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Supplementary Materials for

Neuromorphic learning, working memory, and metaplasticity in nanowire networks

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The PDF file includes:

Supplementary Text
Figs. S1 to S7
Legends for movies S1 to S4
Legend for Source Data File S1

Other Supplementary Material for this manuscript includes the following:

Movies S1 to S4
Source Data File S1

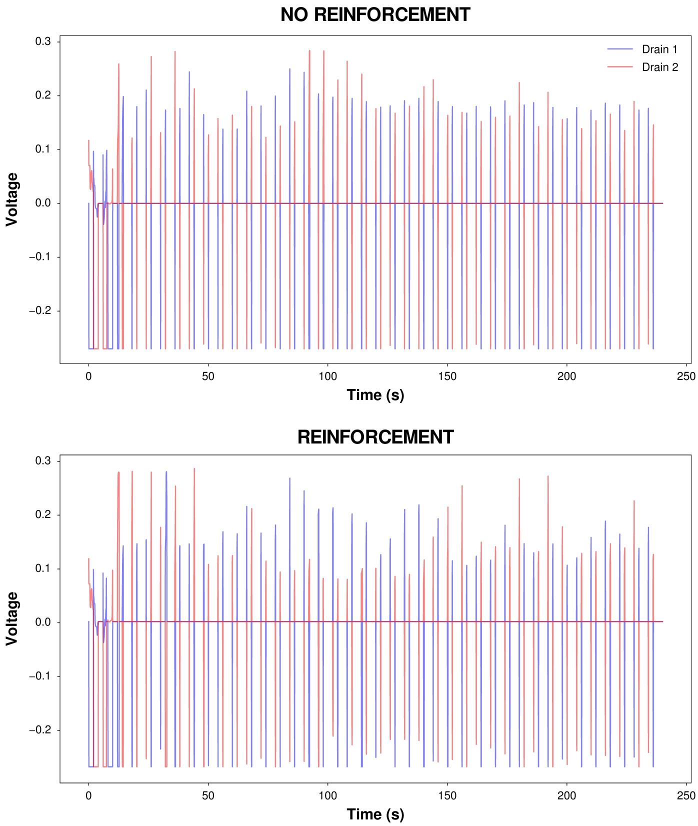

Fig. S1 Voltage readouts for drain 1 (blue) and drain 2 (red) during simple binary classification (Task 1) in simulation. The gradient descent-like algorithm introduced in Algorithm 1 of the main text adjusts drain voltage in order to match current output to reach θ (cf. Figure 2 of main text).

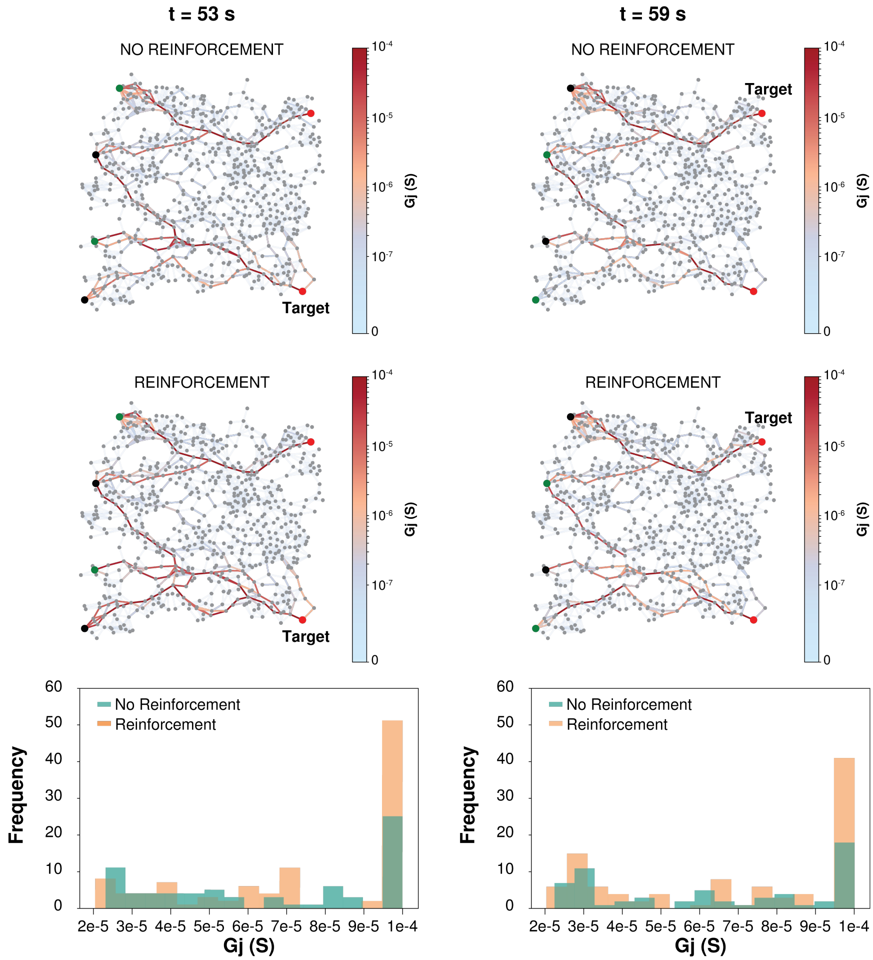

Fig. S2 Network connectivity maps and junction conductance (Gj) histograms for Figure 2 of the main text). Left column: t = 53 s; right column: t = 59 s. The difference in junction conductance for networks with (orange) and without (green) reinforcement is highlighted by histograms.

Simulation junction filament decay rate (b)

The filament decay parameter b was varied from very low ($b = 0.1$) to high ($b = 5$) and the average junction conductance (Gj) was recorded across all 2582 junctions at each timestep. The goal of this was to better constrain this parameter from the experimental measurements using working memory. 7 inputs were used with 2 drains, with placements identical to Tasks 1 and 2. Voltage was set at $V_{\mathrm{i}} = 0.3\,\mathrm{V}$ for the first 30 s and then reset to zero for the final 70 seconds. All 7 inputs and 2 drains were opened.

As Figure S3 shows, higher b values resulted in significantly faster decay, with Gj in both $b = 5$ and $b = 2$ resetting to zero, approximately 2 and 4 seconds after V_{i} was reset to zero, respectively. In contrast, low filament decay parameters took longer to decay, with $b = 0.1$ taking over 50 seconds to fully reset after V_{i} was reset to zero. It is important to note that b cannot be controlled experimentally, other than, for example, by varying properties such as the physical size of the inductive PVP layer between silver nanowires in an Ag-PVP NWN. However, the experimental filament decay rate is significantly lower than even $b = 0.1$, sometimes taking over 24 hours to fully reset.

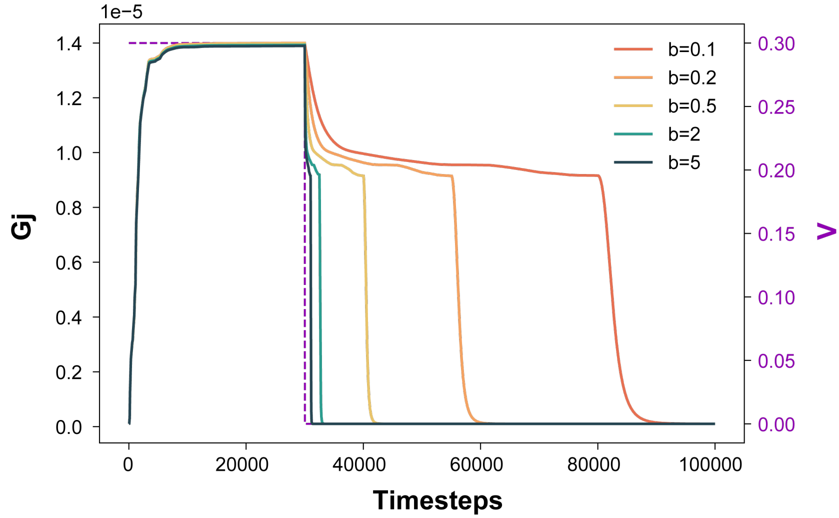

Fig. S3 Average junction conductance (Gj; left axis) for varying filament decay parameter values (b) in simulation. The dotted purple line is the input voltage (V; right axis), which is set to 0.3 V for 3000 timesteps, and reset to 0 V for the rest of the simulation. For higher b values (e.g. $b = 5$), average junction conductance drops to zero more quickly than for lower b values (e.g. $b = 0.5$).

Varying decay rate b for tasks 2 and 3

To demonstrate the effect of varying filament decay rate, b, we repeated Task 2 with five b values (0.1, 0.2, 0.5, 2 and 5). Figure S4 shows change in accuracy as n is increased from 2 to 6, with varying b values. This is for the no-reinforcement condition. $b = 0.5$ was chosen in the main text for clarity of visualisation across all tasks.

We repeated this for Task 3, with n ranging from 1 to 7 (cf. Figure S5).

Network connectivity with varying b

In Figure 5 of the main text, network connectivity maps are shown comparing pathway formation for simulated NWNs with and without reinforcement. For

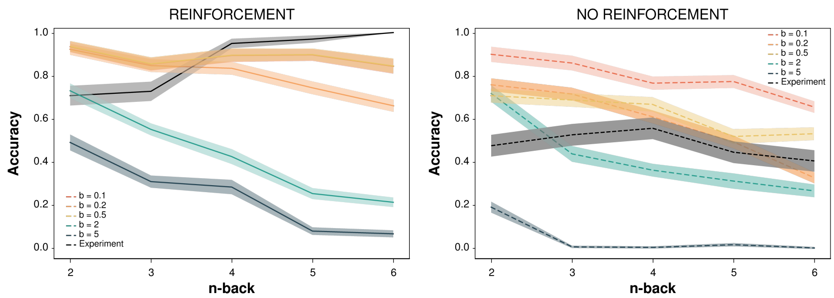

Fig. S4 Accuracy vs n-back for Task 2 with varying b values, with and without reinforcement.

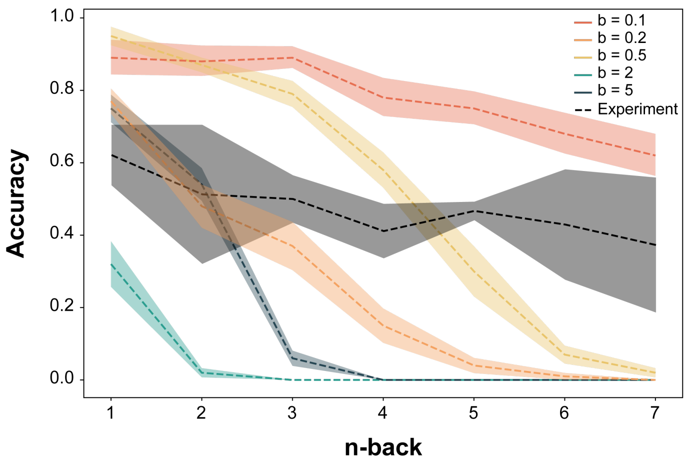

Fig. S5 Accuracy vs n-back for Task 3 with varying b values without reinforcement. The black line represents the mean accuracy of the experimental no-reinforcement condition, as a reference point.

that figure, $b = 2$ was used for clarity of visualisation. However, the results shown for Task 3 (Figure 4) were for those with $b = 0.5$. Supplementary Figure S6 shows pathways for $b = 0.5$.

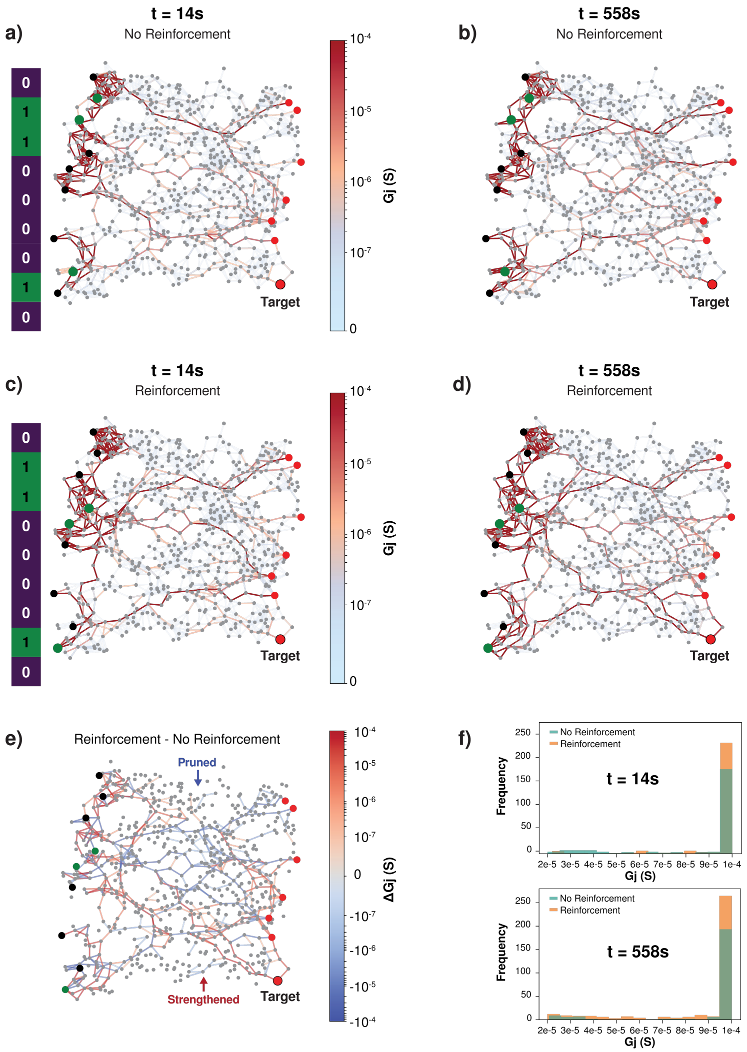

Fig. S6 Simulated nanowire network connectivity snapshots during memory recall. a) & **b)** Network connectivity maps visualising junction conductance (G_{j}) snapshots at early ($t = 14\,\mathrm{s}$, epoch 1/70) and middle ($t = 558\,\mathrm{s}$, epoch 36/70) testing periods of the WM n-back task (with $n = 3$), respectively, without reinforcement. Active and inactive source electrodes are highlighted in green and black, respectively, with active drain electrodes in red and target drain indicated. **c)** & **d)** Same as a) and b), but with reinforcement. **e)** Topological reconfiguration map highlighting the junction conductance change ΔG_{j} between reinforced and non-reinforced paths. Values are calculated by comparing functional maps as follows: $(d - c) - (b - a)$. Here, the effect of PRL is less visually clear, but still significant. **f)** G_{j} histograms corresponding to a) & c) (top panel), and b) & d) (bottom panel). For clarity, G_{j} is thresholded at $2 \times 10^{-5}\,\mathrm{S}$. Here, filament decay, $b = 0.5$.

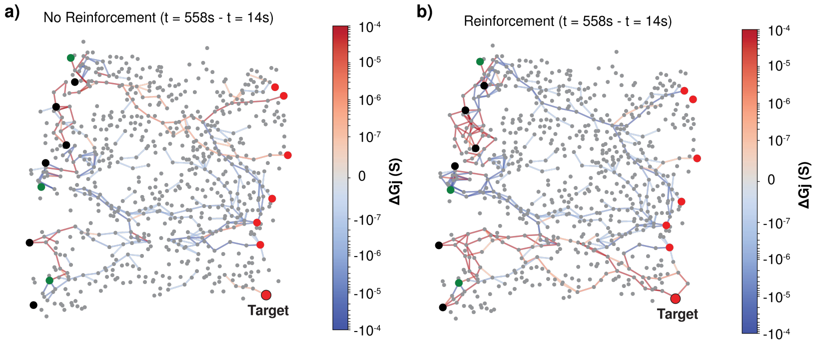

Fig. S7 Topological reconfiguration maps used to calculate Figure 5e in main text. a) Synaptic pathway strengthening (red) and pruning (blue) between t = 14 s and t = 558 s for no-reinforcement. **b)** Same as a) but for reinforcement. As in the main text, $b = 2$ for clarity of visualisation.

Movie. S1 Movie of Task 3 with No Reinforcement for b = 0.5.

Movie. S2 Movie of Task 3 with Reinforcement for b = 0.5.

Movie. S3 Movie of Task 3 with No Reinforcement for b = 2.

Movie. S4 Movie of Task 3 with Reinforcement for b = 2.

Data. S1 Source Data for Experimental Measurements.