Sequential effects in motor adaptation: the importance of far back trials

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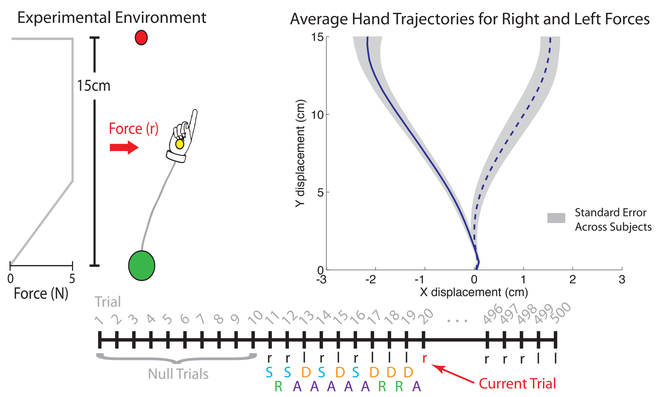
1. Introduction

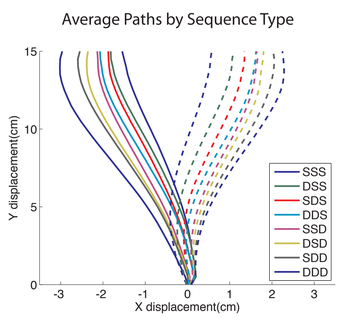
- The psychological literature has a rich history showing the effects of far back trials in choice tasks [1]. However, most motor adaptation studies only identify effects of the previous trial (e.g., [2]).
- Can we expose sequential dependencies in motor adaptation that extend more than two trials back?
- How well can psychological models of sequential effects capture human behavior in movement experiments?
- In choice tasks, subjects adapt to higher-order properties of the sequences (i.e., sequences of repetitions or alternations). Is there evidence of this in motor tasks?

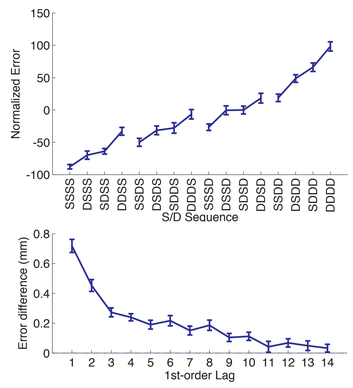
2. Movement Task (Experiment 1)

- Manipulandum task designed to be similar to classical two-alternative choice tasks in psychology
- Subjects move their hand 15cm in the sagittal plane to a target and randomly experience one of two lateral perturbation forces (from the right (r) or left (l))



- Strong sequential effects across 10 subjects
  - maximum error depends on recent history



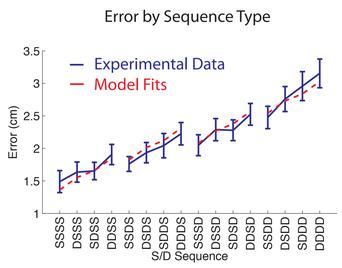


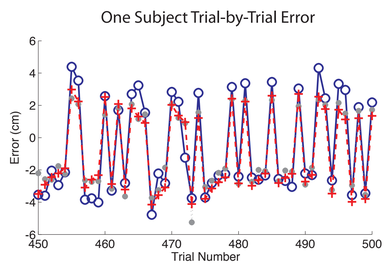
3. Exponential Model

- Error is a function of recently experienced forces
  - Not dependent on recent performance/error
- Recent experience is weighted via exponential decay
- Can add arbitrary number of previous trials without increasing the number of parameters (3 total params)

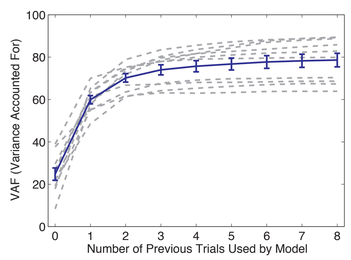
$$\hat{e}_t = \alpha(B_t - \beta \sum_{k=1}^{n} \lambda^k B_{t-k}), \text{ with } 0 < \lambda < 1$$

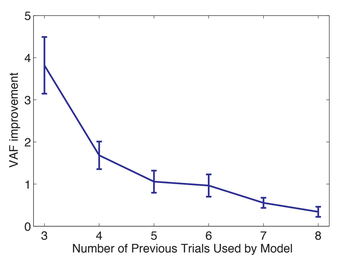
- Model accounts for 97.2% of the variance in error across sequence types
- Captures 78.6% of the trial-by-trial variance in error





- Variance accounted for (VAF) by the model increases significantly as more past trials are incorporated



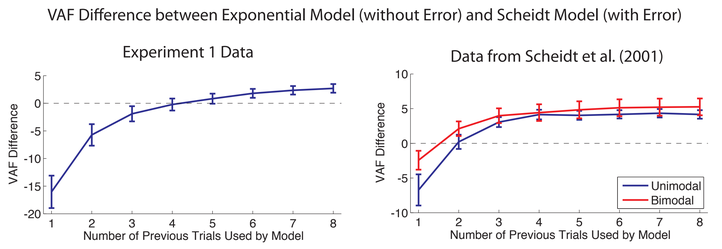


4. Comparison to error-driven model

- Scheidt et al. (2001) predict error using previous error

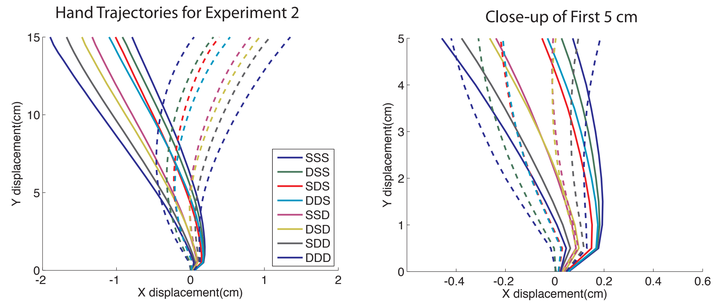
$$\hat{e}_t = a_1 e_{t-1} + b_0 B_t + b_1 B_{t-1}$$

- Same as exponential model when expanded recursively except that predictions are biased by random noise in previous error
- Exponential model (no error) fits data slightly better

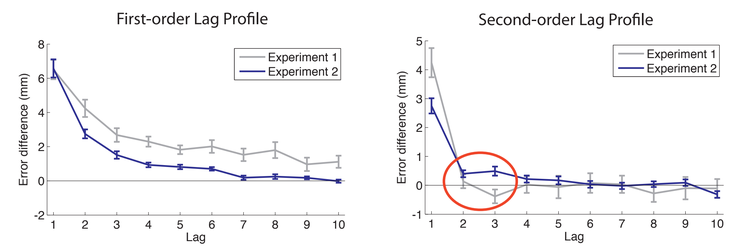


5. Second-order Effects (Experiment 2)

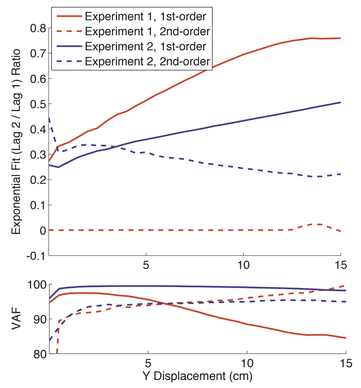
- Subjects also adapt to 2nd-order structure of choice task trials (i.e. series of repetitions and alternations)
- Experiment 2 attempts to evoke 2nd-order effects
  - Reliable directional cue provided at trial onset
  - 19 subjects, 1000 valid trials, same dynamics
- Smaller error, strong 1st-order effect, weak but present 2nd-order effect



- 2nd-order lag significantly non-zero at lag 2 and 3



- Lag pattern changes throughout movement
- Parameter of exponential fits shows 2nd-order effect early that decays as opposed to increasing 1st-order effect (in Expt 2)
- Simultaneous 1st and 2nd order effects consistent with model in [3]



6. Conclusions

- Motor adaptation utilizes a long trial history
- Adaptation is not necessarily error-driven
- Subjects also adapt motor behavior to the 2nd-order structure of the trial sequence

References

[1] Remington, R. (1969). Analysis of sequential effects in choice reaction times. *Journal of Experimental Psychology*, 82 (2), 250-257.

[2] Scheidt, R., Dingwell, J., & Mussa-Ivaldi, F. (2001). Learning to move amid uncertainty. *Journal of Neurophysiology*, 86 (2), 971.

[3] Wilder, M., Jones, M., & Mozer, M. C. (2010). Sequential effects reflect parallel learning of multiple environmental regularities. *NIPS, 22*, 2053-2061.