Variability in Motor Learning

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Motivation

• The variability of sensory feedback places fundamental limits on how much a subject can correct for a perturbation (Burge et al. 2008)
• Very popular models (e.g. linear state space) are agnostic to noise (Smith & Shadmehr 2006)

\[ x(n + 1) = A \cdot x(n) + B \cdot e(n) \]

\[ x_1(n + 1) = \min(0, [A \cdot x_1(n) + B \cdot e(n)]) \]
\[ x_2(n + 1) = \max(0, [A \cdot x_2(n) + B \cdot e(n)]) \]
\[ x = x_1 + x_2 \]

\[ x_1(n + 1) = A_f \cdot x_1(n) + B_f \cdot e(n) \]
\[ x_2(n + 1) = A_s \cdot x_2(n) + B_s \cdot e(n) \]
\[ x = x_1 + x_2 \]

\( x(n) \) — 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
\( A \) — Retension factor
Leveraging DREAM gets you 372 subjects!

<table>
<thead>
<tr>
<th>Perturbation</th>
<th># Targets</th>
<th># Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mattar 2007</td>
<td>Force field 1,2,6,7</td>
<td>198</td>
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<tr>
<td>Mattar 2010</td>
<td>Visual rotation 1</td>
<td>35</td>
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<td>Ostry 2010</td>
<td>Force field 1</td>
<td>30</td>
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<td>Vahdat 2011</td>
<td>Force field 1</td>
<td>11</td>
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<tr>
<td>Morehead (Unpub)</td>
<td>Visual rotation 8</td>
<td>98</td>
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</table>
Visual perturbation

High baseline variability
Low learning rate

Low baseline variability
High learning rate
Force perturbation

High baseline variability
High learning rate

Low baseline variability
Low learning rate
Methods

- Perpendicular displacement
- Variability in the baseline
- End of perturbation block variability
- Learning rate
- Learning Magnitude
Non-normalized data
Final variability vs. baseline variability (sanity check)
Beginning and end variability by perturbation type

Visual rotation

- Mattar 2010
- Morehead

Force field

- Ostry 2010
- Vahdat
- Mattar

R value = 0.40417
p value = 1.4031e-006

R value = 0.15356
p value = 0.01752
Magnitude of learning vs. baseline variability

Baseline Variability vs. Final Training Variability

R value = 0.041536
Perturbation type breakdown

**Visual rotation**
- Mattar 2010
- Morehead

- $R$ value = -0.14067
- $p$ value = 0.10632

**Force field**
- Ostry 2010
- Vahdat
- Mattar

- $R$ value = 0.13772
- $p$ value = 0.033331
Force field, target break down

- **Force field only 1 target**
  - Ostry 2010
  - Vahdat
  - Mattar 1- target

  **R value = 0.084**

- **Force field only 2 target**
  - Mattar 2- target

  **R value = 0.34**
  **p value = 0.014**

- **Force field multi target**
  - Mattar 6 and 7 target

  **R value = 0.068**
Learning rate vs. baseline variability

Baseline Variability vs. Learning rate

R value = -0.13175
p value = 0.023871
Learning rate by perturbation type

**Visual rotation**
- R value = 0.011325

**Force field**
- R value = -0.16306
- p value = 0.011584
Visual rotation, # of targets

**Visual Rotation - One Target**

- **Metric:** Z score of learning rate
- **Data Source:** Mattar 2010
- **Correlation:** R value = -0.19219
  - **P value:** 0.26869

**Visual Rotation - Multiple targets**

- **Metric:** Z score of learning rate
- **Data Source:** Morehead
- **Correlation:** R value = -0.12177
  - **P value:** 0.2323
Force field by # of targets

- Force field only 1 target
  - Ostry 2010
  - Vahdat
  - Mattar 1- target
  - $R$ value = -0.22503
  - $p$ value = 0.0047382

- Force field only 2 target
  - Mattar 2- target
  - $R$ value = -0.10565
  - $p$ value = 0.46059

- Force field multi target
  - Mattar 6 and 7 target
  - $R$ value = 0.057292
Visual rotation, target breakdown

**Visual Rotation - One Target**
- R value = 0.03524

**Visual Rotation - Multiple targets**
- R value = -0.03252
Summary

• Variability before and after training is correlated
• Baseline variability is not strongly correlated with anything in our data
• Learning rate is significantly correlated with baseline variability in force-field learning tasks
• Data issues?
Thanks!