Tutorial 4: Iterative control modelling of motor adaptation

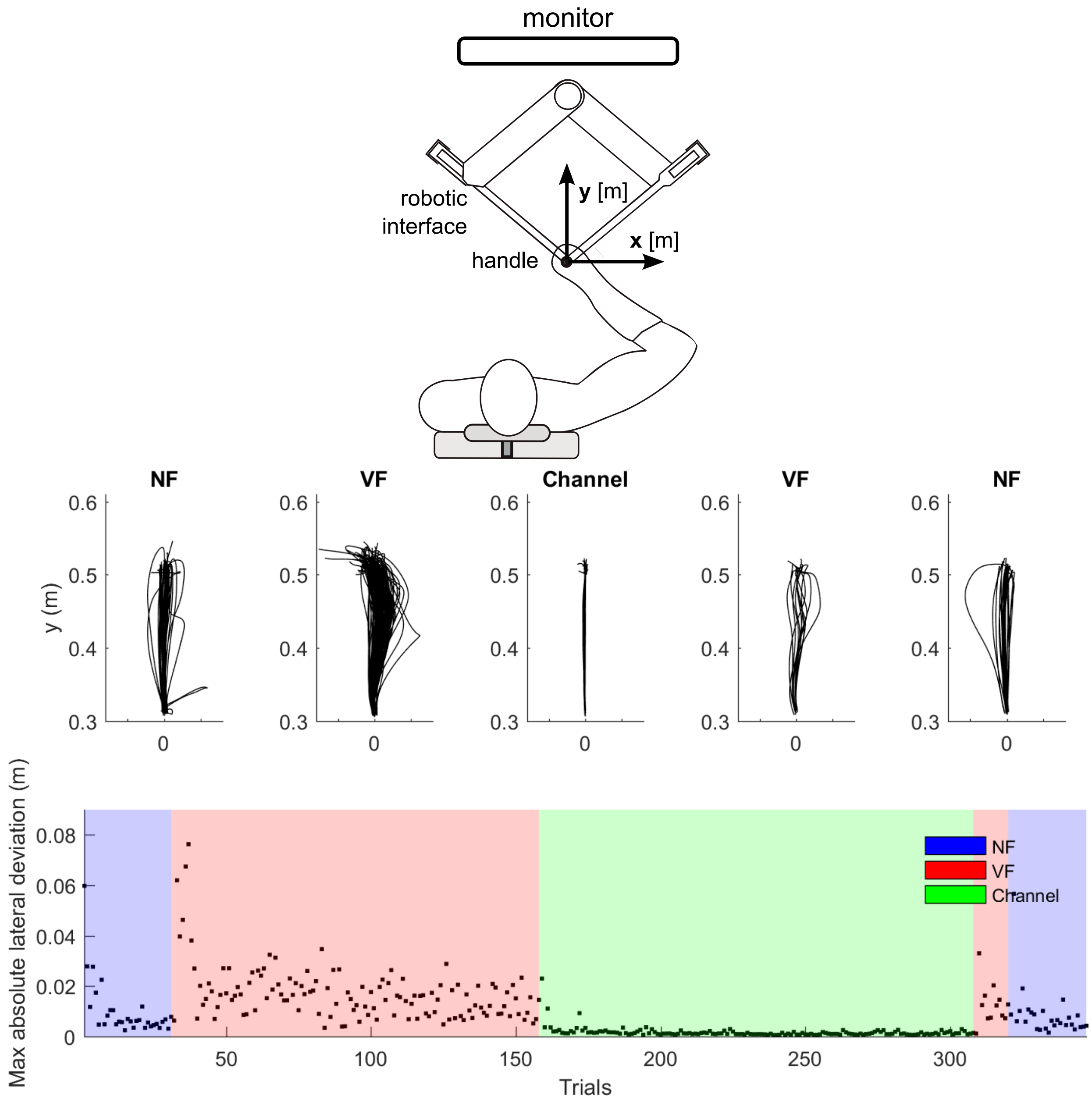

Figure 1: Motor adaptation of horizontal arm movements in a lateral force field. (top) Experimental setup, (middle) paths in repeated reaching arm movements, and (bottom) corresponding maximum absolute lateral deviation.

An experiment was conducted to investigate how humans adapt horizontal arm movements in an unknown force field. Figure 1 shows the experimental setup and results. A subject used their hand to hold onto a handle of a 2DOF robotic device, which records the kinematics of the movement and provides force perturbations. The subject went through 5 conditions:

Null field (NF) First, the subject performed 32 point-to-point reaching movements in the null-field (NF) condition, i.e. the subject experiences no forces from the interface.

Velocity-dependent force field (VF) Next, the subject did the same reaching movements but the interface applied a velocity-dependent force

$$\mathbf{F}_{\mathrm{VF}} = \begin{bmatrix} 0 & 25 \\ -25 & 0 \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} N \tag{1}$$

where $\dot{x}$ and $\dot{y}$ are the velocities (m/s) in the x and y dimensions; the subject completed 127 movements in this velocity-dependent force field (VF) condition.

Force channel In the third condition, the subject did the same reaching whilst the interface constrained the movement along the $\{x = 0\}$ line through a strong force channel

$$\mathbf{F}_{\mathrm{c}} = \begin{bmatrix} -10000\,x \\ 0 \end{bmatrix} N. \tag{2}$$

The force channel guides the subject's movement in x, but not in the movement direction y. The subject went through 150 force channel trials.

Re-testing VF In the second final condition, the subject once again completed 12 reaching movements in the VF to test the retention of the motor adaptation in the previous VF.

Washout NF Finally, the subject performed 26 reaching movements in NF to observe their re-adaptation to the normal, unperturbed environment.

Question 1: Experiment (5 marks)

Describe what is happening to the deviation in the VF. Justify whether the channel hinders the retention of the motor adaptation in the first VF condition.

Question 2: Computational modelling (15 marks)

A proportional-derivative feedback controller guides the arm along a pre-defined straight-line trajectory, as in the NF condition in the data. If the motion of the arm is disturbed, the controller will send motor commands to the joints to stay along the NF trajectory. If the disturbance is similar trial after trial, these motor commands from the feedback controller can be gradually identified, i.e. a series of *feedforward (FF) motor commands* can be learned iteratively from the feedback motor commands.

For each shoulder and elbow joints, the feedback motor commands sent to this joint will be

$$u_{\mathrm{FB}}(t) = Pe(t) + D\dot{e}(t) \tag{3}$$

where P and D are the proportional and derivative gains, and $e(t) = q_d(t) - q(t)$ is the difference between the desired ($q_d(t)$) and current ($q(t)$) joint angles at time t. The feedforward command along the movement at trial j will be given by

$$u^{j}_{\mathrm{FF}}(t) = \alpha\, u^{j-1}_{\mathrm{FB}}(t) + (1-\gamma)u^{j-1}_{\mathrm{FF}}(t) \tag{4}$$

where u^{j-1}_{FB} is the feedback command at the $(j-1)^{\mathrm{th}}$ trial, $\alpha > 0$, $\gamma > 0$ are rates of change (you will see their effects in the question). The total motor command sent to the joint at trial j is

$$u(t)^j = u_{\mathrm{FB}}(t)^j + u_{\mathrm{FF}}(t)^j\,. \tag{5}$$

(a) Implement the nonlinear feedforward control in eqs.(3 to 5) for both the shoulder and elbow joints to follow the given desired trajectory *NFTraj* in the code. Use the values of $\alpha \equiv 0.08$ and $\gamma \equiv 0.001$ for your feedforward controller. You must simulate the trials in **all conditions** (the number of trials in each condition is predefined in the MATLAB code).

Create the same plot as Figures 1b&c, but for your simulations, describe the difference in the maximum lateral deviation in the last NF condition between the data and your simulation.

Note: the MATLAB script has the variables *NFTraj* and *qDesired* which conveniently contain the desired trajectory in Cartesian and joint coordinates (refer to the top of Tutorial4.m to see what is contained in each row).

[10 marks]

Plot Hint: An example MATLAB plot code was provided. This is the script we used to plot Figure 1 from the experimental data. You can use the script as a guideline and adapt it to plot your simulation results.
Alternatively you can create a single figure with 2×5 *subplots*; on the top row, plot the simulated trajectories for each condition. On the bottom row, plot a single subplot with the maximum absolute lateral deviation (i.e. maximum absolute value in x) of the trajectory in as a function of the trial number, which should be continuously counting up from the first condition. Use the *fill* function to colour the background of the plot with each condition (NF, VF and channel).

(b) Repeat your simulations with different values for α and γ. Describe how these two parameters affect your simulations, using maximum lateral deviation plots to support your argument. When comparing the maximum lateral deviation between different simulation parameters, please place them on the same plot.

[3 marks]

(c) What is different between the maximum absolute lateral deviation in the data and your simulation in Q2(a) in the washout NF condition? What parameter α or γ is causing this difference, and why would it be different between the first VF and the washout NF?

[2 marks]