Reaching for a Good Aiming Strategy in People with Cerebellar Degeneration

J. Ryan Morehead[1,2], Jordan A. Taylor[3], Richard B. Ivry[1]

[1]UC Berkeley, [2]Harvard University, [3]Princeton University

ivrylab.berkeley.edu

ryanmorehead@seas.harvard.edu

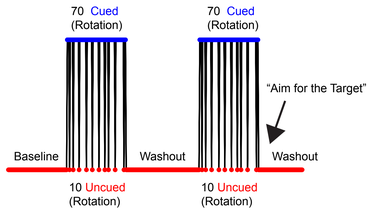
Background

A classic observation in the field of motor control is that persons with cerebellar ataxia exhibit deficits not only in the coordination of movements, but also in sensorimotor adaptation tasks. The specific cause of this deficit has, however, remained elusive. Much recent work has attempted to break sensorimotor adaptation into various components, such as implicit and explicit processes, action-selection and error-based learning, or temporally stable and labile motor memories. Distinctions such as these may yield new insigths if applied to the motor learning deficit in cerebellar ataxia.

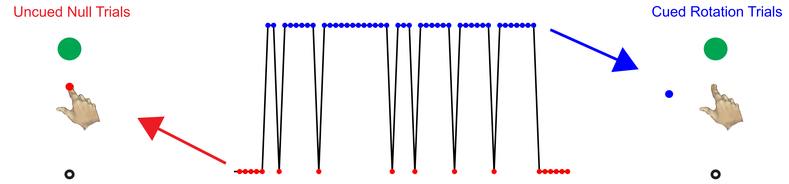
Here we examined learning in two task contexts where we could dissociate action-selection from implicit adaptation to sensory prediction errors. The first task employed arbitrary color cues that allow the flexible use of aiming strategies to boost task performance. By switching the color cue on and off, we can reveal the relative contribution of both processes. The second task induces task-irrelevant sensory prediction errors to assay implicit learning in relative isolation.

Summary of Results

- Cerebellar ataxia (CA) patients are only mildly impaired at developing a cognitive aiming strategy when reaching to a single target
- Reaching to more than one target location leads to a substantial impairment for CA patients
- Patients show a deficit in adaptation from sensory prediction errors independent of task performance



Color-Switching Task Design



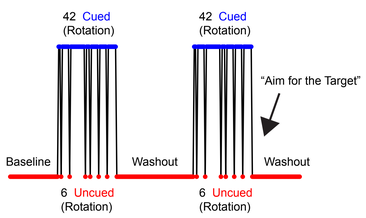
Null Trials: No rotation, cued when cursor is default color (depicted in red).

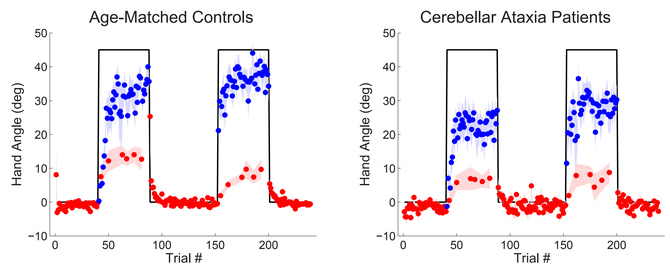
Rotation Trials: 45 degree rotation, cued when cursor changes color to blue.

Rotation block of primarily composed of cued rotation trials, with a fixed number of uncued null trials at irregular intervals.

Participants can use the cue to adopt and aiming strategy in anticipation of the visuomotor rotation.

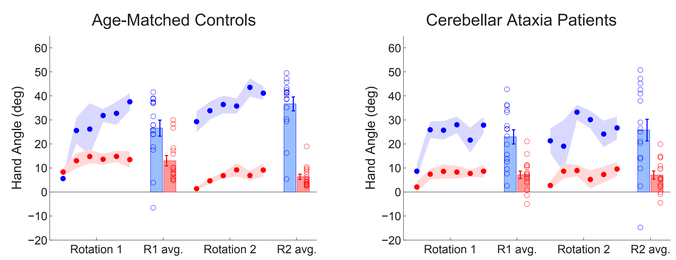
Single Target Results



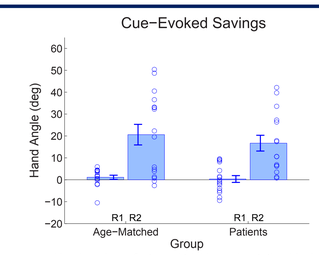


Blue: Rapid improvement on cued trials.

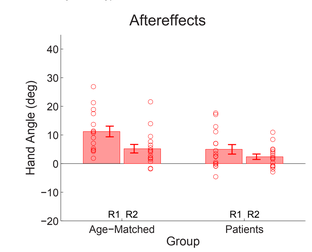
Red Trials: A sensorimotor aftereffect is evident on null trials.



Binned performance for null trials and immediately preceding cued trials. CA group was more variable but many appeared to use an aiming strategy.

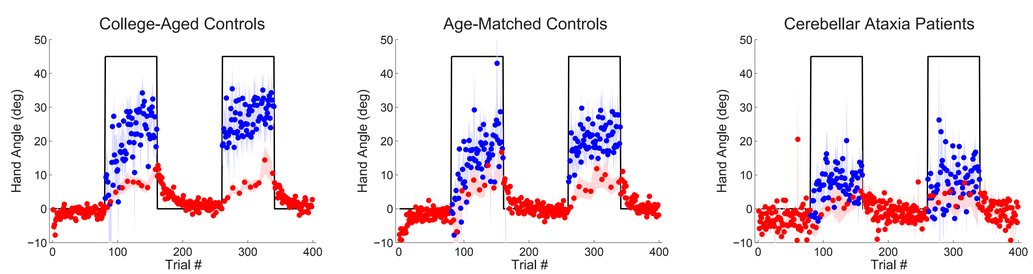


Hand angle on first cued trial in each rotation block. Both groups show substatial savings, indicative of an aiming strategy.

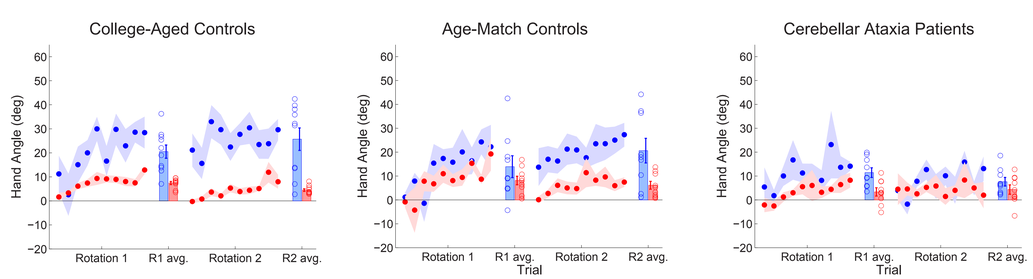


First two trials of washout block in each rotation block. CA group shows a reduced aftereffect, indicative of impaired implicit adaptation. Both groups showed a reduced aftereffect in R2.

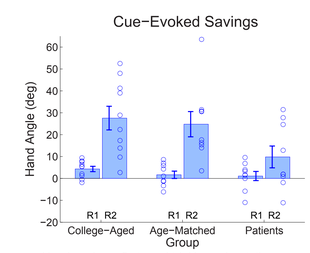
Four Target Results



CA group shows less benefit from the cue . It is not clear that they were able to develop an aiming strategy in this condition.

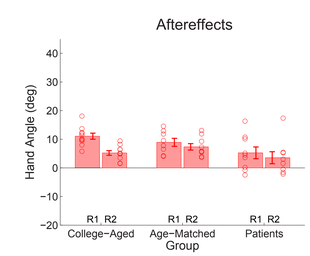


Pairs analysis shows that CA group fails to use the cue information in a consistent manner.



Hand angle on first cued trial in each rotation block. CA group shows less benefit from the cue.

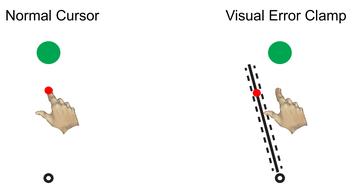
The difference between first trial behavior in the first and second rotation blocks shown above represents cue-evoked re-aiming (savings). This change in behavior can only be attributed to the presence of the color cue, as participants have not yet re-experienced errors introduced by the visuomotor rotation.



Aftereffect size is similar in 1- and 4-target conditions. CA group again shows reduced aftereffect (impaired implicit adaptation). All groups show a trend for a reduced aftereffect in R2.

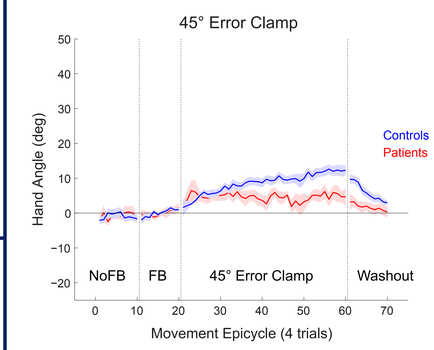
The aftereffect for the second rotation was lower for all groups in both the single- and four-target conditions. This could be because there is a fundamental tradeoff between implicit and explicit learning, however, this could also come about if the locus of implicit learning is the aiming location. If participants only employ an aiming strategy on cued rotation trials, generalization would cause an aftereffect at the goal target that is some fraction of total implicit adaptation.

Error Clamp Task Design

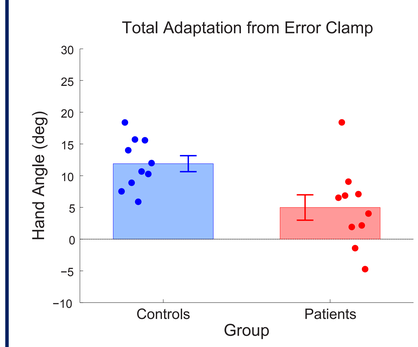


Participants reached to four targets spaced in 90° increments. On visual error clamp trials, the feedback cursor was locked to a fixed heading angle that was offset from the target by 45°. This breaks the contingency between angular deviation of the hand and cursor feedback, while maintaining a temporal correlation.

Error Clamp Results



Hand angle for each movement epicycle of four reaches.



Mean hand angle over the last 10 epicycles (40 trials) of the error clamp block for both groups and individuals. Patients were impaired relative to controls.

Two undergraduate research assistants, Giana Cirolia and Shabnam Bonyadi, made a this work possible through tireless efforts to compensate for Ryan's inability to organize anything. We would like to extend a special thank you for their work.