The difference between stopping and deciding not to go: Behavioral, imaging, and modeling evidence

Kyle Dunovan[2], Tara Molesworth[1], Timothy Verstynen[1]

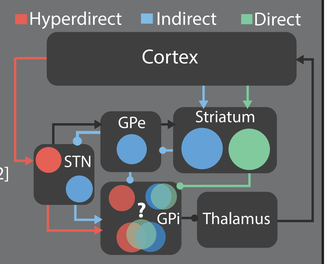
1. Dept. of Psychology & Center for the Neural Basis of Cognition
Carnegie Mellon University

2. Dept. of Psychology & Center for the Neural Basis of Cognition
University of Pittsburgh

Reprints: http://www.psy.cmu.edu/~coaxlab/posters/dunovan_SFN_14.pdf

Background

Inhibitory control can be exercised **proactively** - goal directed suppression of future action, and **reactively** - environmentally cued suppression



Inhibitory processing in the Basal Ganglia:

Proactive : Evidence that direct and indirect pathways converge at GPi, compete to determine motor gating [2]

Reactive: Hyperdirect stop signal races motor signal to GPi [1]

Goals:

* Contrast independent race model with a new alternative that assumes a dependency between stop and go signals
* Distinguish mechanisms responsible for reactive vs. proactive inhibition

Methods

Participants

Neurologically healthy adults (N=60; mean age=22) were recruited from the local student population in Pittsburgh. All testing was approved by the local Institutional Review Board.

Go Trials

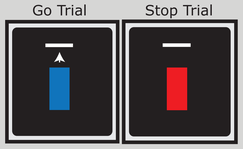
Participants saw a bar "filling" towards a line (the target). The bar reaches the line at 500 ms after trial onset. Participants were instructed to press the space key when the bar reached the target. The bar stopped moving when the key was pressed. Participants were financially rewarded based on how close they were able to stop the moving bar to the target.

On some trials the bar would stop before it hit the line. This stopping was indicated in one of two ways.

Reactive Stopping (121 Go, 100 Stop)

Stopping Cue: The Bar stops & turns red before it hits the line

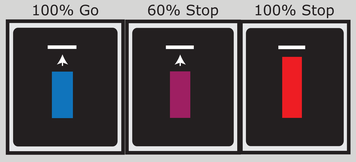
Stopping Times:
- 200 ms (n = 20)
- 250 ms (n = 20)
- 300 ms (n = 20)
- 350 ms (n = 20)
- 400 ms (n = 20)



Proactive Stopping (120 Go, 120 Stop)

Stopping cue: Decide whether or not to stop or go based on the bar's color. Color represents the probability that the bar will stop 100ms before the target line.

Stopping Probability:
- Blue = 0%
- Dark Purple = 20%
- Purple = 40%
- Dark Pink = 60%
- Pink = 80%
- Red = 100%



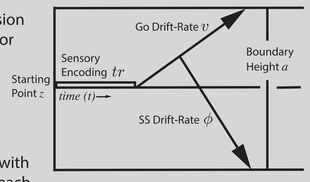
Reward Manipulation

Baseline (BSL): Reward for correctly stopping and penalty for incorrectly going are equal
Penalty (PNL): Penalty for incorrectly going is higher than reward for correctly stopping.

Race Against Drift-Diffusion Model (RADD)

RADD is a stochastic sequential sampling model in which a decision variable θ with positive drift represents the summation of a motor signal at rate v (Eq. 1) towards a response boundary a.

$$d\theta = vdt + \sigma dW \qquad \text{Eq. 1}$$
$$\theta(t < tr) = 0$$

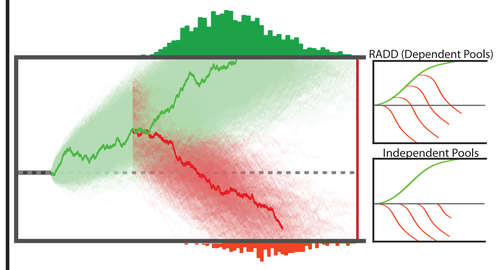


When a stop-signal occurs (t=ssd), a second decision variable γ (with rate ϕ) is instantiated at the current state of θ (Eq. 2) and must reach the bottom boundary in time (before $\theta > a$) to suppress an output.

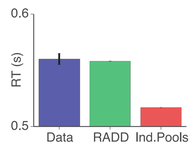
$$d\gamma = \phi dt + \theta(ssd) + \sigma dW \qquad \text{Eq. 2}$$
$$\gamma(t < ssd) = 0$$

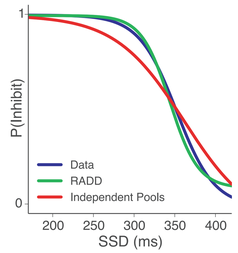
The model was fit to the data by simulating and minimizing the χ^2 statistic for the difference in observed vector of mean stopping accuracy and mean go response time. Fits were performed using a Nelder-Meade simplex algorithm.

Reactive Stopping



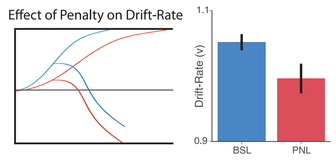
RADD provides a better fit to the group avgerage data than the IP model

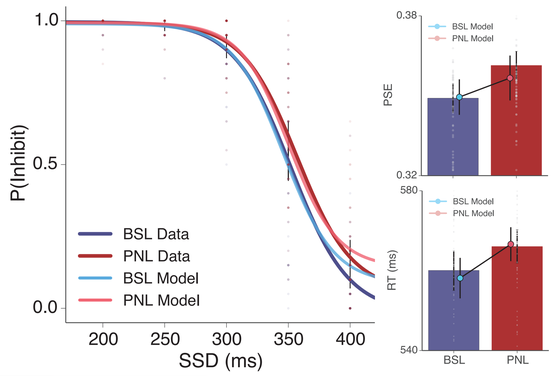




RADD was fit to individual subject data in the baseline (BSL) and penalty (PNL) versions of the SS task

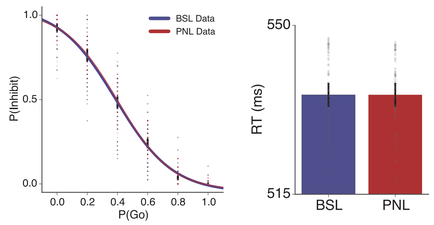
Behavioral changes between baseline and penalty conditions were captured by a change in the drift-rate of the go process

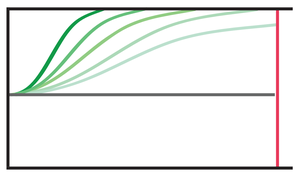


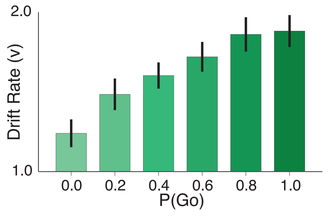


Proactive Inhibition

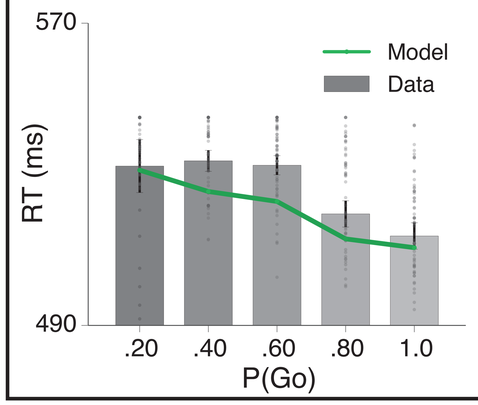
Both response time and number of responses decreased with increasing go probability in the proactive task, however behavior was not statistically different between baseline and penalty conditions.

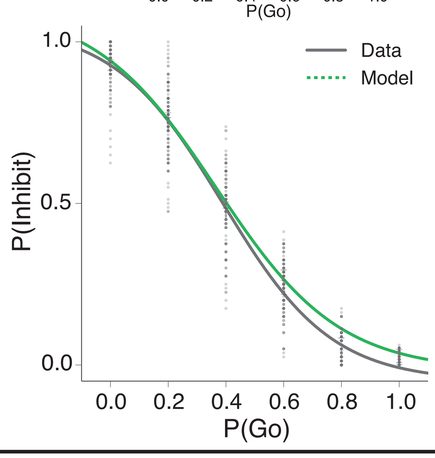






Behavioral effects of the probability manipulation were modeled as a change in the drift-rate of the go process.



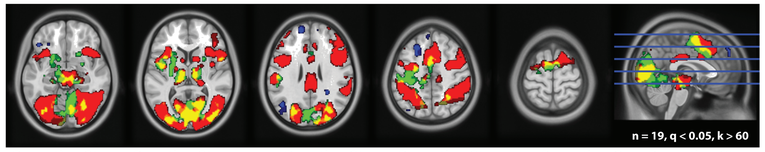


Imaging (Preliminary Findings)

Imaging Methods

Participants were run on 4 blocks of Proactive stopping (0%, 25%, 50%, 75%, 100% Go probability) and 1 Reactive stopping block (40% stopping probability, 350ms stop signal). All data were motion corrected, slice time corrected, normalized into MNI-space, smoothed (4mm FWHM) and analyzed using a reweighted least squares GLM in SPM8.

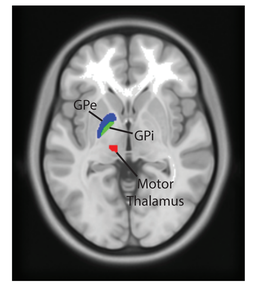
Wholebrain Analysis

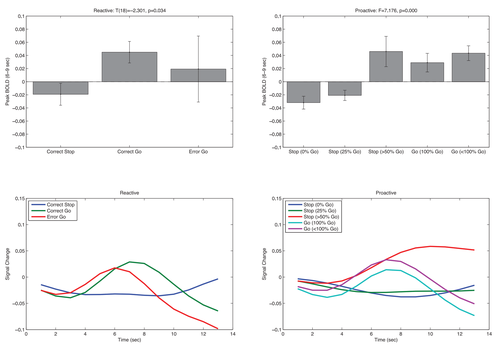


Proactive Stop > Reactive Stop **Reactive Stop > Proactive Stop** **Proactive Go > Proactive Stop**

Relative to reactive stopping, proactive stopping elicited stronger responses in premotor networks, inlcuding preSMA, dorsal premotor, prefrontal cotex, thalamus and the basal ganglia.

Region of Interest (*a priori*)





Responses in the motor thalamus ROI are detected during trials with high Go probability but no executed response. This is confirmed in a subset of subjects (n=12) with MR-compatible EMG on the first dorsal interosseous muscle.

Summary

Model fits to behavior in the reactive task favored RADD over an independent race model, suggesting that "stopping" is a nested process in which a stop signal (hyperdirect) must override the accumulated motor signal (direct) in order to successfully prevent a response.

The RADD model described proactive inhibition by scaling the drift-rate of the go process to adjust the speed and likelihood of crossing the response threshold based on the cued probability of a go trial.

Conclusions

RADD offers a new perspective on the difference between stopping and deciding not to go, demonstrating that reactive and proactive inhibitory control can be distinguished at the behavioral level despite largely overlapping and bottlnecked neural circuitry.

References

1. Schmidt, R., Leventhal, D. K., Mallet, N., Chen, F., & Berke, J. D. (2013). Canceling actions involves a race between basal ganglia pathways. Nature Neuroscience, 16(8), 1118–24. doi:10.1038/nn.3456

2. Smith, Y. , Beyan, M.D., Shink, E., & Bolam, J.P. (1998). "Microcircuitry of the direct and indirect pathways of the basal ganglia." NEUROSCIENCE-OXFORD-86, 353-388.