The Effect of Visual Uncertainty on Implicit Motor Adaptation

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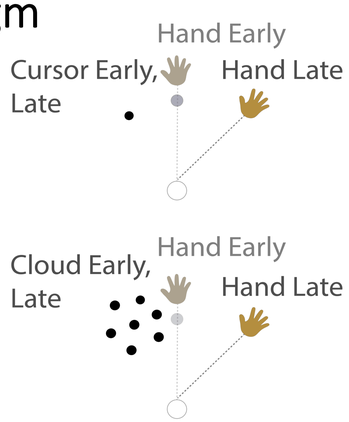
Introduction

- Motor adaptation involves both implicit and explicit processes [1].
- Implicit motor adaptation is driven by sensory prediction error, difference between predicted and actual feedback.
- Noisy error information attenuates motor adaptation. This has been modeled as resulting in a weaker error signal [2, 3].

- We re-examined the effect of visual uncertainty on implicit motor adaptation using a modified visuomotor rotation task [4].
- Prior work with this task has led to a revised model of adaptation, one that emphasizes that constraints associated with motor updating the sensorimotor map rather than the size/strength of the error signal [5].

The Error Clamp Paradigm

- Cursor/cloud path is invariant, deviating by an invariant angle from the target (3.5° or 30°)
- Participants are fully informed of manipulation and asked to ignore the visual feedback
- Adaptation is observed as a change in hand angle opposite of the direction of the feedback
- Participants are unaware of change in hand direction



Experiment 1

Between Subject
(4 targets, n = 64)

Baseline Block
80 Trials

Error Clamp Block
600 Trials

Cursor 3.5° | Cursor 30° | Cloud 3.5° | Cloud 30°

Washout Block
20 Trials

Experiment 2

Within Subject
(1 target, n = 18)

Baseline Block
30 Trials

Day 1: Error Clamp Block
1425 Trials

Cursor
Random Rotation Size
0°, 1.75°, 3.5°, 10°, 18°, 30°, 45°, 60°, 75°, 90°

Day 2: Error Clamp Block
1425 Trials

Cloud
Random Rotation Size
0°, 1.75°, 3.5°, 10°, 18°, 30°, 45°, 60°, 75°, 90°

Washout Block
10 Trials

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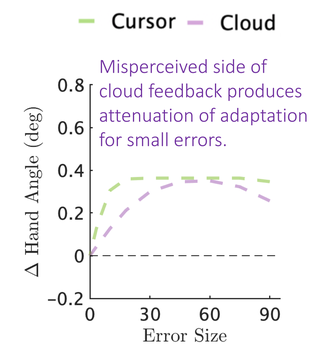
References: *[1] Mazzoni et al 2006 [2] Burge et al 2008 [3] Wei et al 2009 [4] Morehead et al 2017 [5] Kim et al 2018 [6] Kasuga et al 2013*

Modeling Adaptation

Motor Correction Model (MCM)

- Noisy adds variance to the perceived error location.
- Small errors are sometimes perceived with the opposite sign, with the net effect being attenuated adaptation.

$$U(e_n) = \begin{cases} me_n & if\ e_n < e_{sat} \\ U_{max} & if\ e_n \geq e_{sat} \end{cases} \qquad e_n = norm(\hat{e}, \sigma_R) \qquad x_{n+1} = A\,x_n + U(e_n)$$



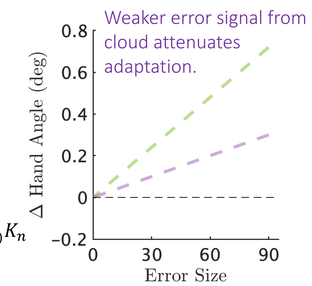
Kalman Filter (KF)

- Noise weakens the error signal.

$$x_n = Ax_{n-1} \qquad K_n = \frac{\sigma^2_{s(n)}}{\sigma^2_{s(n)} + \sigma^2_R}$$

$$\sigma^2_{s(n)} = A^2\sigma^2_{s(n-1)} + Q \qquad x_{n+1} = x_n + K_n e$$

$$\sigma^2_{s(n)} = \sigma^2_{s(n)} - \sigma^2_{s(n)}K_n$$

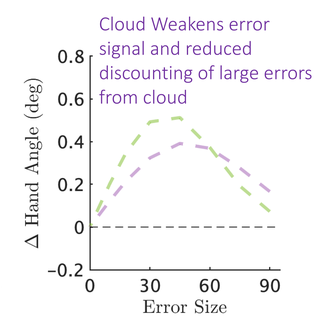


Relevance Estimation Model (REM)

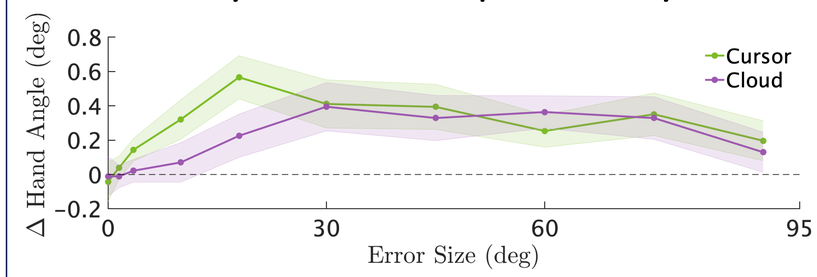
- Noise weakens the error signal.
- Large errors are less likely attributed to the motor system
- Noise adds ambiguity to the estimation, increases likelihood of large errors attributed to the motor system.

$$x_{hand} = \frac{N(x_{vis}, \sigma_{diff})}{N(x_{vis}, \sigma_{diff}) + const} * s_{C=1,hand}$$

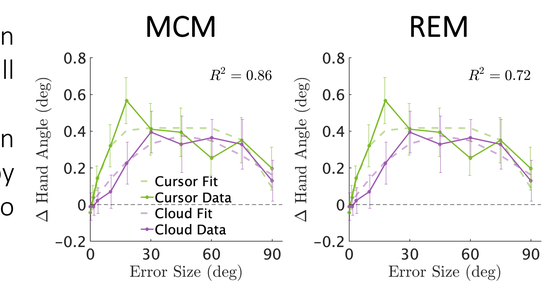
$$\sigma_{diff} = \frac{\sigma^2_{vis}\,\sigma^2_{prop}}{\sigma^2_{vis} + \sigma^2_{prop}}$$



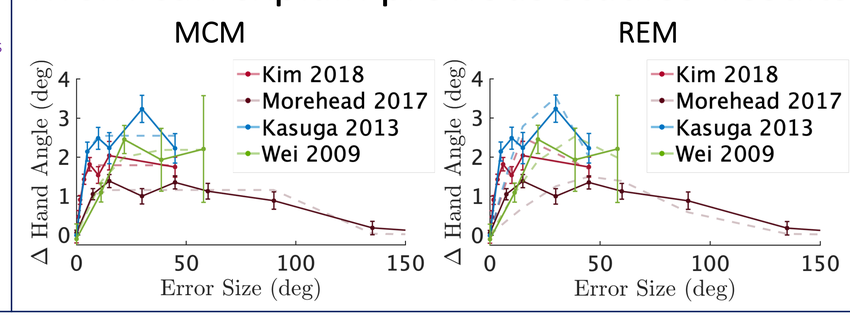
Exp. 2: Implicit Adaptation with visual uncertainty is better explained by MCM



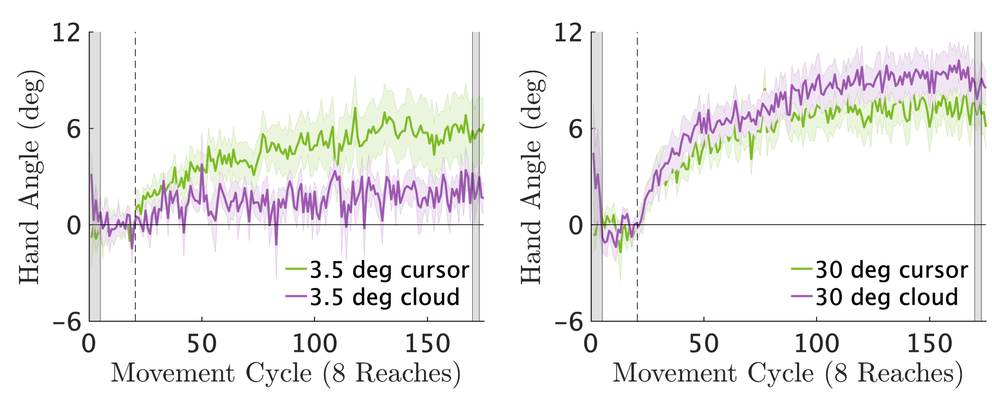
- Adaptation was again attenuated for small but not large errors.
- Implicit adaptation can be better explained by MCM compared to REM.

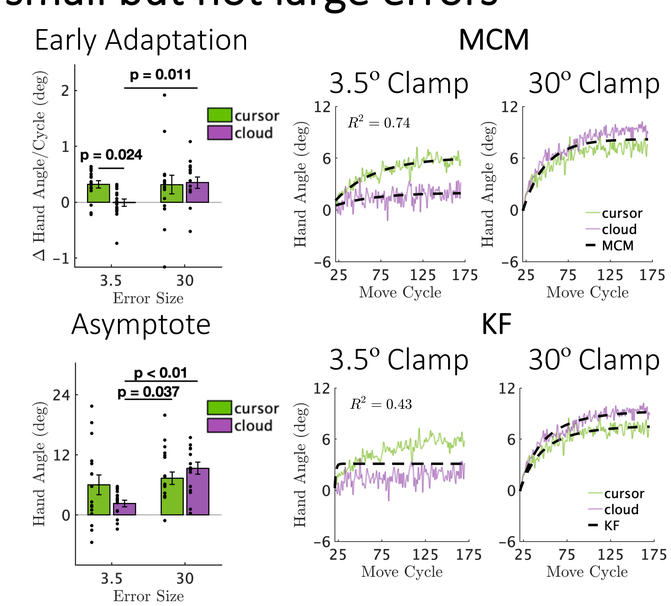


MCM can explain previous studies' results



Exp. 1: Visual Uncertainty attenuates adaptation to small but not large errors





- Early Adaptation Rate was attenuated with the cloud feedback for 3.5° clamp but not for the 30° clamp
- Implicit adaptation can be better explained by the Motor Correction Model compared to the Kalman Filter model.