Simulating the Effects of Direct and Indirect Pathway Balance in a Spiking Basal Ganglia Network

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MOTIVATION

The cortico-basal ganglia-thalamo-cortical loop plays a central role in perceptual decision making[2].

Pathways in basal ganglia play key roles in modulating the decision-making process.

- Direct (STR-GPi) and indirect (STR-GPe) pathways compete for action disinhibition or inhibition[1].

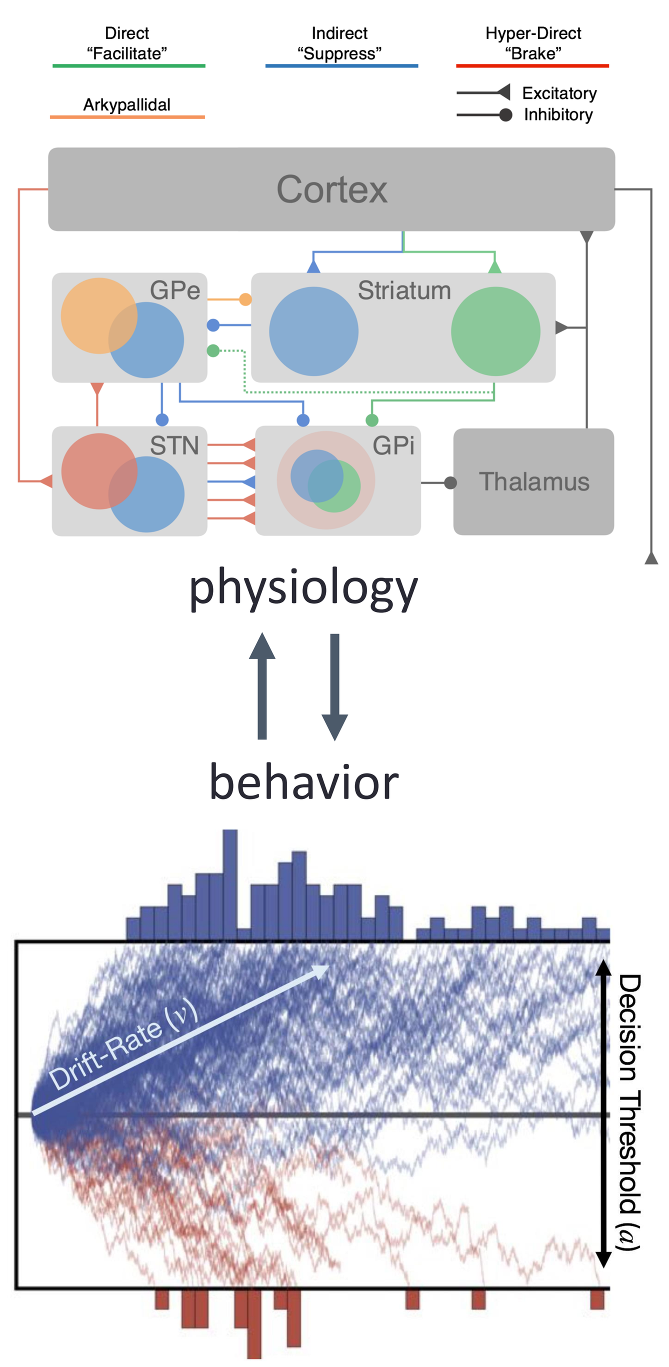
Drift-diffusion is a behavioral model describing evidence accumulation and speed-accuracy tradeoff[3].

- Drift rate: signal-to-noise ratio
- Threshold: confidence in decision

Postulated that striatal pathways influence threshold level and performance tradeoffs[2].

How are drift-diffusion parameters embodied in the physical network?

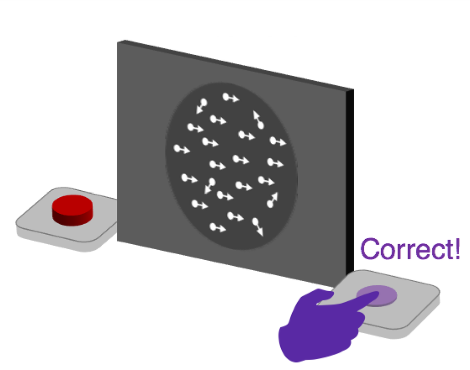
How does variation in direct/indirect pathway relative strength affect decision-making?



METHODS

Simulation of random dot motion visual discrimination task

- Choice between two alternatives based on sensory data



Fully spiking basal ganglia network model

- Two action channels, one per alternative, each containing cortical, basal ganglia, and thalamic populations
- Includes direct, indirect, and arkypallidal (GPe-STR) pathways
- Two striatal populations (D1 and D2) per channel

Sensory input represented by excitatory input to cortical populations

Ramping of thalamic activity to a cut-off (30 spikes / sec) was interpreted as a decision made by the network. Maximum trial length was 1 second; trials in which the cut-off was not reached were deemed incomplete decisions.

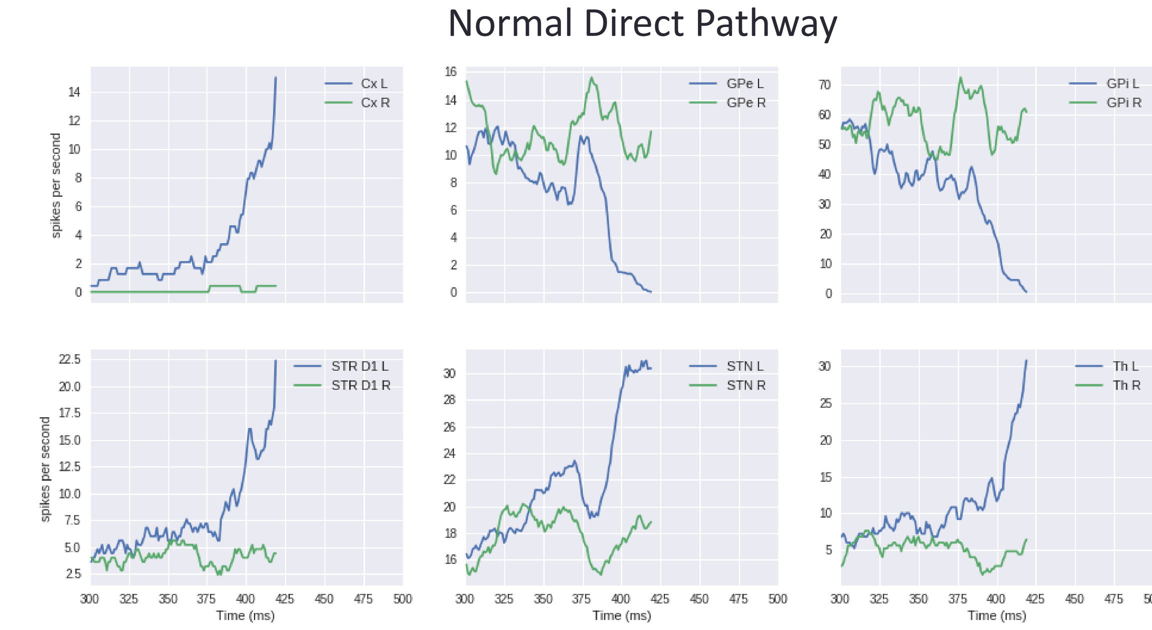
Reaction time distributions fit to drift-diffusion model using Bayesian estimation

REACTION TIME AND ACCURACY

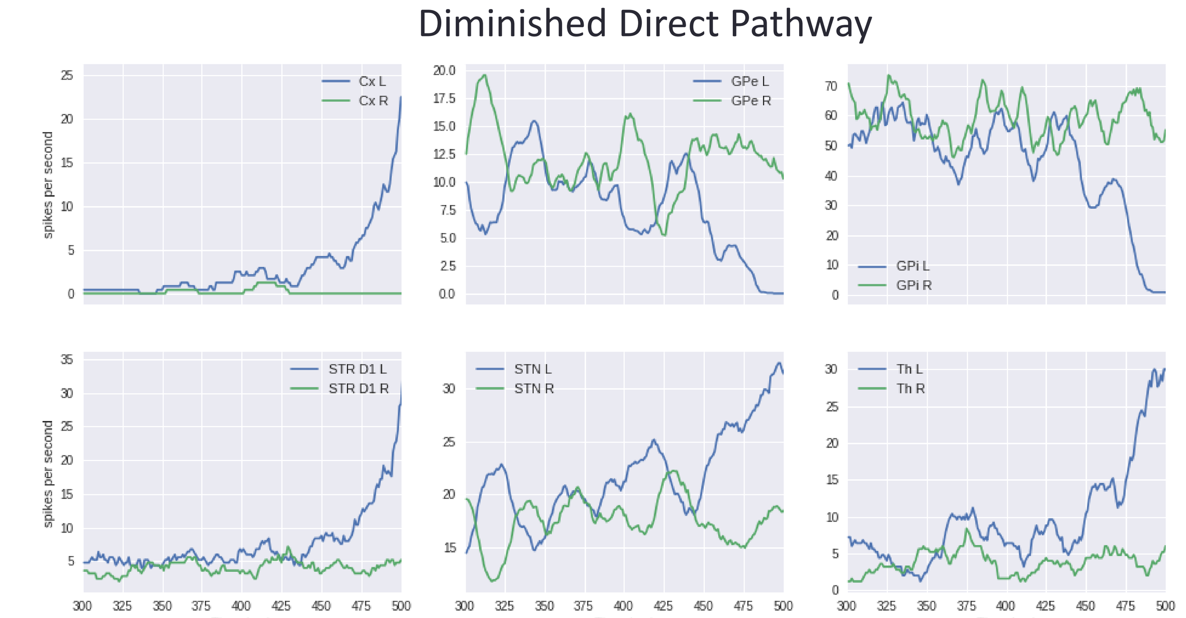
Relative pathway strengths affect rate of activity ramping in the Cx-BG-TH loop.

- Decreased direct pathway strength leads to slower ramping and slower reaction times, but improved accuracy.

Normal Direct Pathway

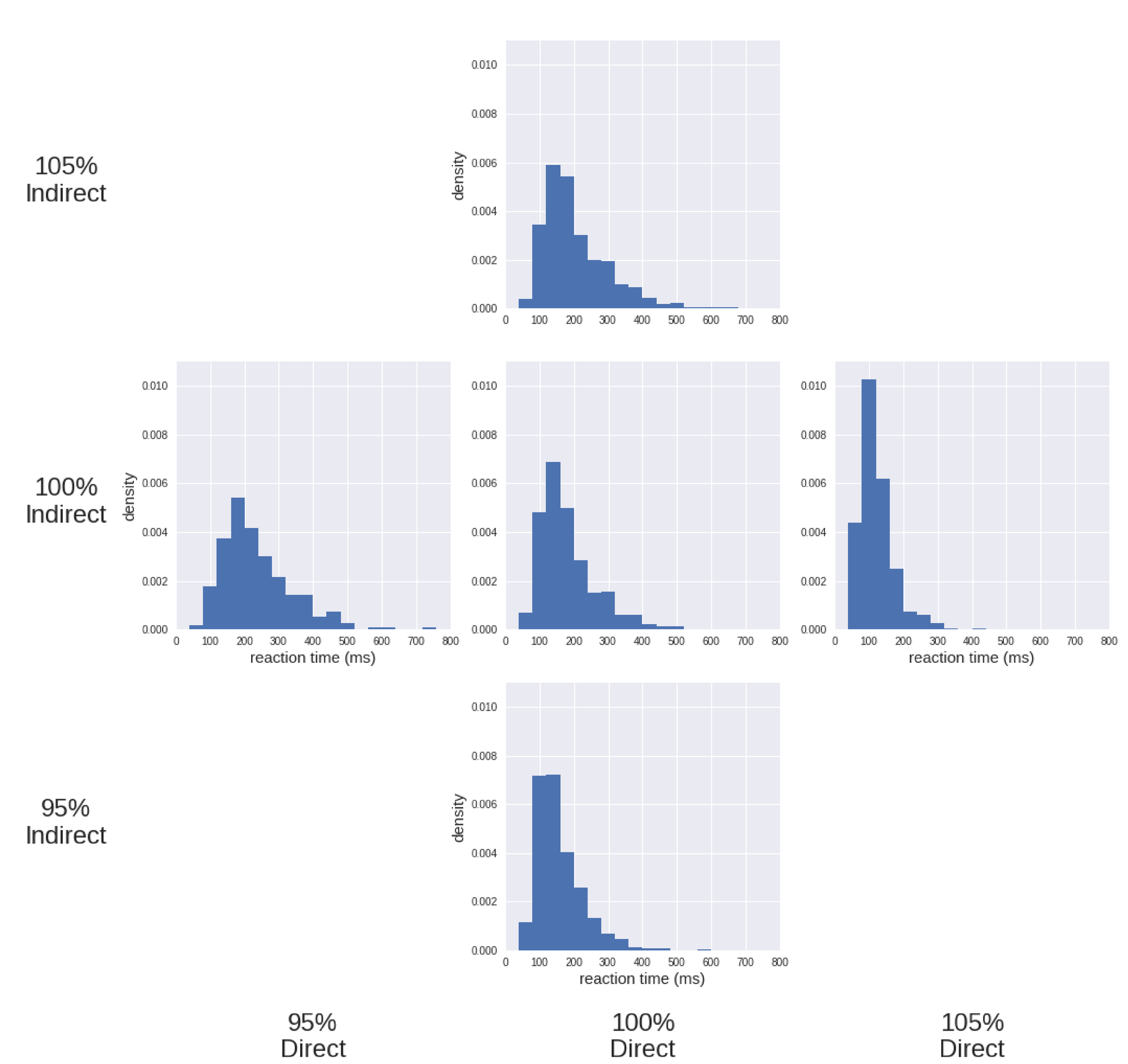


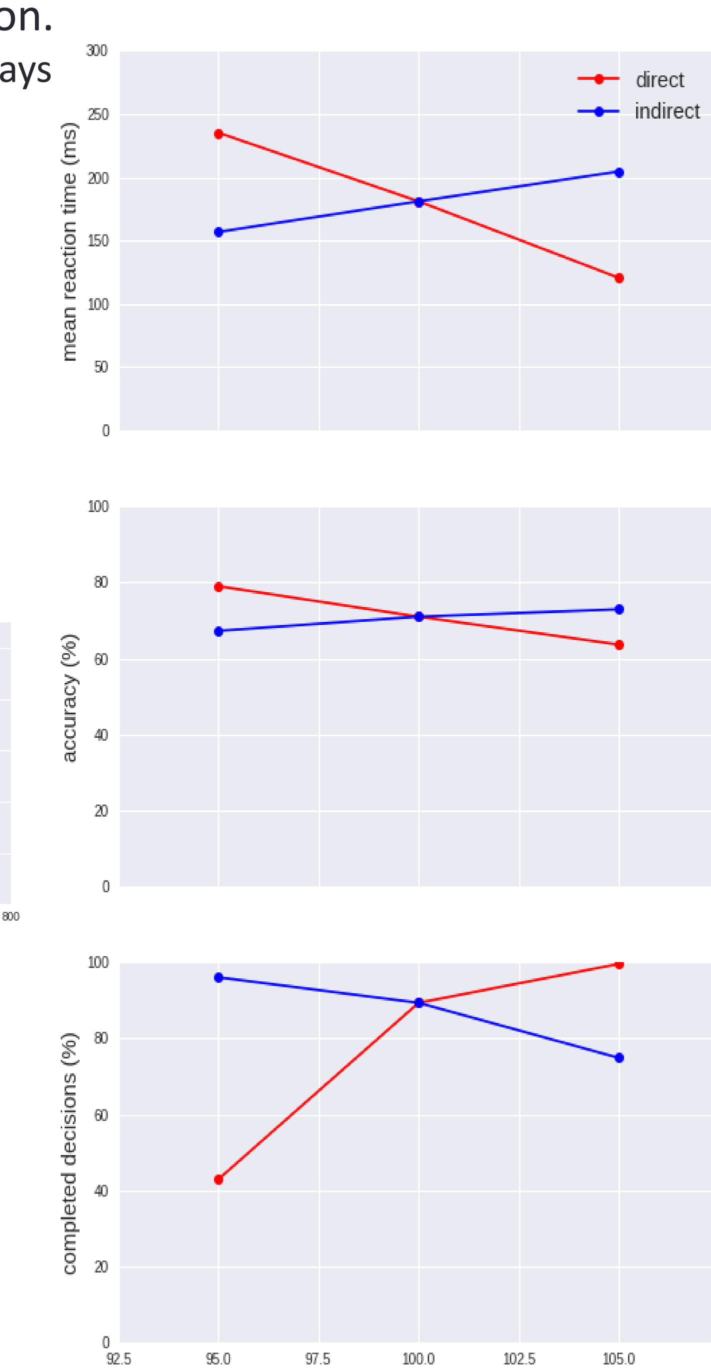
Diminished Direct Pathway



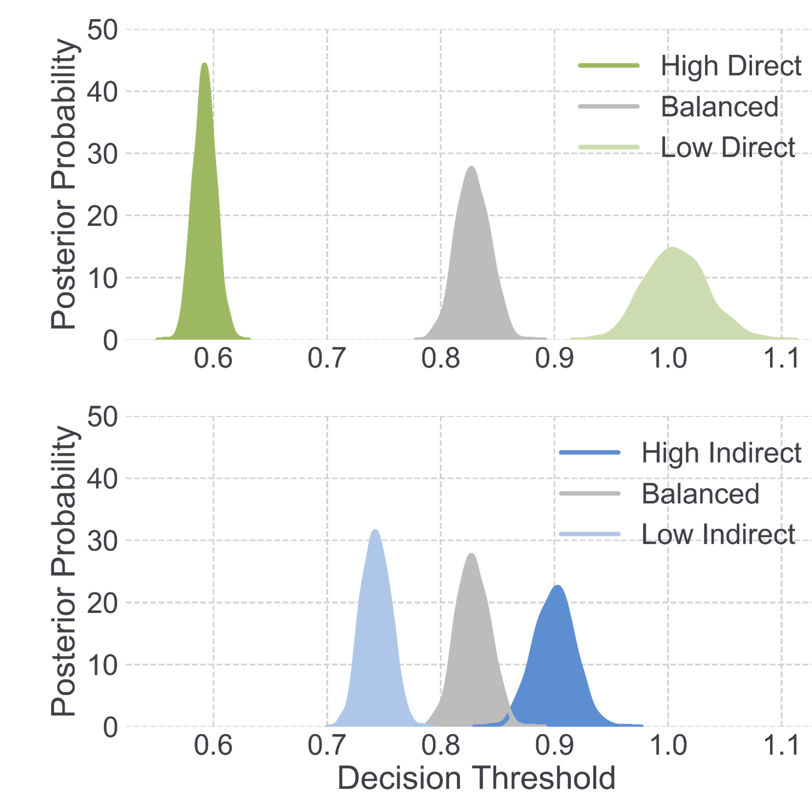
Direct and indirect pathways have opposing effects on reaction time, decision accuracy, and decision completion.

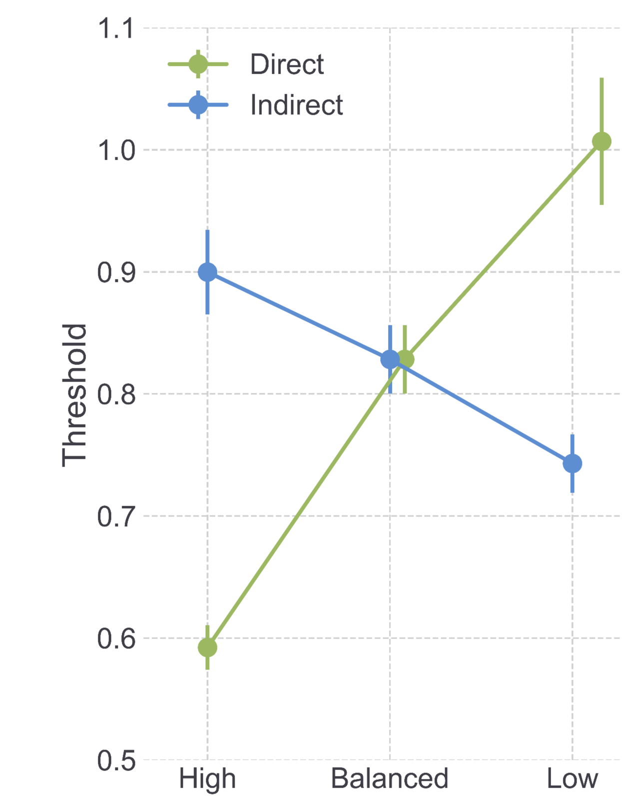
- Strengthened direct pathways and weakened indirect pathways lead to shorter reaction time, narrower RT distributions, decreased accuracy, and increased response rate.
- Variation of direct pathway had larger influence.





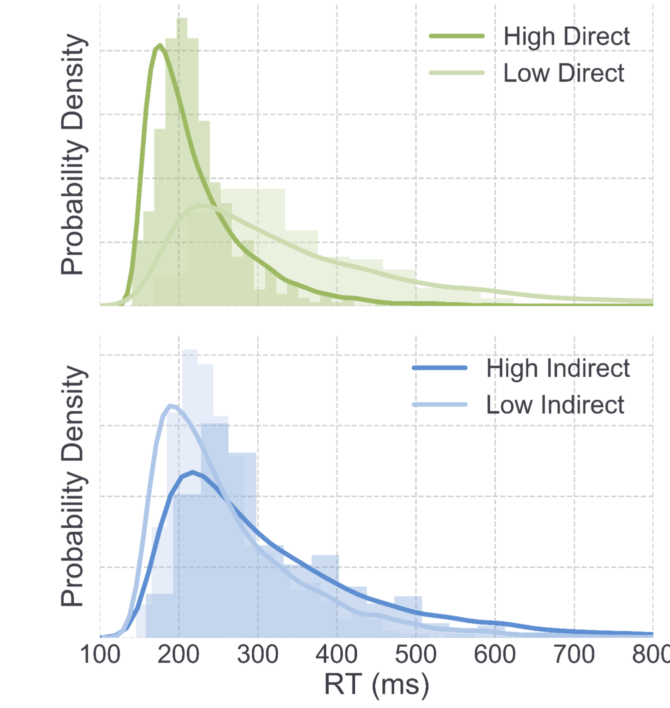
BEHAVIORAL MODEL FITTING





Pathway strength affects the behavioral decision threshold – the level of confidence necessary to evoke a response.

- High direct lowers threshold while high indirect raises threshold.
- Variation in RT distributions is better explained by changes in decision threshold than in drift rate.
- RT distributions reasonably fit those predicted by drift-diffusion model.



SUMMARY & DISCUSSION

Direct and indirect pathway strengths have counterbalancing effects on speed-accuracy tradeoff.

- High direct and low indirect associated with faster speed and lower accuracy.

Tradeoff can be explained as modulation of behavioral decision threshold.

- Drift rate might be primarily determined by other simulation parameters.

Change in direct pathway had stronger effect on decision threshold and performance tradeoff.

REFERENCES & ACKNOWLEDGEMENTS

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