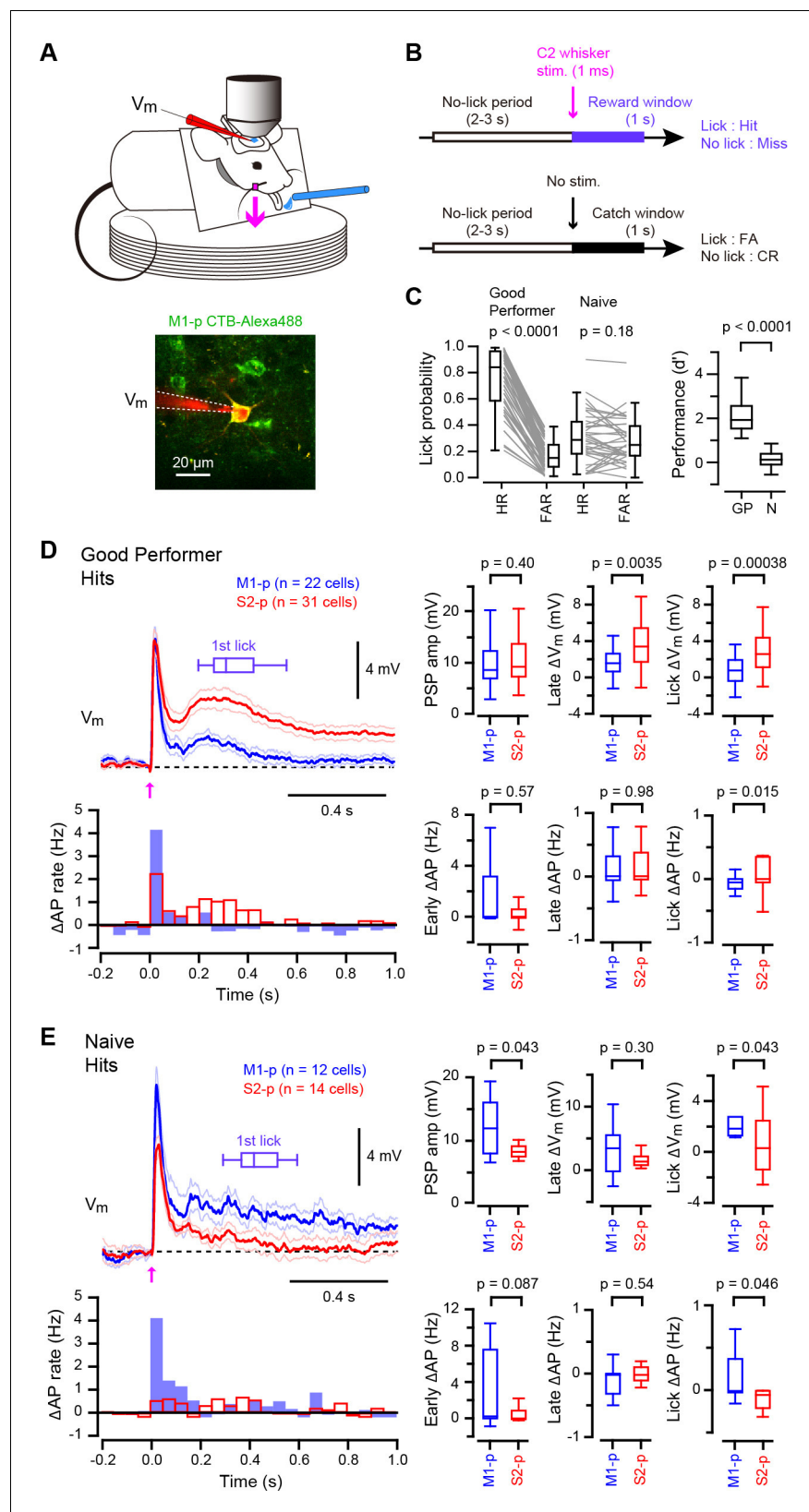


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## Figures and figure supplements

Target-specific membrane potential dynamics of neocortical projection neurons during goal-directed behavior

**Takayuki Yamashita and Carl CH Petersen**



**Figure 1.** Target-specific  $V_m$  dynamics in S1 projection neurons during task performance. (A) Top, the experimental setup. Bottom, a representative two-photon image of a CTB-labeled M1-p neuron (green) with a recording pipette (red). (B) Detection task trial structure (FA: false alarm, CR: correct rejection). (C) Behavioral performance. (D) Good Performer Hits. (E) Naive Hits. *Figure 1 continued on next page*

*Figure 1 continued*

performance during whole-cell recordings (HR: hit rates, FAR: false alarm rates, GP: 'Good performer', N: 'Naive'). (D, E) Left, grand average changes in  $V_m$  (thick line: mean, thin lines:  $\pm$  sem) and action potential (AP) firing rate for hit trials recorded from S2-p neurons (red) and M1-p neurons (blue) in 'Good performer' (D) and 'Naive' (E) mice (Arrow: 1 ms stimulation of the C2 whisker). A box plot indicates reaction time (1st lick). Right, box plots for postsynaptic potential (PSP) amplitude, secondary late  $V_m$  depolarization quantified at 0.05–0.25 s,  $V_m$  depolarization during the lick period (at 0.25–1.0 s), and evoked AP rates at early (0–0.05 s), late (0.05–0.25 s) and lick (0.25–1.0 s) periods.

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The following source data is available for figure 1:

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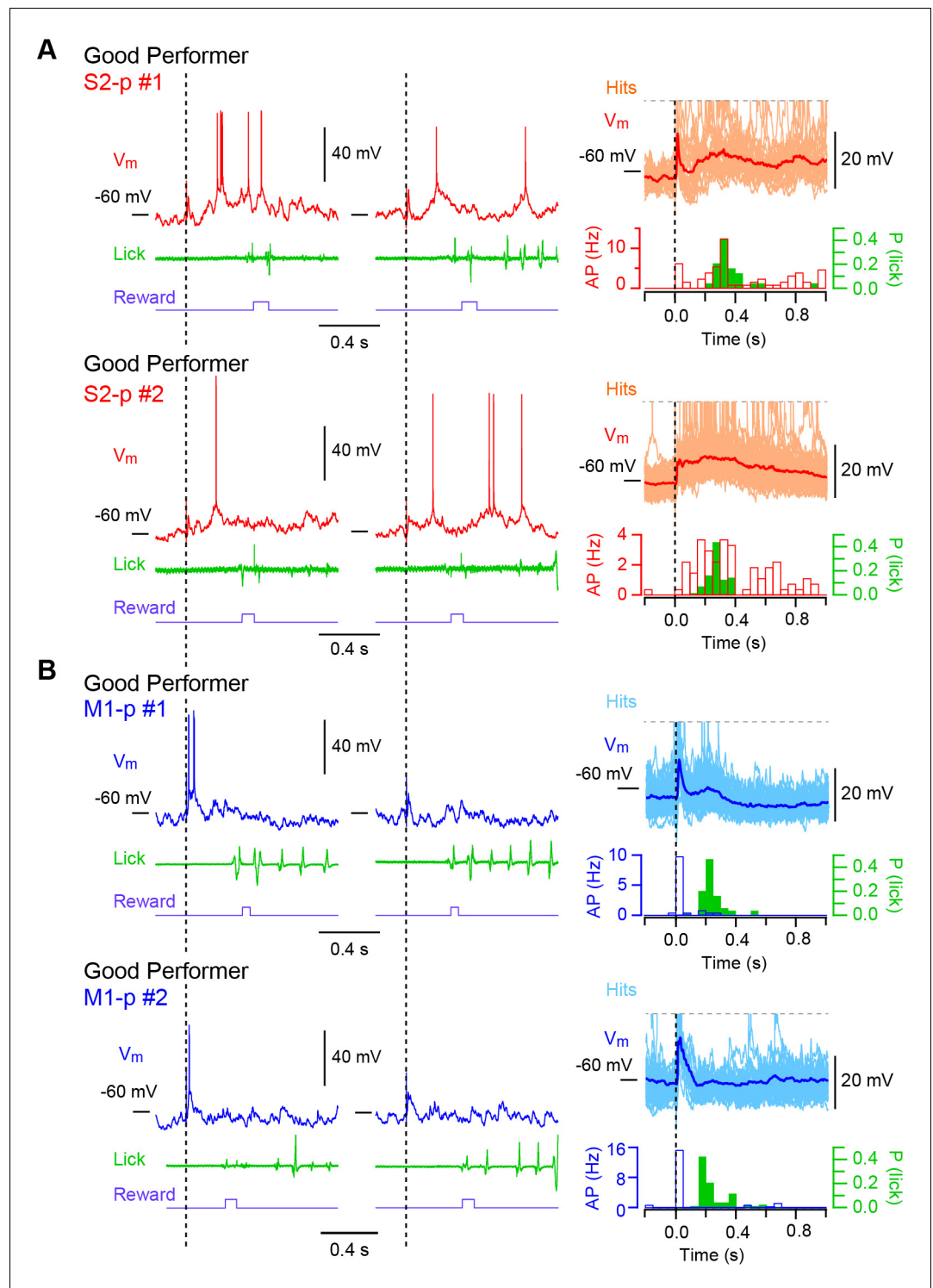
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**Source data 2.** Data values and statistics underlying **Figure 1—figure supplement 3**.

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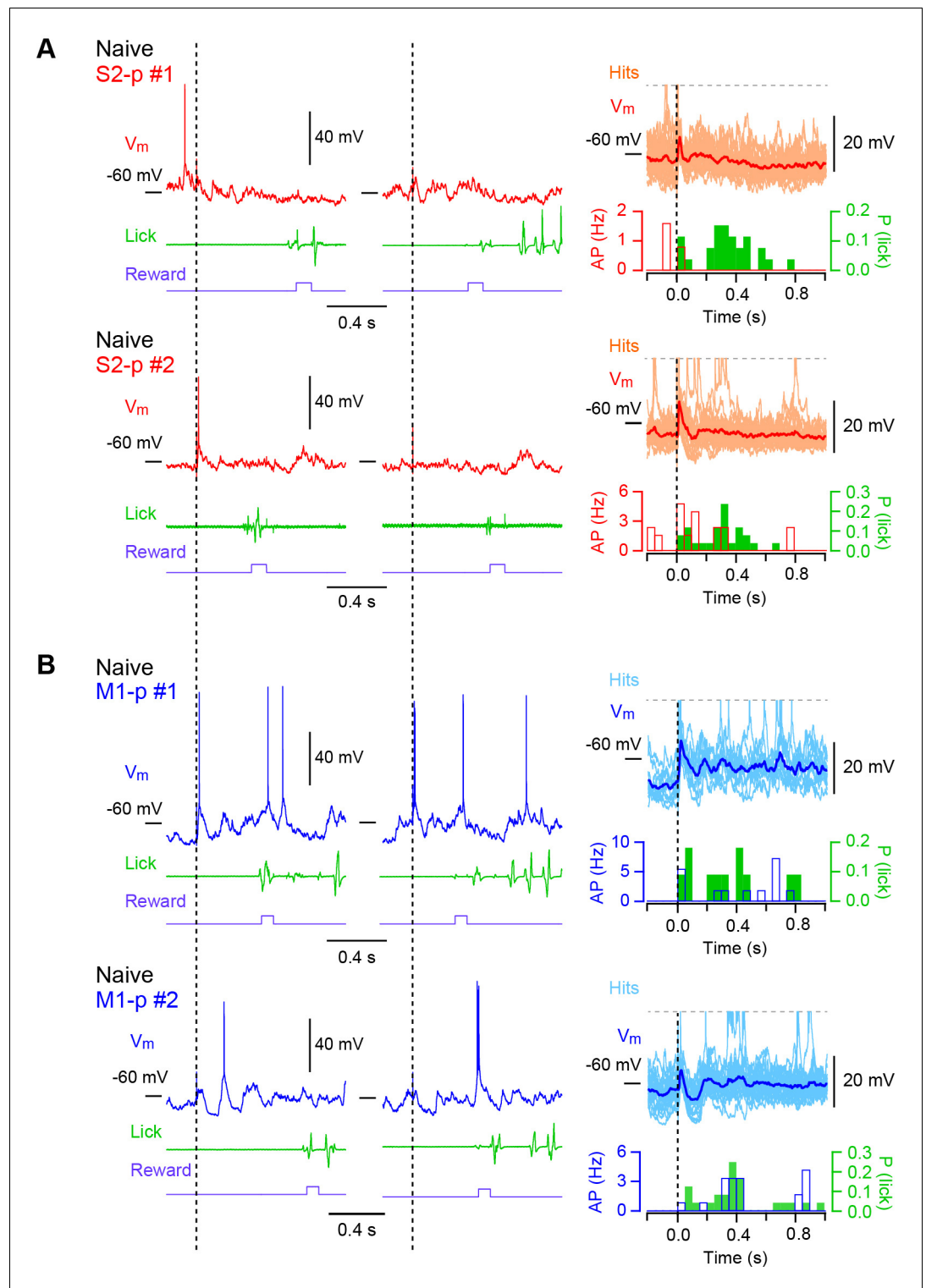
**Source data 3.** Data values and statistics underlying **Figure 1—figure supplement 4**.

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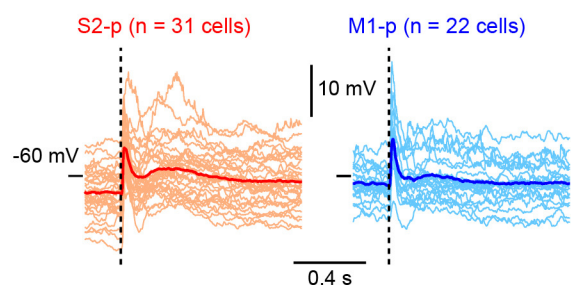
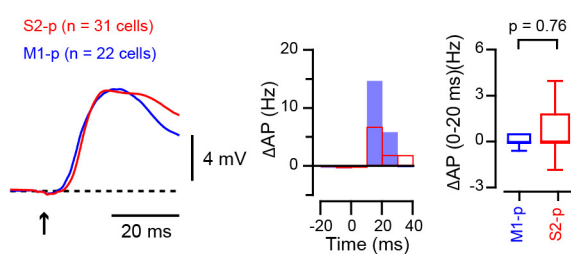
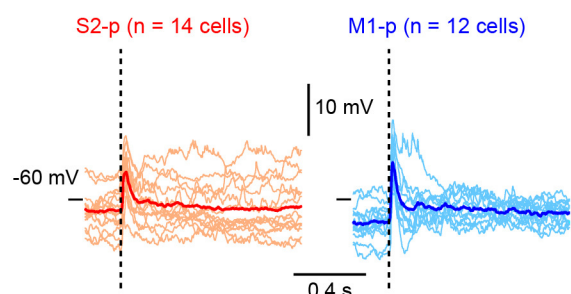
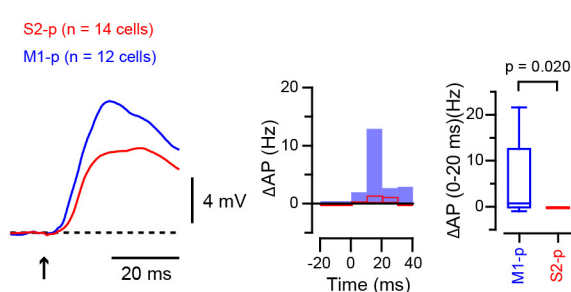
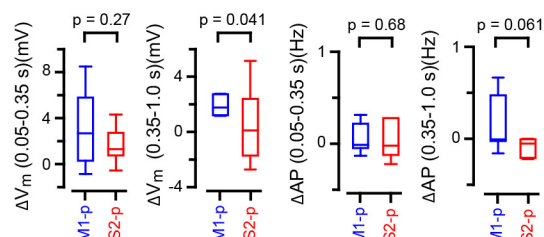
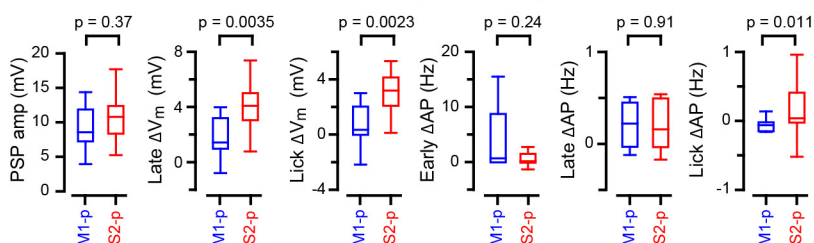
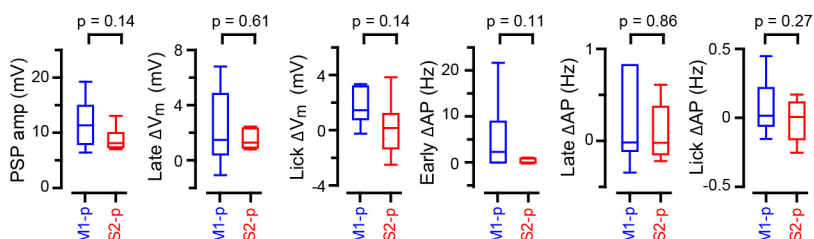
**Figure 1—figure supplement 1.** Hit  $V_m$  traces from S1 projection neurons in 'Good performer' mice. (A) Left and middle, example  $V_m$  traces obtained from two individual S2-p neurons on two representative hit trials. Right, the averaged subthreshold  $V_m$  trace is superimposed with individual traces. APs are truncated. PSTHs for corresponding AP rates and the distribution of the first lick timings are also shown. (B) Same as A, but for M1-p neurons.

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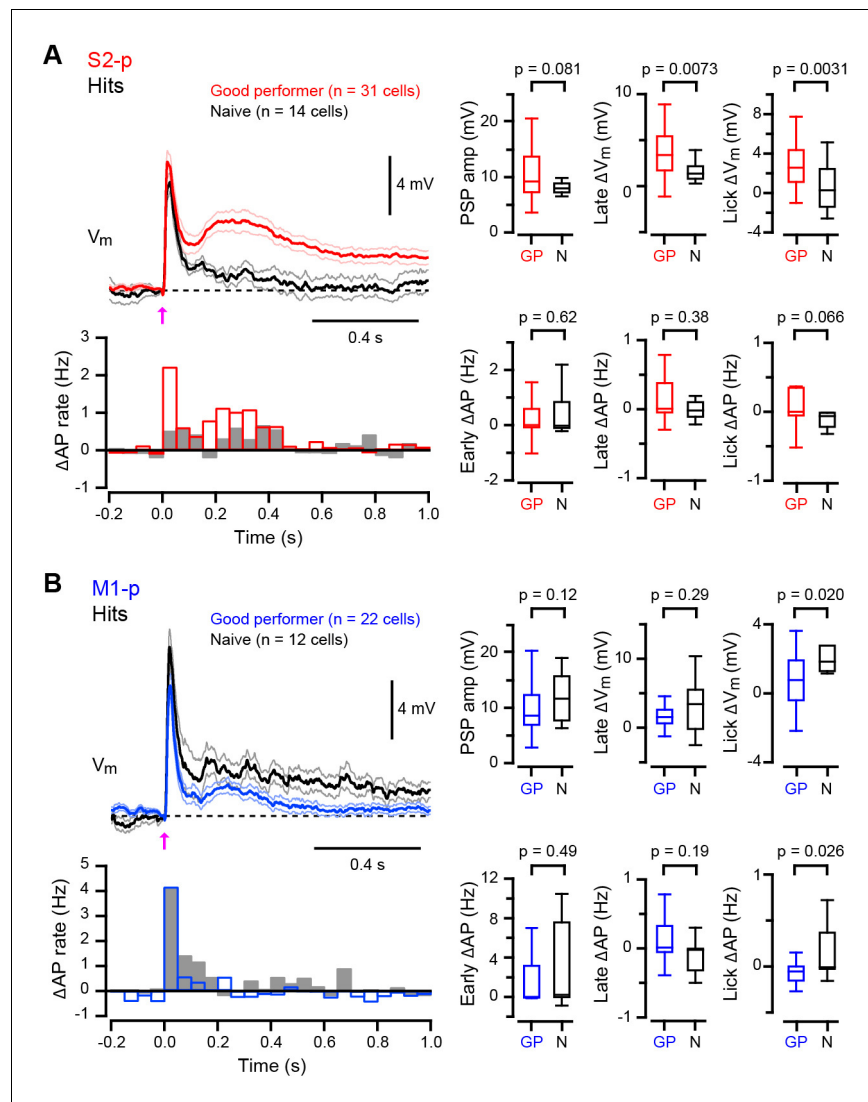
**Figure 1—figure supplement 2.** Hit  $V_m$  traces from S1 projection neurons in 'Naive' mice. (A) Left and middle, example  $V_m$  traces obtained from two individual S2-p neurons on two representative hit trials. Right, the averaged subthreshold  $V_m$  trace is superimposed with individual traces. APs are truncated. PSTHs for corresponding AP rates and the distribution of the first lick timings are also shown. (B) Same as A, but for M1-p neurons.

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**A** Good performer - Hits**B****C** Naive - Hits**D****E** Naive - Hits**F** Good Performer - Hits (mouse-by-mouse)**G** Naive - Hits (mouse-by-mouse)

**Figure 1—figure supplement 3.** Average hit  $V_m$  traces and PSTHs. (A) Average hit  $V_m$  traces obtained from individual cells (thin lines) from S2-p (left) and M1-p (right) neurons of ‘Good performer’ mice. The grand average  $V_m$  traces (thick lines) are superimposed. The dotted line indicates the stimulus onset. (B) Left, grand average of subthreshold responses from S2-p (red) and M1-p (blue) neurons are shown at high temporal resolution (superimposed with the baseline  $V_m$  subtracted). An arrow indicates the onset of whisker stimulation. Middle, grand average PSTHs at high temporal resolution with the baseline AP rates subtracted. Time 0 is the onset of whisker stimulation. Right, quantification of evoked AP rate at initial 20 ms after whisker deflection. (C and D) Same as A and B, but for ‘Naive’ mice. (E) Quantification of  $\Delta V_m$  and  $\Delta$ AP rate at 0.05 – 0.35 s and 0.35 – 1.0 s on hit trials in ‘Naive’ mice. (F) PSP amplitude,  $V_m$  depolarization at the late (0.05–0.25 s) and lick (0.25 – 1.0 s) periods and evoked AP rates at early (0 – 0.05 s), late (0.05 – 0.25 s) and lick (0.25 – 1.0 s) periods were analyzed on a mouse-by-mouse basis for ‘Good performer’ mice (n = 9 mice for M1-p neurons; n = 17 mice for S2-p neurons). (G) Same as F, but for ‘Naive’ mice (n = 6 mice for M1-p neurons; n = 9 mice for S2-p neurons).

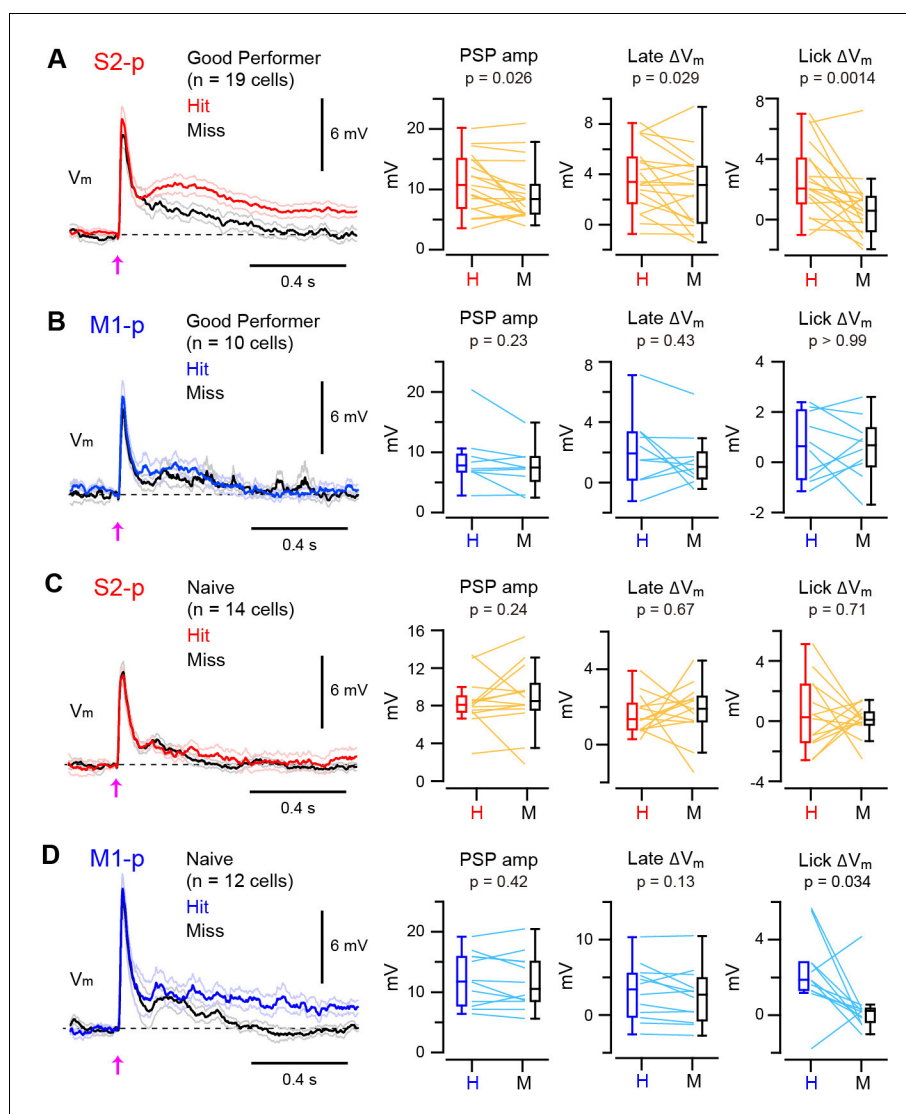
DOI: [10.7554/eLife.15798.009](https://doi.org/10.7554/eLife.15798.009)



**Figure 1—figure supplement 4.** Target-specific changes of hit responses with task learning. (A and B) Left, grand average changes in  $V_m$  (thick line: mean, thin lines:  $\pm$  sem) and AP rate for hit trials recorded from S2-p neurons (A) and M1-p neurons (B) in 'Good performer' (colored) and 'Naive' (black) mice (Arrow: 1 ms stimulation of the C2 whisker). Right, box plots for PSP amplitude,  $V_m$  depolarization at the late (0.05–0.25 s) and lick (0.25–1.0 s) periods and evoked AP rates at early (0–0.05 s), late (0.05–0.25 s) and lick (0.25–1.0 s) periods.

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**Figure 2.** Target-specific  $V_m$  correlation with task execution. (A) Left, grand average  $V_m$  traces (thick line: mean, thin lines:  $\pm$  sem) of S2-p neurons during hit (red) and miss (black) trials for ‘Good performer’ mice. Right, data for each cell (thin lines) and box plots for PSP amplitude and  $V_m$  depolarization at the late (0.05–0.25 s) and lick periods (0.25–1.0 s) on hit (H) and miss (M) trials. (B) Same as A, but for M1-p neurons. (C) Same as A, but for S2-p neurons in ‘Naive’ mice. (D) Same as C, but for M1-p neurons.

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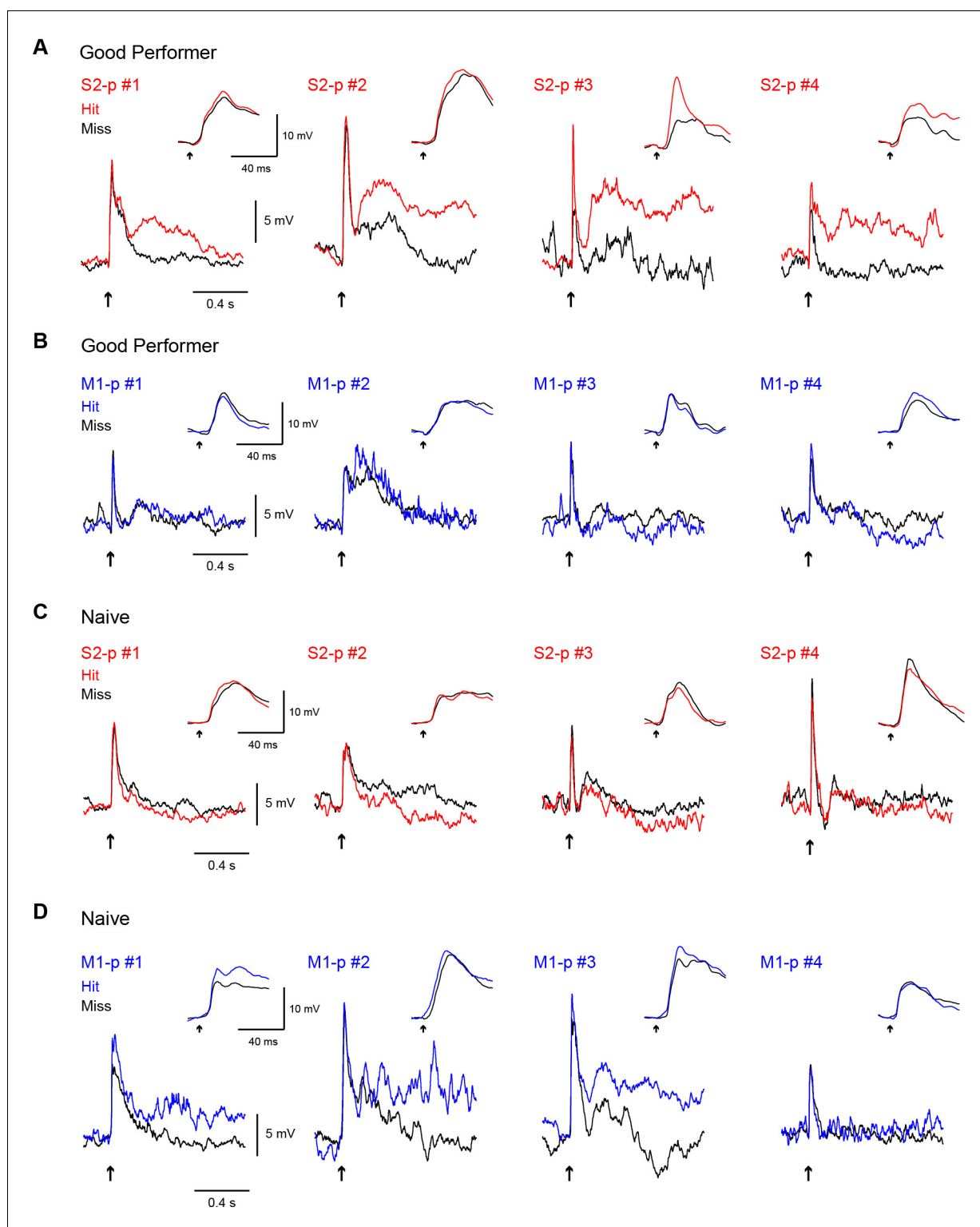
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DOI: [10.7554/eLife.15798.012](https://doi.org/10.7554/eLife.15798.012)

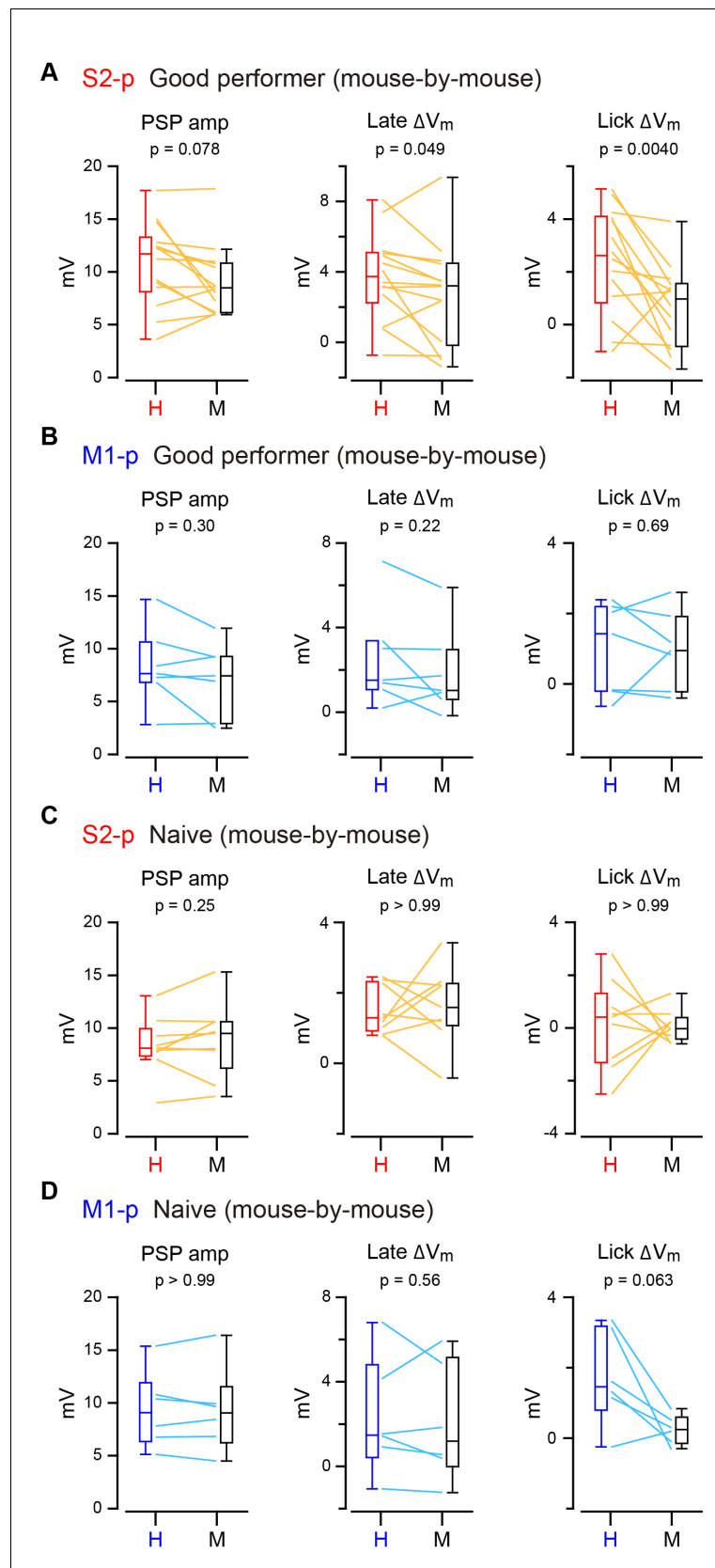
**Source data 2.** Data values and statistics underlying **Figure 2—figure supplement 2**.

DOI: [10.7554/eLife.15798.013](https://doi.org/10.7554/eLife.15798.013)



**Figure 2—figure supplement 1.** Representative hit/miss  $V_m$  traces. (A) Example average subthreshold  $V_m$  traces on hit (colored) and miss (black) trials from four individual S2-p neurons in trained 'Good performer' mice. Arrows: the onset of whisker stimulus. Insets: PSPs of corresponding traces at high temporal resolution. (B) Same as A, but for M1-p neurons. (C) Same as A, but for S2-p neurons in 'Naive' mice. (D) Same as C, but for M1-p neurons.

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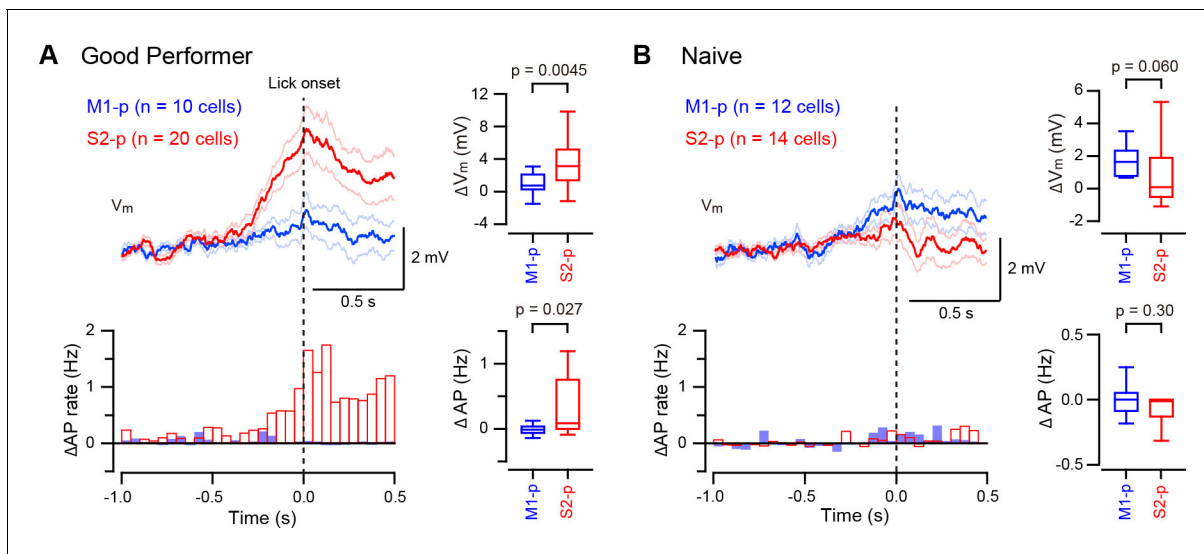


**Figure 2—figure supplement 2.** Mouse-by-mouse analysis of hit/miss responses. (A) Data from S2-p neurons in 'Good performer' mice averaged for each mouse (thin lines,  $n = 14$  mice) and box plots for PSP amplitude and  $V_m$  Figure 2—figure supplement 2 continued on next page

*Figure 2—figure supplement 2 continued*

depolarization at the late (0.05–0.25 s) and lick periods (0.25–1.0 s) on hit (**H**) and miss (**M**) trials. (**B**) Same as **A**, but for M1-p neurons (n = 7 mice). (**C**) Same as **A**, but for S2-p neurons in 'Naive' mice (n = 9 mice). (**D**) Same as **C**, but for M1-p neurons (n = 6 mice).

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**Figure 3.** Target-specific  $V_m$  depolarization during spontaneous unrewarded licking. (A, B) Left, grand average change in  $V_m$  (thick line: mean, thin lines:  $\pm$  sem) and AP rate aligned at the onset of detected spontaneous licking (dotted line) in M1-p and S2-p neurons of 'Good performer' (A) and 'Naive' (B) mice. Right, quantifications at  $\pm 0.1$  s around the detected lick onset.

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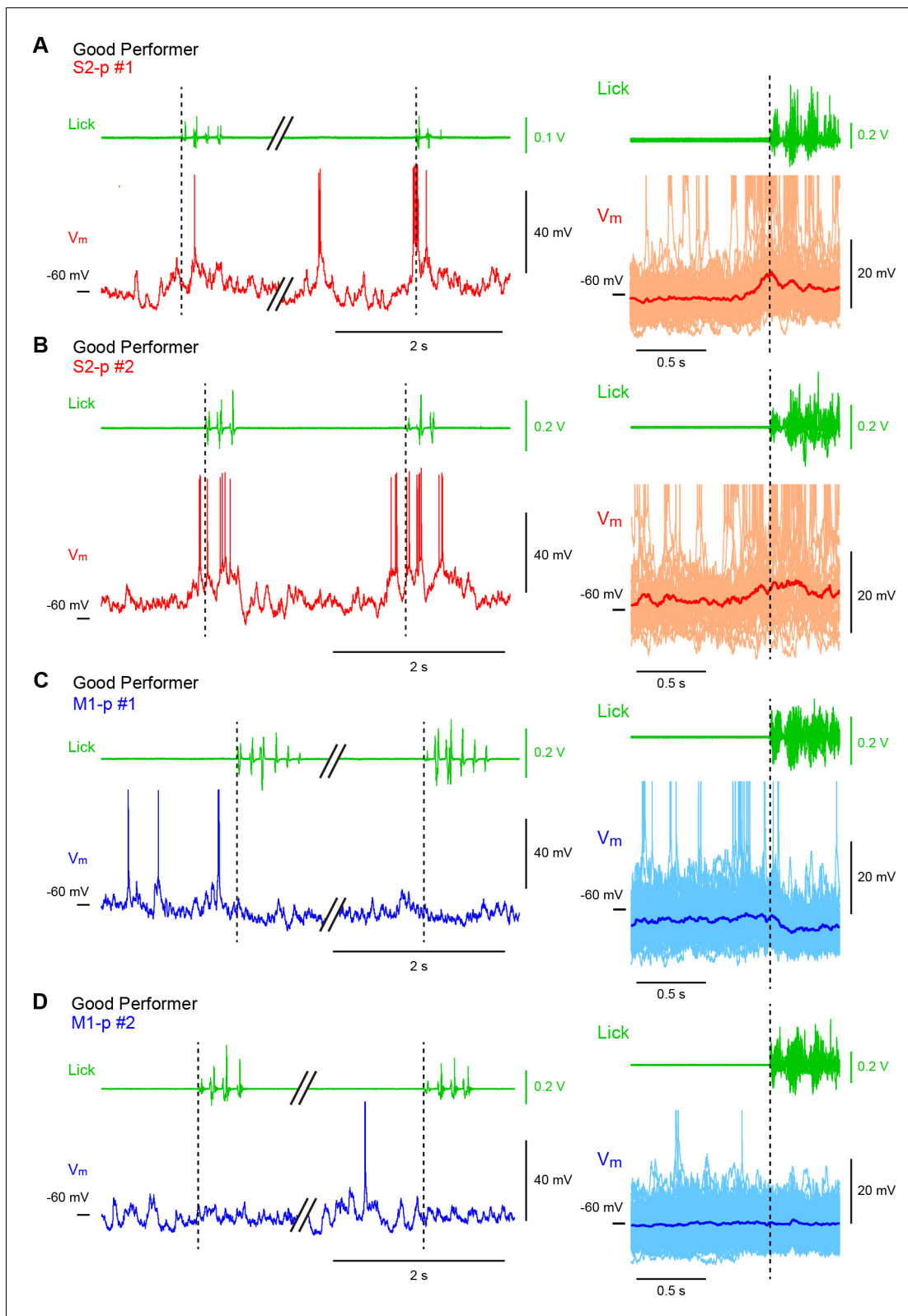
The following source data is available for figure 3:

**Source data 1.** Data values and statistics underlying **Figure 3**.

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**Source data 2.** Data values and statistics underlying **Figure 3—figure supplement 3**.

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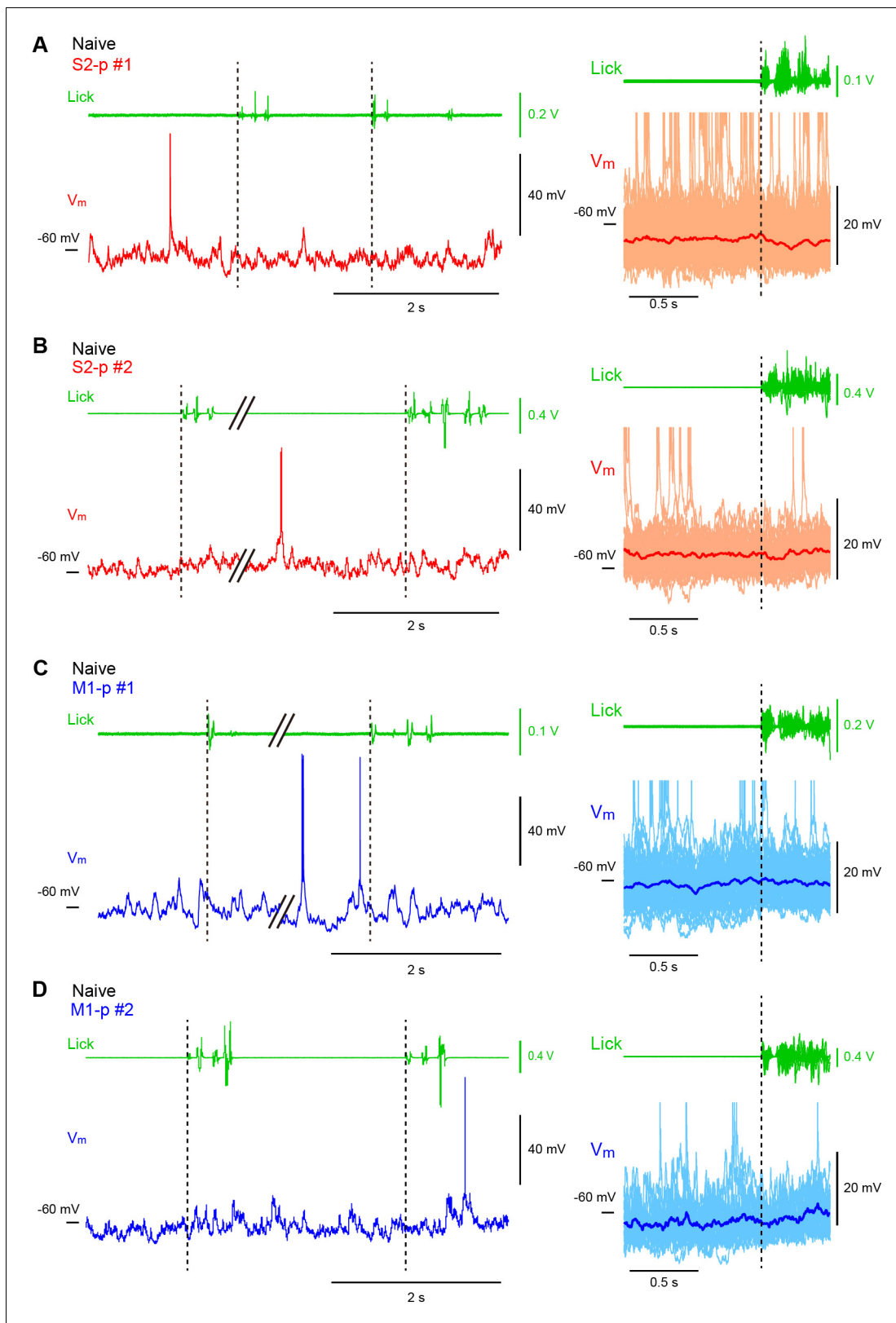
**Figure 3—figure supplement 1.** Licking-related  $V_m$  dynamics of S2-p and M1-p neurons in 'Good performer' mice. (A) Left, an example  $V_m$  trace (below) from an S2-p neuron during spontaneous unrewarded licking and the corresponding lick-sensor signal (above). Right, individual lick-sensor signals (above) and  $V_m$  traces (below, thin lines; APs are truncated) aligned and superimposed at the onset of detected licking (the time when the tongue first contacted the water spout; dotted line), obtained from the cell shown on the left. The average subthreshold  $V_m$  trace (thick line) is

Figure 3—figure supplement 1 continued on next page

*Figure 3—figure supplement 1 continued*

superimposed. (B) Another example from an S2-p neuron different from the cell shown in A. (C) Same as A, but for an M1-p neuron. (D) Another example from an M1-p neuron different from the cell shown in C.

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**Figure 3—figure supplement 2.** Licking-related  $V_m$  dynamics of S2-p and M1-p neurons in 'Naive' mice. (A) Left, an example  $V_m$  trace (below) from an S2-p neuron during spontaneous unrewarded licking and the corresponding lick-sensor signal (above). Right, individual lick-sensor signals (above) and  $V_m$  traces (below, thin lines; APs are truncated) superimposed and aligned at the onset of detected licking (the time when the tongue first contacted

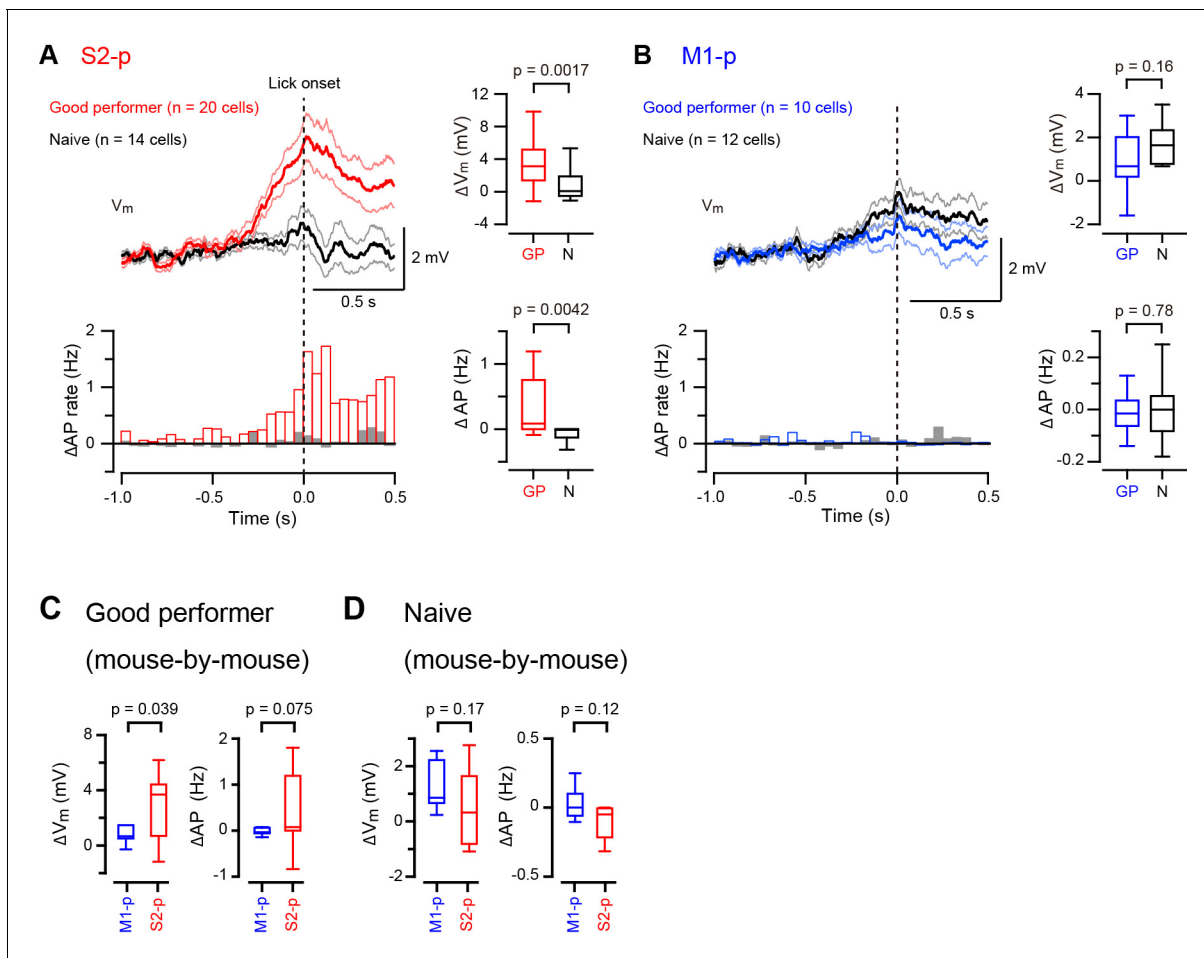
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Figure 3—figure supplement 2 continued

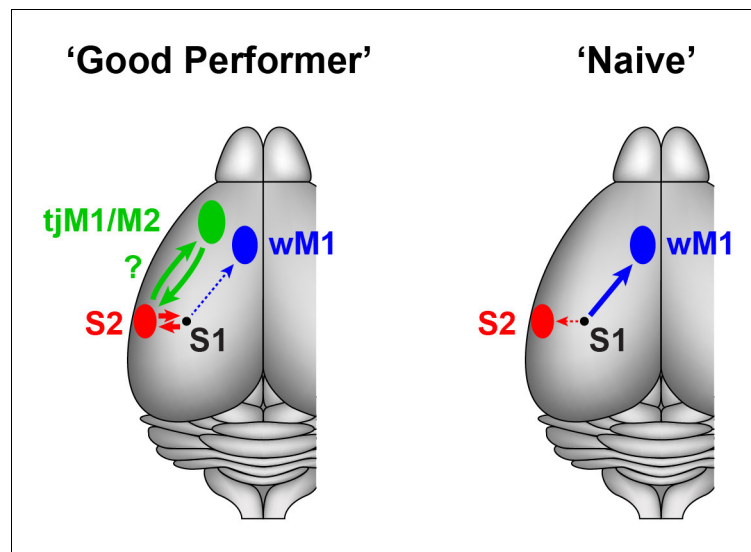
the water spout; dotted line), obtained from the cell shown on the left. The average subthreshold  $V_m$  trace (thick line) is superimposed. (B) Another example from an S2-p neuron different from the cell shown in A. (C) Same as A, but for an M1-p neuron. (D) Another example from an M1-p neuron different from the cell shown in C.

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**Figure 3—figure supplement 3.** Further analysis of  $V_m$  dynamics during spontaneous unrewarded licking. (A, B) Left, grand average change in  $V_m$  (thick line: mean, thin lines:  $\pm$  sem) and AP rate aligned at the onset of detected spontaneous licking (dotted line) in S2-p (A) and M1-p (B) neurons of 'Good performer' and 'Naive' mice. Right, quantifications at  $\pm 0.1$  s around the detected lick onset. (C) The lick-related change of  $V_m$  and AP rate was analyzed on a mouse-by-mouse basis for 'Good performer' mice (n = 7 mice for M1-p neurons; n = 15 mice for S2-p neurons). (D) Same as C, but for 'Naive' mice (n = 7 mice for M1-p neurons; n = 9 mice for S2-p neurons).

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**Figure 4.** Schematic summary of target-specific output signals from S1 during execution of the whisker detection task, together with speculative hypothesis relating to possible cortico-cortical signalling pathways from S1 to tongue/jaw area of motor cortex. Left, In 'Good performer' mice, S2-p neurons, not M1-p neurons, in S1 develop depolarization correlated with task performance. The activities of S2-p neurons could be routed toward the tongue/jaw area of M1/M2 (tjM1/M2). Right, In 'Naive' mice, M1-p neurons, not S2-p neurons, exhibit depolarization correlated with task execution. wM1: whisker M1.

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