Supplementary Material

We based our implementation of feedback control with a forward model on a model presented by Bhushan & Shadmehr (1999). However, we made a few minor changes to this forward model-based controller and these changes are detailed below. Their model derived a planned set of joint torques derived from an inverse model of arm dynamics and a desired trajectory (in our case a 0.5s, 10cm minimum jerk movement at 45 degrees from the x-axis). Online errors were accounted for by two systems. A spinal feedback reflex controller produced stiffness and viscosity error gains at a small time delay. At a later time delay, a forward model of plant dynamics combined delayed sensory information with a past and future history of joint torques to predict the future state of the arm, and plan a correction if the future state deviated from the desired state. Moreover, the predictions of this forward model were subsequently used by the inverse model when converting desired joint accelerations to joint torques. Bhushan and Shadmehr, however, cited instability as a result of delayed feedback control, and adjusted parameters accordingly. This instability is clear in figure **S1A**. Rather than adjust parameters, however, and in light of the fact that large force pulses we delivered might induce even greater instability than the test cases examined in their paper, we gave the forward model the ability to predict the effect of spinal feedback, simply by using its already available state predictions. In this way, the forward model is aware of the effect of spinal feedback and does not overcompensate. This procedure eliminates the instability caused by delayed spinal feedback in the model, as shown in Figure **S1B**. Moreover, it is logical for a forward model of plant dynamics to include all features of the plant, including spinal feedback. We also adjusted parameters (robot-arm inertia, link lengths, and robot-arm configuration) to better reflect our paradigm, shown in Figure **S1C**. Additionally, we found that the simulated velocity profiles in the baseline (null field condition) on pulsed trials more accurately reflected our data with forward model stiffness and viscosity gains set to 20N/m and 8Ns/m respectively, as opposed to the 40N/m and 4N/m cited in their paper. Finally, we gave the forward model delayed knowledge of the change in task dynamics on pulsed trials. After knowledge of the pulse reaches the forward model (which we considered to be halfway through the duration of the pulse), we allowed it to accurately predict the presence of the

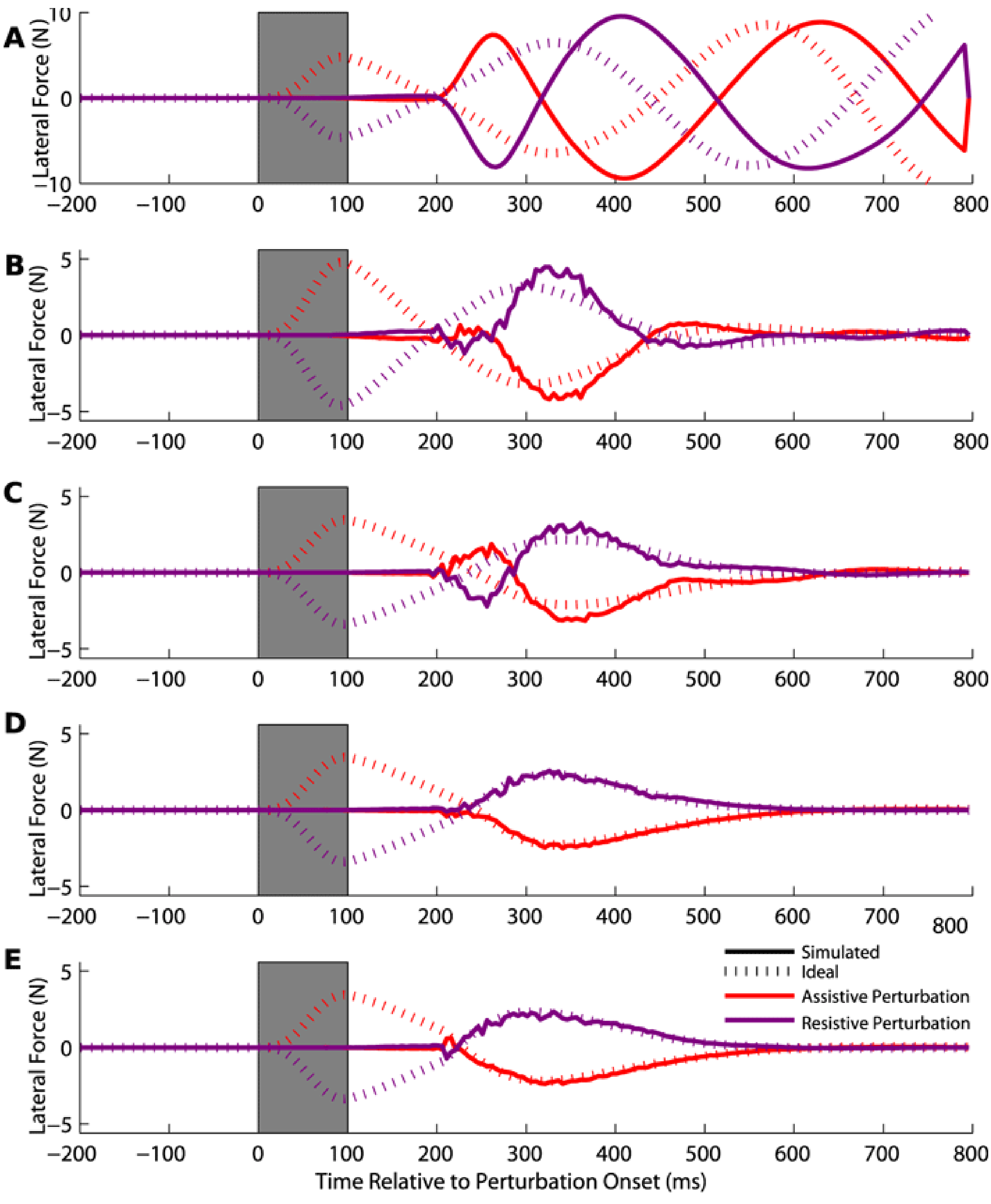

Figure S1: Modifications to Bhushan & Shadmehr (1999) predictive forward model simulations.

lateral error clamp (Figure **S1D**) as well as the full time course of the pulse (Figure **S1E**). This eliminates the initial lateral correction seen in Figure **S1C**, but retains the 'ideal' compensation from the inverse model, as a result of accurate prediction from the forward model, which is most similar to our data. That is, once the forward model begins to correctly predict the change in longitudinal velocity on pulsed trials, the inverse model begins to produce the lateral forces to compensate the expected curl field corresponding to that change in velocity.

In Figure S2, we examine the extent to which movements are altered on error-clamp trials. Here we compared error-clamp and non-error-clamp trials both in the baseline condition and late in learning the force-field, across all subjects. Figures S2A and S2C show that the error clamp has no significant effect on longitudinal velocity profiles. However, as expected, a small but significant effect of reducing lateral velocity can be seen in Figures S2B and S2D. This pattern is consistent with our interpretation that the only important effect of the error-clamp in this study is to reduced lateral movement errors.

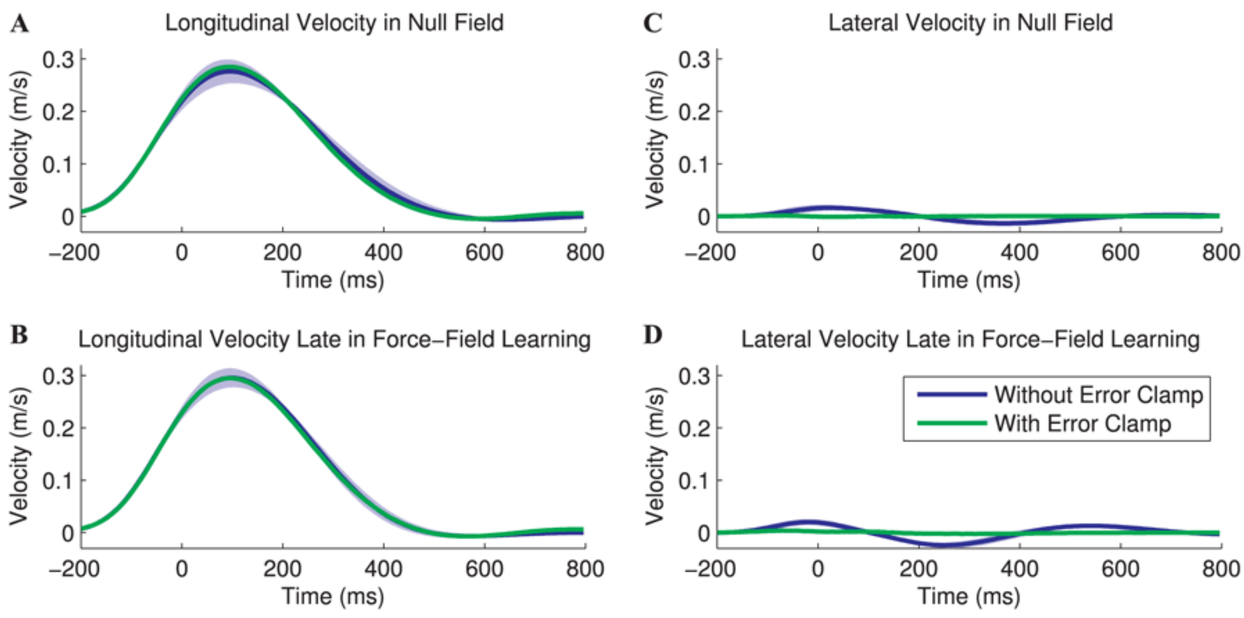

Figure S2: Velocity Profile Comparison In and Out of Error Clamp
(A) and (B) longitudinal velocity profiles, (C) and (D) lateral velocity profiles shown both in the baseline period (A,C) and late in learning the force-field (B,D). Shaded areas denote 95% confidence intervals on the mean across subjects. In the longitudinal direction, velocity profiles are not significantly different in and out of the lateral error clamp. Lateral velocity profiles are different, as expected - because the error-clamp trials are essentially straight and the non-error-clamp trials tend to deviate from a straight line by 2mm or so over the course of a movement.