Brain Pulse Music @ Cafe Oto, Masaki Batoh

LETTER

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Corticostriatal plasticity is necessary for learning intentional neuroprosthetic skills

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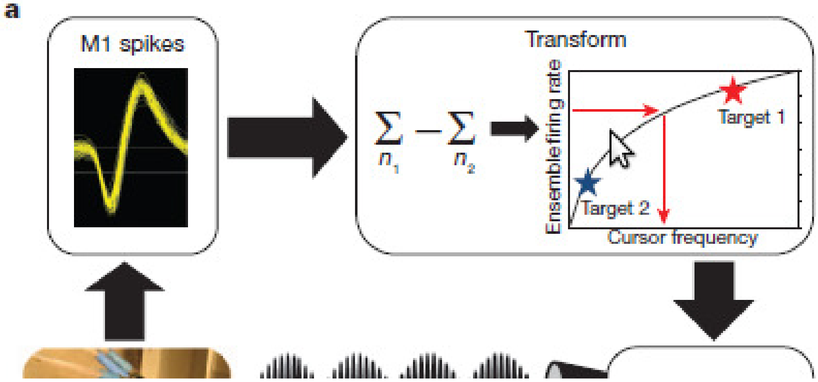
The ability to learn new skills and perfect them with practice applies not only to physical skills but also to abstract skills[1], like motor planning or neuroprosthetic actions. Although plasticity in corticostriatal circuits has been implicated in learning physical skills[2–4], it remains unclear if similar circuits or processes are required for abstract skill learning. Here we use a novel behavioural task in rodents to investigate the role of corticostriatal plasticity in abstract skill learning. Rodents learned to control the pitch of an auditory cursor to reach one of two targets by modulating activity in primary motor cortex irrespective of physical movement. Degradation of the relation between action and outcome, as well as sensory-specific devaluation and omission tests, demonstrate that these learned neuroprosthetic actions are intentional and goal-directed, rather than habitual. Striatal neurons change their activity with learning, with more neurons modulating their activity in relation to target-reaching as learning progresses. Concomitantly, strong relations between the activity of neurons in motor cortex and the

of M1 ensemble activity resulted in changes in the pitch of an auditory cursor, which provided constant auditory feedback to rodents about task performance. Reward was delivered when rodents precisely modulated M1 activity to move this auditory cursor to one of two

a



Motivation

Corticostriatal circuits have been implicated in learning physical skills, is this also the case for abstract skills (no physical movement)?

Examples of abstract skills:

- Playing board games
- Controlling neuroprosthetic devices.

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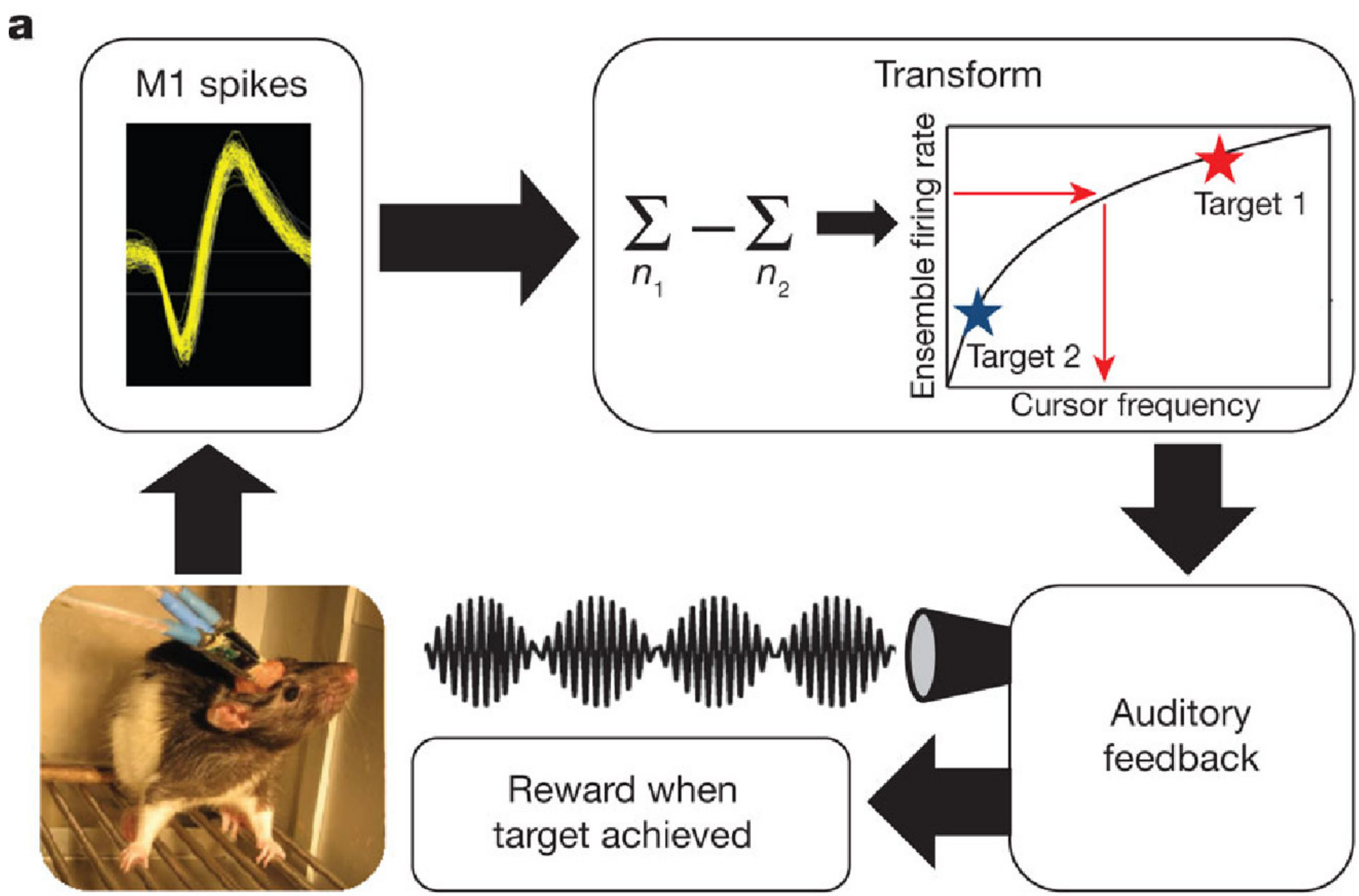
Volitional / goal-directed / intentional action rather than habitual (operant conditioning).

Volitional and Abstract Task



Task details

Two ensembles of 2-4 well-isolated whisker-pad M1 units.

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Transform used (fine-tuned daily):

$$f(t) = A_1 e^{\left(\sum_{i \in N_1} r_i(t)\right)} - A_2 e^{\left(\sum_{i \in N_2} r_i(t)\right)} + B$$

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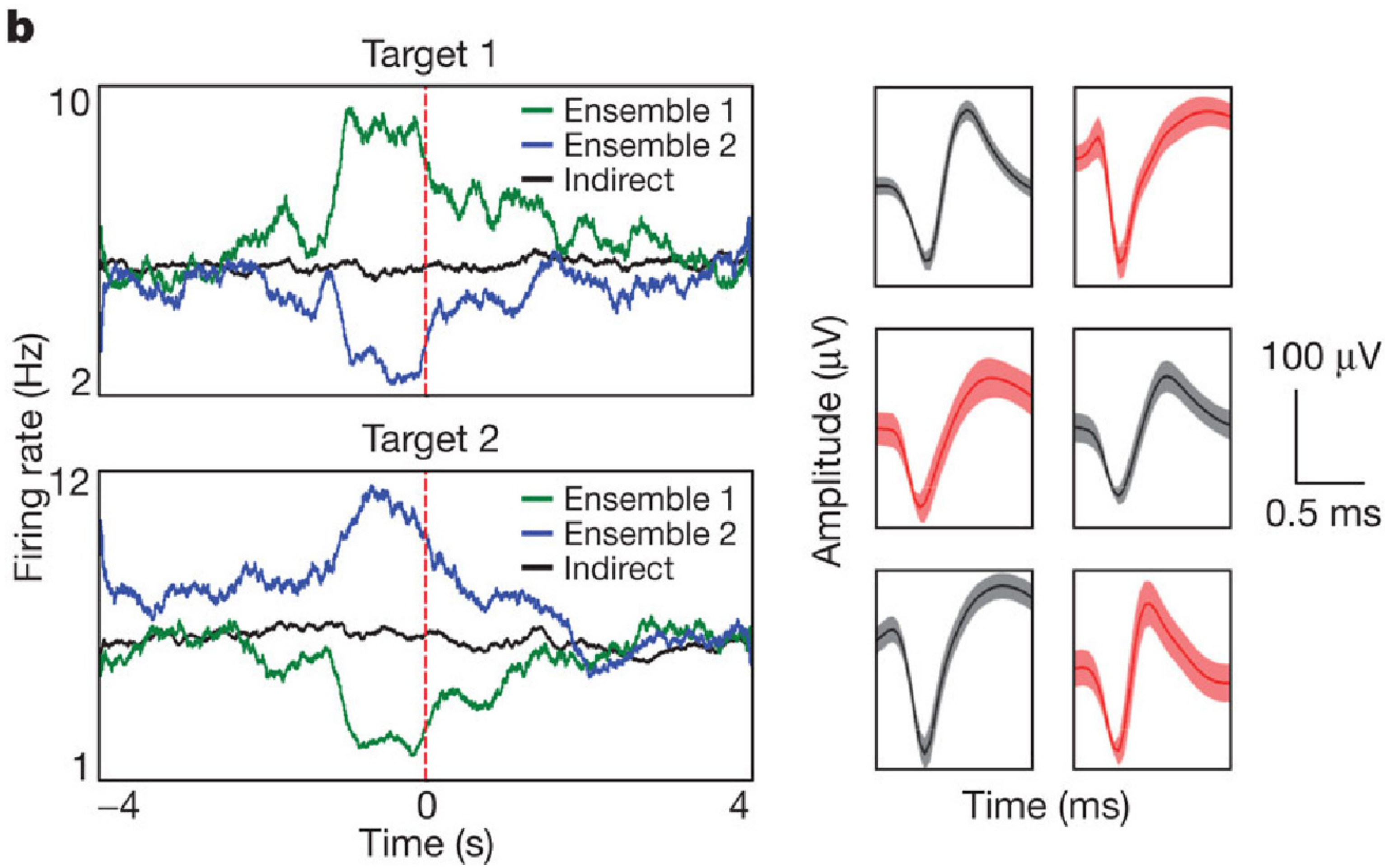
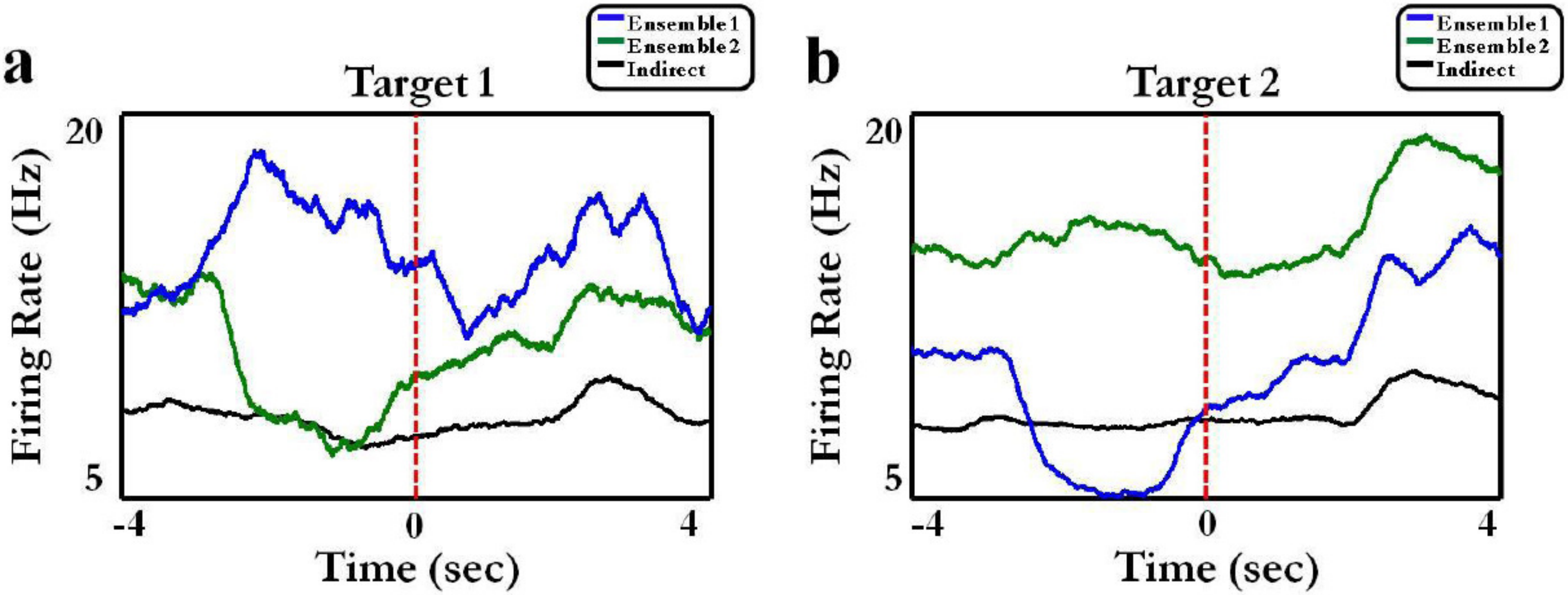
2 types of rewards:

- sucrose solution
- food pellet.

M1 firing rate modulations

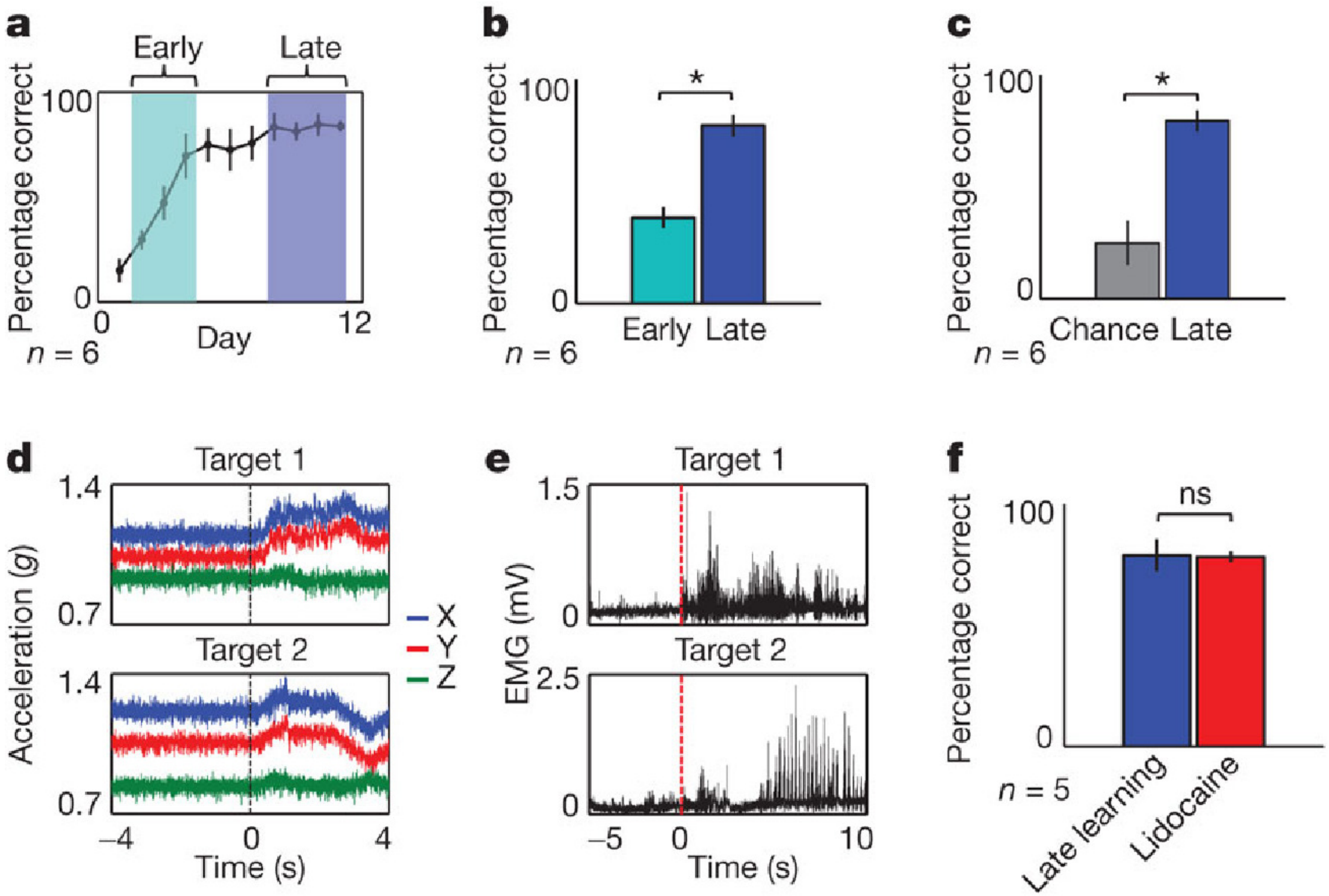


M1 firing rate modulations: across all animals

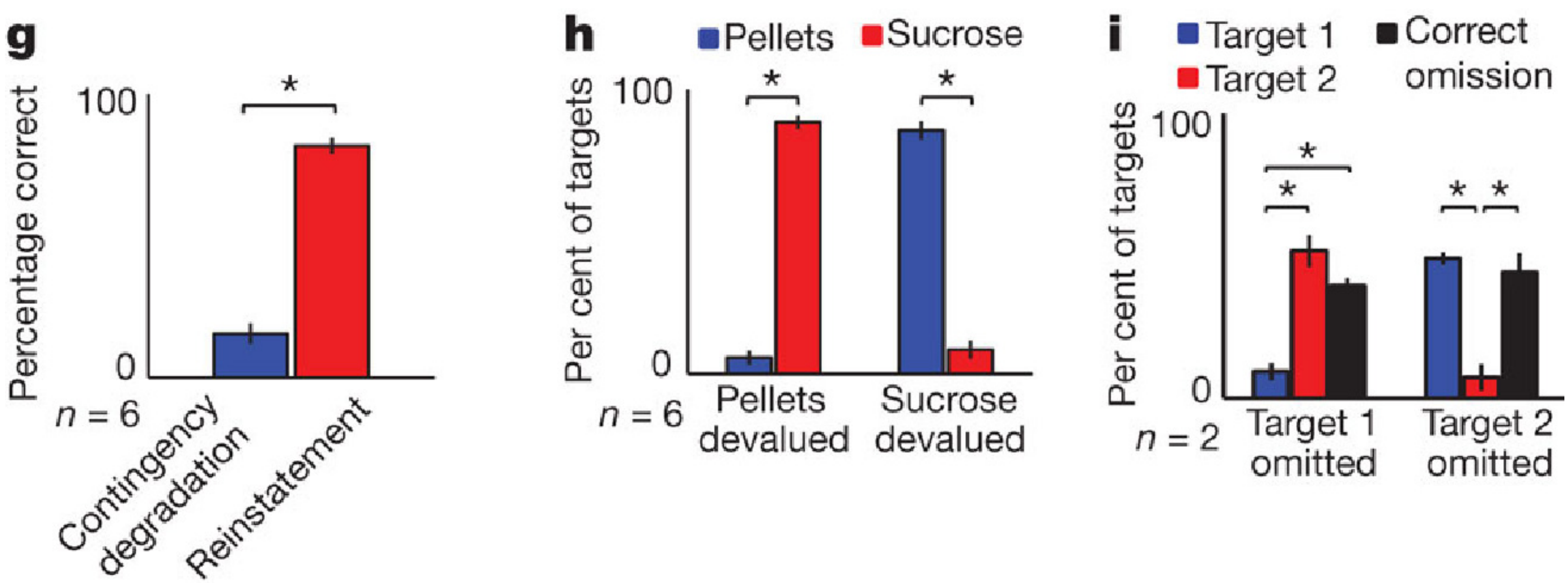


Supplementary Figure 3. Mean M1 firing rates across all animals. M1 firing rates for units in ensemble 1 (blue), ensemble 2 (green), and units not used for the task (black) averaged across all animals and time-locked to achievement of target 1 (a) or target 2 (b). Rodents were producing the desired ensemble rate modulations to properly perform the task. The units not used for the task did not show modulation during target reaching (before 0) but did show modulation during movement to retrieve the earned reward (between +2 and +4 secs, see also accelerometer data).

Task learnt without overt movement



Intentional action



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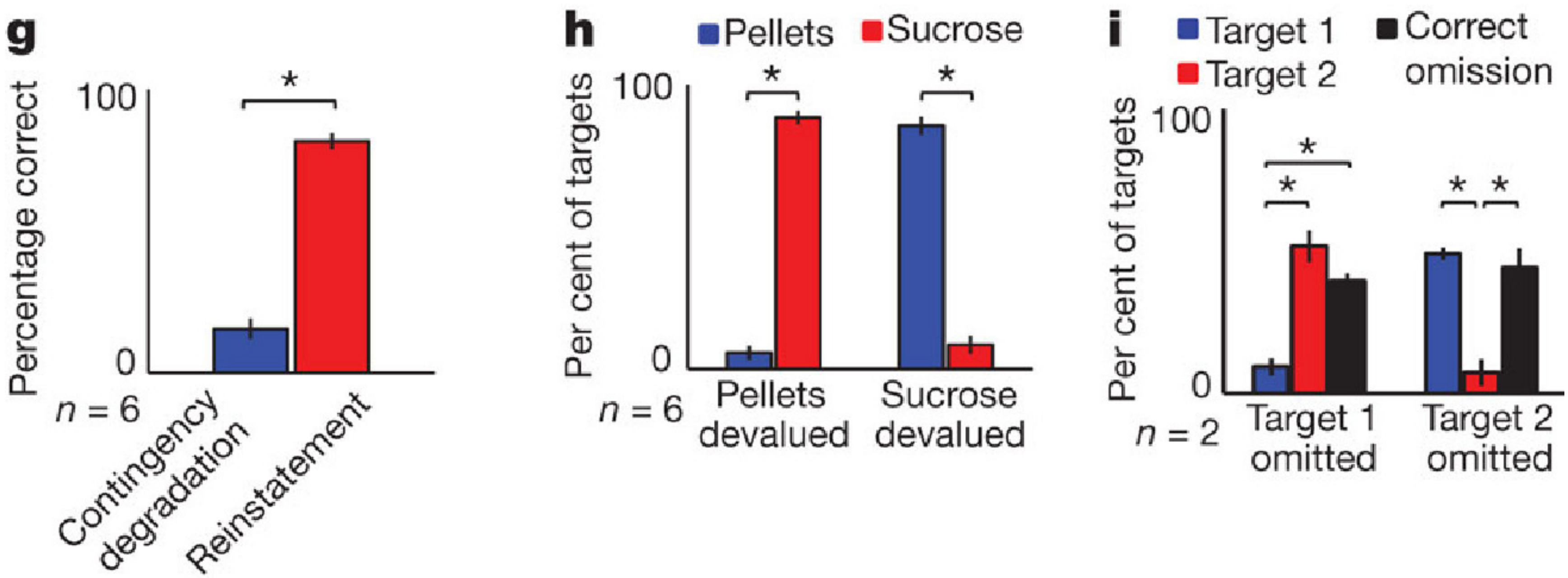
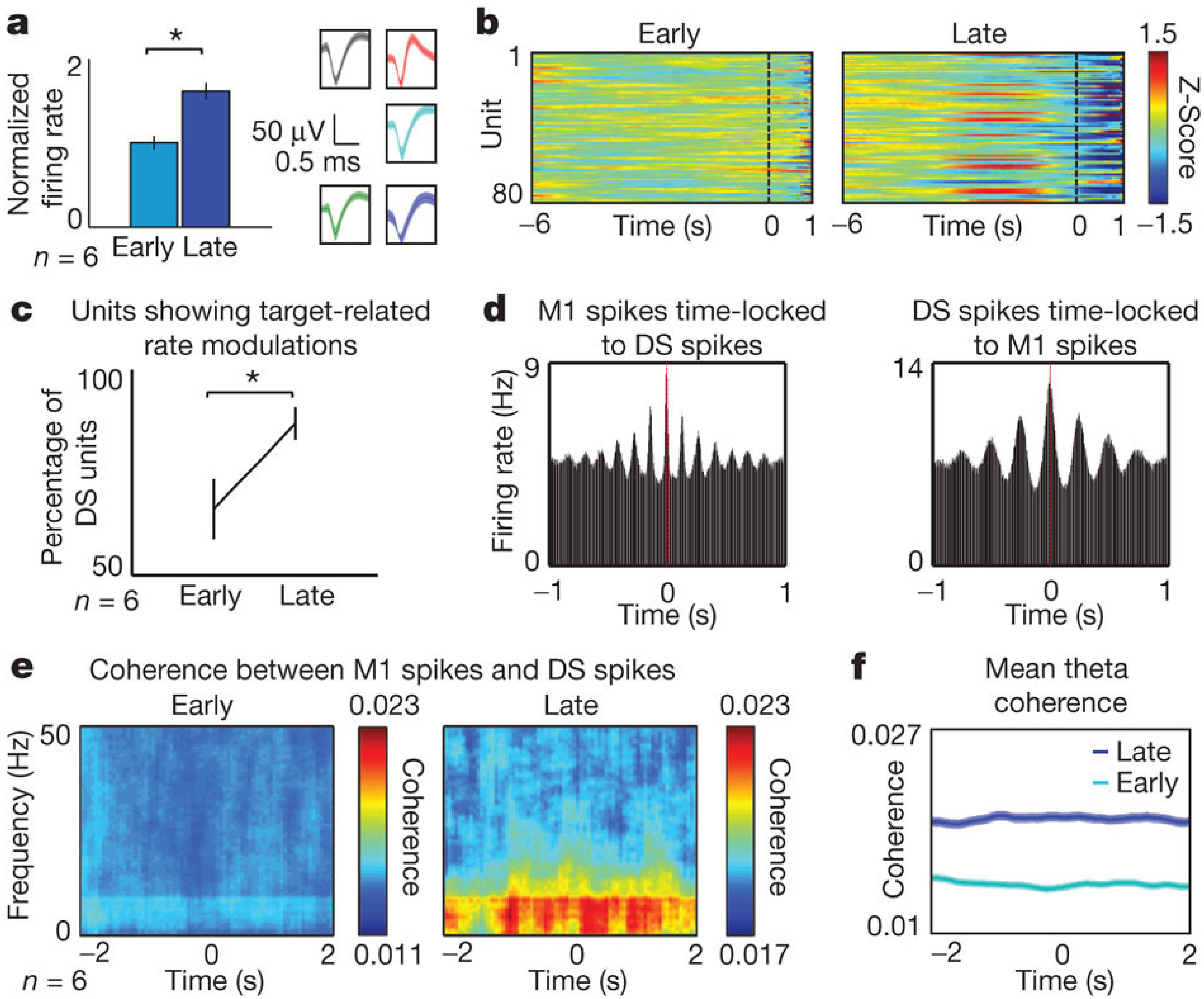


Not just a habitual action, as sensitive to changes in:

- the causal relation between performing the action and obtaining reward (contingency degradation and omission test).
- expected value of reward (sensory-specific devaluation).

Corticostriatal plasticity involved



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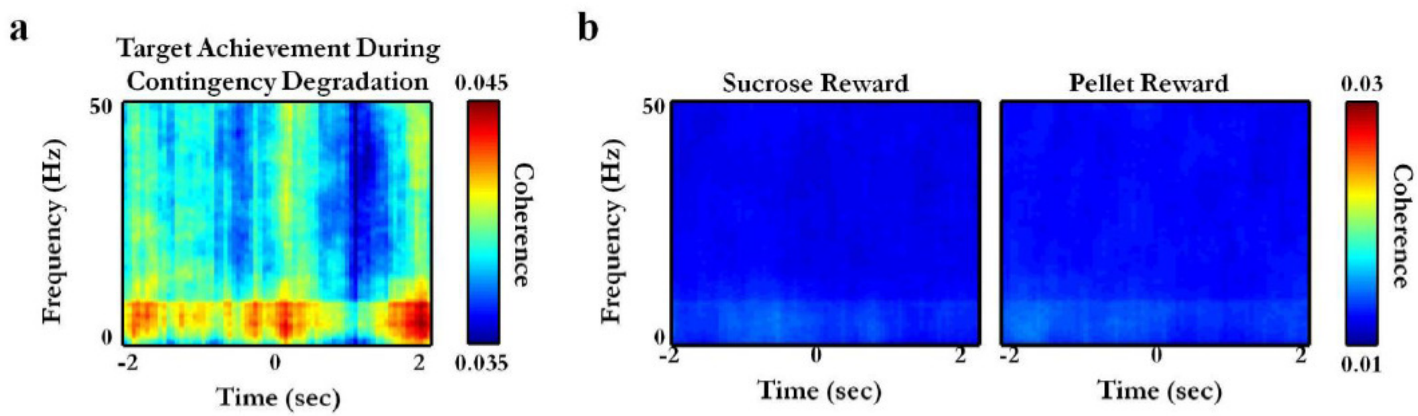

Supplementary Figure 9. Coherence remains high during contingency degradation. a. When target achievement was no longer rewarded, coherence between M1 spikes and DS spikes remained high surrounding target achievement. **b.** Coherence was very low when rewards were delivered to the animal during the contingency degradation experiment. Together, these suggest that coherence is not due to reward expectation, but rather relates to task performance.

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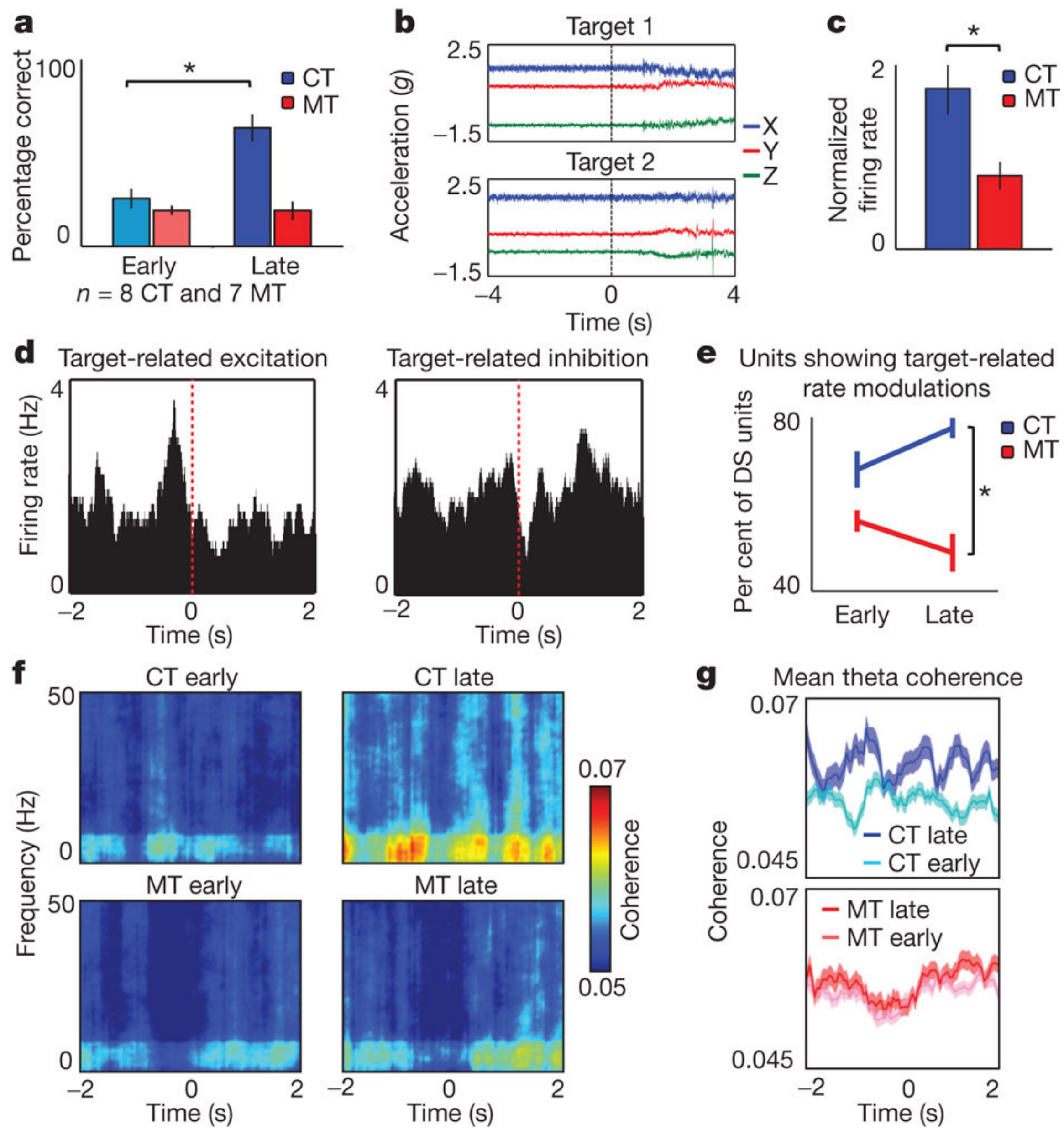

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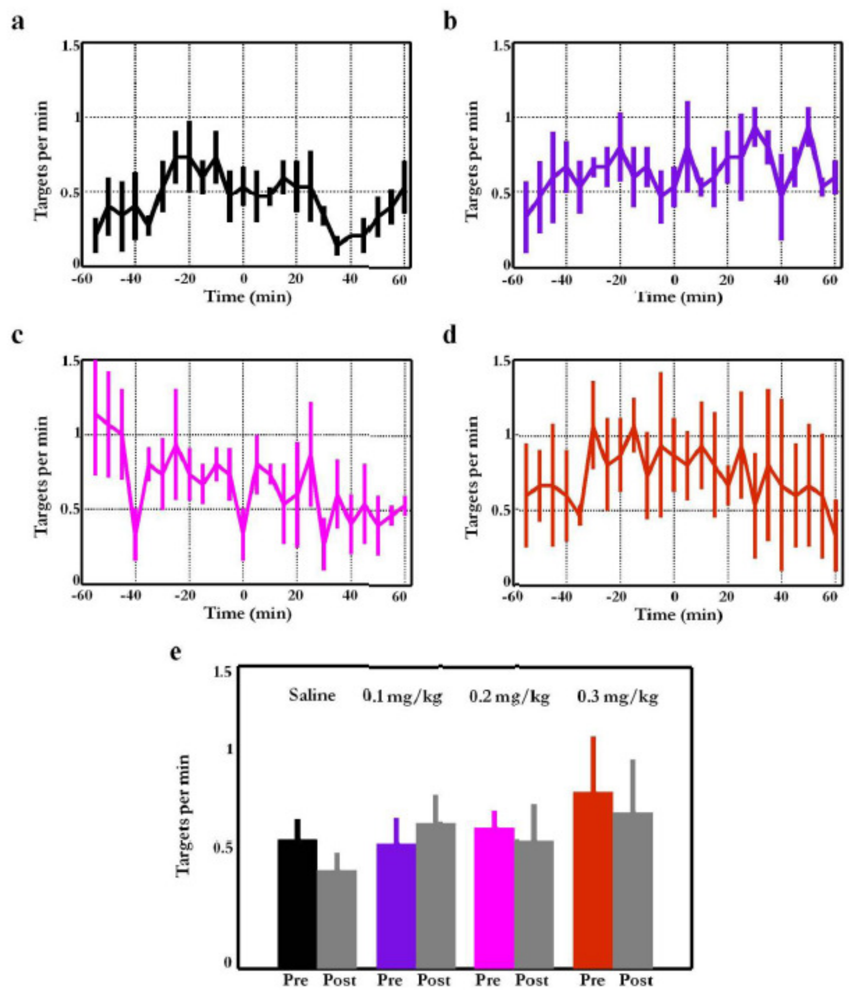
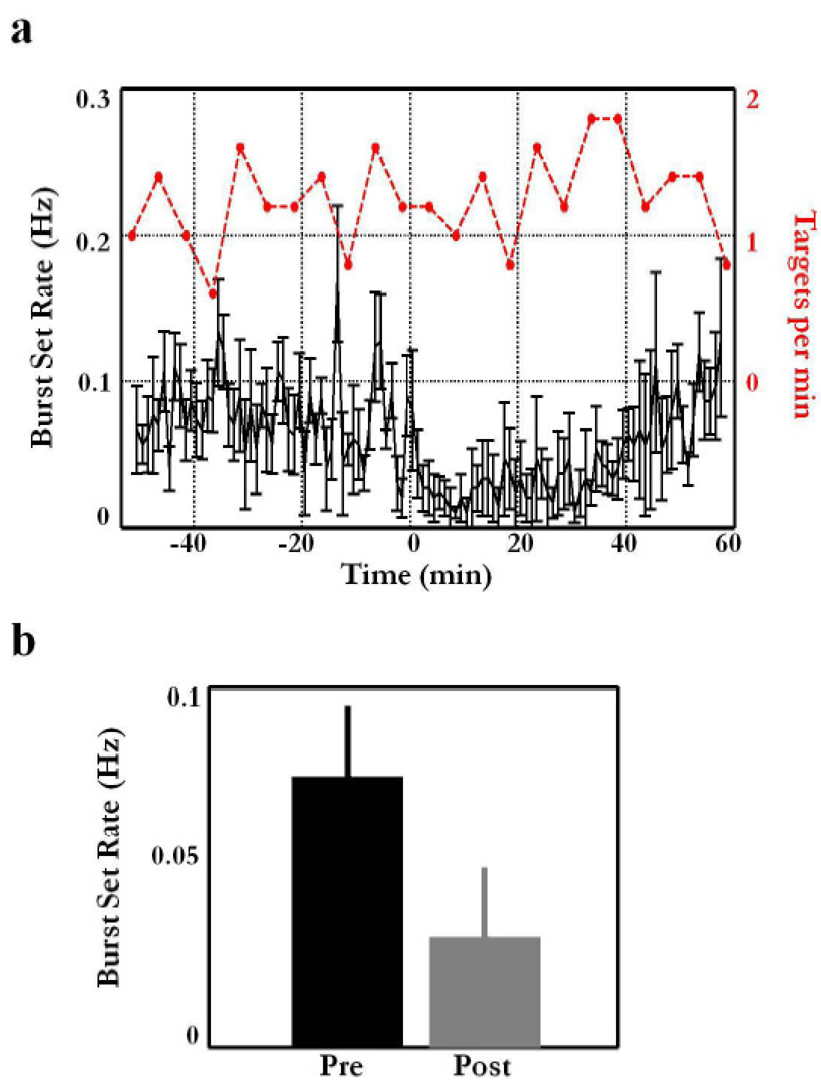


Supplementary Figure 12. Blockage of NMDA receptors after training has no effect on BMI performance. a-d. Behavioral performance in trained mice before and after systemic administration (i.p.) of NMDA receptor antagonist MK-801 (a: saline, b: 0.1 mg/kg; c: 0.2 mg/kg; d: 0.3 mg/kg). Time zero in each case indicates time of injection **e.** Summary of the effect of NMDA receptor blockade on task performance in trained animals. There is no general effect of drug treatment ($F_{2,7} = 0.45$, $P = 0.86$; $P > 0.05$ for all pairs of comparison).

Corticostriatal plasticity necessary



Supplementary Figure 13. Blockage of NMDA receptors impairs striatal MSNs burst firing. a. The burst activity of striatal MSNs (black line) was greatly decreased after application of NMDA antagonist MK-801 at higher dose (0.3 mg/kg at time zero), but the mouse was able to maintain its performance throughout the time (red line). **b.** Statistical results of striatal MSNs burst activity pre- and post- NMDA receptor blockage. There was a significant decrease of burst set rate ($P < 0.01$).

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Neuroprosthetics can capitalize on the neural circuitry involved in natural motor learning.

Discussion

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M1 vs other regions?

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Meaning of the DS-M1 oscillatory coupling?

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Any (creepy) applications?