Supplemental Information

Causal Role of Motor Preparation during Error-Driven Learning

Saurabh Vyas, Daniel J. O'Shea, Stephen I. Ryu, and Krishna V. Shenoy
Causal role of motor preparation during error-driven learning
Saurabh Vyas\textsuperscript{1,9,*}, Daniel J. O’Shea\textsuperscript{2,3}, Stephen I. Ryu\textsuperscript{2,8}, Krishna V. Shenoy\textsuperscript{1,2,4,5,6,7}

\textsuperscript{1}Department of Bioengineering, Stanford University, Stanford, CA 94305
\textsuperscript{2}Department of Electrical Engineering, Stanford University, Stanford, CA 94305
\textsuperscript{3}Neurosciences Graduate Program, Stanford University, Stanford, CA 94305, USA
\textsuperscript{4}Department of Neurobiology, Stanford University, Stanford, CA 94305
\textsuperscript{5}Bio-X Program, Stanford University, Stanford, CA 94305
\textsuperscript{6}Wu Tsai Neurosciences Institute, Stanford University, Stanford, CA 94305
\textsuperscript{7}Howard Hughes Medical Institute, Stanford University, Stanford, CA 94305
\textsuperscript{8}Palo Alto Medical Foundation, Palo Alto, CA, 94301

*Corresponding author: smvyas@stanford.edu

\textsuperscript{9}Lead contact

Supplemental Figures S1 - S3
Figure S1. Related to Figure 4: Microstimulation is subthreshold and does not affect current trial behavior.

A. Histogram of forces measured at the hand and wrist using a load cell attached to the handle of the haptic device. Force is measured during a 200ms window around ICMS (including the 60ms of ICMS). The p-values were obtained from two-tailed Student’s t-tests.

B. For each reach condition (top row, black circle shows condition) velocity profiles (mean and standard error of the mean) in the X and Y direction intra-trial. Red shows ICMS trials, black shows non-ICMS trials. No statistically significant differences are noted across groups.

C. Same as (B) but positions over time intra-trial.

D. Same as (B) but mean peak (i.e., maximum) speed plotted across trials for ICMS (red) and non-ICMS (black) conditions during a block of baseline (no VMR) trials.
Figure S2. Related to Figure 4: Reaction time is slowed more by ICMS early versus late in learning.
Cumulative reaction time distributions (pooled across all sessions in PMd) for the ICMS (red) and non-ICMS (black) trials for Monkey P. Dotted red lines denote data from ICMS early (first 3 blocks) during adaptation compared to dotted black, which are the same number of non-ICMS trials early during adaptation. Solid red lines denote data from ICMS late (last 3 blocks) during adaptation compared to solid black, which are the same number of non-ICMS trials late during adaptation. ICMS was performed for an identical number of trials on all sessions. ICMS was performed either early or late during learning, never both. The $p$-values were obtained from the Wilcoxon rank-sum test and compare early ICMS (dotted red) with late ICMS (solid red), and early no-ICMS (dotted black) with late no-ICMS (solid black).
Figure S3. Related to Figure 4: Learning is disrupted following ICMS trials.

A. Error angle plotted a function of trials for ICMS (red) and non-ICMS (black) for all sessions for both animals.

B. Same as (A) but for one single representative session from Monkey P. Here, ICMS is magenta, and non-ICMS is in blue.

C. Trials from (B) are sub-selected such that red denotes ICMS trials following a non-ICMS trial, and black denotes non-ICMS trials following a second non-ICMS trial.

D. Data from (C) analyzed. Black dots show differences in errors between pairs of adjacent trials that are both non-ICMS. Red dots show differences in errors between pairs of adjacent trials, where the first trial (K) is ICMS, and the second trial (K+1) is non-ICMS. Red and black dotted lines are the means. The green dotted line is the mean trial-by-trial difference if all possible pairs of trials are considered (e.g., here we do not consider pairs of the form: ICMS & ICMS, no-ICMS & ICMS, etc.). This green dotted line matches the trial-by-trial difference for the data in (B) if condition is ignored. The red and black data are one session for the analysis from Figure 4E.