What (some) models can and cannot do

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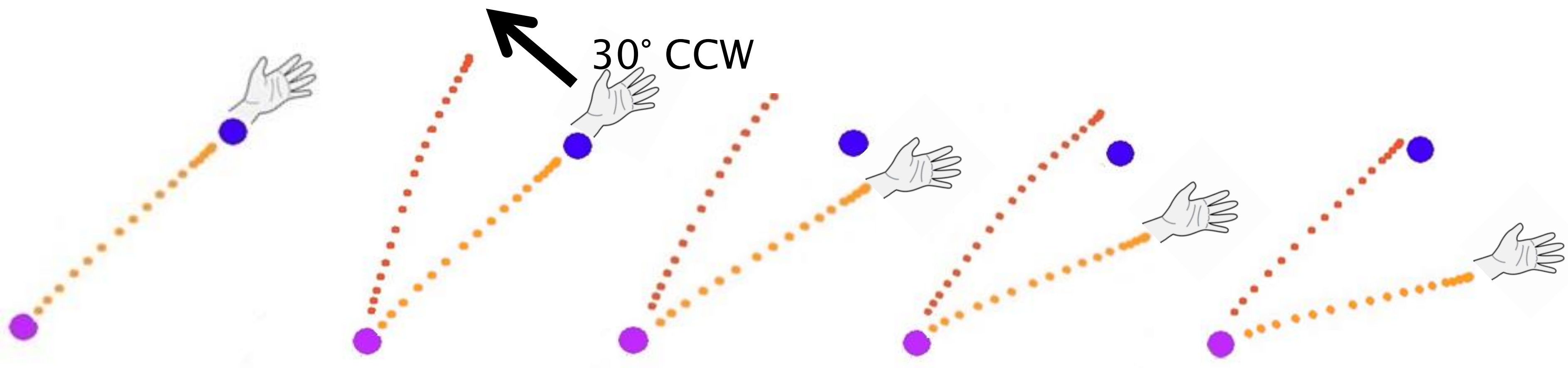
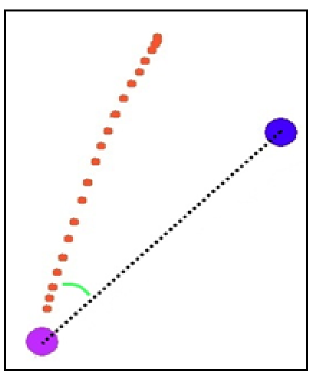
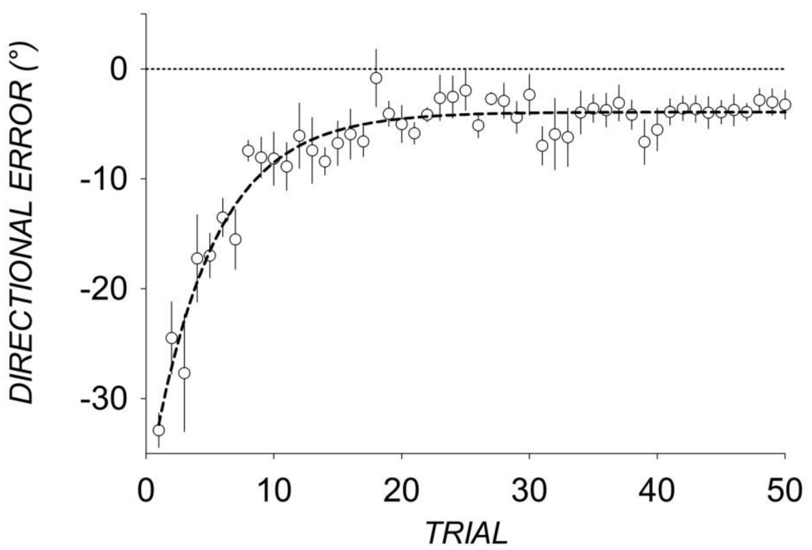
Visuomotor adaptation



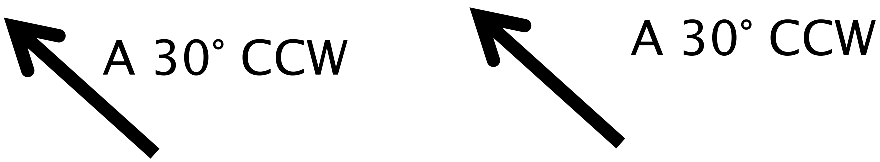


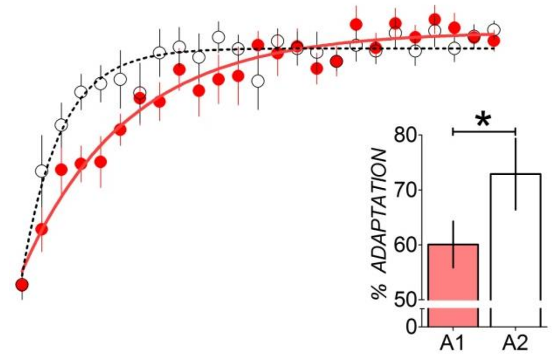
Directional error



Savings: Better subsequent learning

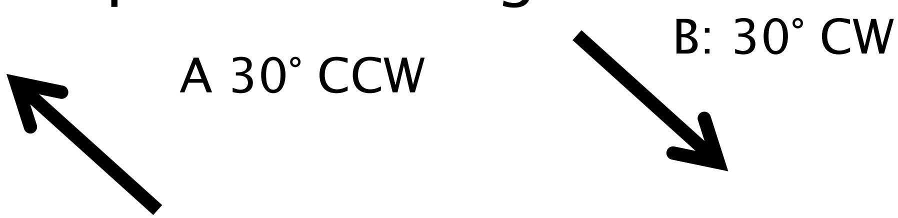
Perturbation in initial learning same as that in subsequent learning

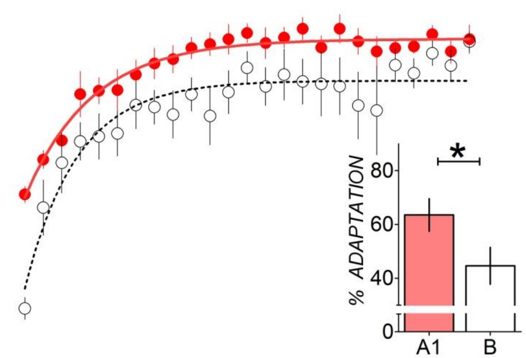




Anterograde Interference: Worse subsequent learning

Perturbation in initial learning opposes that in subsequent learning





Two-State Model

- Fast state: adapts quickly but poor retention
- Slow state: adapts slowly but good retention.

Key assumption:

learning rates $B_{slow} < B_{fast}$

retention rates $A_{fast} < A_{slow}$

$$x_{fast}(n+1) = A_{fast}\, x_{fast}(n) + B_{fast}\, e(n);$$

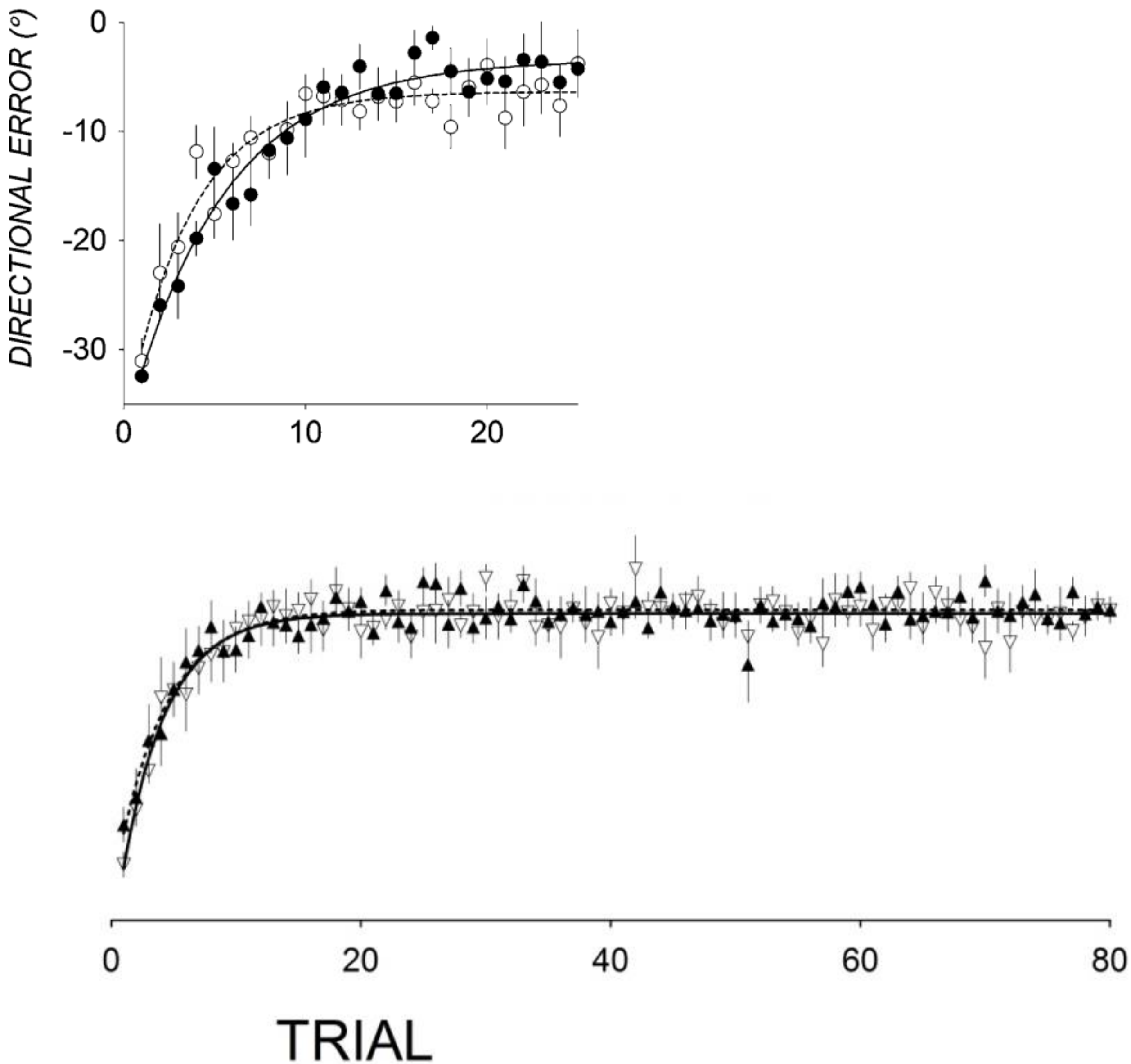
$$x_{slow}(n+1) = A_{slow}\, x_{slow}(n) + B_{slow}\, e(n)$$

$$x(n) = x_{slow}(n) + x_{fast}(n);$$

$$e(n) = perturbation - x(n);$$

(Smith, Ghahzizadeh, Shadmehr, 2006)

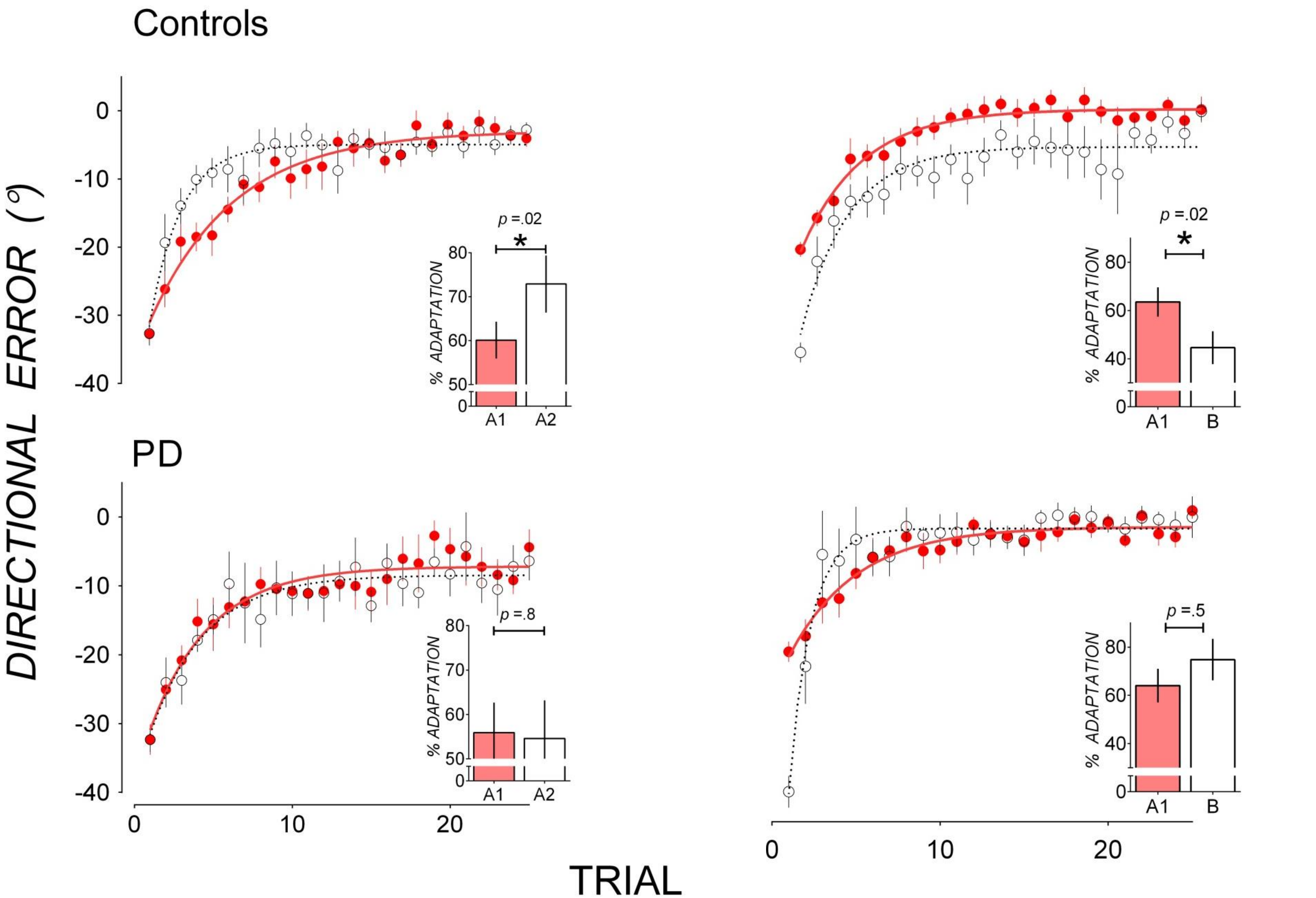
PD patients show intact learning from fast state

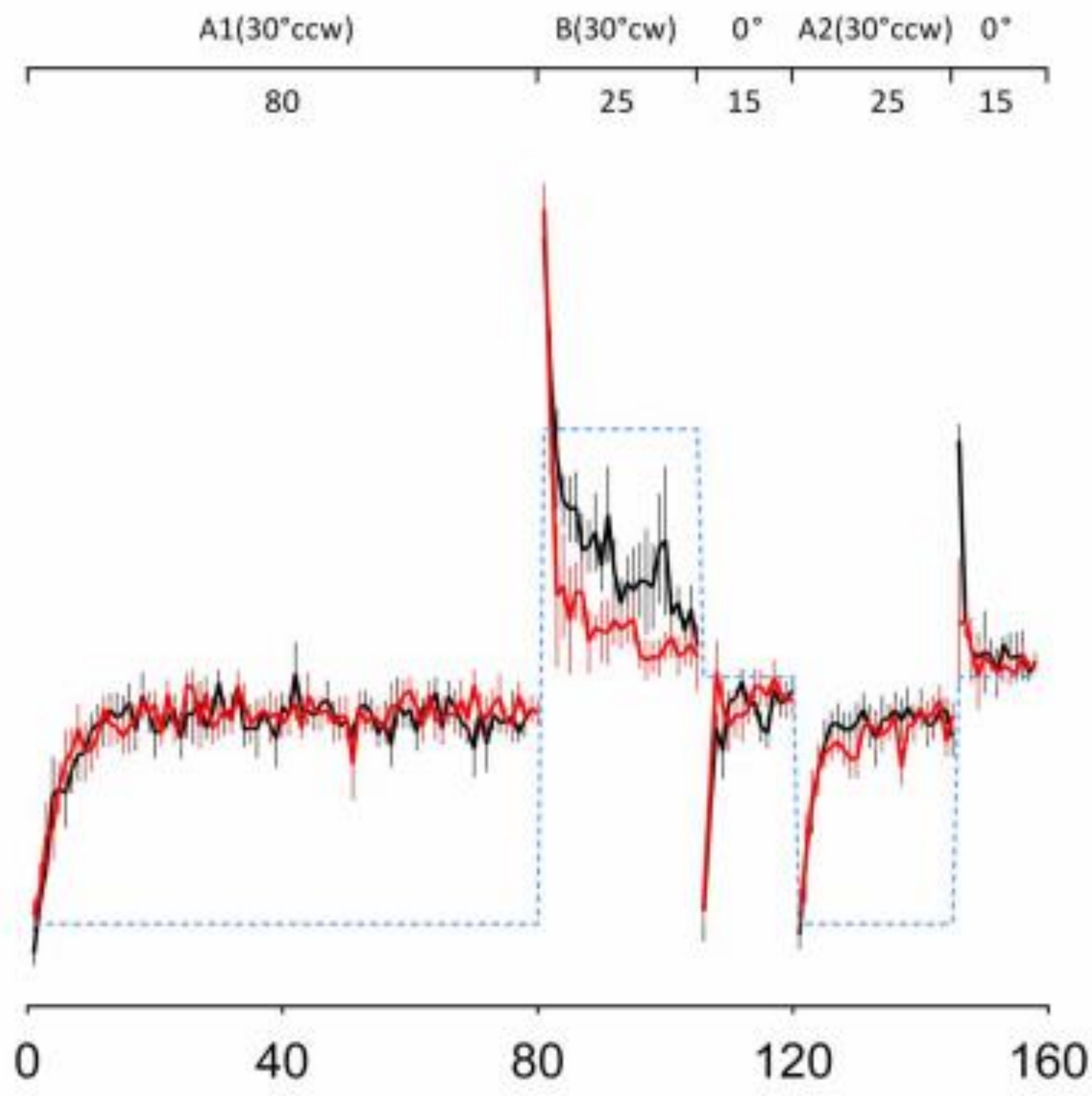


PD: selective impairment of the slow state

Savings

Anterograde Interference

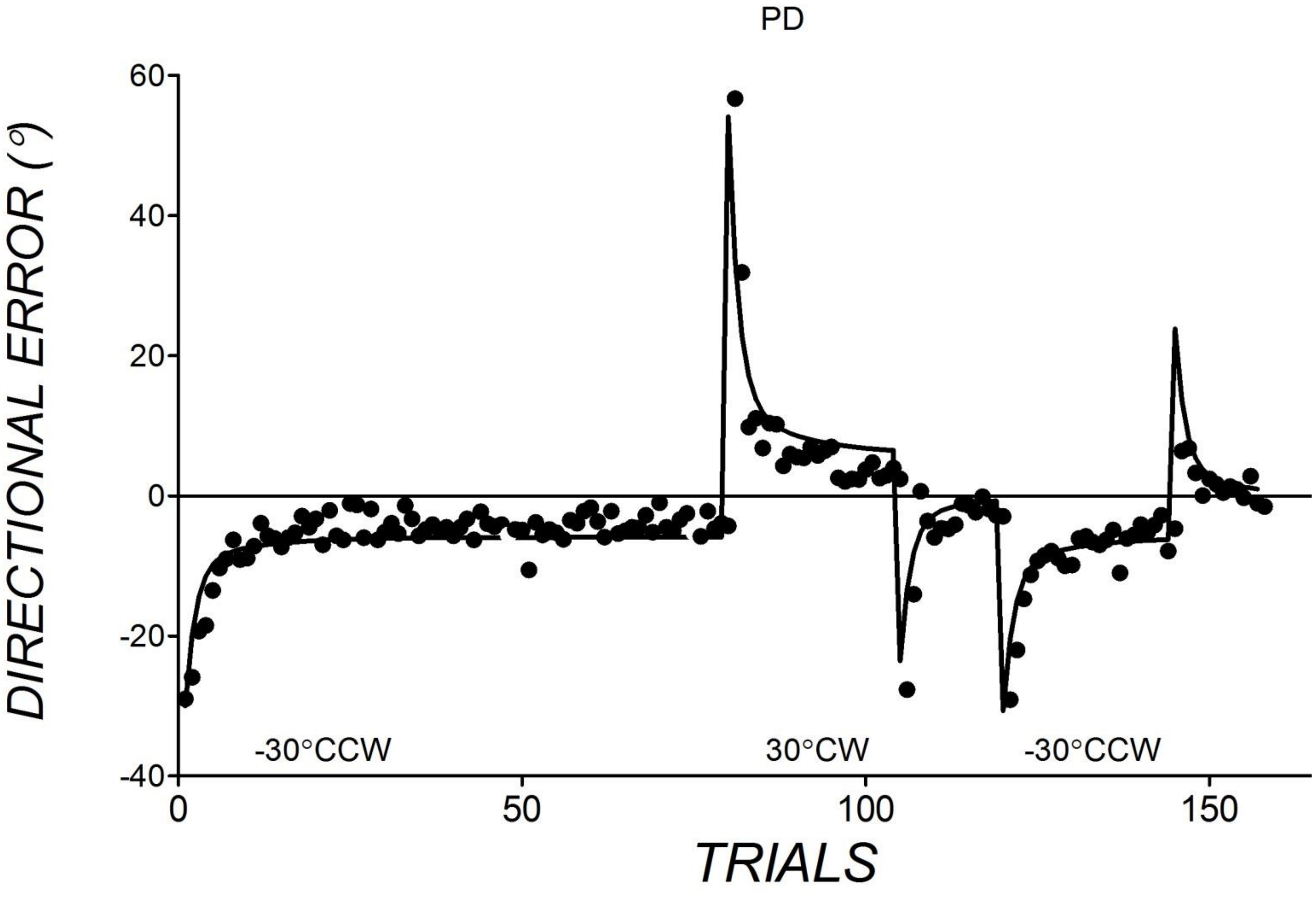



A1(30°ccw)
B(30°cw)
0°
A2(30°ccw)
0°
80
25
15
25
15
0
40
80
120
160

PD: more consistent with a one-state model

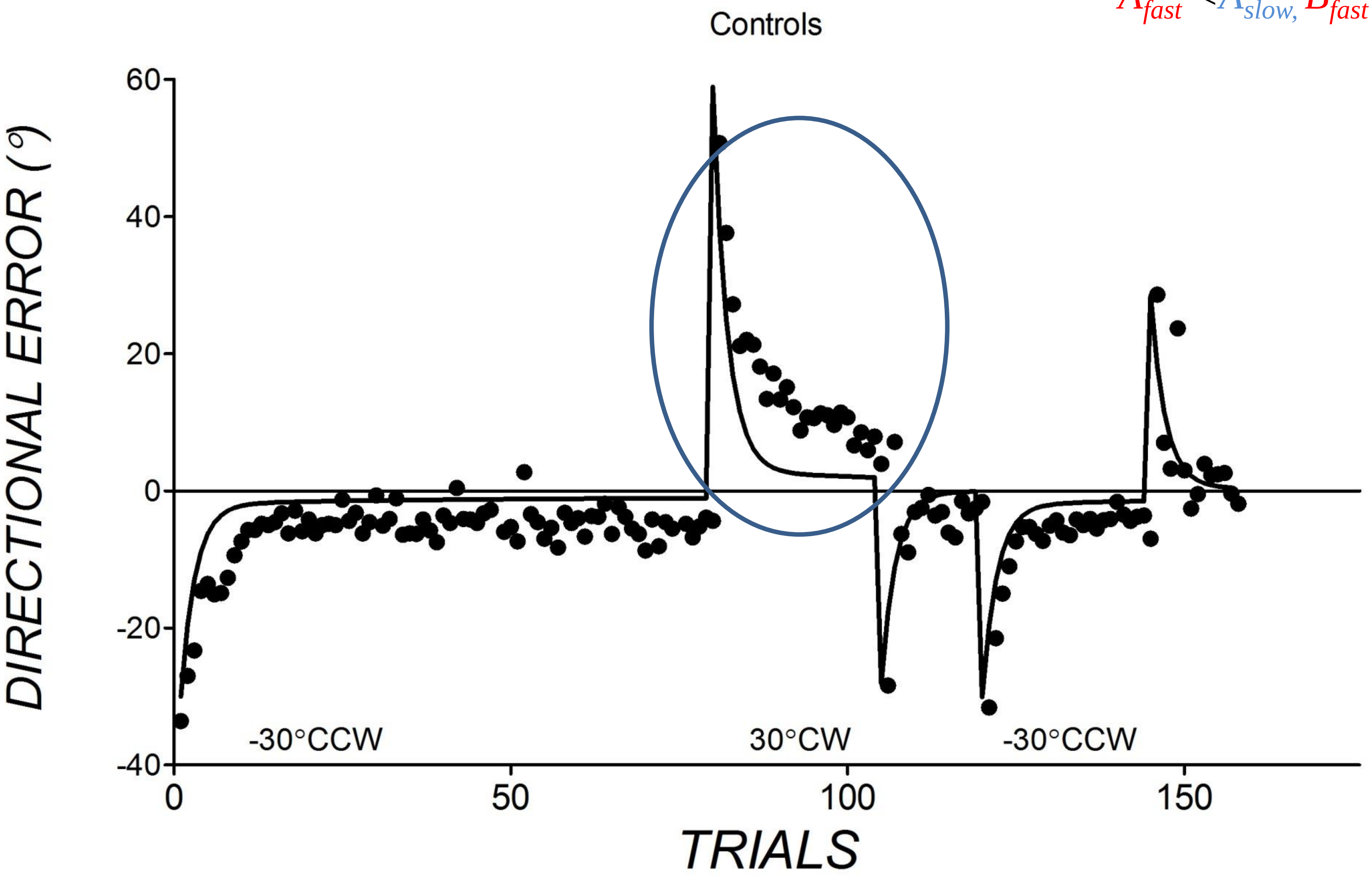
Two state model: $A_{fast} < A_{slow}, B_{fast} > B_{slow}$

PD: $A_{fast} \approx A_{slow}, B_{fast} \approx B_{slow}$



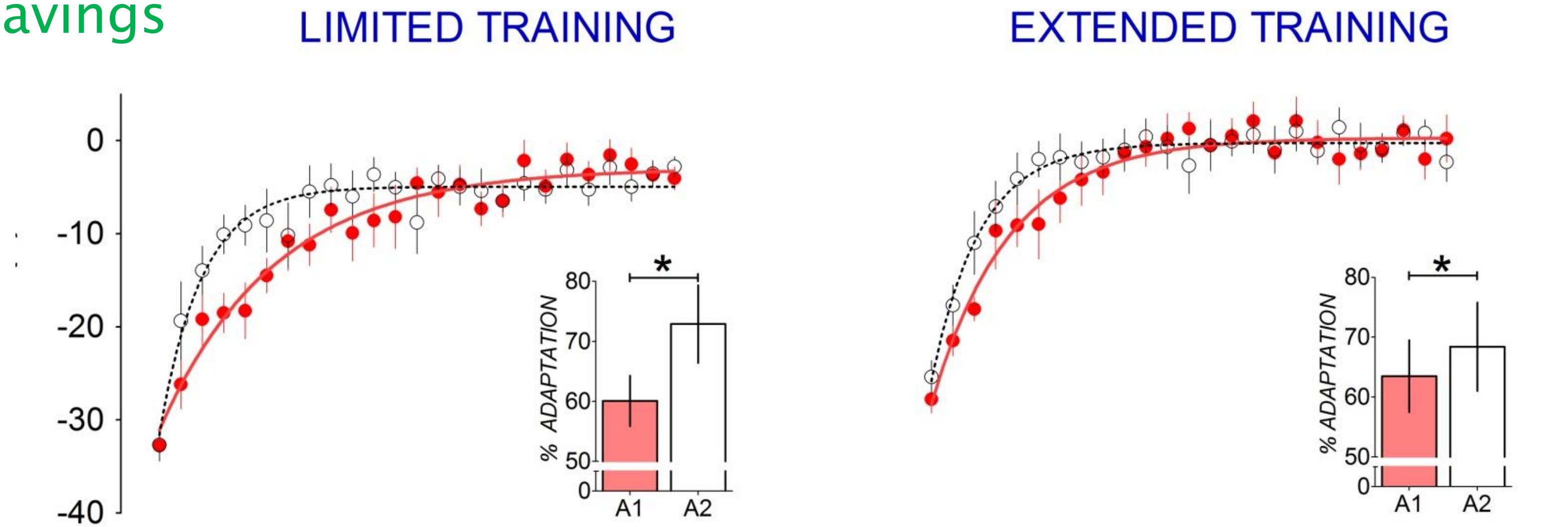
Two-state model cannot explain both anterograde interference and savings

$A_{fast} < A_{slow}, B_{fast} > B_{slow}$

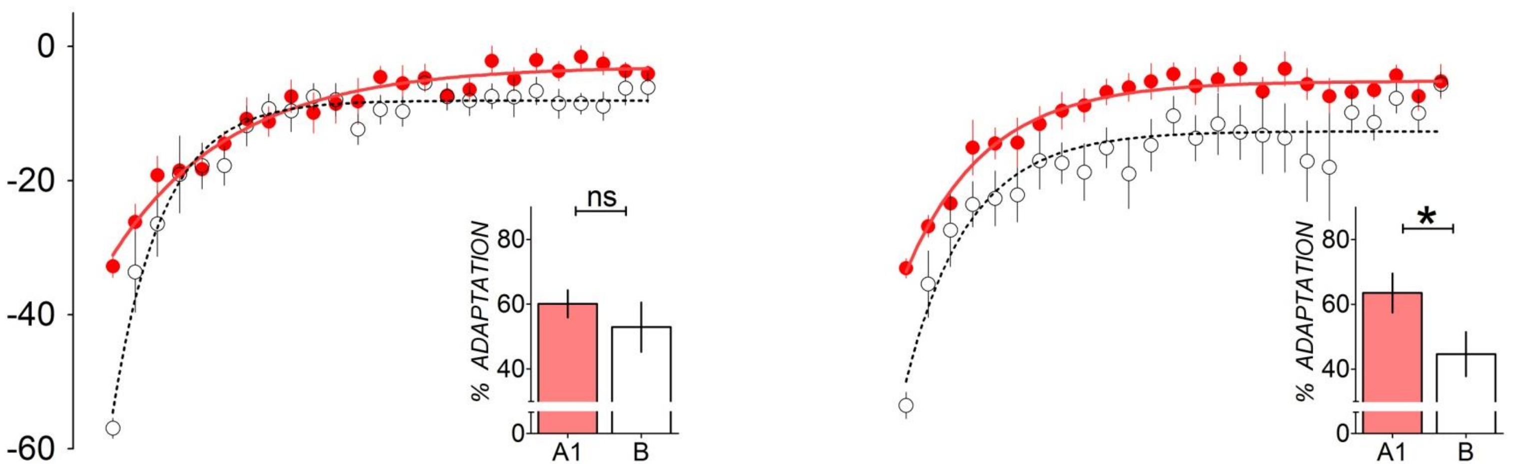


Anterograde interference requires more training than savings. Different mechanisms?

Savings



Interference



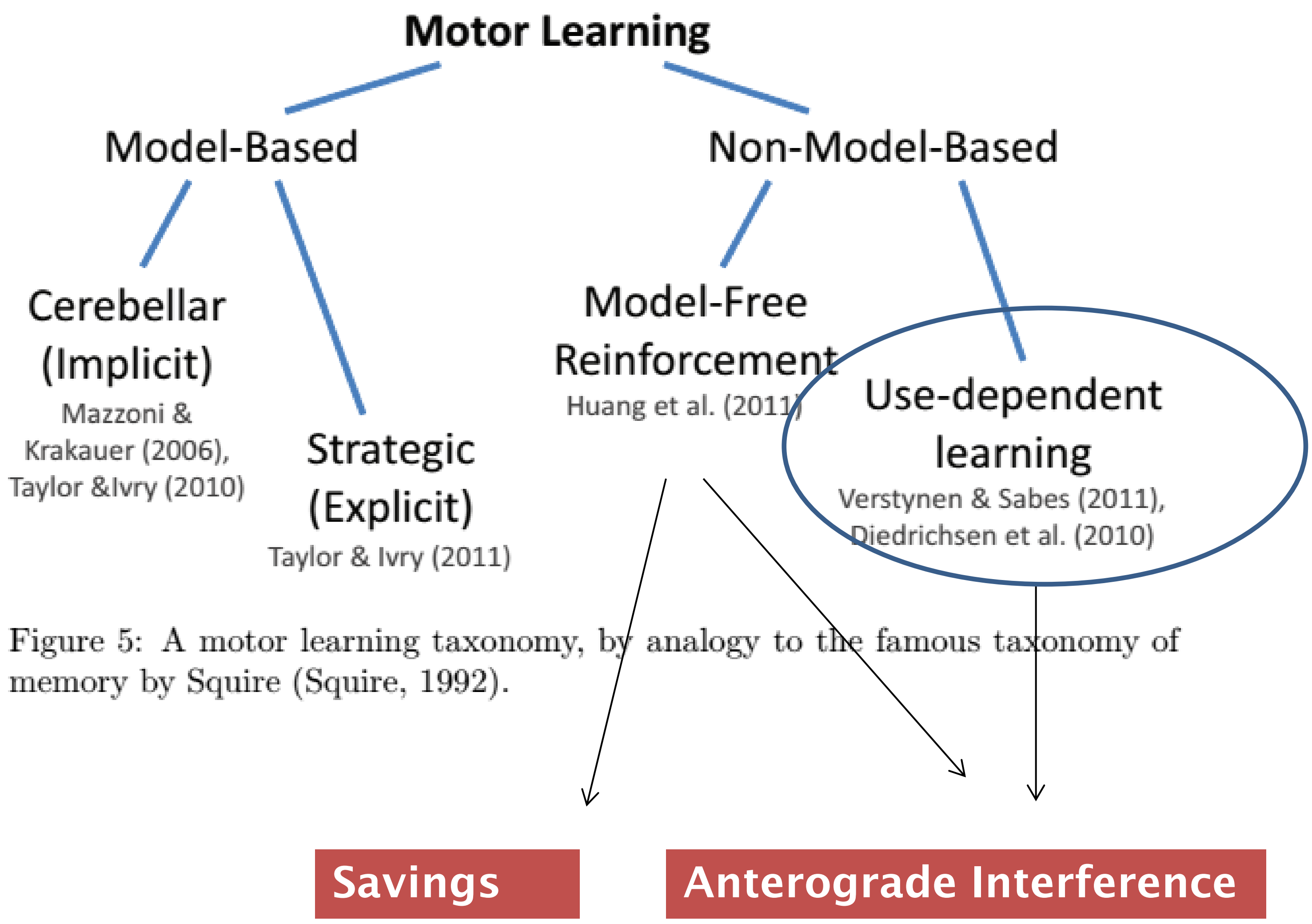
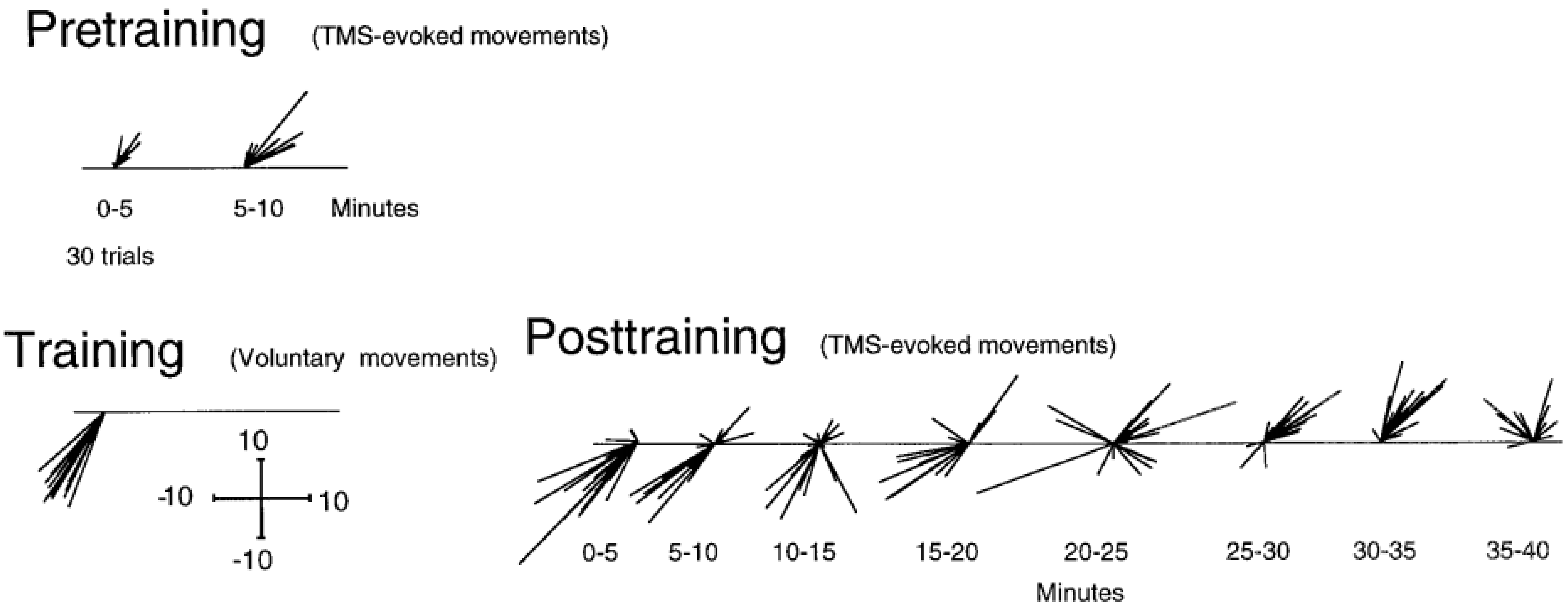


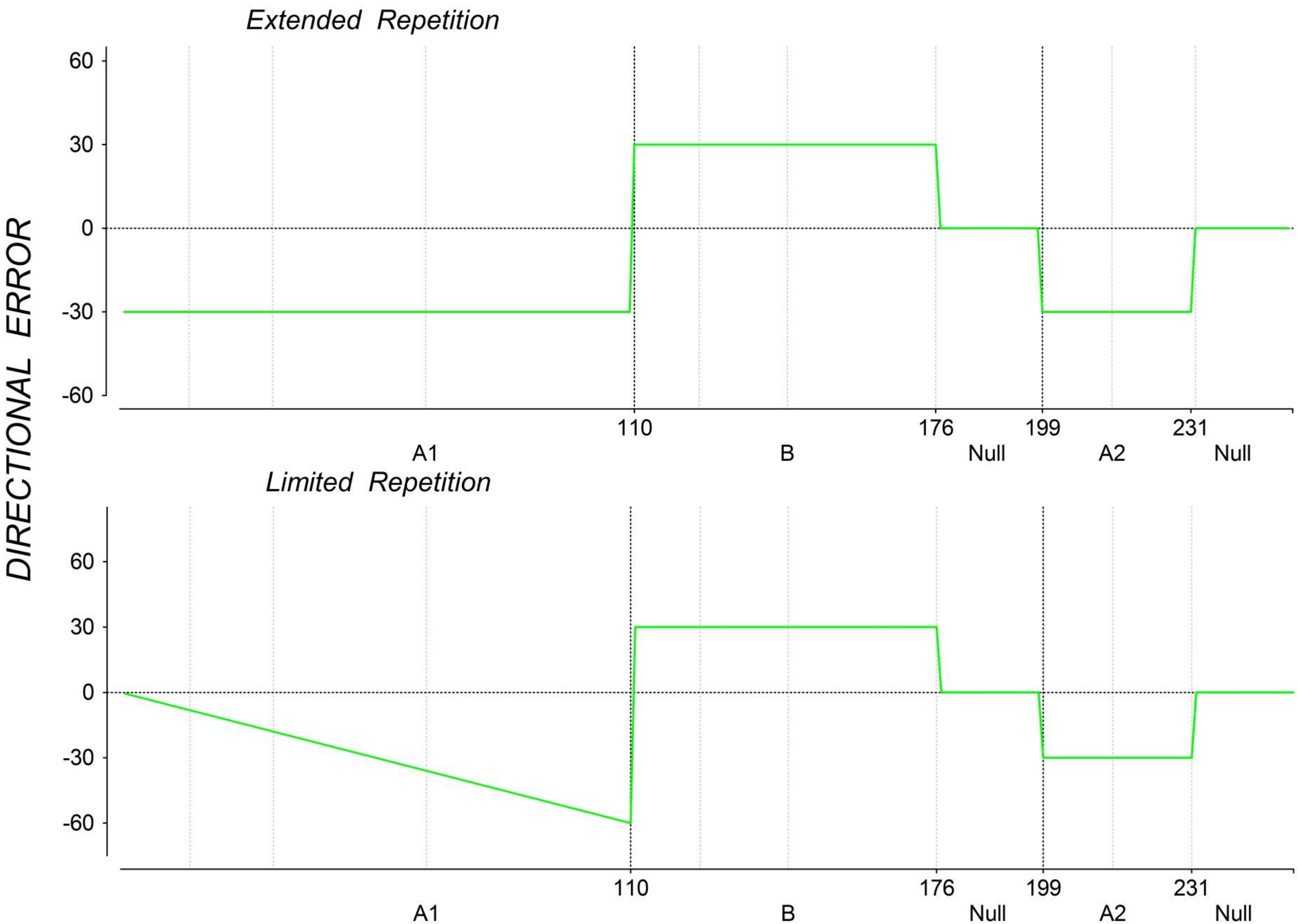
Figure 5: A motor learning taxonomy, by analogy to the famous taxonomy of memory by Squire (Squire, 1992).

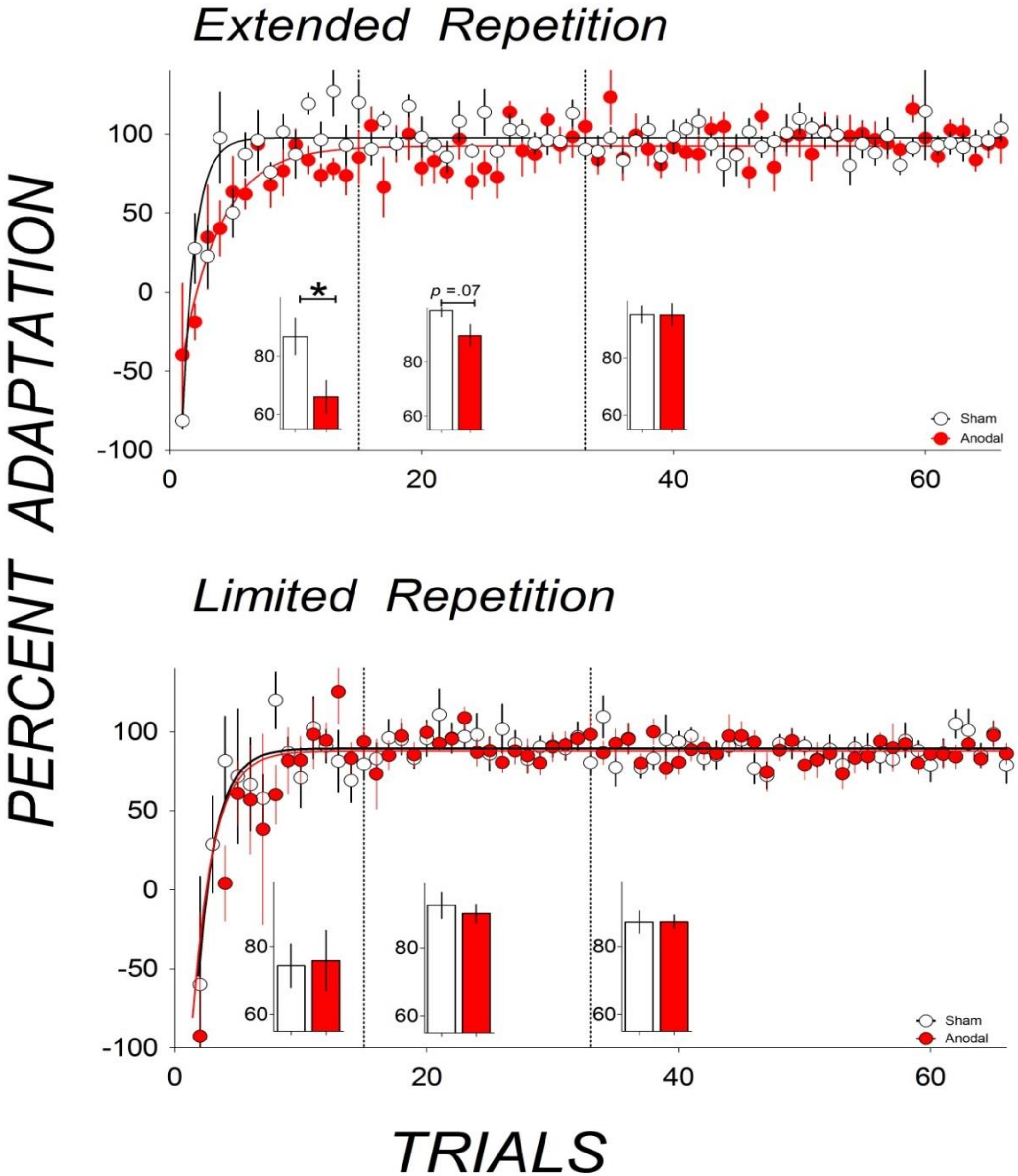
Use-dependent plasticity

Movement repetition biases subsequent movements to be similar to the repeated movement (Classen et al. 1998).

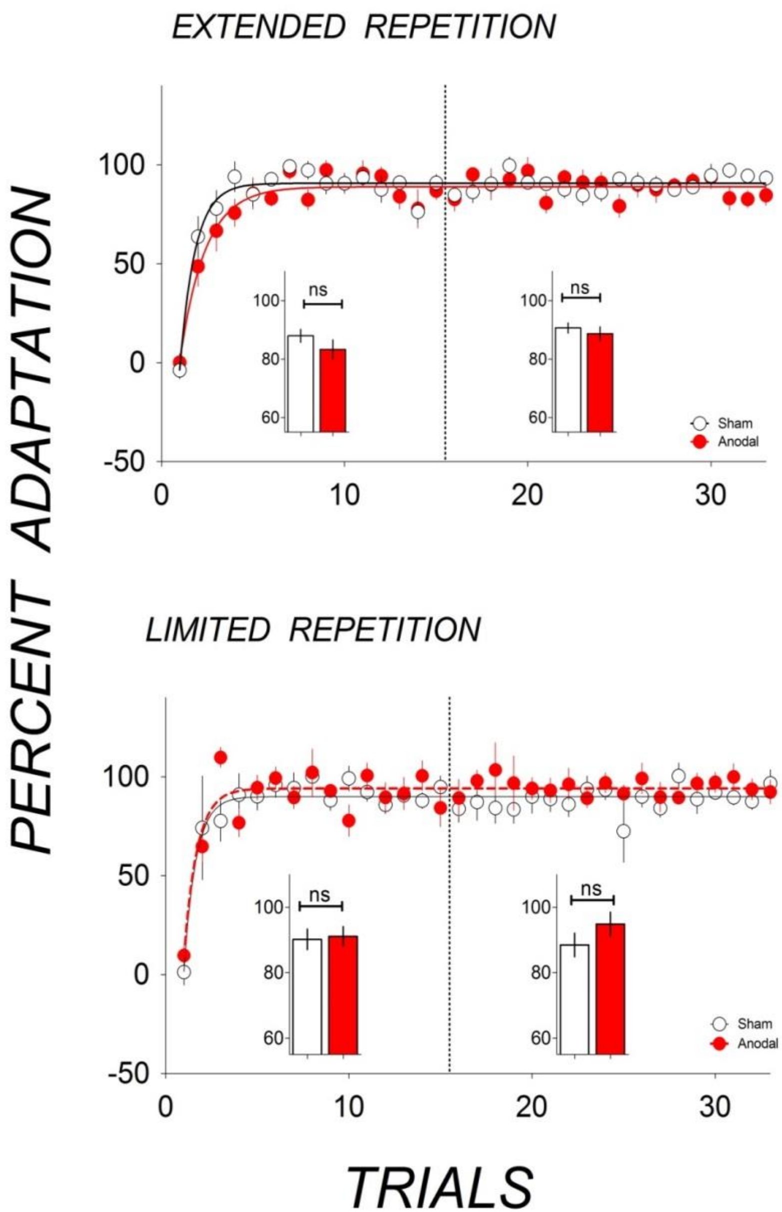


Can anterograde interference be increased by augmenting use-dependent plasticity with motor cortex tDCS?





Increasing use-dependent plasticity increases anterograde interference



Increasing use-dependent plasticity does not increase savings

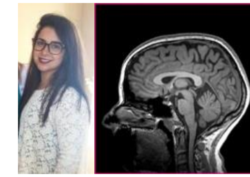
Use-dependent plasticity=Increased likelihood of moving in one direction given prior history of moving in that repeated movement direction

When recent movements are made to a target location, subsequent movements to that target become less variable, but at the cost of increased bias for reaches to other targets.

Variance-bias tradeoff: Bayesian estimation.

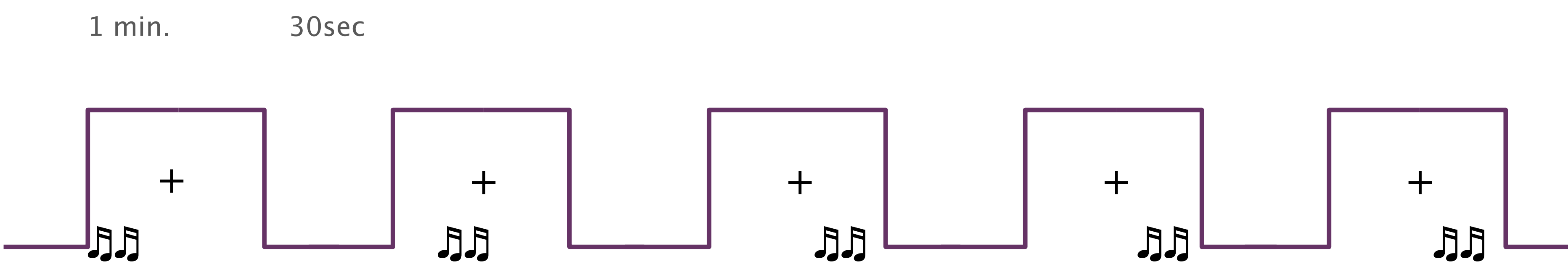
(Verstynen & Sabes, 2009)

Naturalistic motor learning



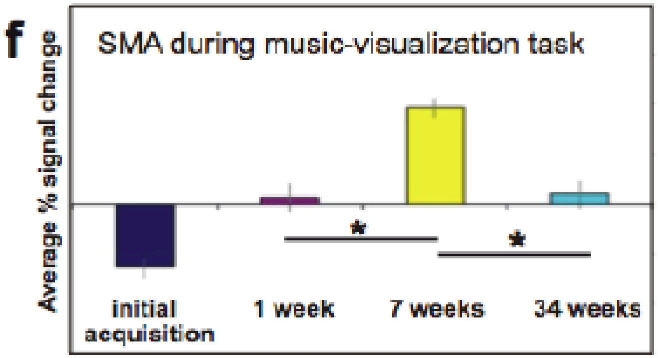
fMRI pilot data

- **5 professional ballet dancers** from the National Ballet of Canada
- Scanned 4 times over a 34-week program
  - **Scan 1:** Baseline
  - **Scan 2:** 1 week of rehearsal
  - **Scan 3:** 7 weeks of rehearsal + performance
  - **Scan 4:** 34 weeks of rehearsal + performance
- Visualize performing newly learned dance in time with the music from a first-person perspective;

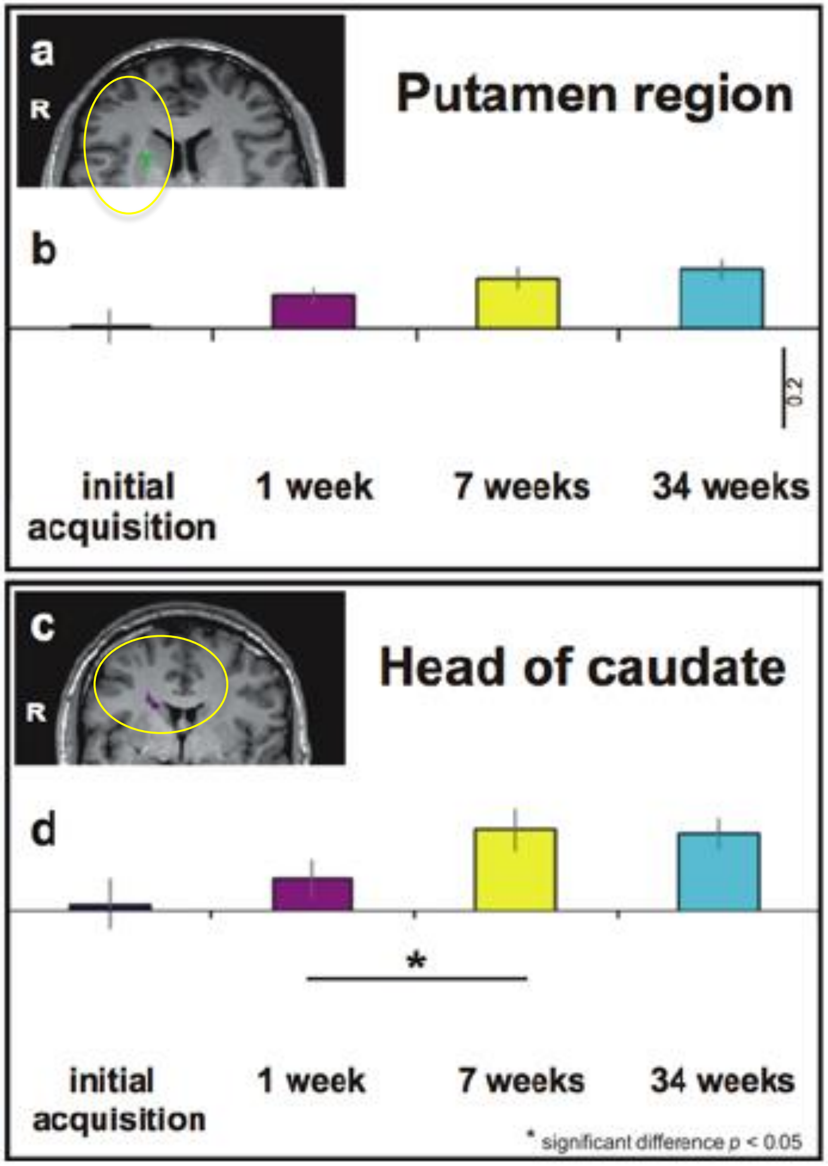


From DeSouza & Bar, under preparation

Supplementary Motor Area



* significant difference $p < 0.05$

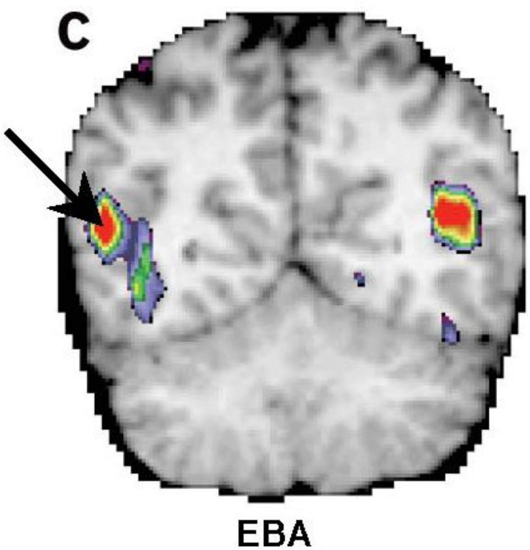


DeSouza & Bar, Seeing & Perc, under preparation

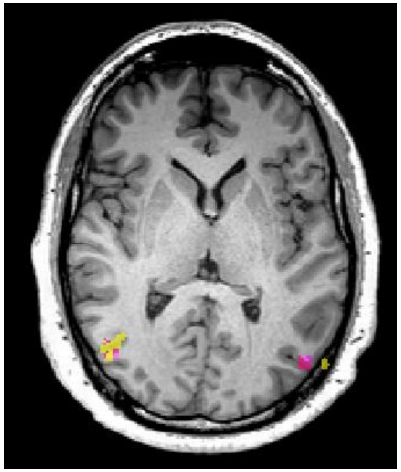
Extrastriate Body Area (EBA)- Body perception-

Activated by images (static and dynamic) of bodies and body parts

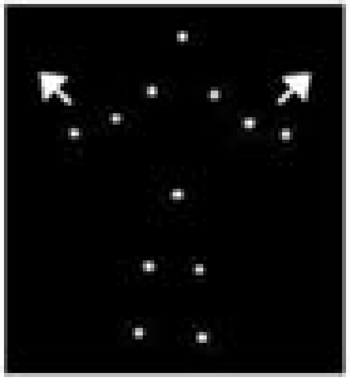
Motor imagery task



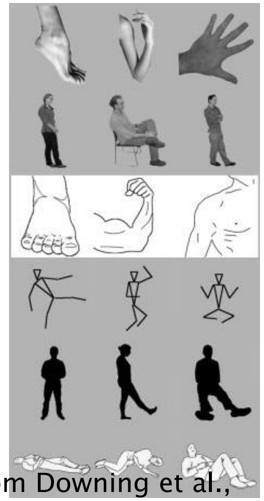
Astafiev et al.,
Nat Neuro, 2004



Functional (yellow) vs anatomical (pink) ROIs (n=6)



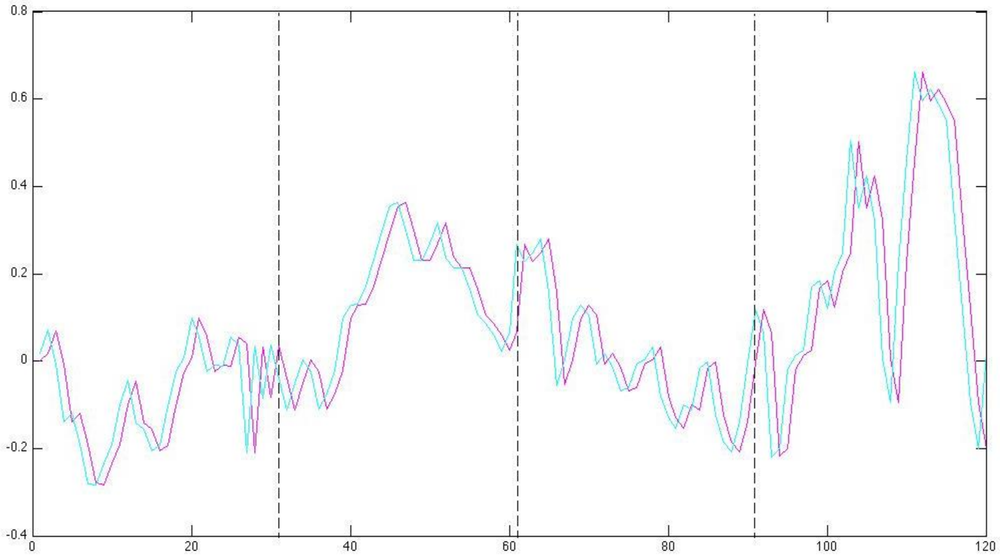
From Peelen et al.,
Neuron, 2006

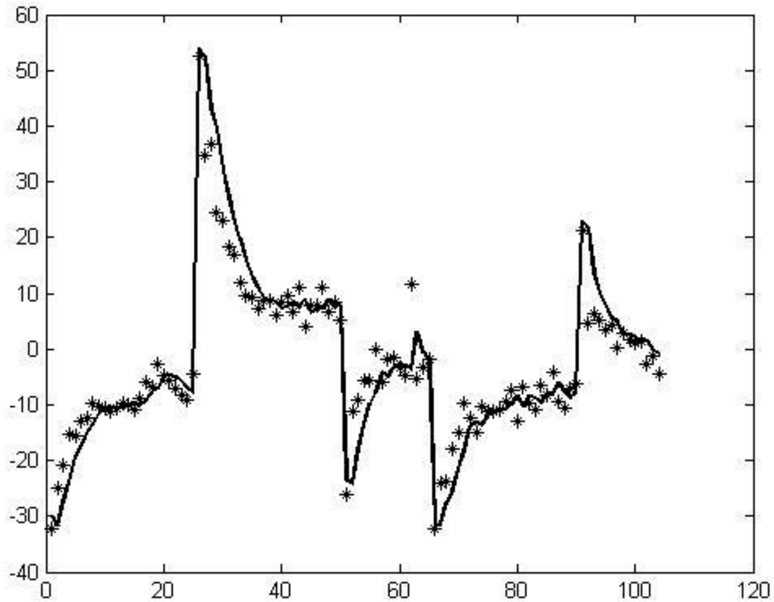


From Downing et al.,
Science, 2001

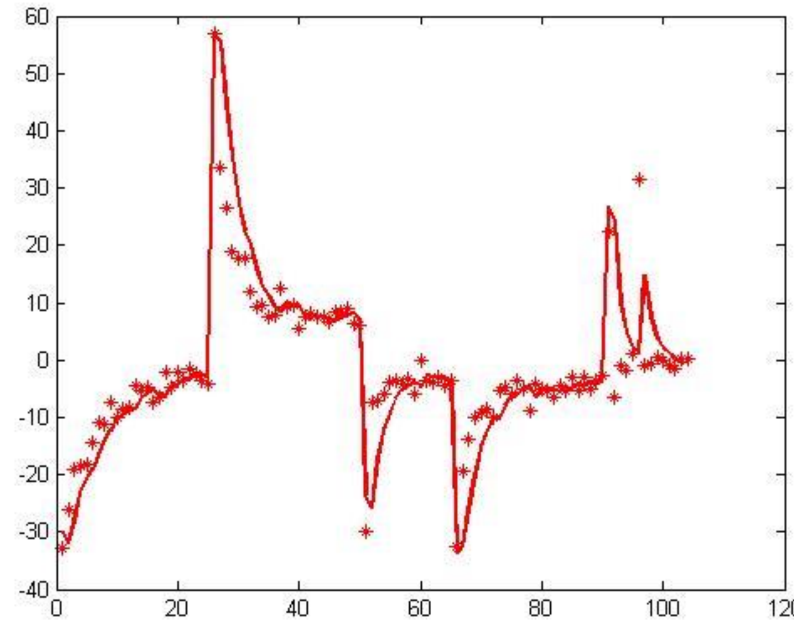
Extrastriate Body Area & Motor Learning

- Kalman filter to predict motor learning





60
50
40
30
20
10
0
-10
-20
-30
-40
0
20
40
60
80
100
120



60
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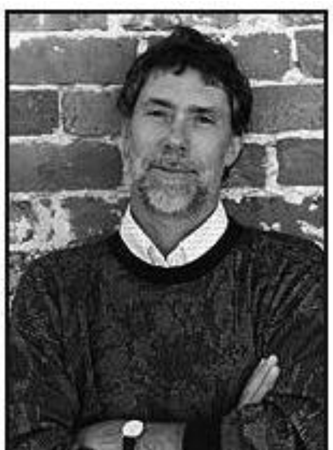
120

Thank you!

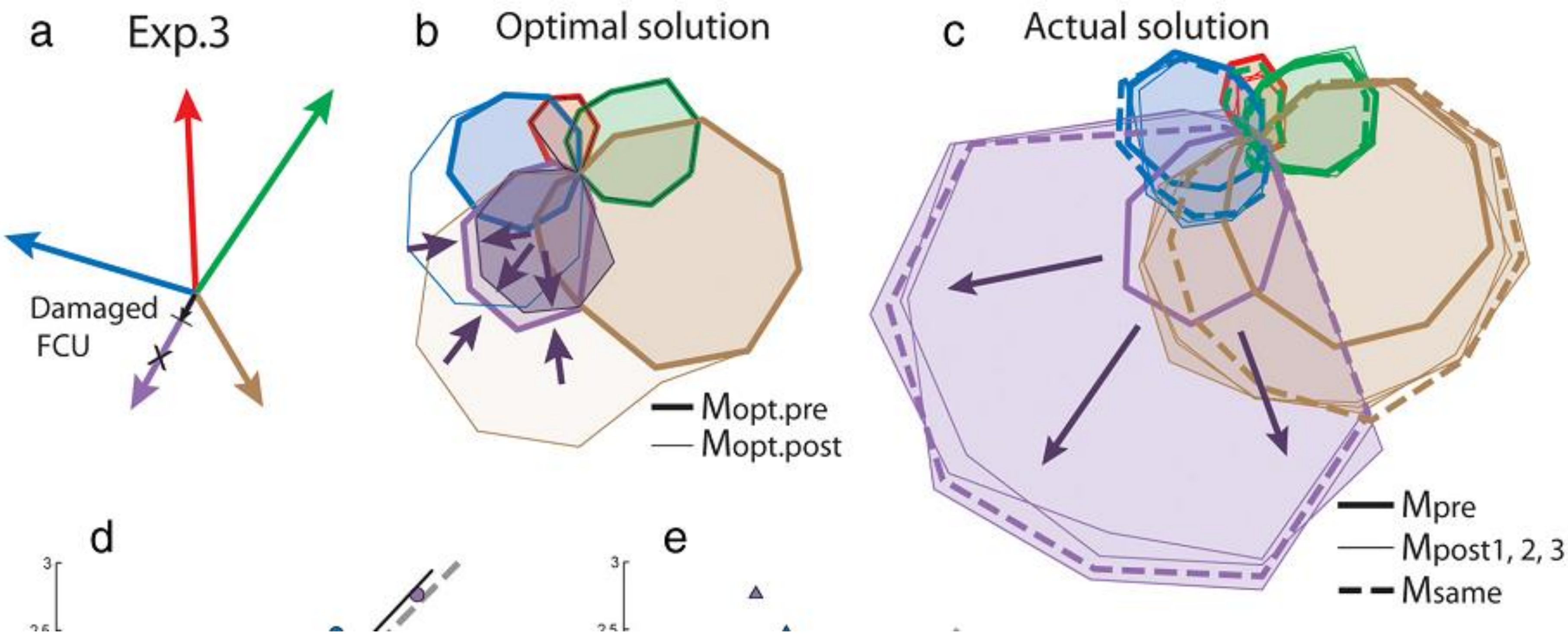


Geoff Hammond

Aymar de Rugy

Andrea Loftus

Joe de Souza



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Behavioral/Systems/Cognitive

Muscle Coordination Is Habitual Rather than Optimal

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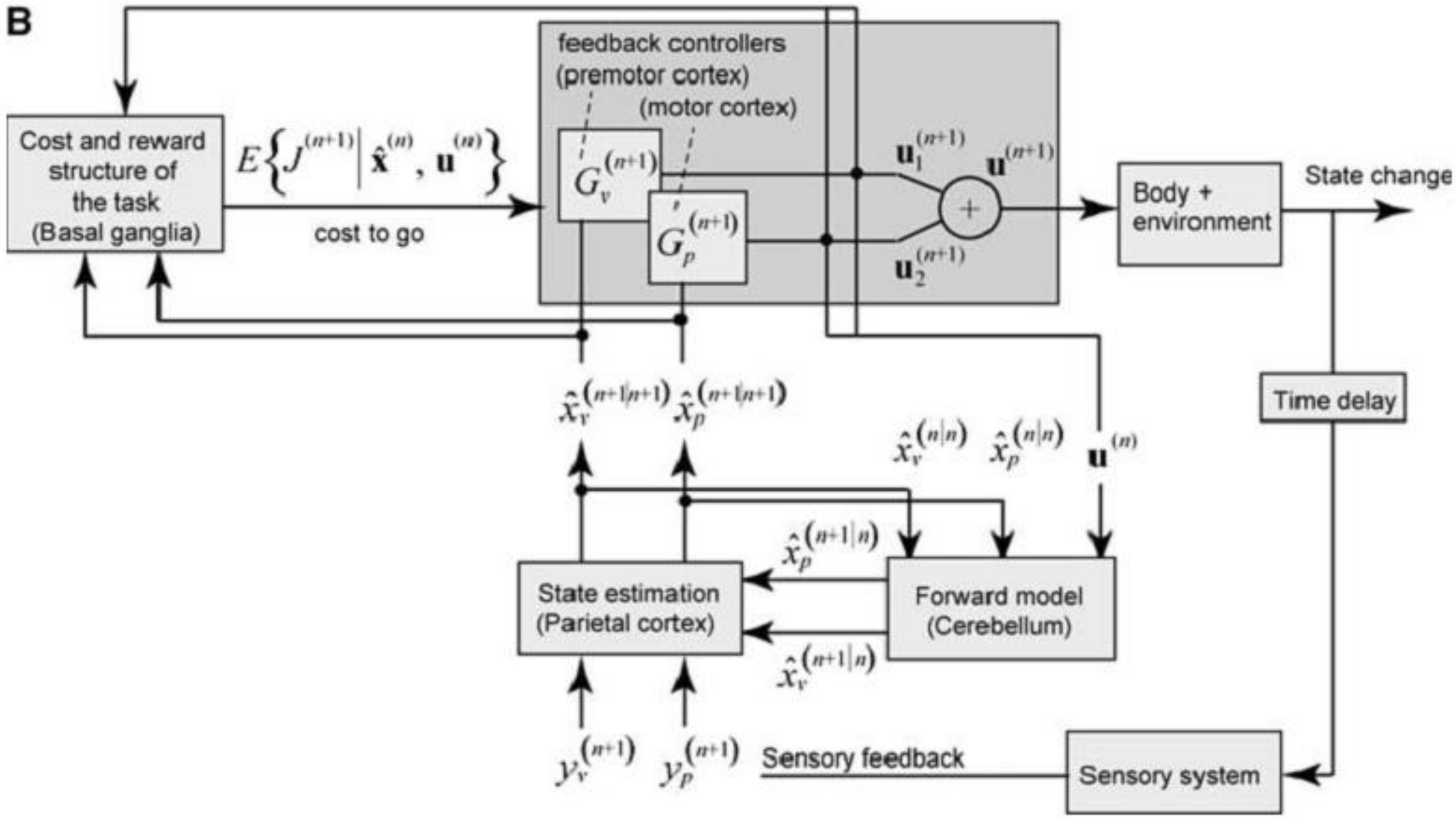
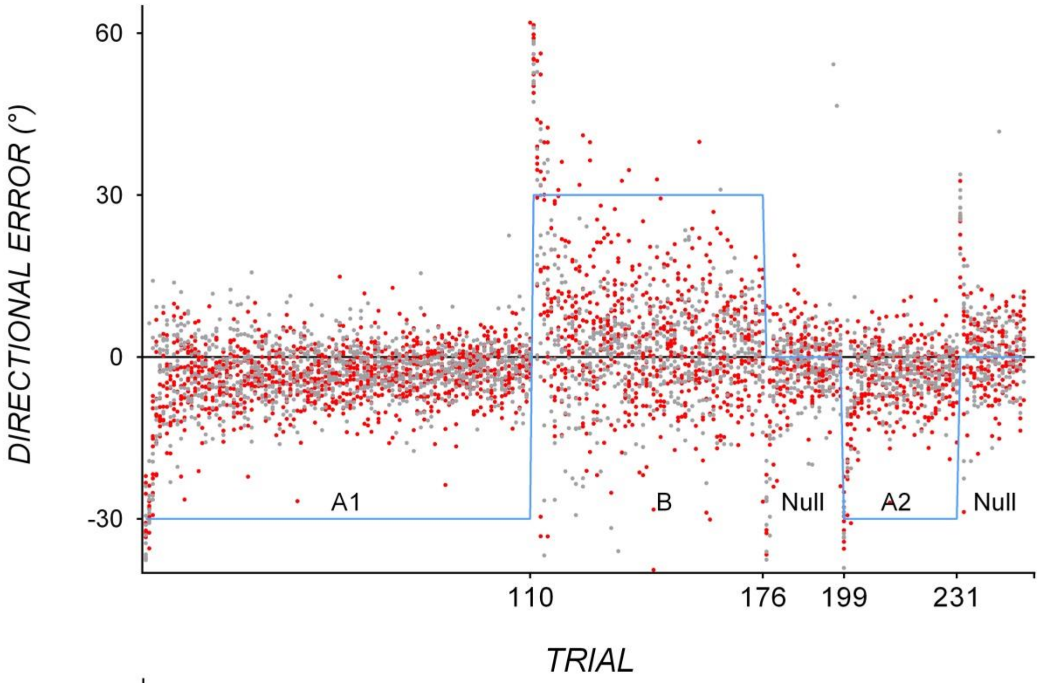
B

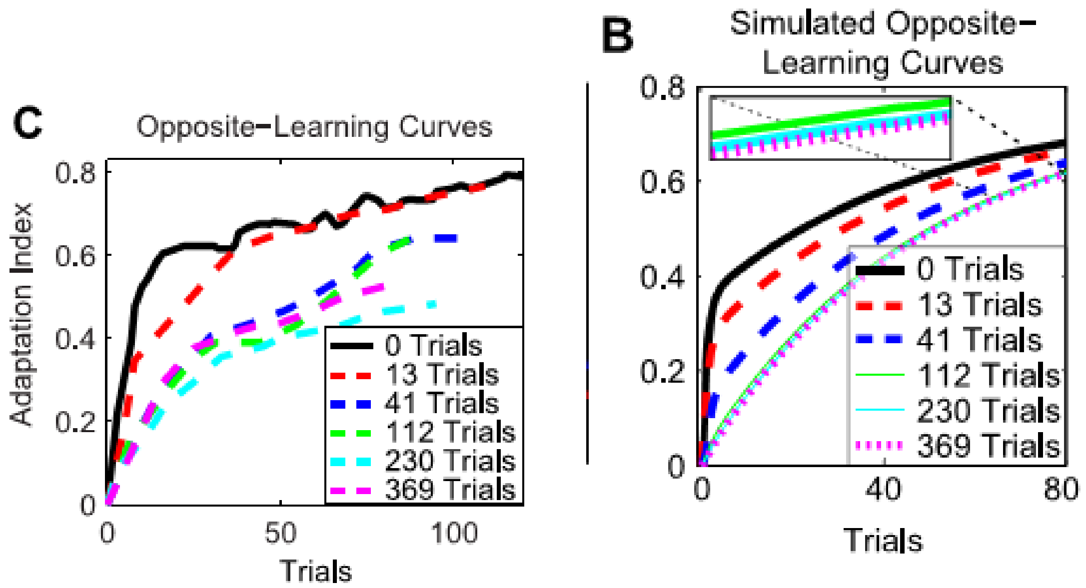


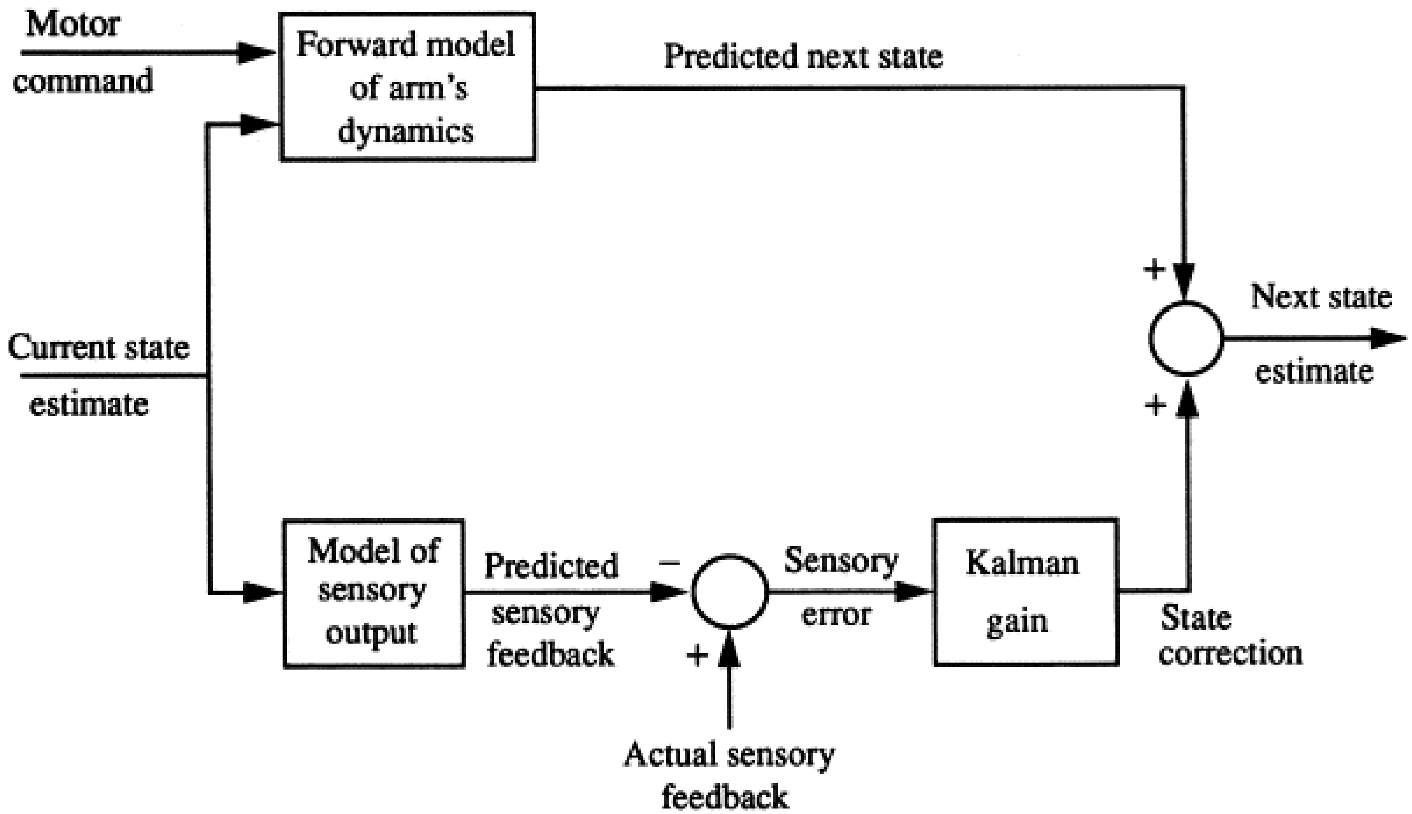
Cost and reward structure of the task (Basal ganglia)
$E\left\{J^{(n+1)} \middle| \hat{\mathbf{x}}^{(n)}, \mathbf{u}^{(n)}\right\}$
cost to go
feedback controllers
(premotor cortex)
(motor cortex)
$G_v^{(n+1)}$
$G_p^{(n+1)}$
$\mathbf{u}_1^{(n+1)}$
$\mathbf{u}_2^{(n+1)}$
$\mathbf{u}^{(n+1)}$
+
Body + environment
State change
Time delay
$\hat{x}_v^{(n+1|n+1)}$
$\hat{x}_p^{(n+1|n+1)}$
$\hat{x}_v^{(n|n)}$
$\hat{x}_p^{(n|n)}$
$\mathbf{u}^{(n)}$
$\hat{x}_p^{(n+1|n)}$
$\hat{x}_v^{(n+1|n)}$
State estimation (Parietal cortex)
Forward model (Cerebellum)
$y_v^{(n+1)}$
$y_p^{(n+1)}$
Sensory feedback
Sensory system

Two state model also doesn't explain variability



Two-state model





Motor
command
Forward model
of arm's
dynamics
Predicted next state
Current state
estimate
+
Next state
estimate
+
Model of
sensory
output
Predicted
sensory
feedback
−
+
Sensory
error
Kalman
gain
State
correction
Actual sensory
feedback