Smith, Ghazizadeh, Shadmehr - Interacting Adaptive Processes with Different Timescales Underlie Short-Term Motor Learning (2006)

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```
clear; clc;
cd('/Users/duncan/OneDrive - University of Delaware - o365/Documents
```

Two State State-Space Model

$$x_1(n+1) = A_f \cdot x_1(n) + B_f \cdot e(n)$$

$$x_2(n+1) = A_s \cdot x_2(n) + B_s \cdot e(n)$$

$$B_f > B_s, A_s > A_f$$

$$x = x_1 + x_2$$

Variables:

$x(n)$ – *Net motor output on trial n*

x_1, x_2 – *Internal states that contribute to the net motor output*

$e(n)$ – *Error on trial n*

B – *Learning rate*

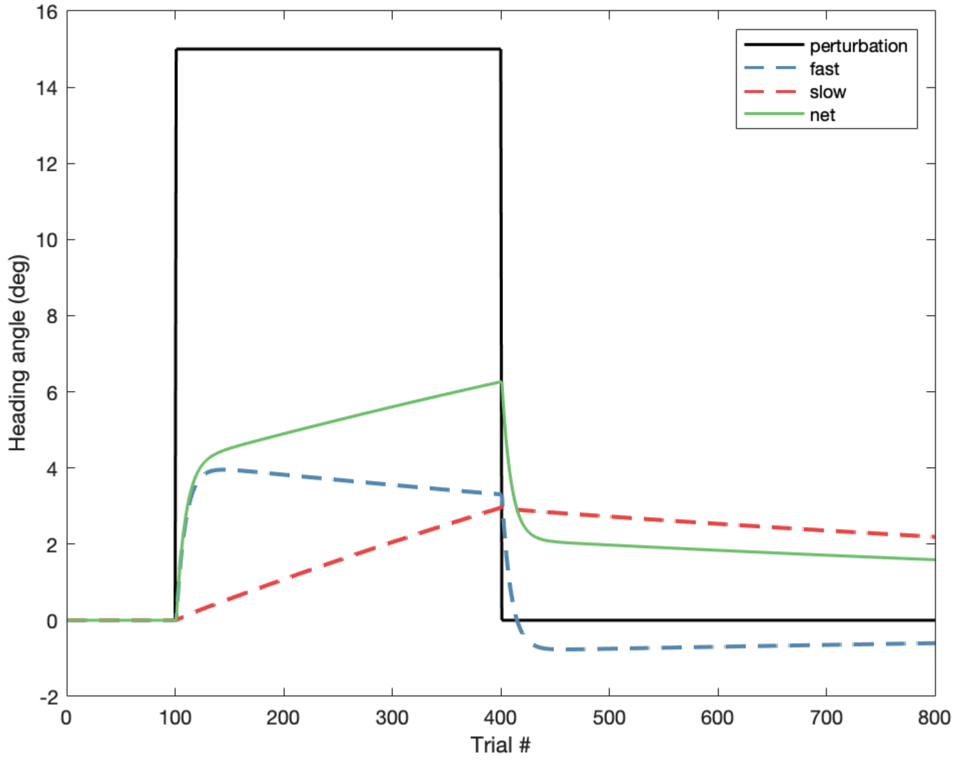
A – *Retention factor*

```
% Perturbation Schedule
schedule = nan([1 800]);
schedule(1:100) = 0; % baseline
schedule(101:400) = 15; % adaptation
schedule(401:800) = 0; % de-adaptation

Af = 0.92; As = 1;
Bf = 0.03; Bs = 0.001;
[fast,slow] = twoSSM(schedule, Af, As, Bf, Bs);
```

```
net = fast+slow;

% visualize
cc = linspecer(3);
figure();
plot(1:800, schedule, 'k-', 'linewidth', 1.5, 'displayname', 'pertur
hold on
plot(1:800, fast, '--', 'color', cc(1,:), 'linewidth', 1.5, 'display
plot(1:800, slow, '--', 'color', cc(2,:), 'linewidth', 1.5, 'Display
plot(1:800, net, '-', 'color', cc(3,:), 'linewidth', 1.5, 'DisplayNa
xlabel('Trial #'); ylabel('Heading angle (deg)');
legend('location', 'best')
```



Simulate expeirment

```
rotationD = 15; % degrees
T1 = [0 0]; T2 = [0 10]; % targets

reaching = net + rnd_btw(-1, 1, size(net));

% visualize
figure('visible', 'on', 'position', [400 400 800 400]);
```

```
% behavior
subplot(1,2,1);
plot(T1(1), T1(2), 'go', 'markersize', 10, 'linewidth', 2, 'DisplayN
hold on
plot(T2(1), T2(2), 'mo', 'markersize', 10, 'linewidth', 2, 'DisplayN
plot(T1(1), T1(2), 'o', 'color', [.7 .7 .7], 'markerfacecolor', [.7
plot(T1(1), T1(2), 'wo','markerfacecolor', 'w', 'markersize', 8, 'li
axis padded
ax1 = gca;
set(ax1, 'ylim', [-2 17])
kBackground(ax1);
xlabel('X (cm)'); ylabel('Y (cm)');
% paper figure
subplot(1,2,2);
plot(1:800, schedule, 'k-', 'linewidth', 1.5, 'displayname', 'pertur
hold on
plot(1:800, fast, '--', 'color', cc(1,:), 'linewidth', 1.5, 'display
plot(1:800, slow, '--', 'color', cc(2,:), 'linewidth', 1.5, 'Display
plot(1:800, net, '-', 'color', cc(3,:), 'linewidth', 1.5, 'DisplayNa
plot(1:800, reaching, 'o', 'color', cc(3,:), 'markersize', 7, 'displ
xlabel('Trial #'); ylabel('Heading angle (deg)');
legend('location', 'best')
ax2 = gca;
% simulate reaches
x_reach = @(radius, theta, originX) radius * cosd(theta) + originX;
y_reach = @(radius, theta, originY) radius * sind(theta) + originY;
x_rot = @(x,y,rot) x * cosd(rot) - y * sind(rot);
y_rot = @(x,y,rot) x * sind(rot) + y * cosd(rot);
for t = 1:20:length(reaching)

    % highlight dot on experiment figure
    plot(ax2, t, reaching(t), 'go', 'markerfacecolor', 'r', 'display

    % reach with bell shaped velocity
    [reachXR, reachYR] = T1reachT2(T1, [x_reach(0, reaching(t), T1(1
    for i = 1:15:length(reachXR)
        % hand
        set(ax1.Children(2), 'xdata', reachXR(i));
        set(ax1.Children(2), 'ydata', reachYR(i));
        if t >= 101 && t <= 400
            % cursor
            set(ax1.Children(1), 'xdata', x_rot(reachXR(i), reachYR(
            set(ax1.Children(1), 'ydata', y_rot(reachXR(i), reachYR(
        else
            % cursor
            set(ax1.Children(1), 'xdata', reachXR(i));
            set(ax1.Children(1), 'ydata', reachYR(i));
        end
        pause(0.001);
    end
    pause(0.01)
    % reach back
    for i = length(reachXR):-15:1
        % hand
        set(ax1.Children(2), 'xdata', reachXR(i));
        set(ax1.Children(2), 'ydata', reachYR(i));
        % cursor
        if t >= 101 && t <= 400
            % cursor
            set(ax1.Children(1), 'xdata', x_rot(reachXR(i), reachYR(
            set(ax1.Children(1), 'ydata', y_rot(reachXR(i), reachYR(
        else
            % cursor
            set(ax1.Children(1), 'xdata', reachXR(i));
            set(ax1.Children(1), 'ydata', reachYR(i));
        end
        pause(0.001);
    end

    % delete hilighted
    delete(ax2.Children(1));
end
```

```
function [fast, slow] = twoSSM(schedule, Af, As, Bf, Bs)
% INPUTS:
% schedule: perturbation schedule
% Af, Bf, As, Bs: parameters

% OUTPUTS:
% adaptVec: adaptation vector

% ICs
```

```
x_1 = 0;
x_2 = 0;
net = 0;

fast = zeros(size(schedule));
slow = zeros(size(schedule));

for i = 1:length(schedule)-1
    % error
    er = schedule(i) - net;
    % fast
    fast(i+1) = Af * x_1 + Bf * er;
    % slow
    slow(i+1) = As * x_2 + Bs * er;
    % net
    net = fast(i+1) + slow(i+1);
    % update
    x_1 = fast(i+1);
    x_2 = slow(i+1);
end

end
```