Legends to Supplemental Movies

Supplemental Movie 1. Voltage trace and phase plane trajectory of a CS-driven rebound in Model 1 of a DCN neuron, following training with a long interstimulus interval (ISI).

(A) The DCN cell membrane voltage (red curve) as a function of time during presentation of a CS lasting 200 ms (black bar), under the mathematical approximation of instantaneous relaxation of the T-channel activation variable to its asymptotic value. The US was presented during prior training (gray bar) with an ISI of 190 ms between the CS and US onset times. The value of $t_{LTD}$ was set at 75 ms. The dotted horizontal line indicates the resting potential (-58 mV). At the start of the CS, increased spiking by Purkinje cells hyperpolarizes the DCN cell. About 35 ms prior to the time of the expected US, release of the hyperpolarizing drive leads to a rebound depolarization. Dashed vertical lines delineate the three stages of the phase plane trajectory in (B).

(B) The corresponding state trajectory (red curve) in the 2-D phase plane defined by the voltage ($V$) and the T-type inactivation variable ($I$). The black solid and dashed lines are the $I$ and $V$ nullclines, on which the time derivatives $dl/dt$ and $dV/dt$ respectively vanish. The intersection of the two nullclines is an attractive fixed-point of the dynamical system. The open black circle marks the initial fixed-point in the resting state (stage 1). The open green triangle marks the fixed-point from CS onset until $t_{LTD}$ before the expected US (stage 2). The open red square marks the fixed-point for the remainder of the CS (stage 3). The $V$ nullcline shifts at the start of the CS due to the increased Purkinje cell input, attracting the state trajectory from its location at the resting fixed-point (stage 1) towards the more hyperpolarized fixed-point (stage 2). We defined the instantaneous position of the $V$ nullcline by solving the equation $dV/dt = 0$ for $V$, using the steady state values of the synaptic conductances, $g_{syn}$, that would be attained given constant Purkinje cell and mossy fiber spiking at rates equal to their instantaneous values. Approximately $t_{LTD}$ before the expected US, the attractive fixed-point shifts again to a location that is depolarized compared to rest (stage 3), triggering a rebound. The color map near the stage 3 fixed-point encodes the amplitude of the rebound depolarization for trajectories passing through each point in phase space. Warmer hues indicate larger rebounds. Thus, with the interpretation of rebound amplitude as setting the reliability of a conditioned response (Figures 5 and 6), the neighborhood around the stage 3 fixed-point can be viewed as a zone of reliable memory recall, with warmer hues indicating greater reliability.
Supplemental Movie 2. Voltage trace and phase plane trajectory of a CS-driven rebound in Model 1 of a DCN neuron, following training with a short interstimulus interval (ISI).

(A,B) This movie presents the same material as Movie 1, except that the ISI value is 85 ms. Since $t_{LTD}$ is 75 ms, stage 2 lasts only 10 ms. As a result, the rebound amplitude is diminished and the phase plane trajectory does not move as far into the reliable retrieval zone as with a long ISI value.

Supplemental Movie 3. Voltage trace and phase plane trajectory of a CS-driven rebound in Model 2 of a DCN neuron, following training with a moderate interstimulus interval (ISI).

(A) Using Model 2, we simulated the membrane potential of a DCN neuron. The stochastic arrival times of synaptic inputs leads to variations in the voltage dynamics between the 20 traces shown, despite identical initial conditions at $t = -100$ ms (red and blue traces). We chose an intermediate ISI value of 90 ms, for which 12 out of the 20 simulated trials result in a Ca$^{2+}$ spike (red traces). On the 8 other trials no Ca$^{2+}$ spike occurs (blue traces). Thus, this ISI value leads to unreliable retrieval of the stored memory. For comparison, the deterministic trajectory of the model cell given synaptic inputs occurring uniformly at the same average rate as for the noisy traces is also shown (large black dot moving along black trace).

(B) Each of the 20 model trajectories is depicted through the dynamics of a moving dot in the $(V, l)$ phase plane. The resulting cloud of 20 points moves under the influence of synaptic input and active conductances. As in Movies 1 and 2, the black solid and dashed lines are the $V$ and $l$ nullclines. When the $V$ nullcline shifts at the start of the CS due to increased Purkinje cell input, all 20 trajectories begin to move from the resting (stage 1) fixed-point towards the more hyperpolarized (stage 2) fixed-point. However, noisy synaptic inputs lead some trajectories (red dots) closer to the reliable retrieval zone (warm colors in color map) and toward a higher level of deinactivation of T-type Ca$^{2+}$ channels, while other trajectories are more distant from the reliable retrieval zone (blue dots). Approximately $t_{LTD}$ before the expected US, the fixed-point shifts to a more depolarized location (stage 3). Trajectories that have attained a higher level of deinactivation generate larger amplitude rebounds, resulting in a large Ca$^{2+}$ spike (red dots). Trajectories attaining lower levels of deinactivation do not trigger a Ca$^{2+}$ spike (blue dots). The large black dot traces the deterministic phase plane trajectory for a cell receiving synaptic inputs uniformly in time at the same average rate as for the noisy traces.