Human Neuromechanical Control and Learning
Tutorial 4: Iterative Control Modeling of Motor Adaptation

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Question 1

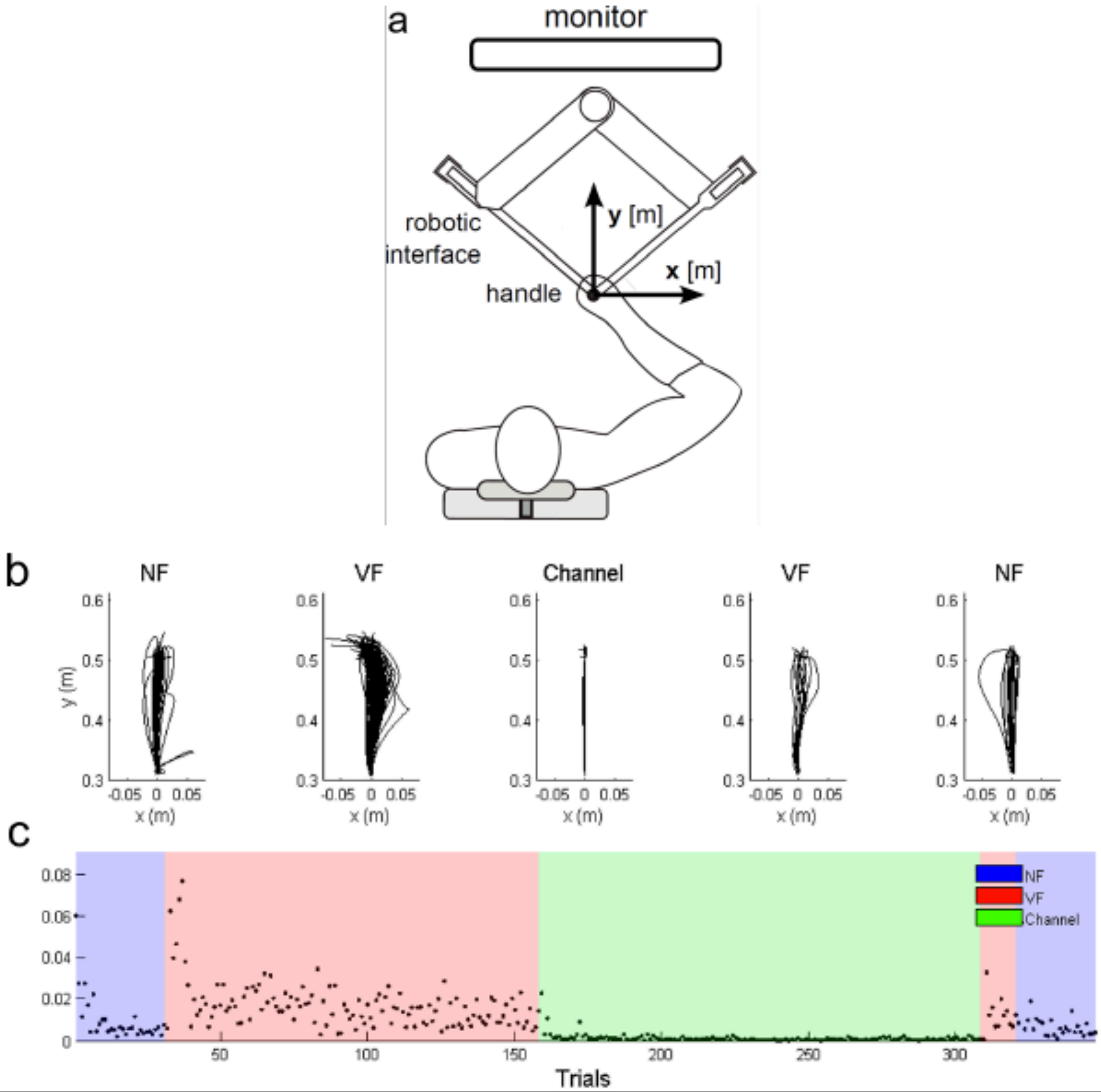

Figure 1: Motor adaptation of horizontal arm movements in a lateral force field. (a) Experimental setup, (b) paths in repeated reaching arm movements in five different phases with different force fields, and (c) maximum absolute lateral deviation during these phases.

When the velocity-dependent force field (VF) is applied to the subject in phase 2 of the experiment, as seen in the first red section of Figure 1C, initially there is a large spike in maximum absolute lateral deviation. In the transition from the null field (phase 1) to the VF (phase 2), the arm is first exposed to the external forces of the VF and has not had a chance for motor learning, therefore, deviation is increased. The value goes from around 0.01 at the end of phase 1 to as high as 0.08 at the start of phase 2, from trial 30 to trial 50. Over time the lateral deviation experienced by the arm in phase 2 decreases. After the initial spikes seen in the first 20 trials of phase 2 the deviations become more consistent and never exceed the value of 0.025 between trials 50 to 160.

When the channel is introduced in phase 3, as seen in the green section of Figure 1C, the deviations of the arm transition from as high as 0.025 to all consistently 0. The deviations stay at 0 for the completeness of phase 3: from trials 160 to 310. This is especially evident in Figure 1B, as the trajectory is clearly a straight line with no minimal deviations.

During the transition from phase 3 to phase 4, as seen in the second red section of Figure 1C, the channel is removed from the test and the VF is activated again. The deviations in phase 4 initially spike, but the deviations only spike for 1 trial to a value of 0.03, and then remain below 0.02 for the remainder of the phase. This behaviour is similar to the transition from phase 1 to 2, however, the deviations in phase 4 do not register as large, nor for as long as the spikes in phase 2. From this information, it can be inferred that after the channel, the human is keeping what they have learned. The channel does not hinder the retention of the motor adaptation. After the channel, the performance of the human improves because the second VF phase required fewer trials to produce constantly low deviations.

Question 2

Part A

A plot presenting the trajectory and maximal lateral deviation results for Question 2A is presented below in Figures 2. Note, the y axis limits were adjusted from the assignment template for better clarity.

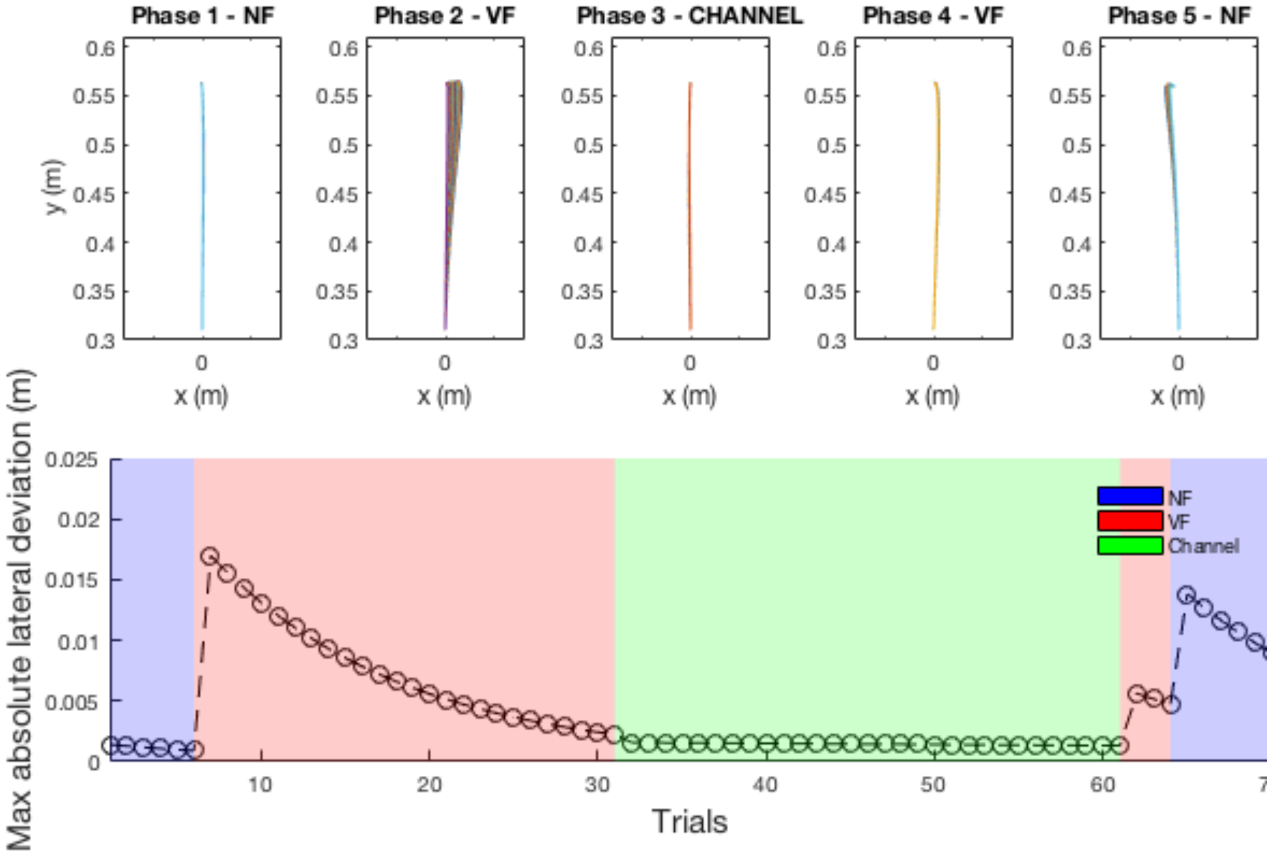

Figure 2: Motor adaptation of horizontal arm movements in a lateral force field with a nonlinear feed forward control implemented where $\alpha = 0.08$ and $\gamma = 0.001$ (Top) paths in repeated reaching arm movements in five different phases with different force fields, and (Bottom) maximum absolute lateral deviation during these phases.

Based on the results presented in Figure 2, when the feed forward nonlinear controller is activated with $\alpha = 0.08$ and $\gamma = 0.001$, the channel appears to effect the learning process of the force field. In the first null phase, phase 1, the trajectory is a straight line and the maximum lateral deviations are constant and approximately 0 - 0.001 throughout the entire phase. These results are expected, as there are no external forces impeding the arms movement.

In the first force field phase, phase 2, the trajectories range from a straight line to a line curving right, which shows that there must be motor learning occurring in this phase. The maximum lateral deviations demonstrate the same results. Initially, during the transition from phase 1 to phase 2, the deviations spike from zero to 0.0175; however, as more trials are completed, the deviations decrease quadratically for the rest of the phase until they reach approximately 0 – 0.001.

During phase 3, the channel phase, trajectory is a straight line and the maximum deviations instantly decrease from 0.0175 to approximately 0 - 0.001 and then stay constant for the remained of the channel phase.

In the second force field phase, phase 4, the trajectory of the arm is consistent and minimally deviates from the straight line. The maximum lateral deviations results change multiples time throughout phase 4. Initially, the deviations change from zero to 0.006 as the arm transitions from the channel to the force field. Throughout the phase, the deviations exhibit decreasing linear behavior from approximately 0.006 to 0.005. This demonstrates that when the force field is reactivated after the channel, the lateral deviations exhibit the same decreasing behavior as phase 2, but the deviations are not as large, therefore the arm has experienced some motor learning.

Finally, in phase 5 when the force field is turned off and the arm experiences another null field, the trajectory of the arm exhibits a curved pathway to the left of the straight line, indicating that the arm has experienced motor learning, because it is attempting to counter the effects of the force field which caused it to move right in phase 2. The maximal deviations demonstrate this behavior, as initially the values spike up from 0.005 to 0.015, but quickly linearly decrease from 0.015 to 0.01.

Part B

Different values of alpha and gamma were tested in this experiment. Initially alpha was kept constant at 0.08 and gamma was changed from 0.001 to 0.04 and 0.1, the results of these trials are shown in Figure 4. Next, the gamma variable was kept constant at 0.001 and the alpha variable was changed from 0.08 to 0.2. The results of this trial is presented din Figure 5 below.

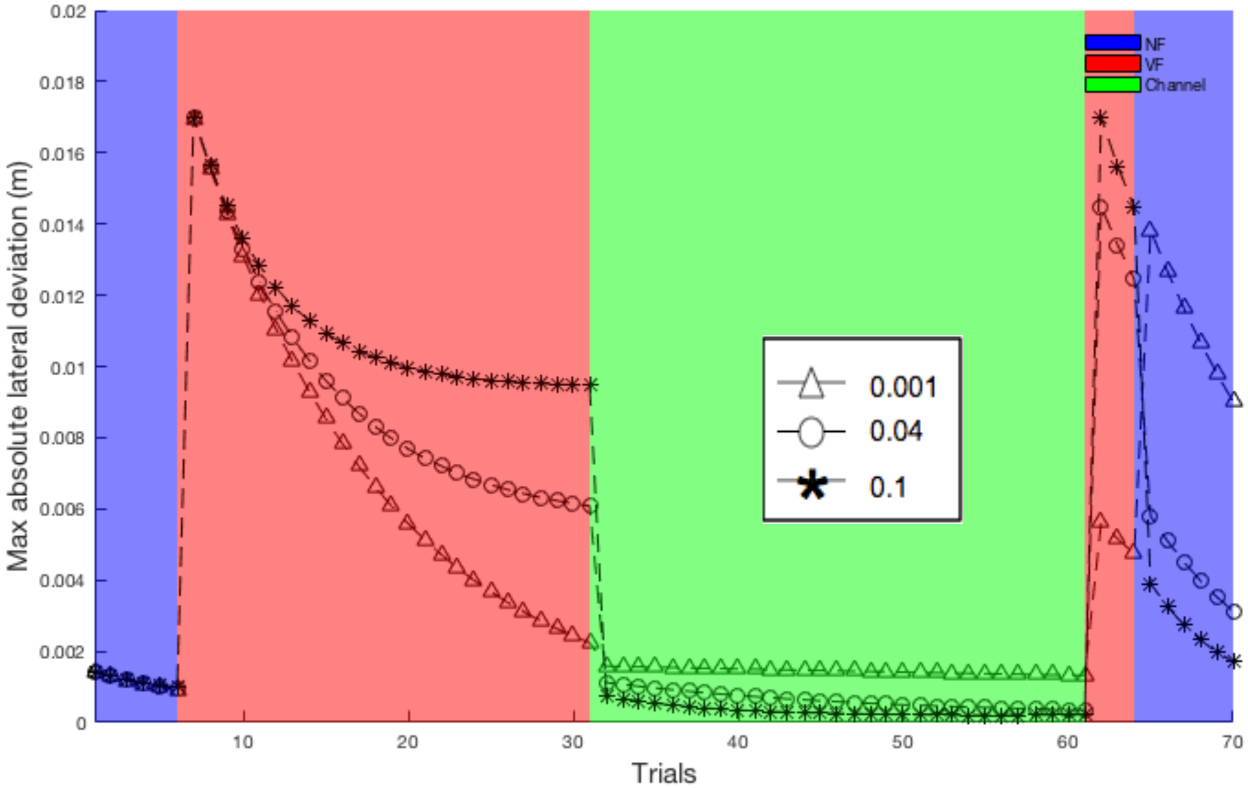

Figure 4: Motor adaptation of horizontal arm movements in a lateral force field with a nonlinear feed forward control implemented where α is kept constant at 0.08 and γ is changed from 0.001 [triangle] to 0.04 [circle] and 0.1 [star]. (Top) paths in repeated reaching arm movements in five different phases with different force fields, and (Bottom) maximum absolute lateral deviation during these phases.

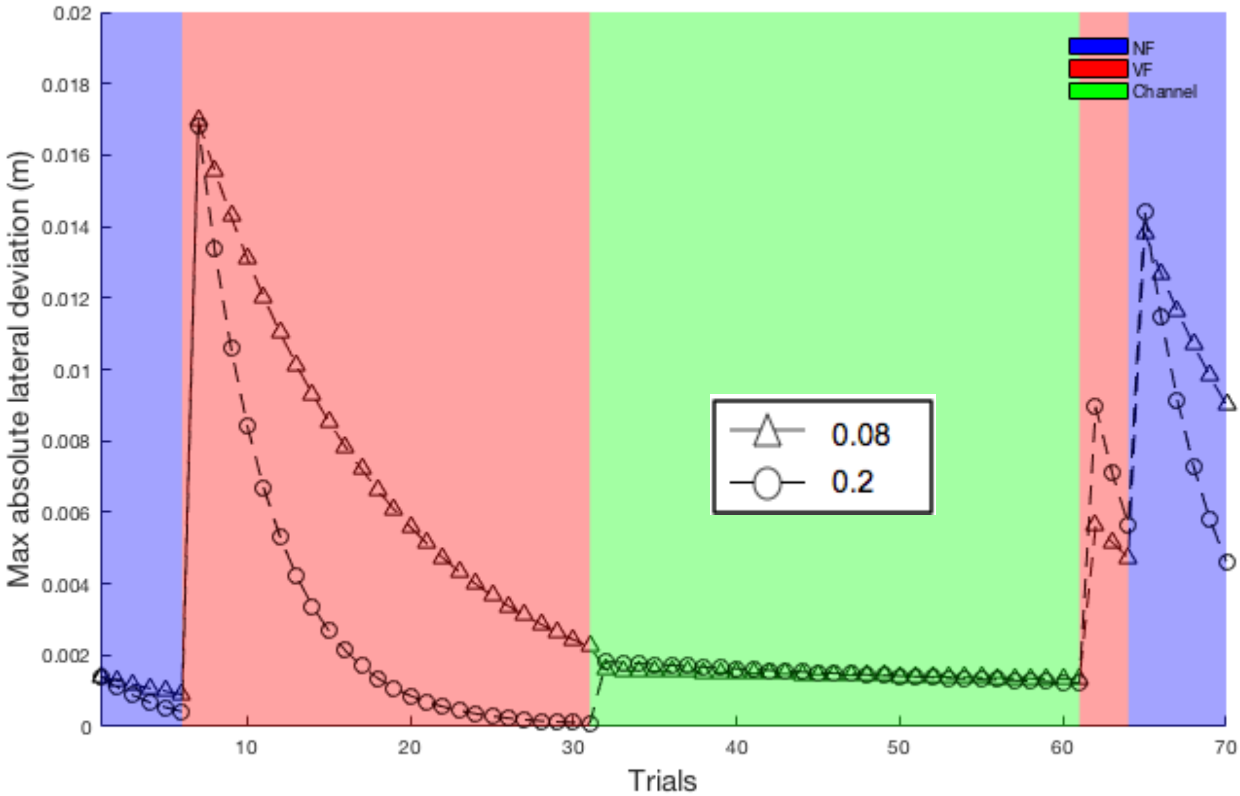

Figure 5: Motor adaptation of horizontal arm movements in a lateral force field with a nonlinear feed forward control implemented where α is 0.08 [triangle] and 0.2 [circle] and γ is kept constant at 0.001. (Top) paths in repeated reaching arm movements in five different phases with different force fields, and (Bottom) maximum absolute lateral deviation during these phases..

From Figure 4, it can be seen that as gamma is changed, the lateral deviations remain identical in the null field of phase 1 and the initial trial of phase 2 because each plot spikes up to the same value of 0.017 in phase 2. However throughout both force field phases a trend emerges. As, gamma increases, the steepness of the plot in both force field phases decreases. There are larger deviations present in phases 2 and 4 when gamma is 0.1 than when it is 0.001. For contrast, in phases 3 and 5, as gamma increases, the lateral deviations in the arm decrease. In the channel phase, as gamma increases, the deviations approach zero, where as in the null field of phase 5, as gamma increases, the deviations are clearly smaller.

From Figure 5, in phases 1 and 3, changing alpha has no effect on the lateral deviation plots. However, there is a contrasting effect between changing alpha in both force fields. In phase 2, when the force field is initially activated, the effect of increasing alpha cause the slope of the line to increase and lateral deviations to approach zero; however in phase 4, when the force field is re- activated for the second time, when alpha is increased, the lateral deviations are larger. In phase 5, it can be seen that the lowest resulting lateral deviations in the arm occur when alpha is increased.

Based on these results and by examining the equation for feedback, shown below, it can be inferred that future iterations of feed forward depend on alpha and gamma. The parameter alpha is the dependence on the feedback control from the previous time step, meaning that when it is increased, uFB(i) dominates. The parameter gamma has a dependence on the feed forward control from the previous time step, but it has an inverse relationship, meaning that when gamma decreases uFF(i) dominates.

$$uFF(i+1) = \alpha * uFB(i) + (1-\gamma) * uFF(i)$$

Part C

The maximum absolute lateral deviation of the data is represented in Figure 1 and the simulation in part A of this question is represented by Figure 2. To compare the washout null field, conditions of both plots we will be looking at phase 5. The data from Figure 1 in phase 5 has no clear relationship, all of the data points are spread out horizontally between approximately 0 lateral deviations and no more than 0.02, while the results from the simulation in Figure 2 demonstrate a linearly, decreasing pattern from 0.015 to 0.01.

The parameter gamma is causing this difference. The reasoning behind this decision is because feed forward is dependent on gamma. When you look at the graph of Figure 4, when gamma is changing, the plots are offset from each other in phases 4 and 5. However when you look at figure 5, when alpha is changing, the plots differ via their slope.

There is a difference between the washout field of phase 5 and the first force field, phase 2 because motor learning retention has transpired between these two phases. During phase 2, motor learning is taking place, due to repetition in the trials of the experiment. However, in phase 3 and 4, the arm is put through scenarios that test the retention level of that learning, therefore in phase 5, the movements are not identical.

Appendix

The results for this assignment were determined using the MATLAB code given to us. I kept the script relatively unchanged, but the line of code that I did change/add was for the feed forward controller. The equations are presented as follows.

```
    if Trial>1
        uFF(:,:,Trial) = Alpha(NUM)*uFB(:,:,Trial-1) + (1-
Gamma(NUM))*uFF(:,:,Trial-1);
    end
```