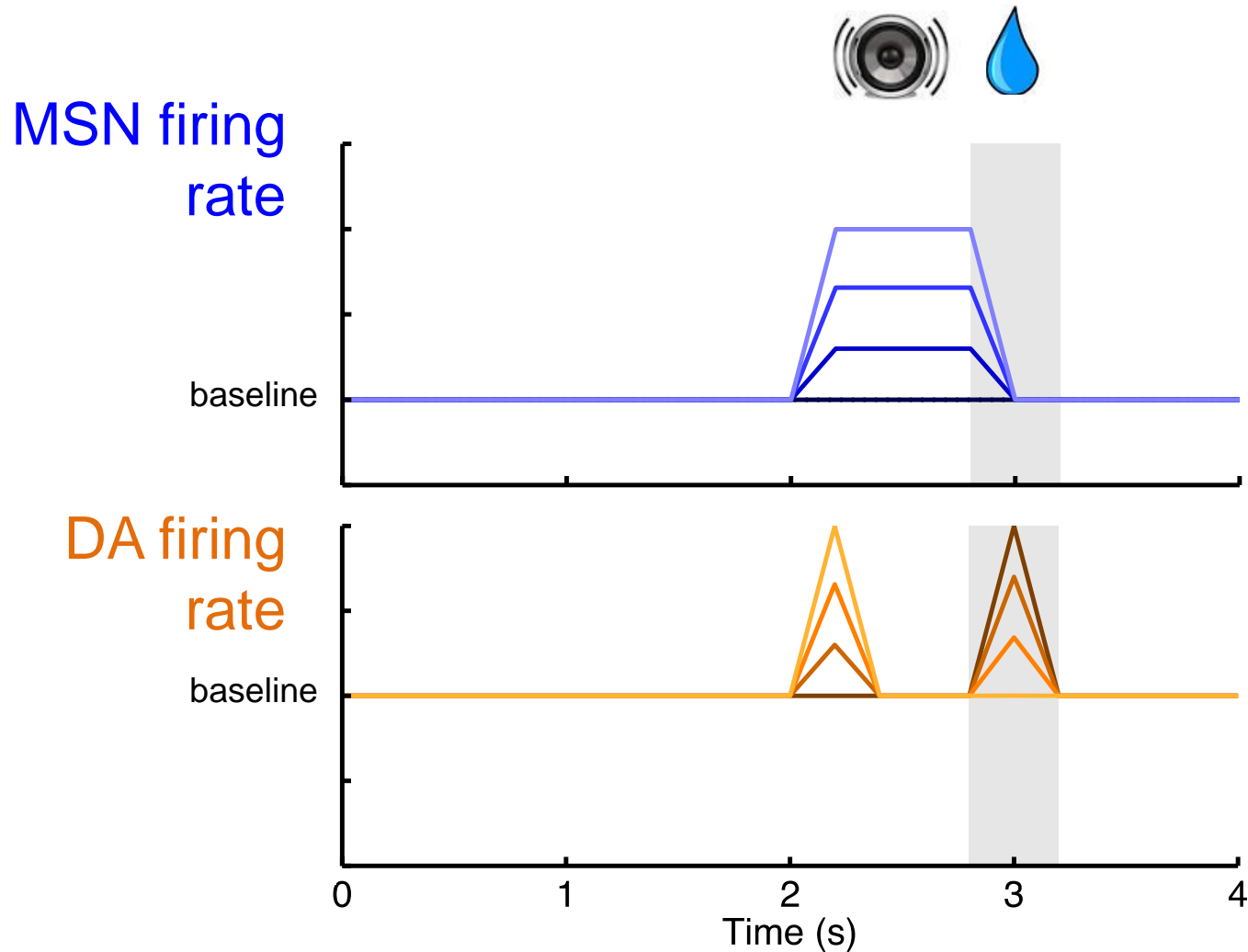
Classical conditioning

Trial 4



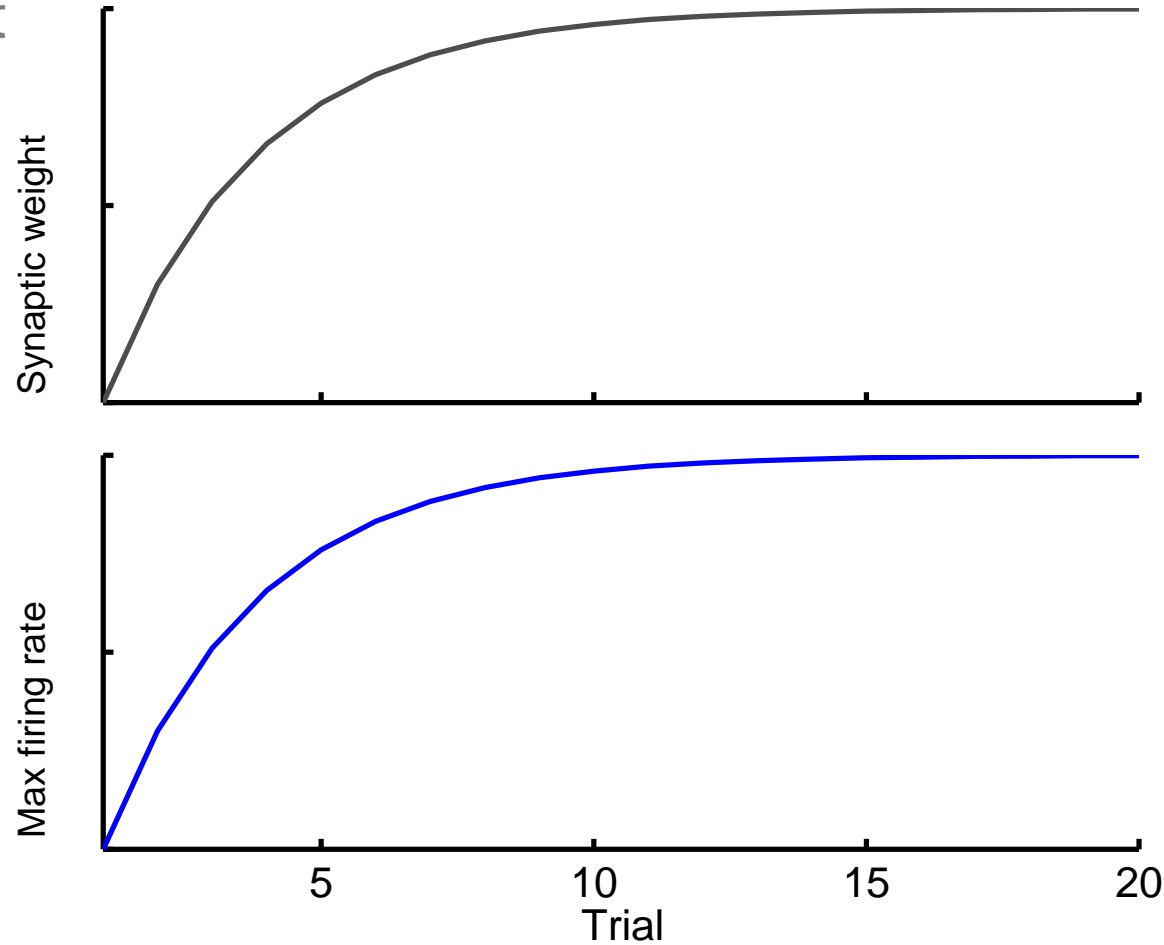
Classical conditioning

Trial 20

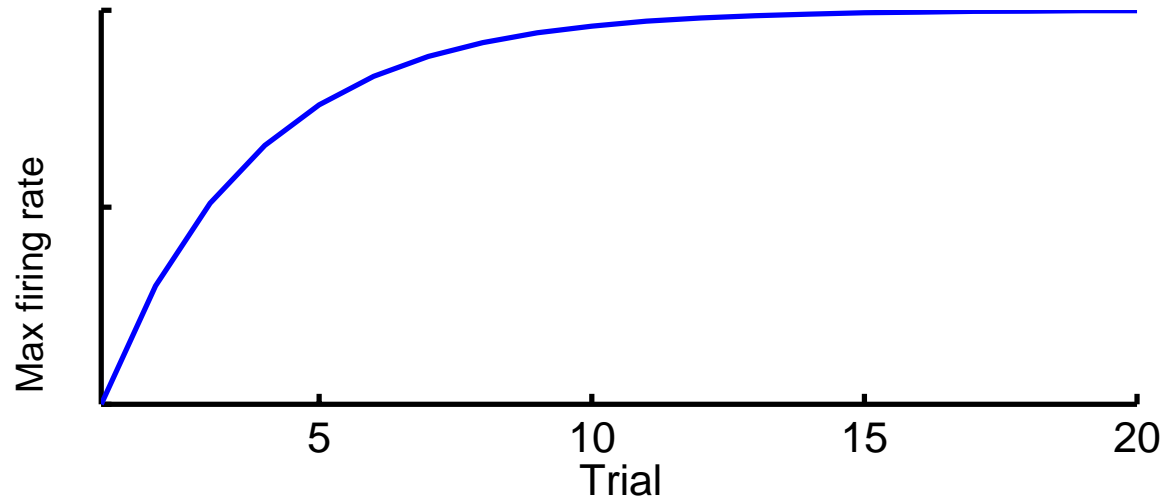


Classical conditioning

Cortico-striatal
weight



MSN value



Outline

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Attention in the striatum?

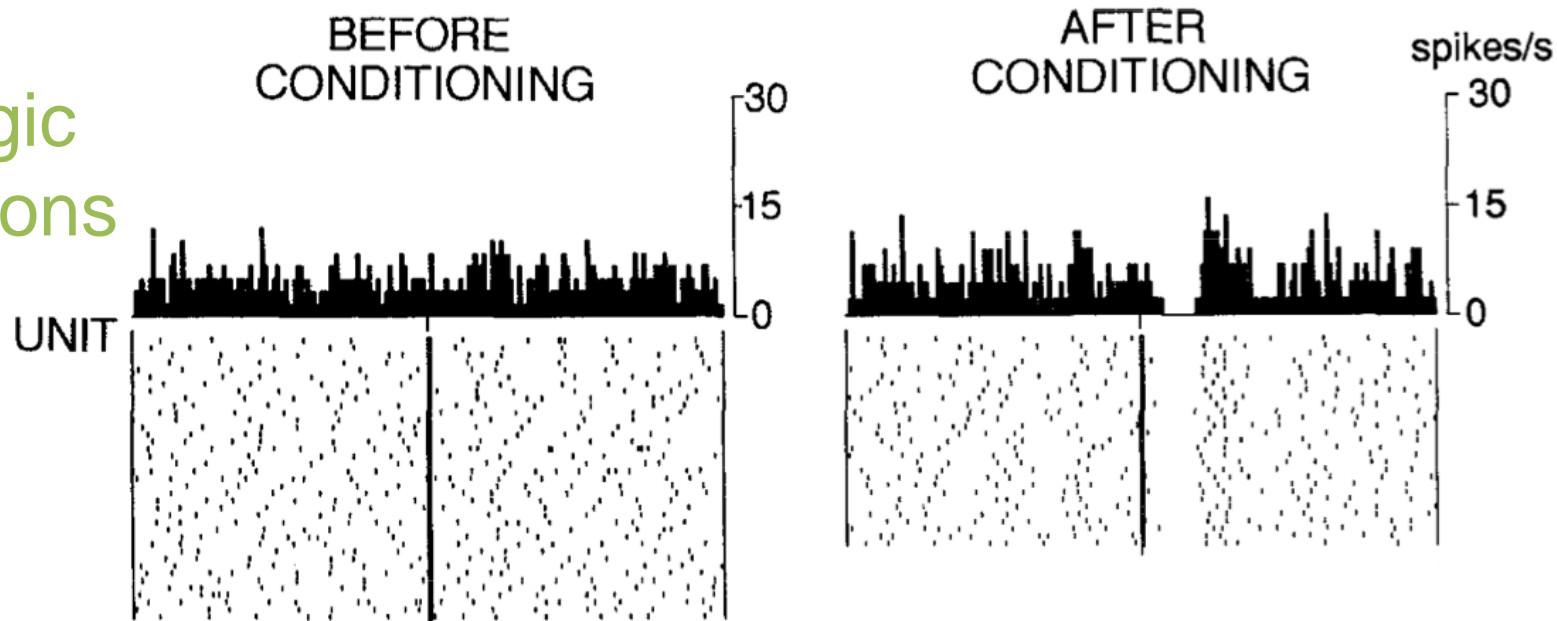
- Cholinergic interneurons
- Cholinergic gating of RL in the striatum

Attention for learning

- Cholinergic-gated RL with multiple stimuli

CINs learn to pause

Cholinergic interneurons



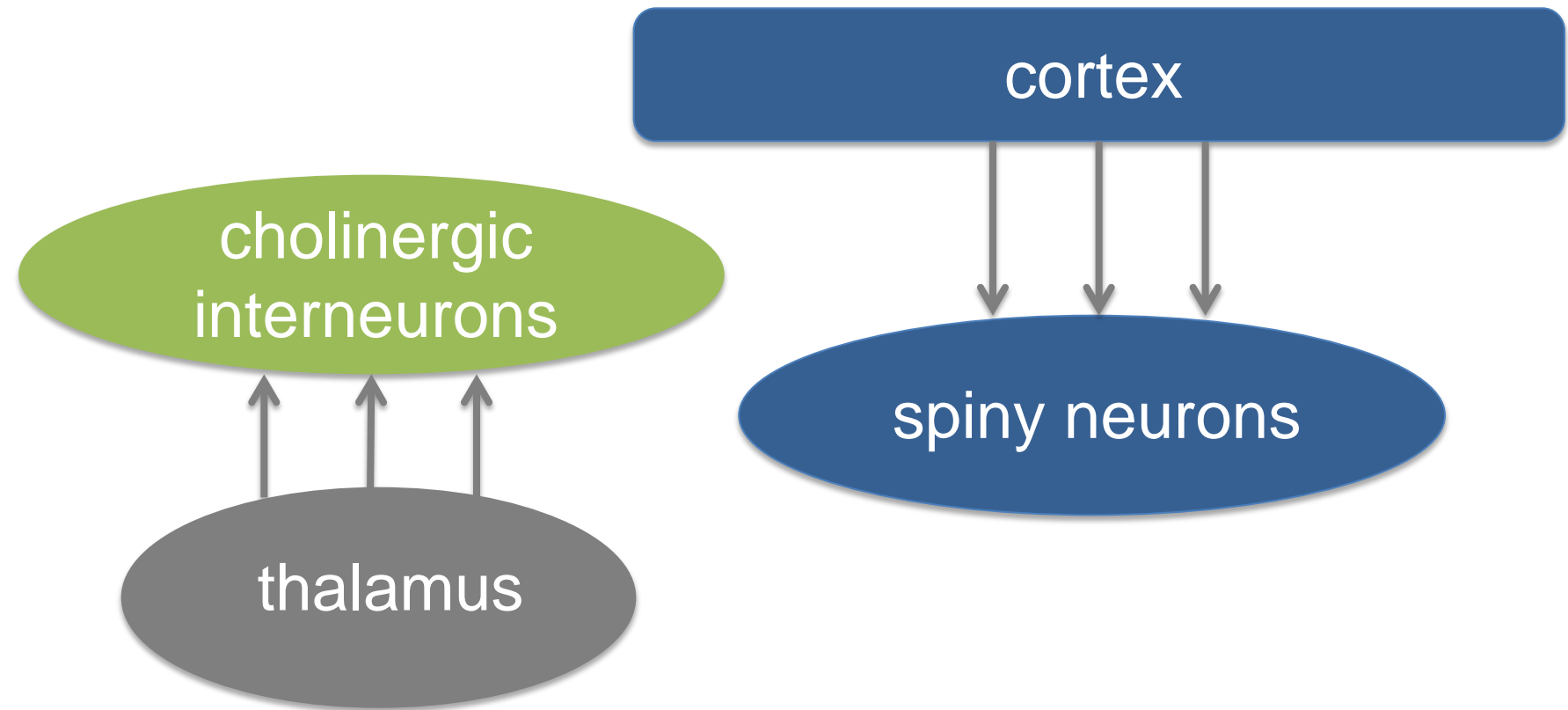
Aosaki et al.

Journal of Neuroscience, 1994

Morris et al., 2004

Apicella, 2002

CI-gated RL in the striatum



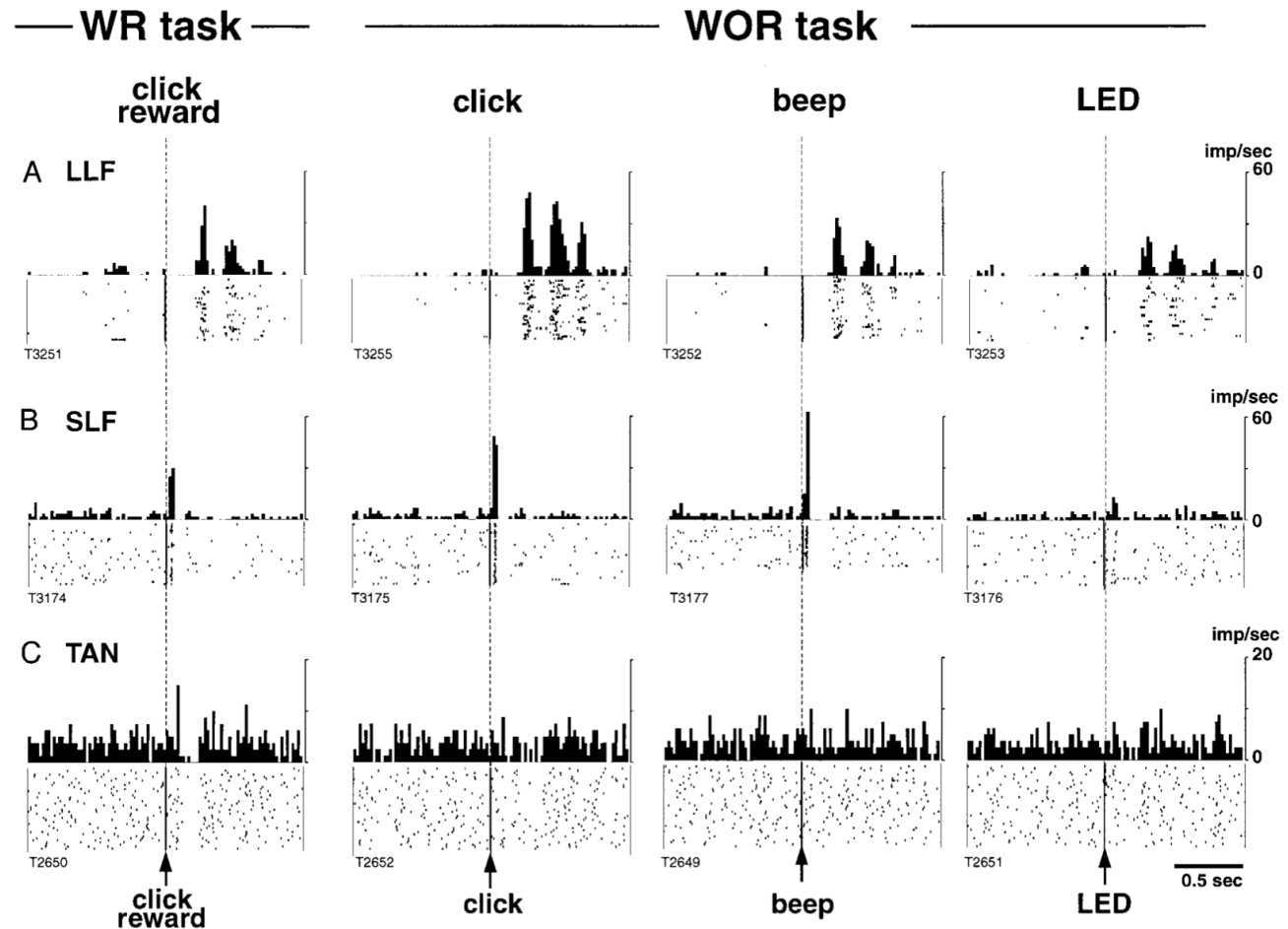
Schulz & Reynolds, 2013
Bradfield et al., 2013

CIN pause only to relevant events

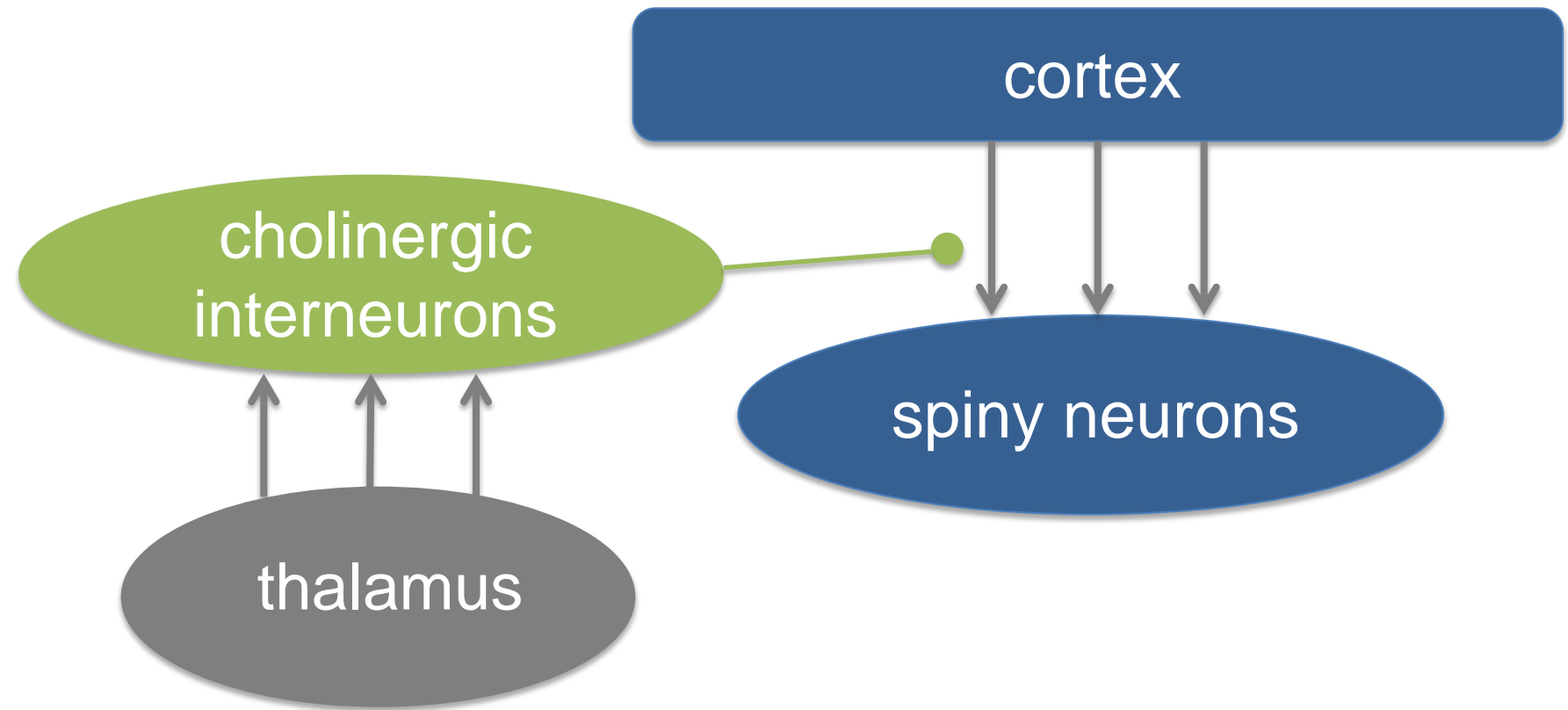
CM-Pf neurons

Cholinergic
interneurons

Matsumoto et al.
J Neurophysiol., 2001

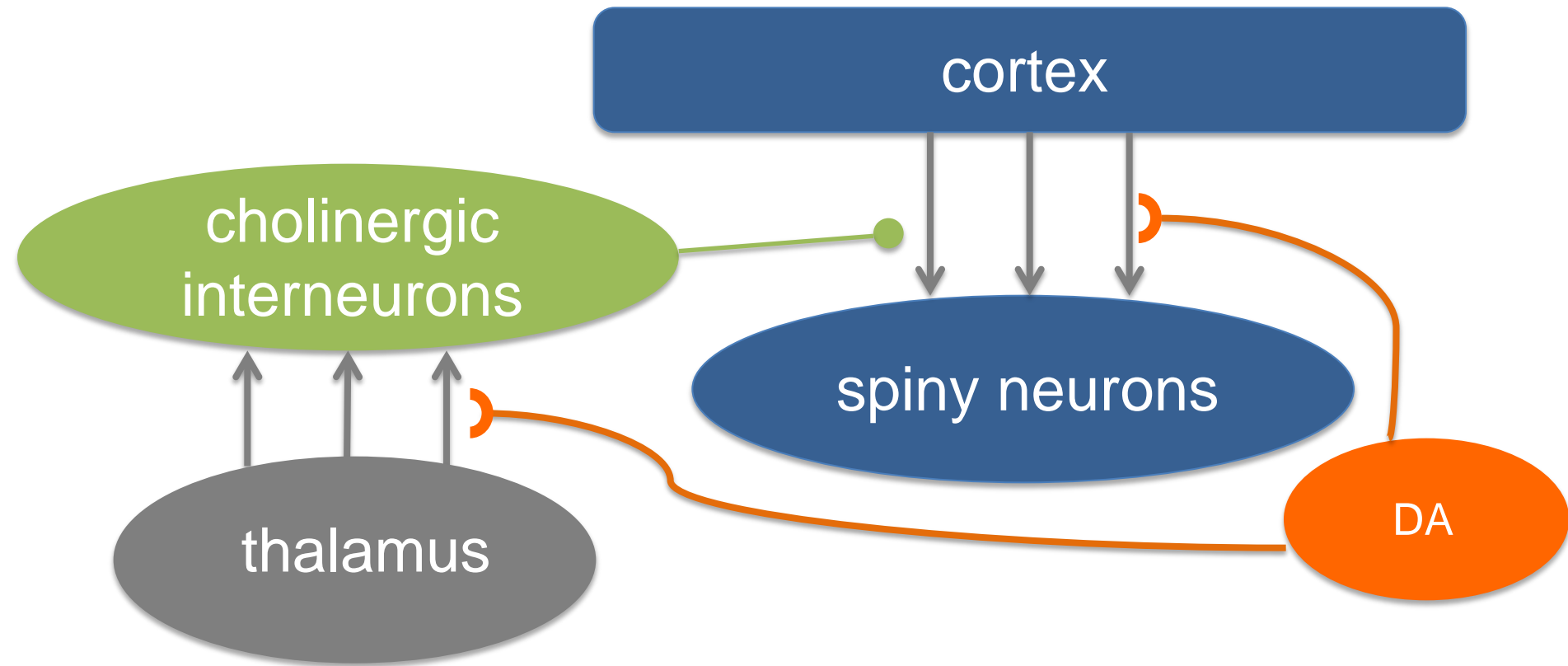


Cholinergic interneurons



Calabresi et al., 2000
Cragg, 2006

Cholinergic interneurons



Suzuki et al., 2001

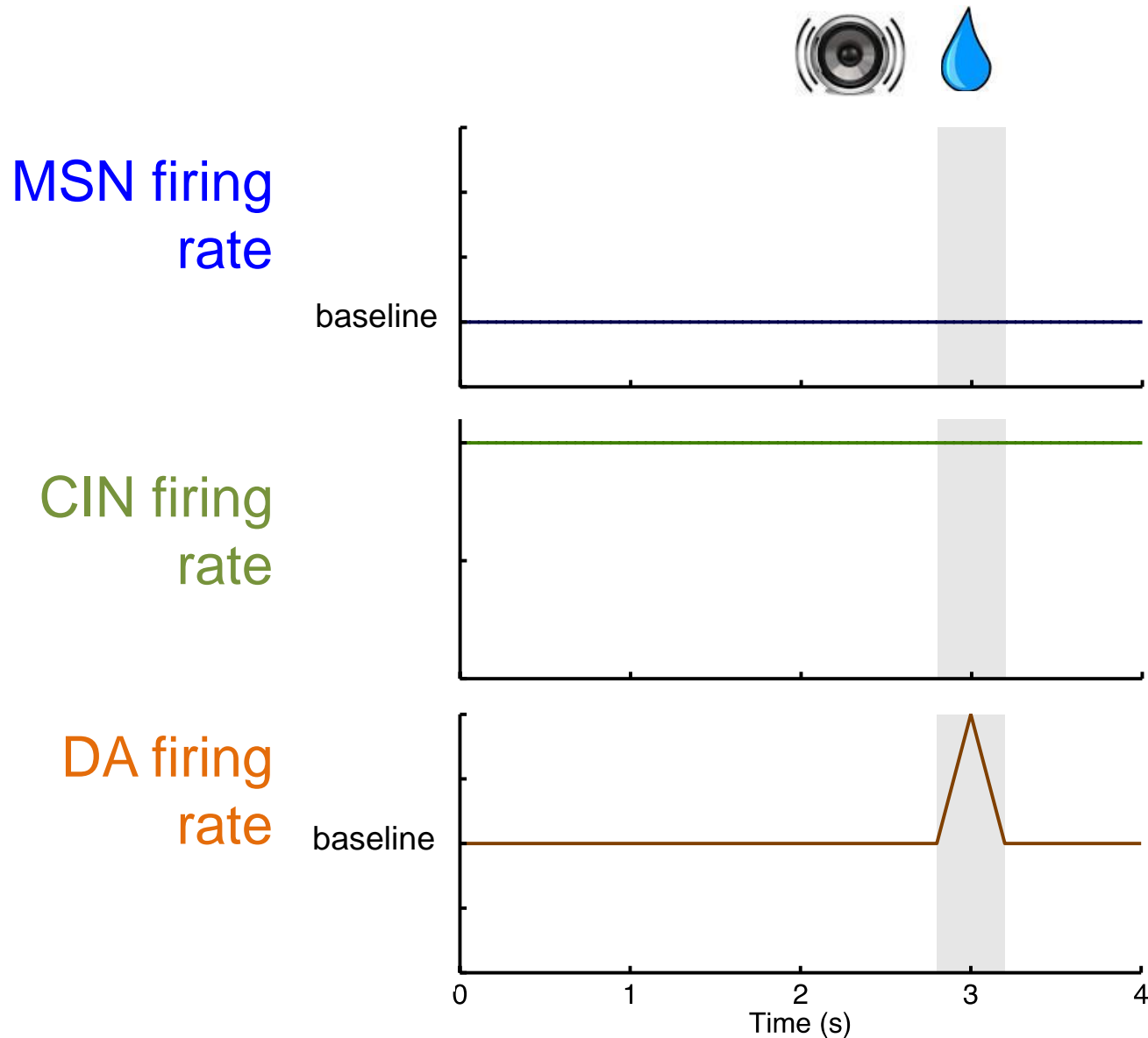
A functional role for cholinergic signalling?

Cholinergic pause reduces synaptic inhibition at the cortico-striatal synapses

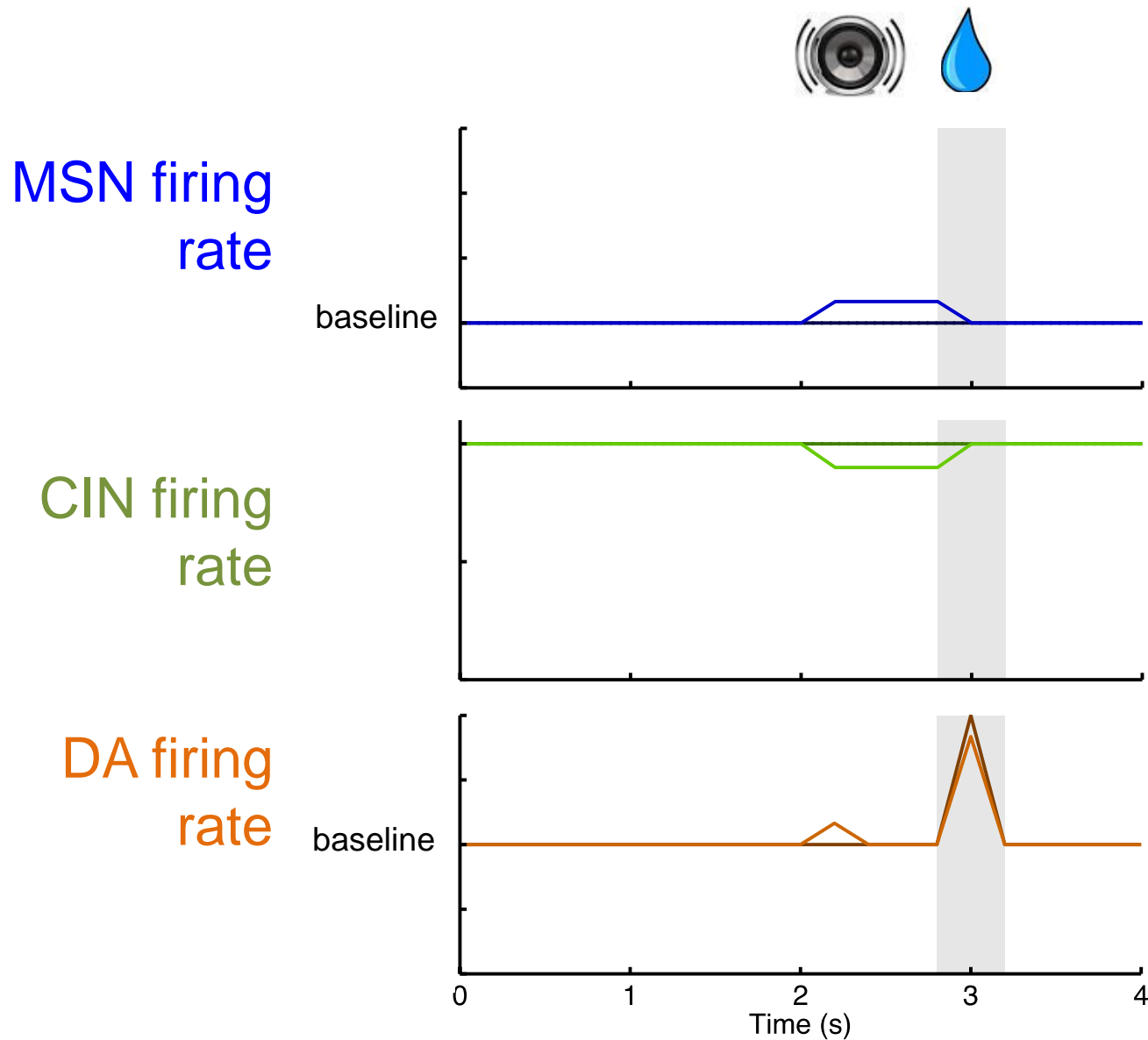


Cholinergic pauses as a stimulus-locked window during which cortico-striatal learning is amplified

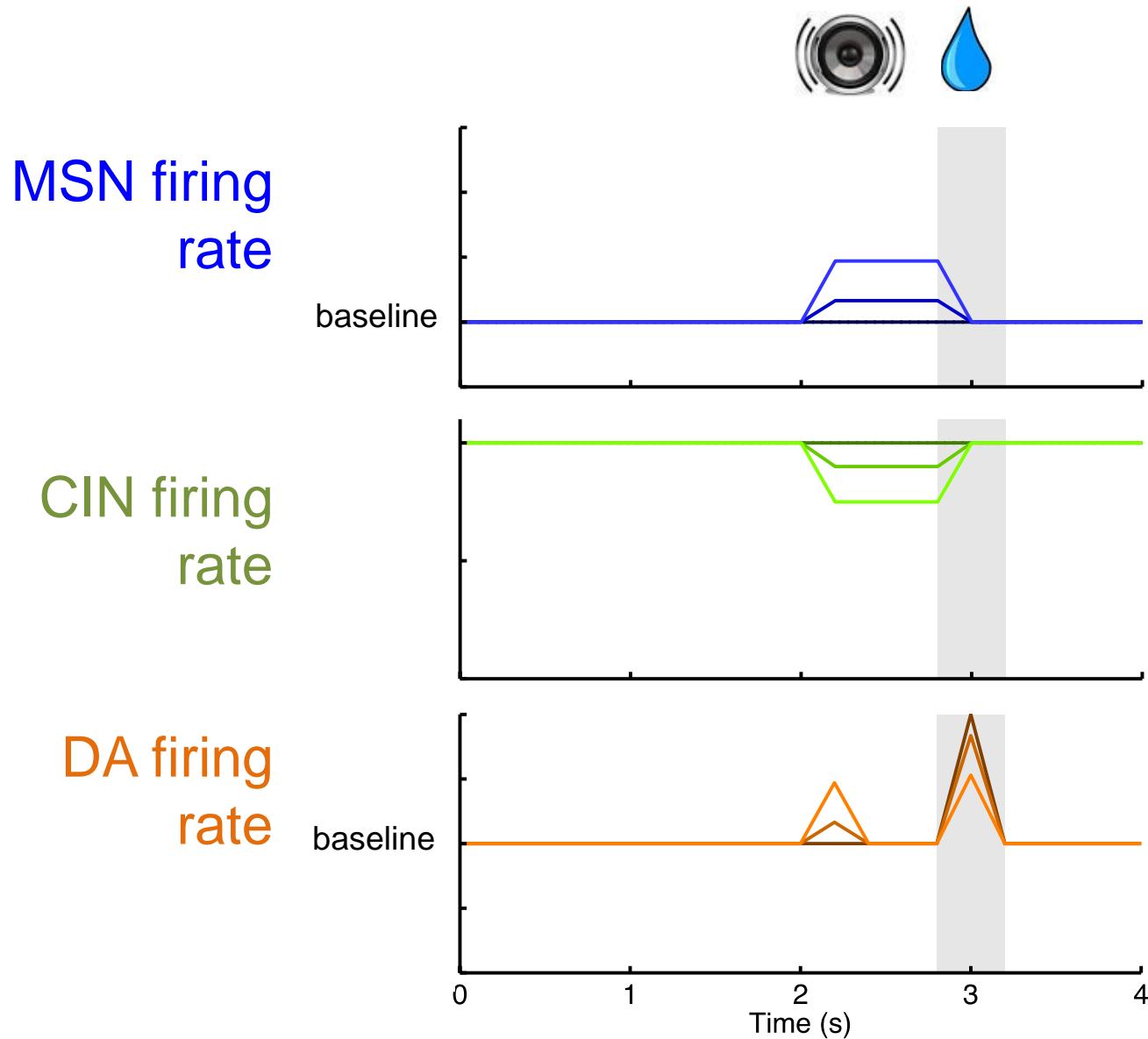
CI-gated RL in the striatum



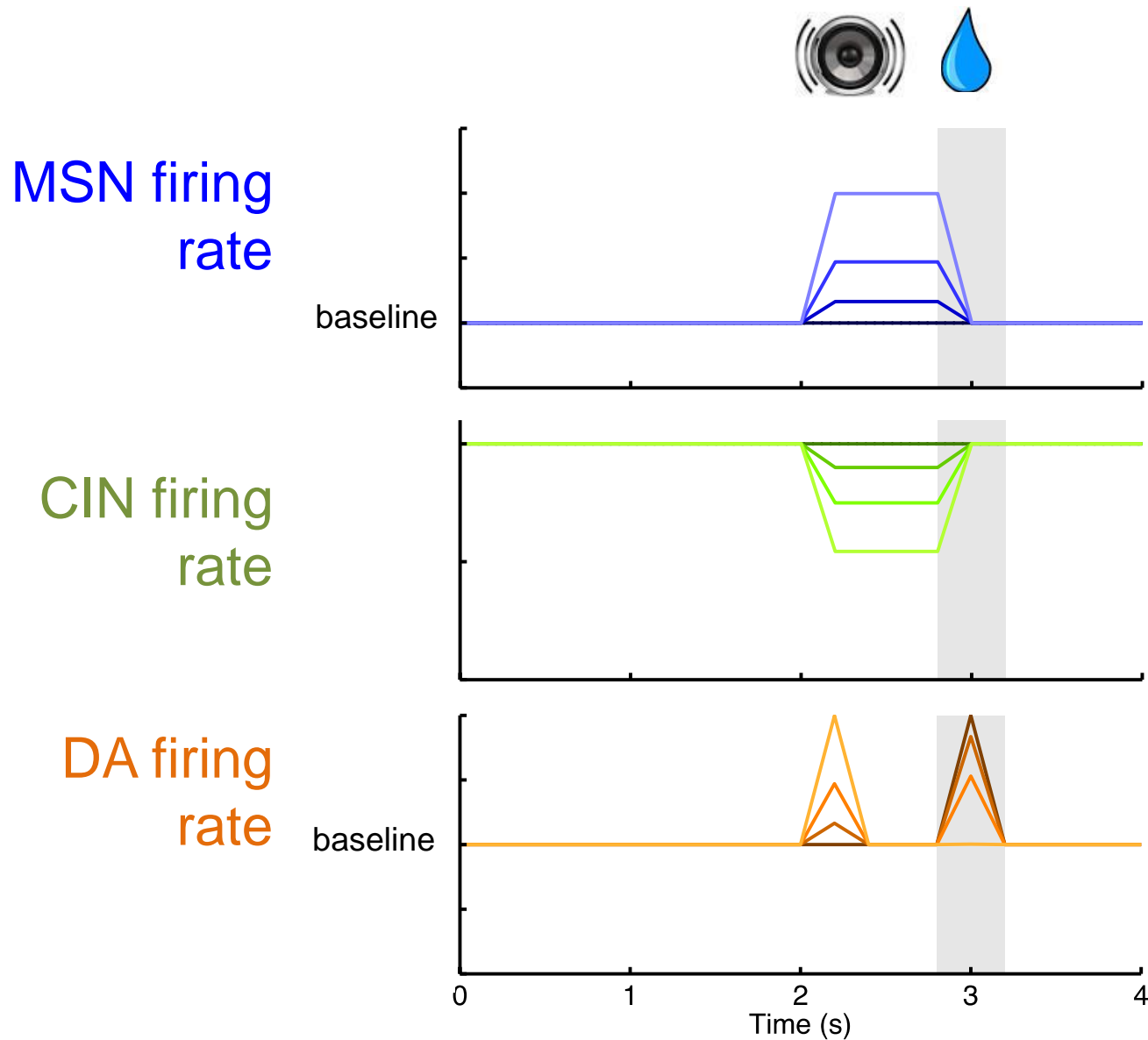
CI-gated RL in the striatum



CI-gated RL in the striatum

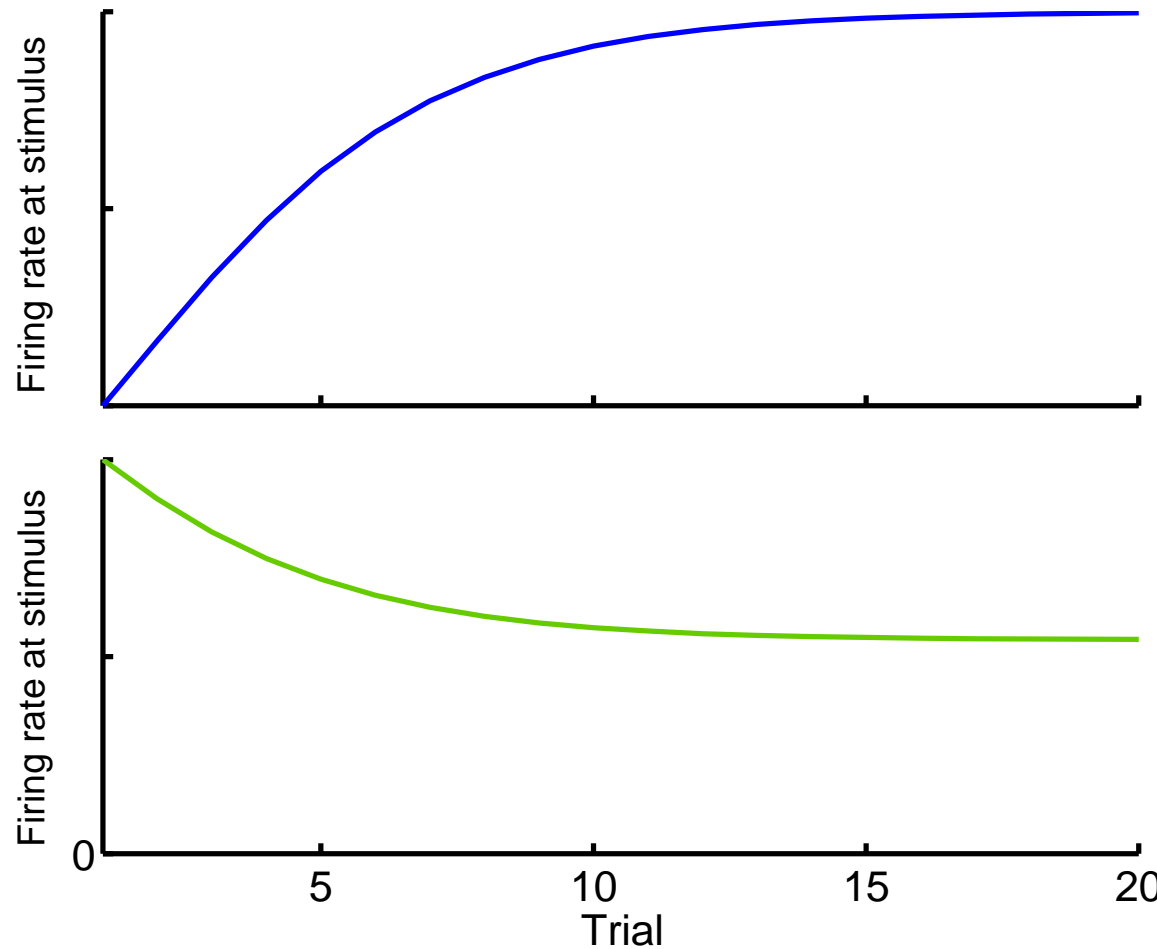


CI-gated RL in the striatum



CI-gated RL in the striatum

MSN value



CIN gating

A functional role for cholinergic signalling?

Cholinergic pauses persist for long periods after a stimulus-reward association is learnt

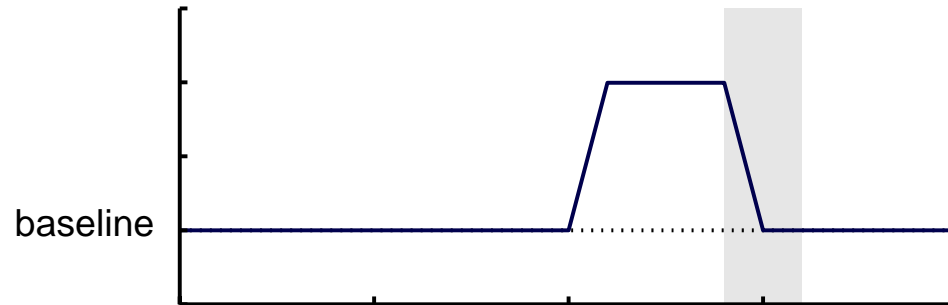


Cholinergic pauses reflect a history of the reward-relevance of a given stimulus

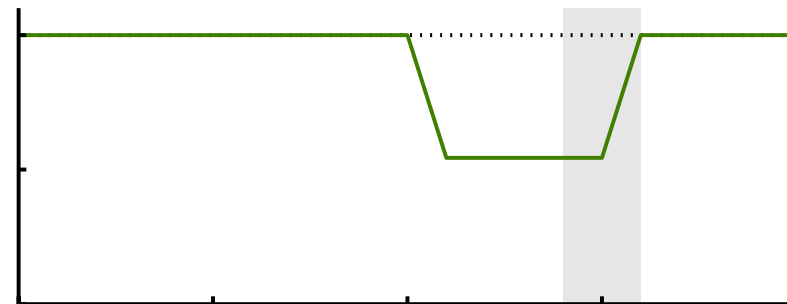
Extinction



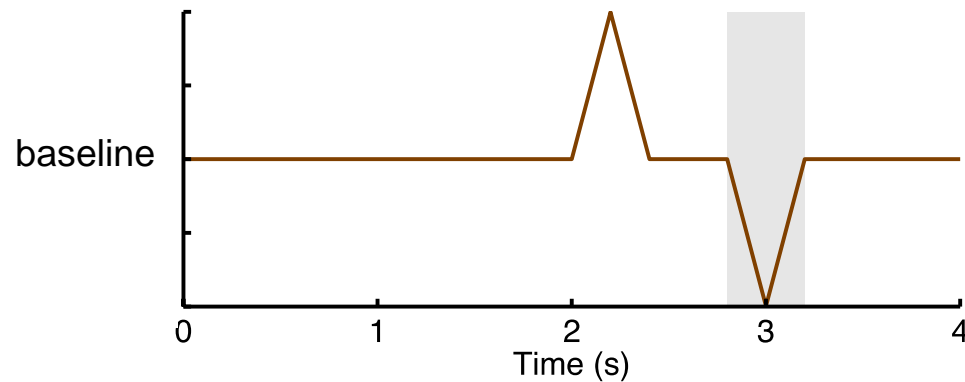
MSN firing
rate



CIN firing
rate



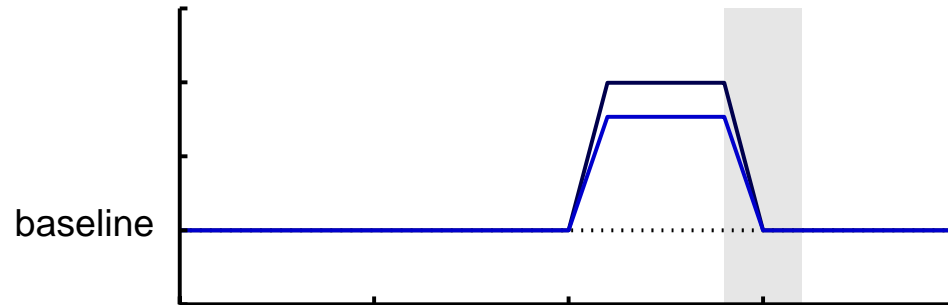
DA firing
rate



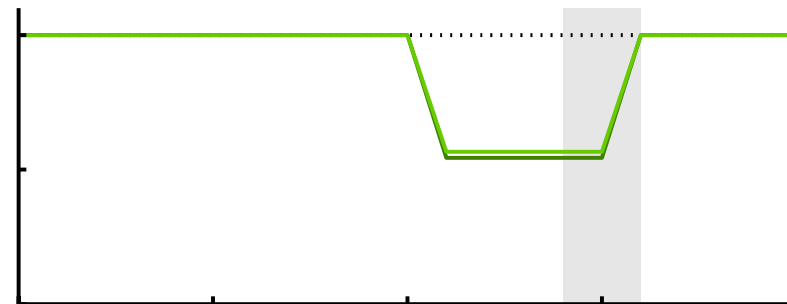
Extinction



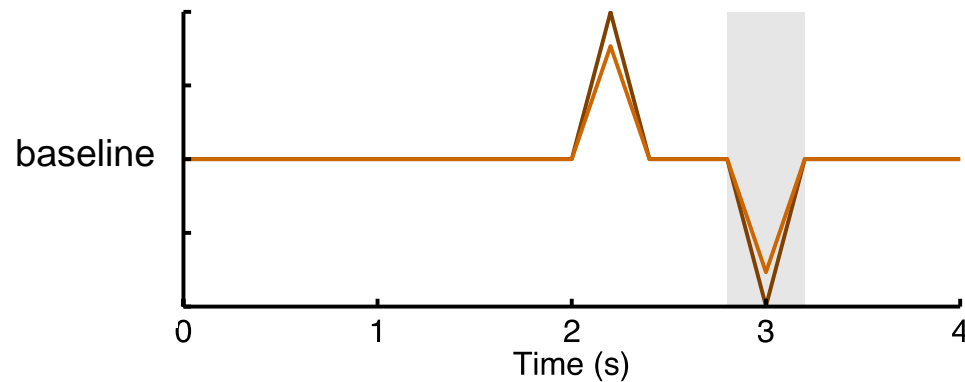
MSN firing
rate



CIN firing
rate



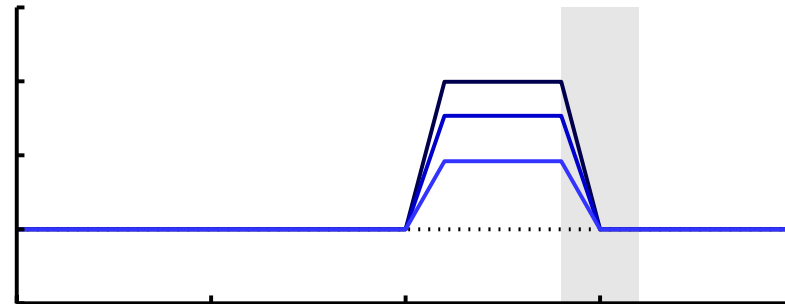
DA firing
rate



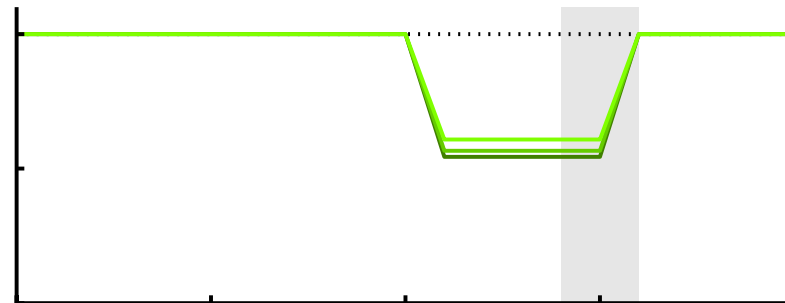
Extinction

MSN firing rate

baseline

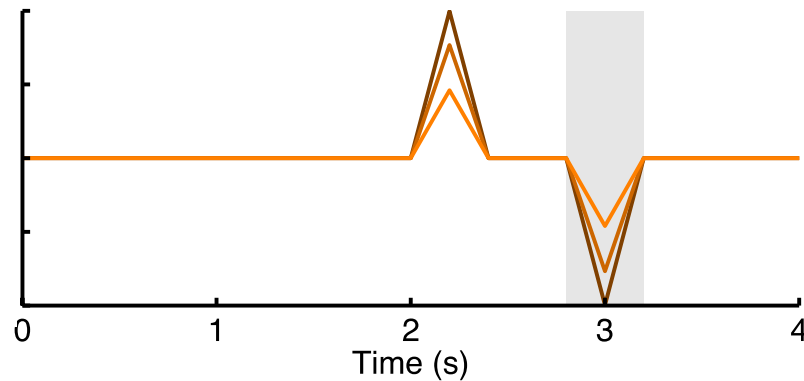


CIN firing rate



DA firing rate

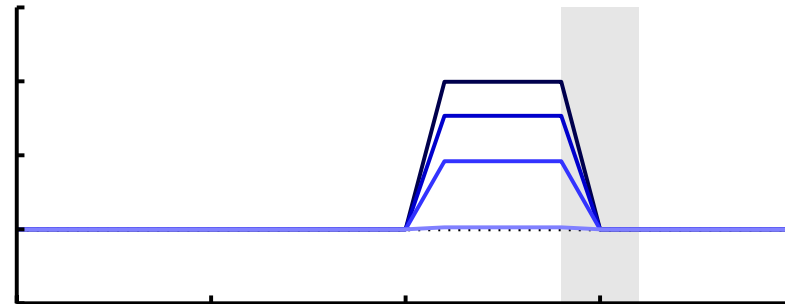
baseline



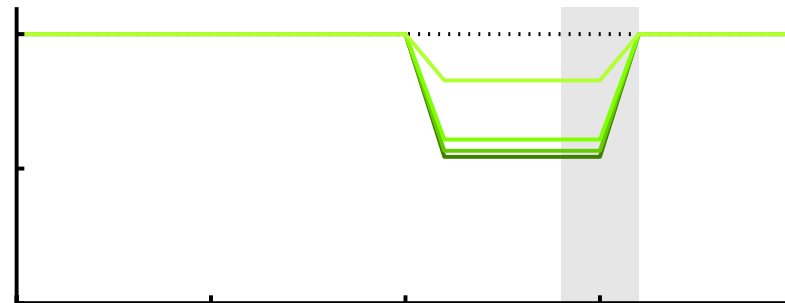
Extinction

MSN firing rate

baseline

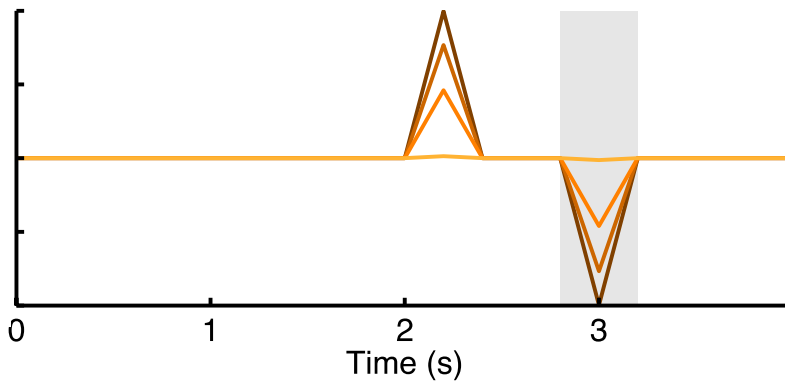


CIN firing rate



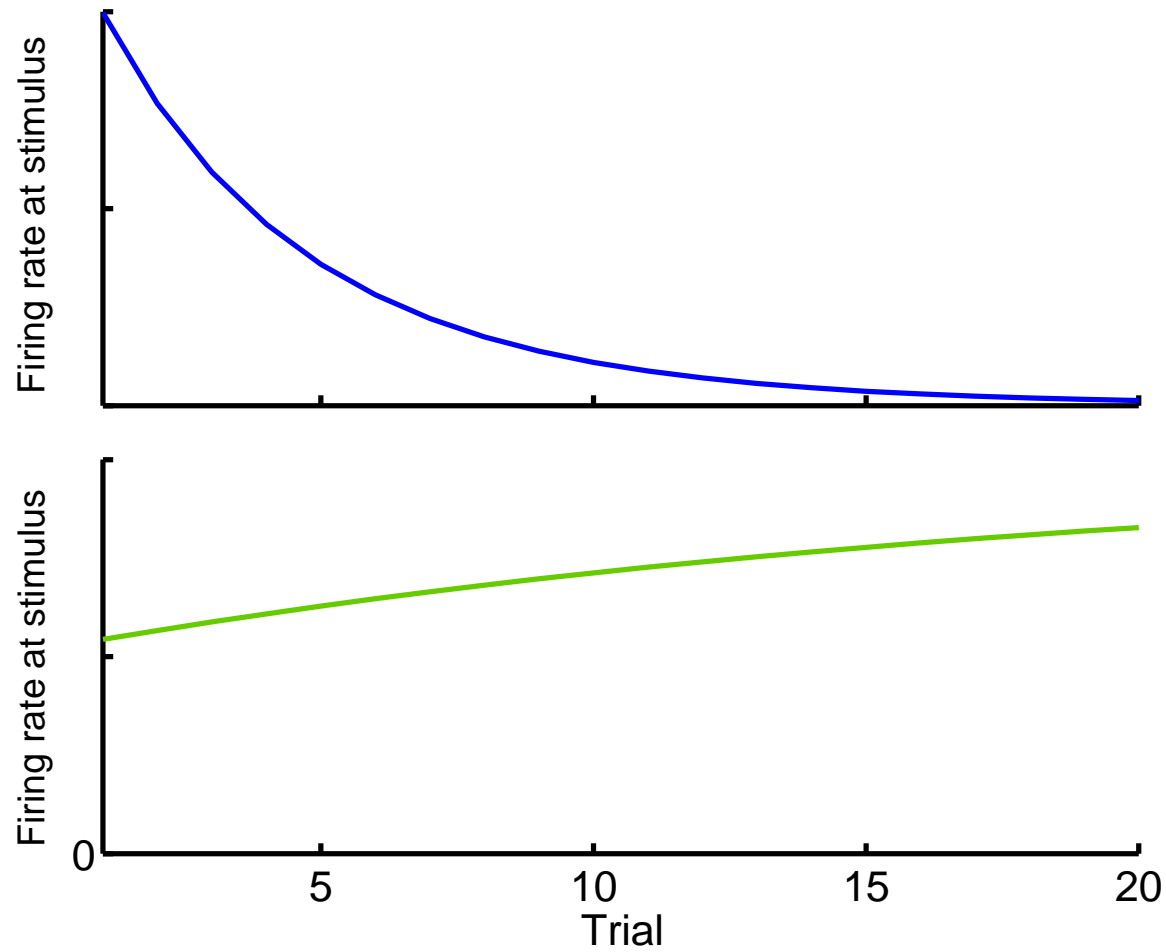
DA firing rate

baseline



Extinction

MSN value



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Multi-stimulus learning

Initial exposure



Multi-stimulus learning

Initial exposure



Extinction



Multi-stimulus learning

Test phase

Tone
(relevant)



Light
(irrelevant)

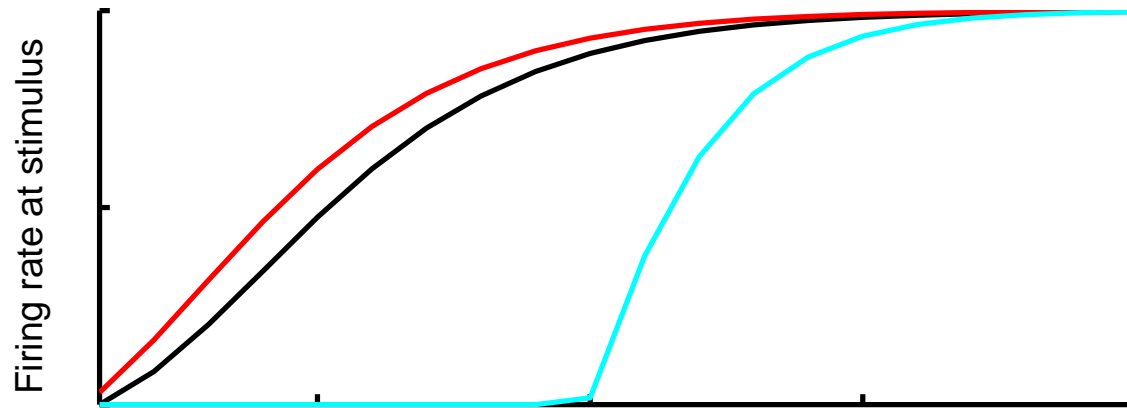


Clicks
(novel)

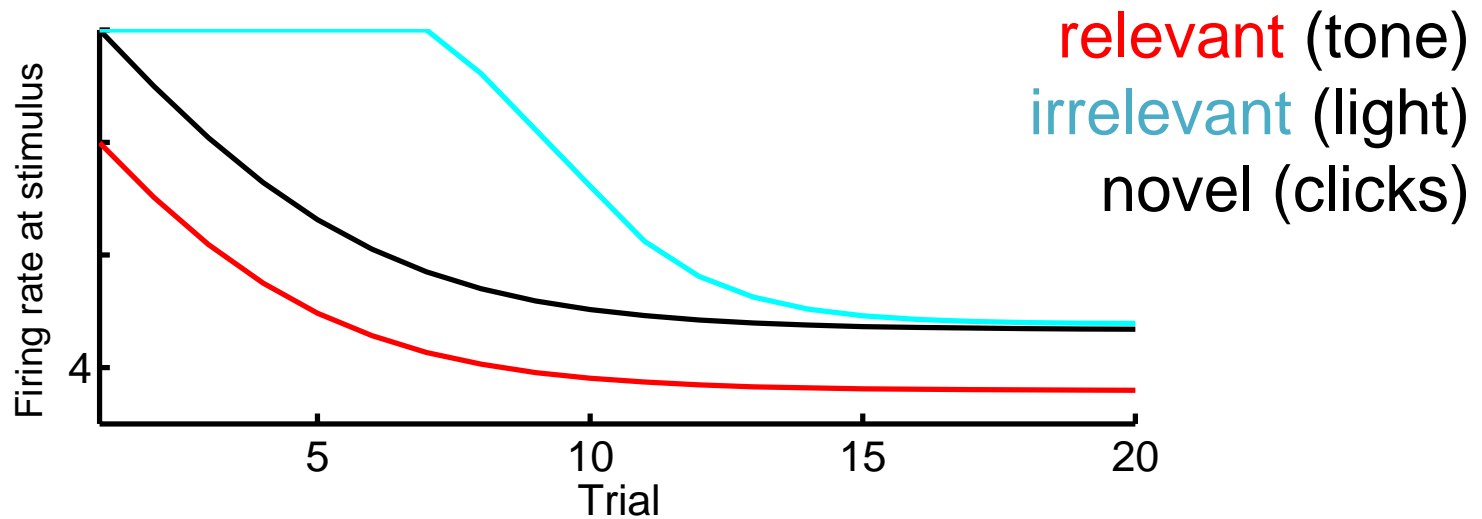


Multi-stimulus learning

MSN value



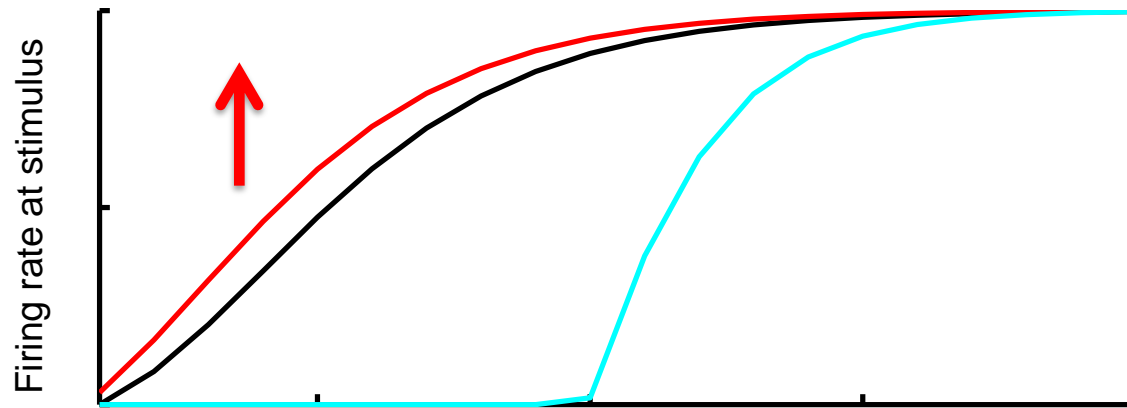
CIN gating



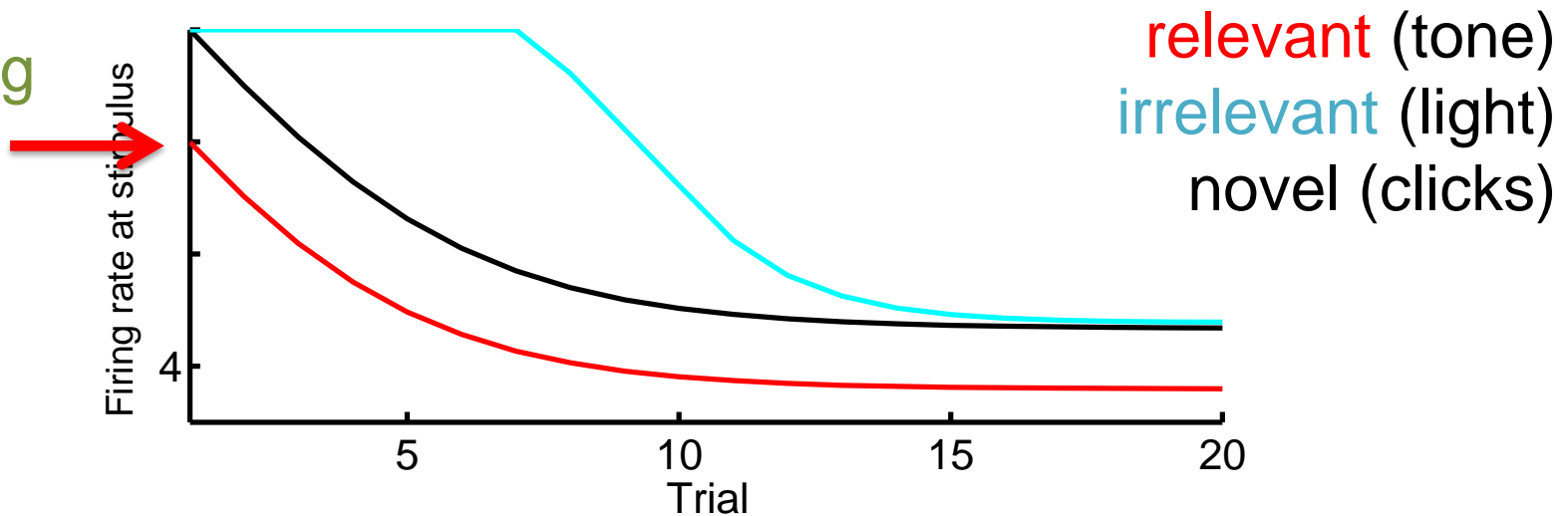
Multi-stimulus learning

Increased learning rate for stimuli previously relevant for reward

MSN value



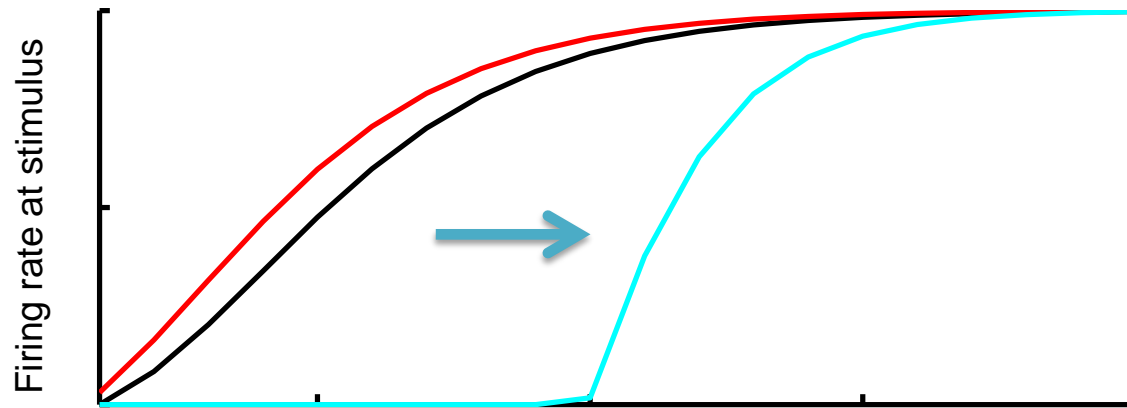
CIN gating



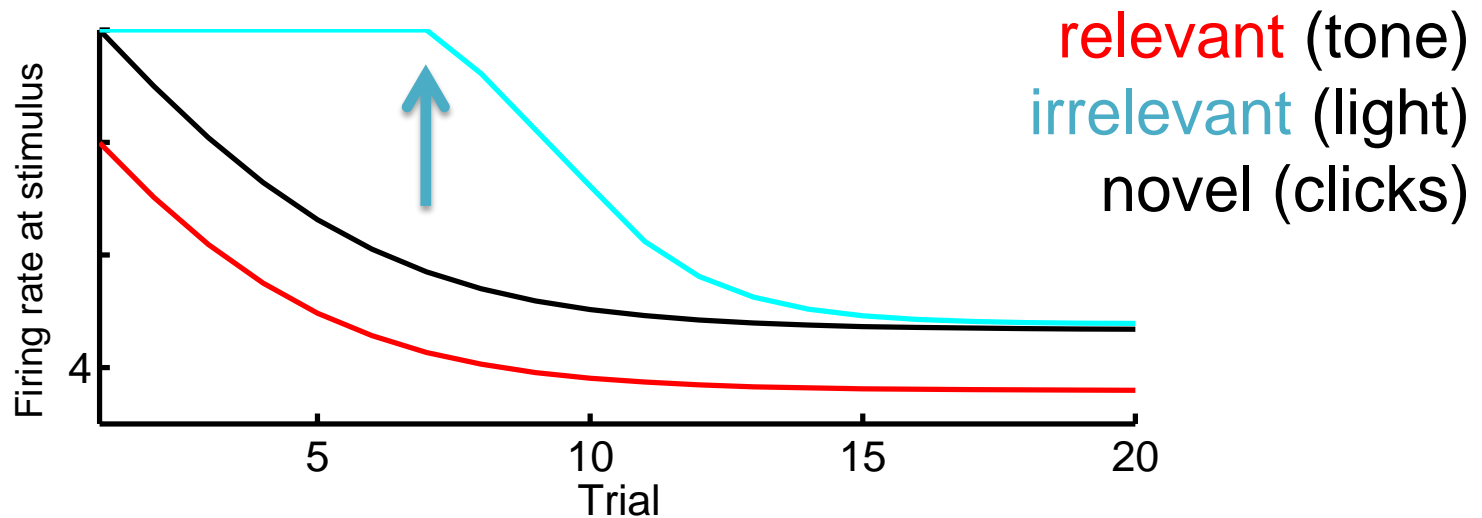
Multi-stimulus learning

Delayed learning for previously irrelevant stimuli

MSN value



CIN gating



Summary

- Cholinergic interneurons in the striatum learn to pause at motivationally relevant events

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- Pauses in cholinergic activity may act as attentional windows during which learning is amplified

Summary

- Cholinergic interneurons in the striatum **learn to pause** at motivationally relevant events
- Pauses in cholinergic activity may act as **attentional windows** during which learning is amplified
- This mechanism may act in multi-stimulus environments to **gate learning according to the relevance of a stimulus** for reward

Acknowledgements

Collaborators

Yael Niv

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Jeff Wickens

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