Good (and bad) learners: behavioral and neuroimaging evaluation of individual differences in motor learning

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Introduction

People are very proficient in learning new skills or modifying the way in which they perform a learned skill. This work addresses 4 key questions in motor learning:

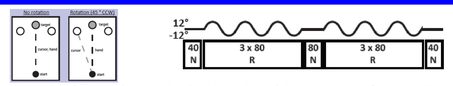
1) **Are individual differences on tests used to study motor learning reliable?** Will measures of learning be consistent across training sessions?

Assuming individual differences are reliable, what accounts for these differences?

2) **Are learning differences related to variability in measures of motor performance?**
3) **Can individual differences be related to intrinsic connectivity between brain regions associated with motor learning?**
4) **Are good learners on one task good in learning other tasks?** Are there common psychological processes and neural mechanisms that account for individual differences across tasks?

Methods

Visuomotor Adaptation: Gradual Rotation



- Gradual & cyclic perturbation, total 12°, steps of ±0-2°,CW & CCW
- 2 sets of target order & perturbation, one per session (640 trials)
- 4 targets, online feedback
- Learning-rate = % of error corrected, per trial; state-space model:

1. $e_n^{target} = (r_n - r_n^{est})$
2. $r_{n+1}^{est} = A\, r_n^{est} + B\,(e_n^{target} + \sigma_n^{sMN})$

e_n^{target} target heading error; r_n input rotation; r_n^{est} internal model rotation estimation; A memory term (fixed to 1); B learning rate (% error corrected); σ_n^{sMN} spatial motor noise $N\sim(0,\sigma_n^{SSN})$

Sequence Learning 1: Serial Reaction Time task (SRT)

- Stimuli appear at one of 4 locations and participants make spatially-compatible responses
- 15 blocks of 84 trials; within a block, stimulus order is either psuedorandom or follows 12-element pattern
- Different patterns used in Session 1 and Session 2
- Learning = RT Final Random blocks – RT Final Sequence blocks

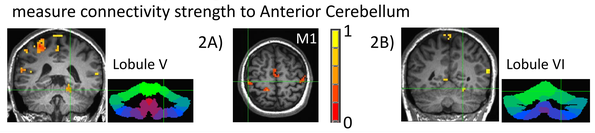
Sequence Learning 2: Alternating-SRT (A-SRT)

- Stimuli appear at one of 4 locations and participants make spatially-compatible responses
- 45 blocks of 85 trials; odd elements form 4-element sequence; Even elements selected at random, e.g.: 1R2R3R4R
- Data separated into:
  High Frequency triplets (e.g., 122, 132)
  Low Frequency triplets (e.g., 211, 231)
- Learning = RT Low-frequency triplets – RT High-frequency triplets

fMRI: Resting-State Connectivity

- Data analyzed with AFNI (InstaCorr) and SUIT

1) Reaching localizer to identify "arm area" in Anterior Cerebellum (lobule V-VI) and M1
2) Resting-state analysis: A) Use cerebellar reaching localizer as seed and measure connectivity strength to M1. B) Use M1 localizer as seed and measure connectivity strength to Anterior Cerebellum



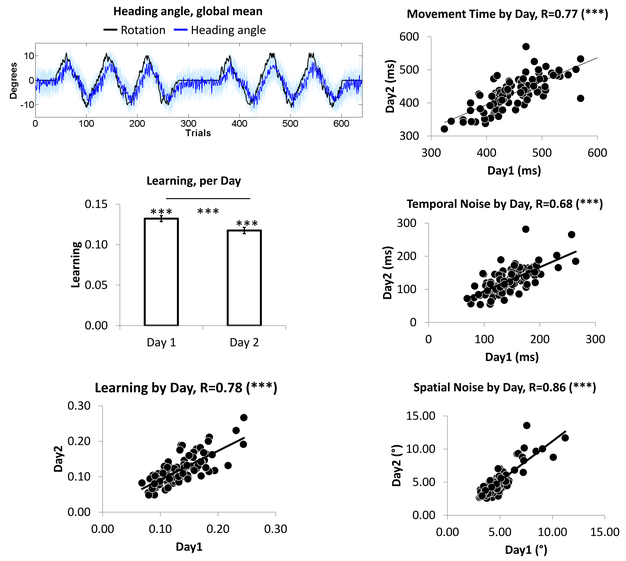
Subject groups:
Adaptation (N=38) } fMRI (N=29)
SRT (N=23)
Adaptation & SRT (N=37)
Adaptation & A-SRT (N=24)

- 122 right-handed college students (63% females)
- 2 sessions per task

* p<0.05, **p<0.01, *** p<0.0001

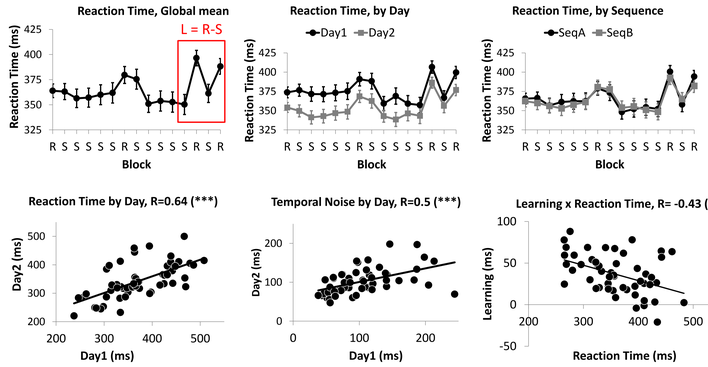
Results

Visuomotor Adaptation: Gradual Rotation (N=99)



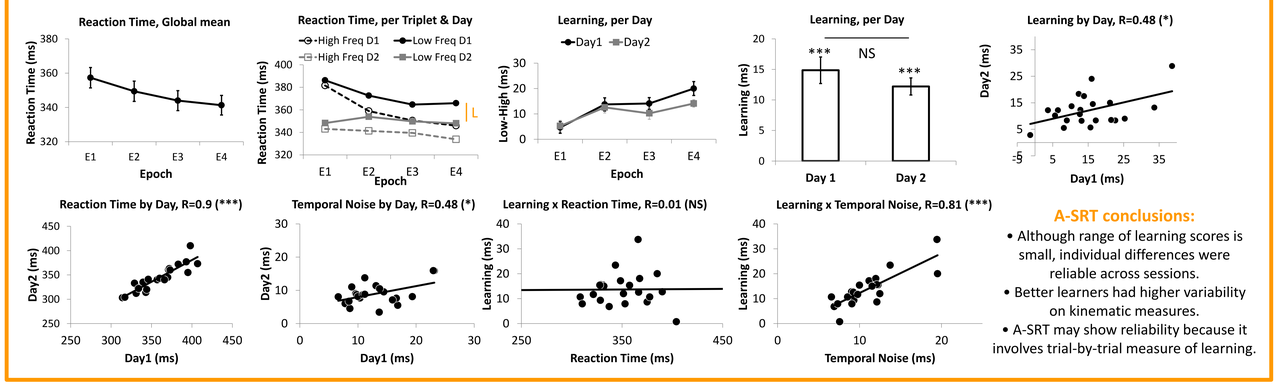
Visuomotor Adaptation Conclusions:
- Individual differences in measure of trial-by-trial learning are reliable across test sessions.
- Better learners were slower and had lower variability on kinematic measures.
- Simulation shows that estimates of learning rate are not biased by motor noise.

Sequence Learning 1: Serial Reaction Time task (N=54)



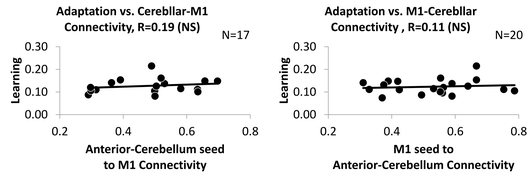
SRT Conclusions:
- Despite group learning, individual differences in learning were not reliable.
- Better learners were faster and had lower kinematic variability.
- Failure to see reliability here may reflect limitations of SRT task; learning is probed in relatively global manner (block-to-block).

Sequence Learning 2: Alternating-SRT (N=22)



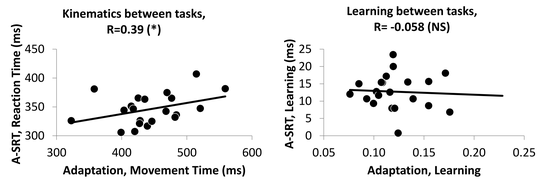
A-SRT conclusions:
- Although range of learning scores is small, individual differences were reliable across sessions.
- Better learners had higher variability on kinematic measures.
- A-SRT may show reliability because it involves trial-by-trial measure of learning.

Adaption vs. Cerebellar-M1 Resting-State Connectivity (N=29)



Adaptation & Resting-Sate Conclusions:
- Individual differences in learning rates during visuomotor adaptation were not correlated to the strength of resting-state connectivity between M1 and anterior cerebellum.
- Current analysis is limited because localizers were highly variable across individuals.

Adaptation vs. Sequence Learning (A-SRT) (N=22)



Adaptation & Sequence Learning Conclusions:
- Variation in kinematics (RT or MT) were correlated between tasks.
- Individual differences in adaptation were not correlated with individual differences in sequence learning (A-SRT only).

Summary & Conclusions

1) Measures of learning were reliable across sessions for visuomotor adaptation and the A-SRT task.
- Both use dependent variables that calculated from trial-by-trial measures of performance.
- Performance on the standard SRT task was not reliable across sessions.

2) Related individual differences in learning to measures of motor noise.
- Visuomotor adaptation was inversely related to motor noise: High noise was associated with slower learning.
- More puzzling, sequence learning (A-SRT) was directly related to motor noise: High noise here was associated with faster learning.
- Does this dissociation relate to how much a task is dependent on exploratory behavior (assuming high noise = more exploration)?

3) To date, measures of resting state connectivity involving cerebellar-M1 pathway do not account for individual variation.
- Future work will use alternative methods to identify seeds.
- Look at alternative resting state pathways.

4) Individual differences in learning measures for adaptation and sequence learning were not correlated.
- No evidence for a general "learning" process.

References: Buckner *et al.* (2011); Cheng & Sabes (2007); Diedrichsen (2006); Diedrichsen *et al.* (2009); Janacsek *et al.* (2012); Kelly & Strick (2003); Krienen & Buckner (2009); Schlerf *et al.* (2013); Taylor & Ivry (2011)