INI Retreat 2023
Decision making and adaptation

Robert Schmidt

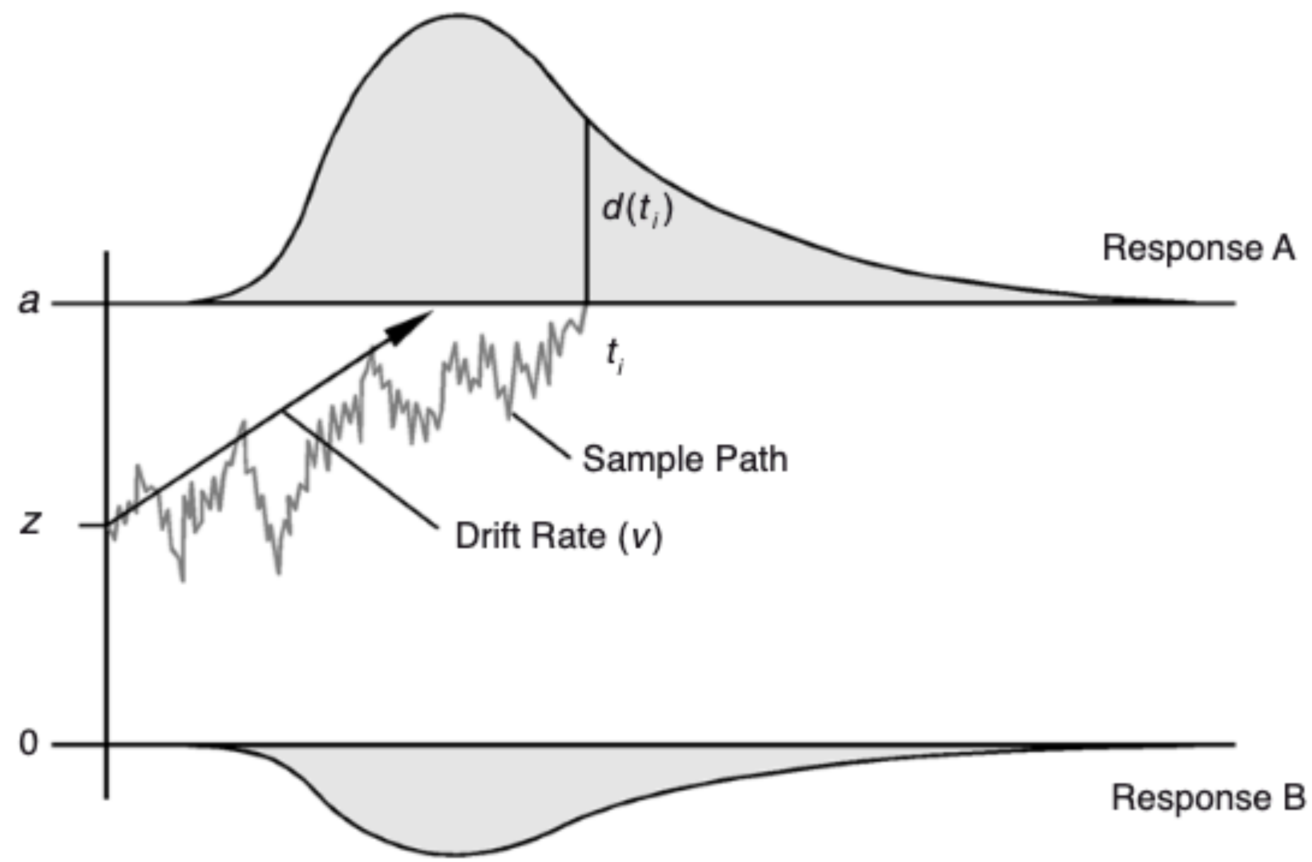
Institute for Neural Computation, Faculty of Computer Science

Overview

1. **Drift-Diffusion model and related models**
2. **Why are these models useful?**
3. **How can decision making be adapted?**
4. **How are these models connected to neuroscience?**

Drift-Diffusion model and related models

The diffusion model



Main Parameters:

- Upper threshold (a) ("conservatism")
- Starting point (z) ("Bias")
- Drift rate (v)

Other Parameters:

- Response time constant (t_0)
- Diffusion constant (s)
- Inter-trial variability of parameters (typically standard deviation of drift rate)

Basic model as a stochastic differential equation:

drift term

$$dx = \nu dt + \sigma dW$$

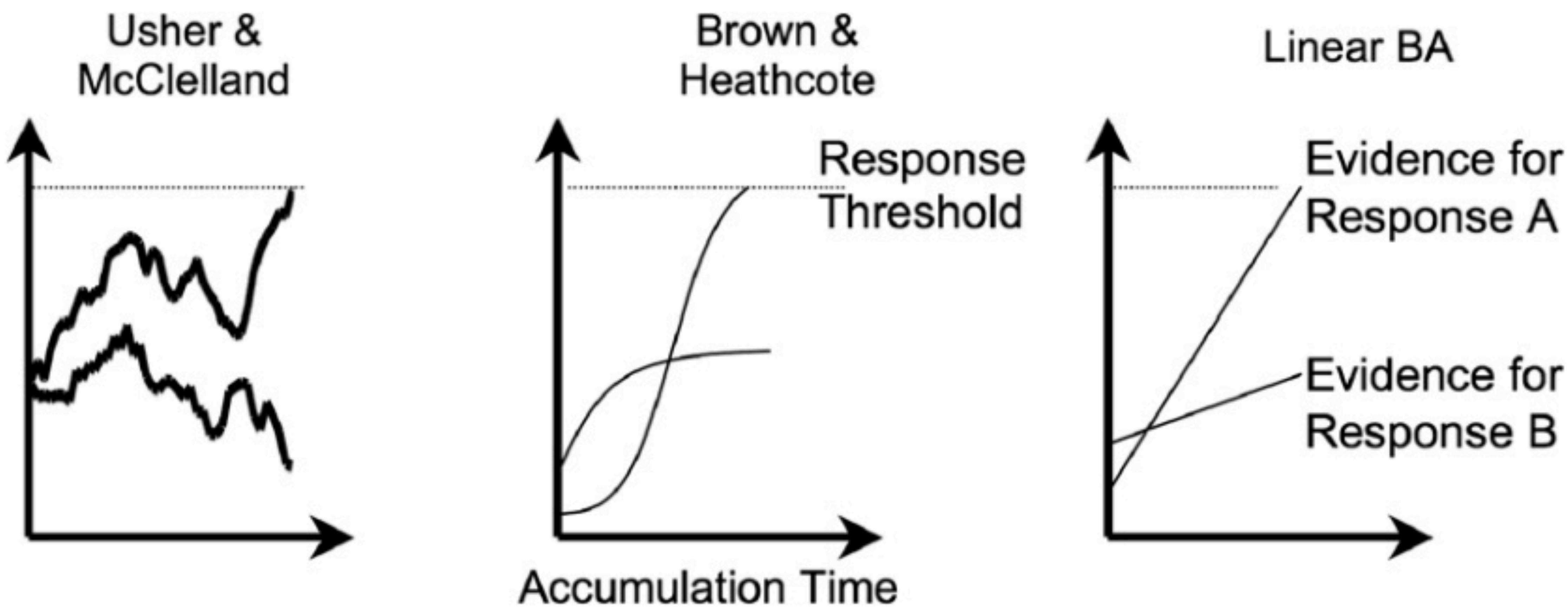
change in decision variable

noise term (Wiener process)

Voss, A., Rothermund, K., & Voss, J. (2004). Interpreting the parameters of the diffusion model: An empirical validation. Memory & cognition, 32, 1206-1220.
Bogacz, R., Brown, E., Moehlis, J., Holmes, P., & Cohen, J. D. (2006). The physics of optimal decision making: a formal analysis of models of performance in two-alternative forced-choice tasks. Psychological review, 113(4), 700.

Some related models

(there is a bit of a zoo of very similar models…)



- Trial-to-trial variability in drift rates and starting points
- Passive decay
- Response competition

- No within-trial randomness

- Linear evidence accumulation
- No competition

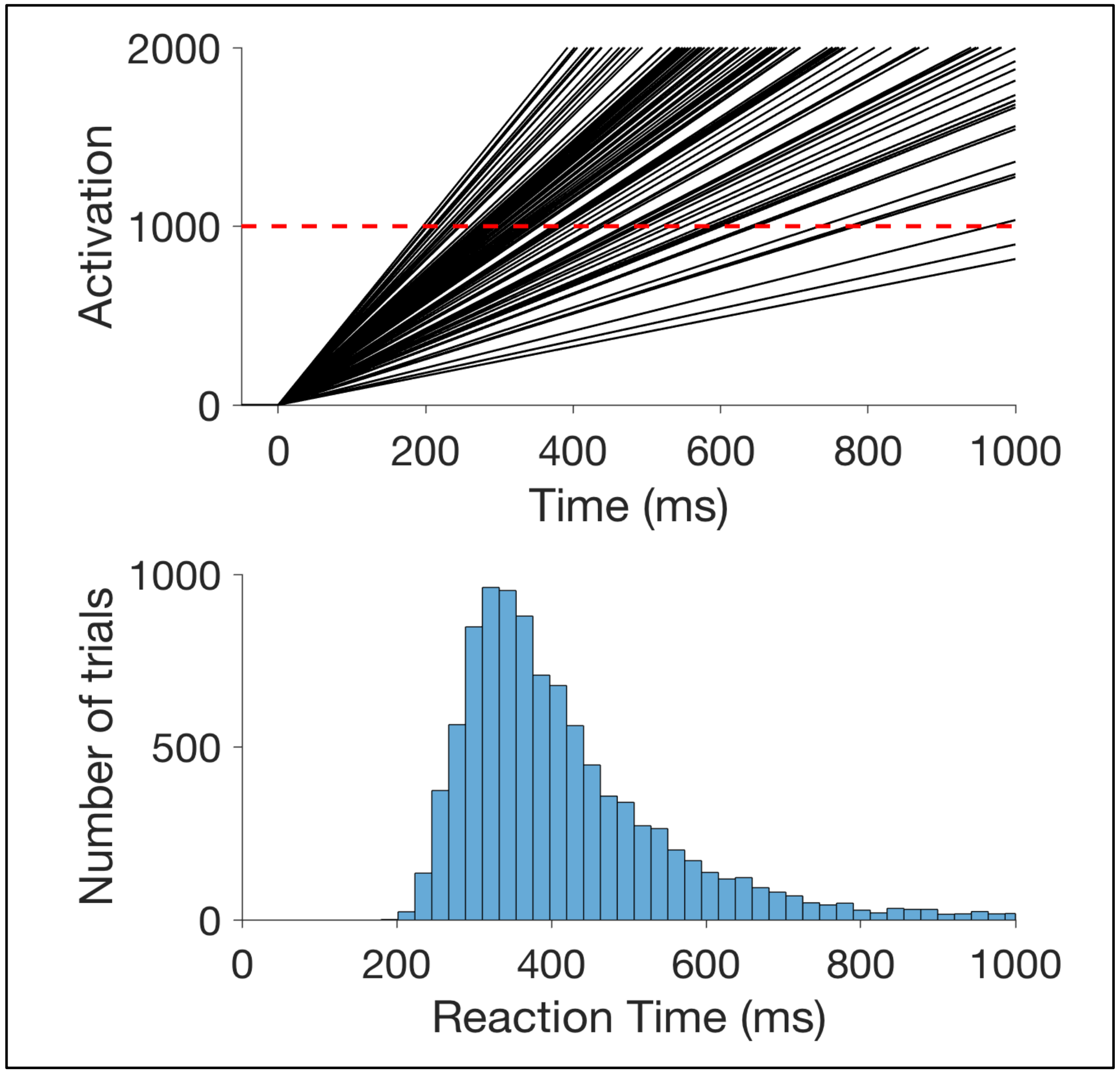
Brown, S. D., & Heathcote, A. (2008). The simplest complete model of choice response time: Linear ballistic accumulation. *Cognitive psychology*, *57*(3), 153-178.

Why are these models useful?

Using models for data analysis

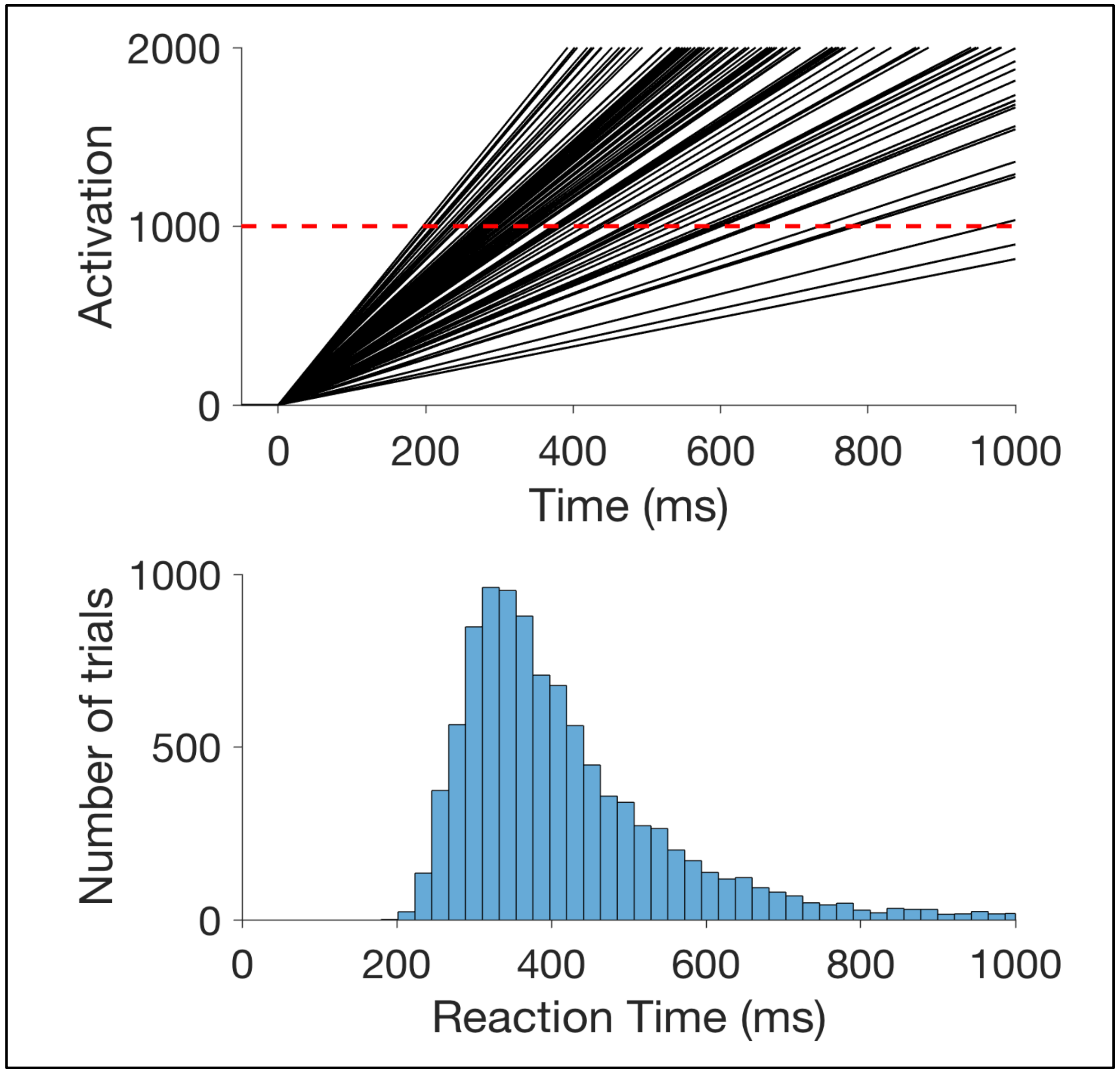
Main idea behind model-based analysis

- Instead of analysing behavioural data (reaction times, accuracy,…) directly, we describe the behavioural data in terms of model parameters
- So behavioural data, from a given participant and task condition, is used to fit model parameters
- Each participant would be associated with a set of model parameters; and often each participant would be associated with a different set of parameters for task conditions of interest
- The data analysis is then done on the model parameters
- Advantages:
    - Compressing large amounts of behavioural data
    - Removing noise and idiosyncratic patterns (considered irrelevant here)
    - Interpretation of results in terms of theoretical frameworks
    - Connection to neuroscience



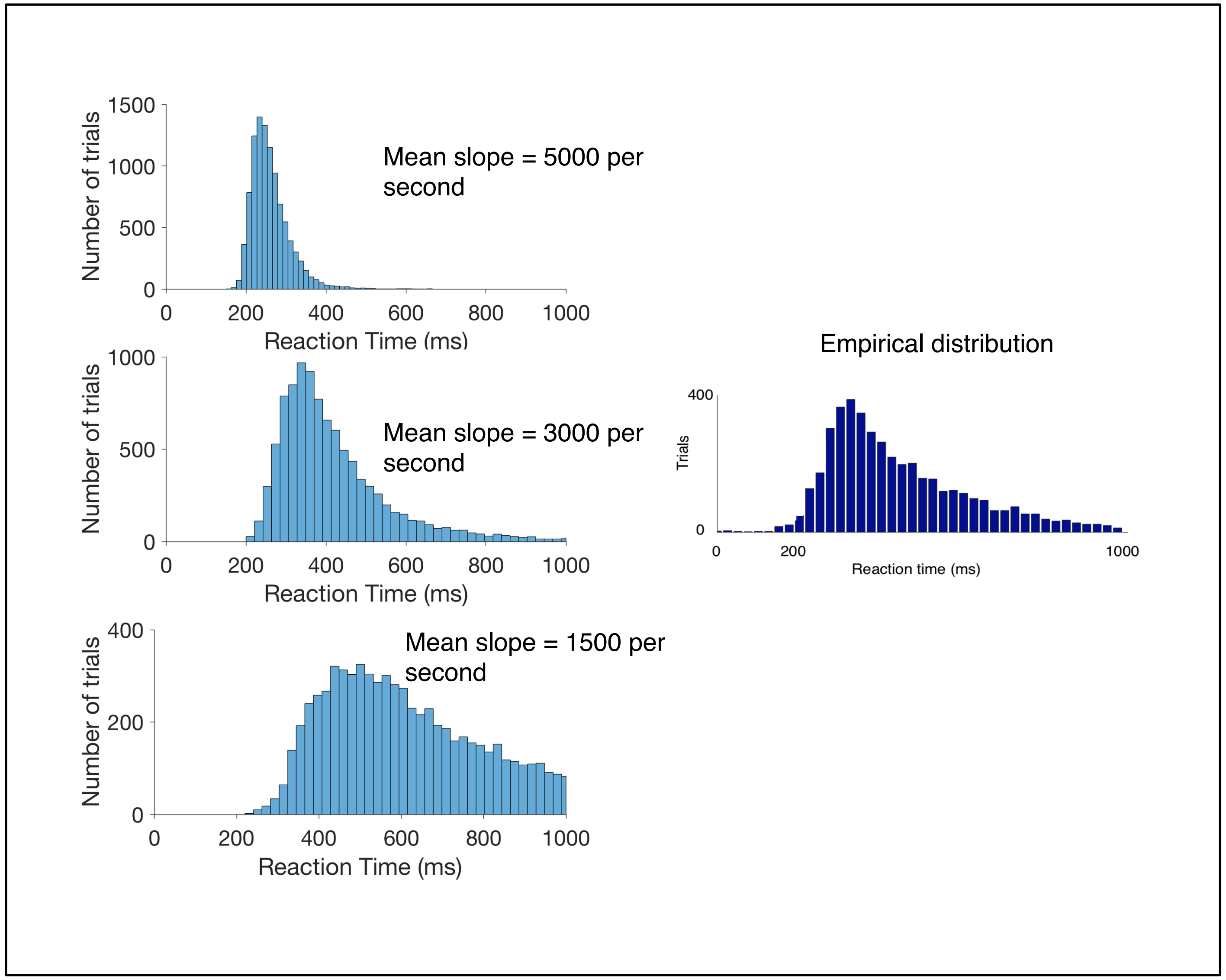
Using models for data analysis

- Example here: how to fit the drift rate to empirical data?
- Assumption: drift rate is a random variable that we sample in each trial from a normal distribution
- Brute force:
    - try out normal distributions with different means and standard deviations
    - For each, you obtain a model reaction time distribution that you can compare with the empirical distribution
    - Pick the one that fits best and you have found your parameters for the slope!



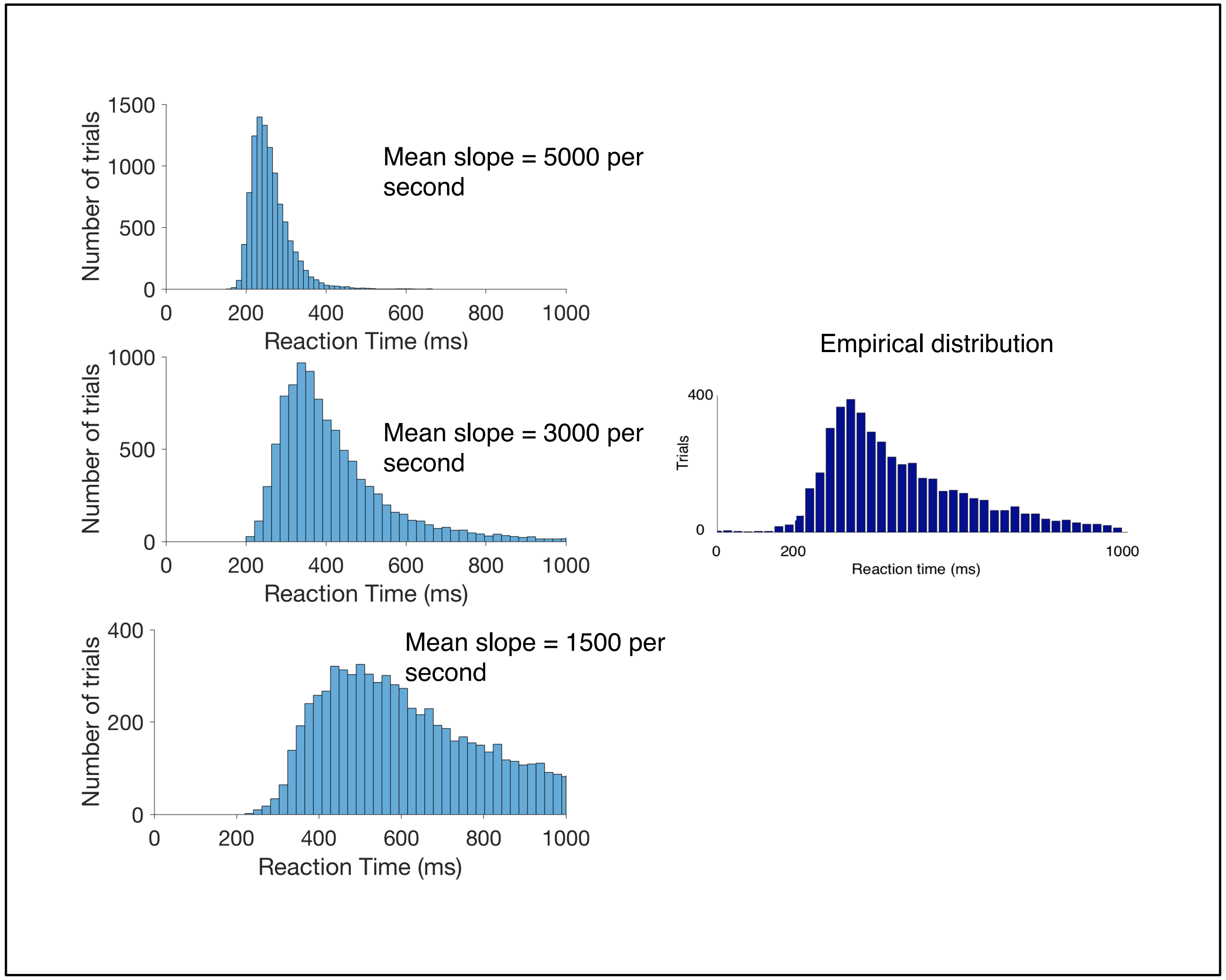
Using models for data analysis

- Example here: how to fit the drift rate to empirical data?
- Assumption: drift rate is a random variable that we sample in each trial from a normal distribution
- Brute force:
    - try out normal distributions with different means and standard deviations
    - For each, you obtain a model reaction time distribution that you can compare with the empirical distribution
    - Pick the one that fits best and you have found your parameters for the slope!



Using models for data analysis

- Different fitting methods available
- Maximum likelihood estimation
- Chi-square and weighted least-square methods
- Statistic of the Kolmogorov-Smirnov test
- R packages, e.g.:
  - code: https://github.com/igmmgi/DMCfun
  - paper: https://doi.org/10.1016/j.metip.2021.100074)

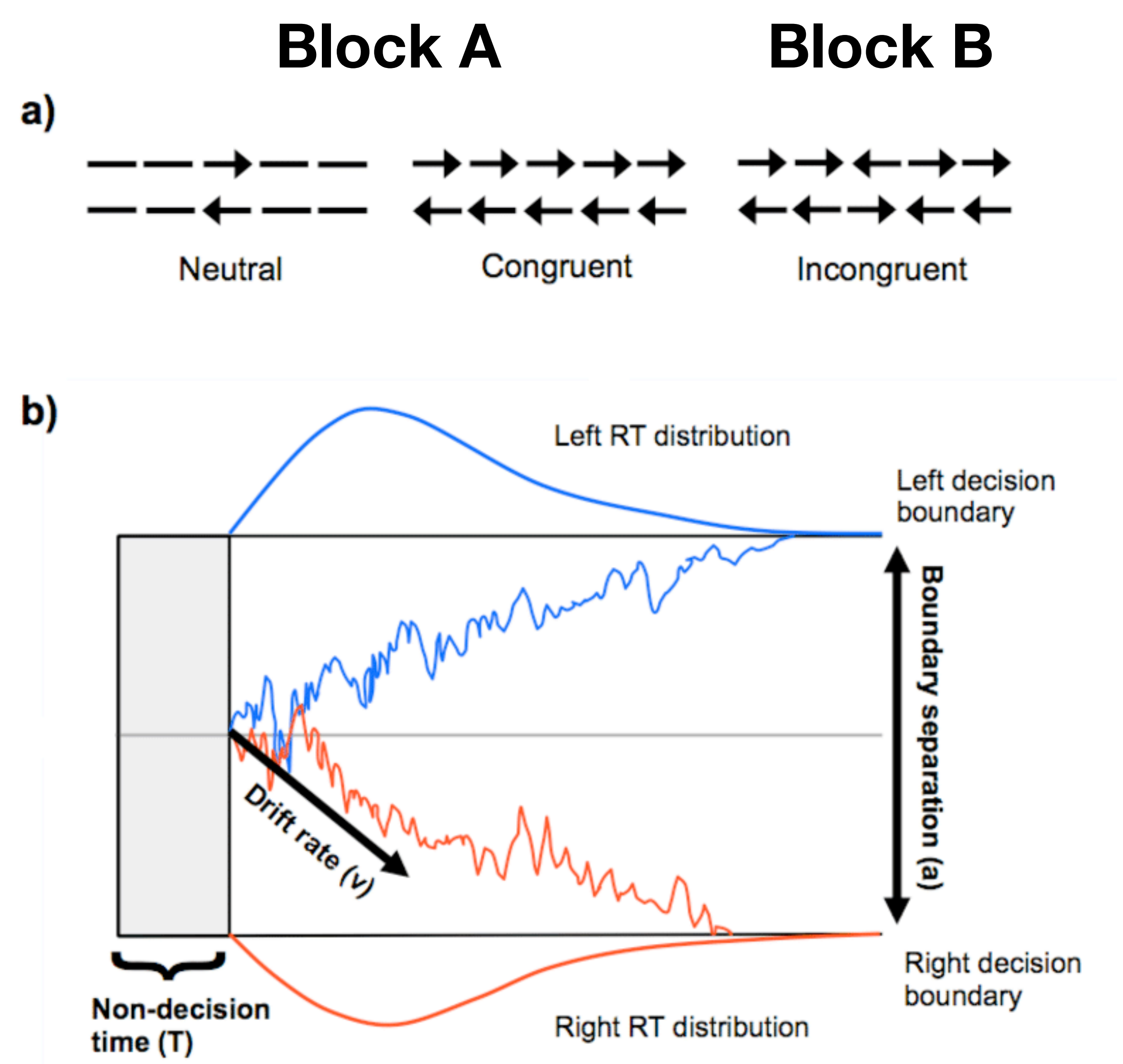


Mackenzie, I. G., & Dudschig, C. (2021). DMCfun: An R package for fitting Diffusion Model of Conflict (DMC) to reaction time and error rate data. *Methods in Psychology*, *5*, 100074.

Adaptation

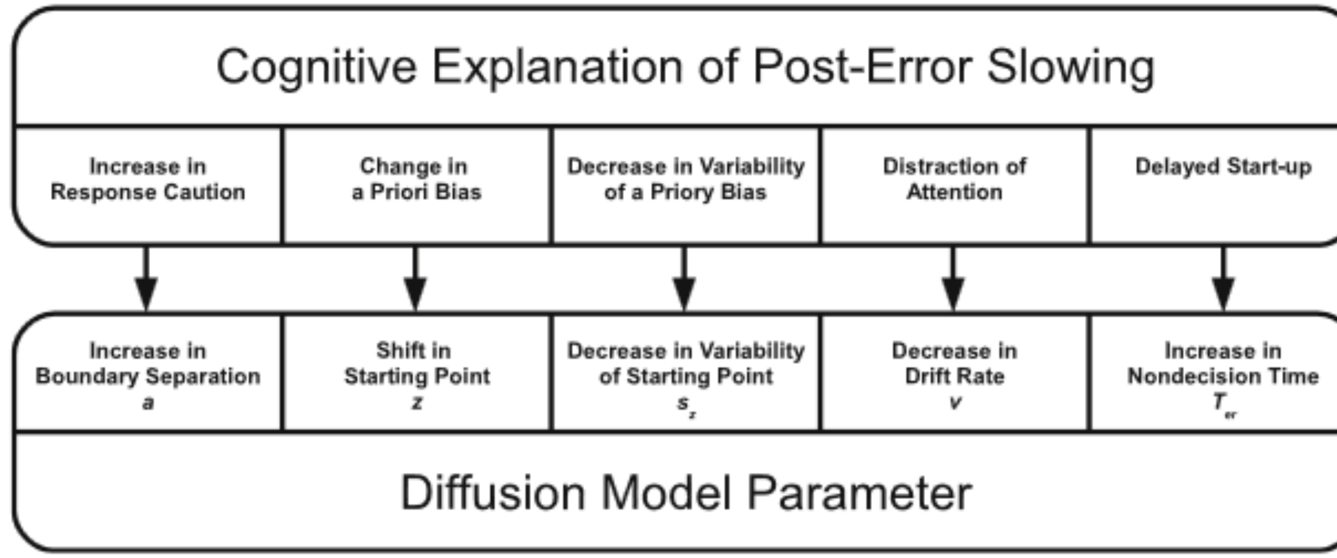
Adaptation of decision making

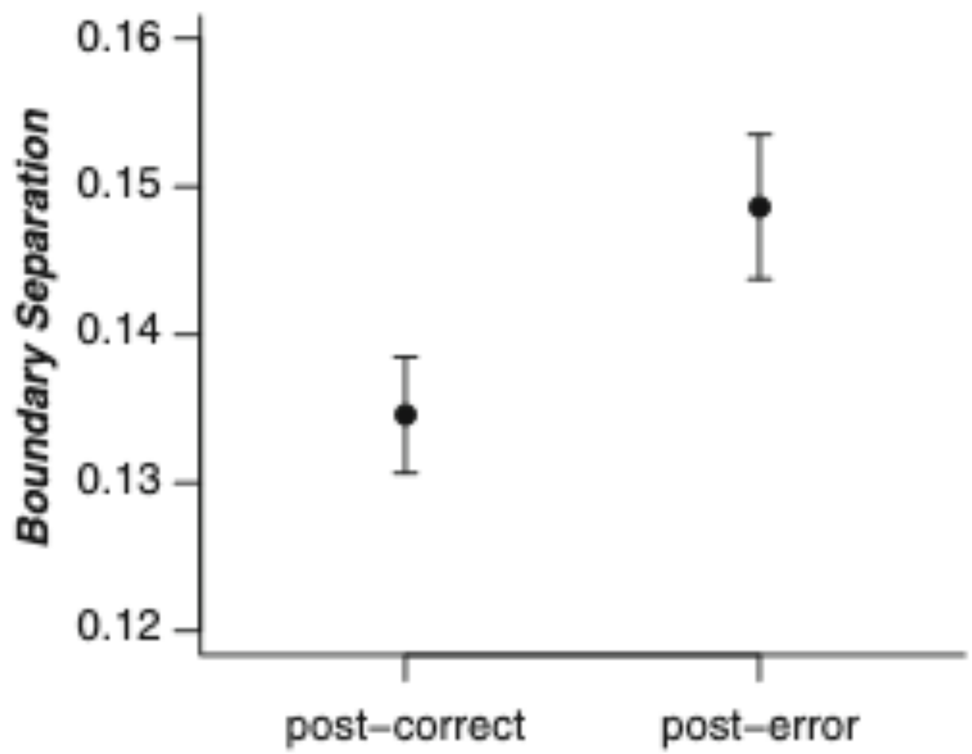
- An interesting aspect of decision making is how it adapts to different demands, situations, and conditions
- Wide range of possible applications of model-based analysis
- Identifying pathological decision making, e.g. comparing distribution of model parameters between Patients and Controls
- Characterising the effects of drug use
- Within-participant comparison of model parameters across different blocks in a task, e.g. task blocks with a high/low probability of a 'Conflict' (see Simon and Flanker tasks)
    - Possible project for this workshop: design a Simon/Flanker task variant with 'High' and 'Low' conflict blocks; how does decision making adapt, e.g. with an increase in the threshold (boundary) for high conflict?



Example: Post-Error Slowing

- In many tasks, after subjects make an error, they have a longer reaction time in the following trial
- There are different explanations for this phenomenon
- These have been proposed to map onto different parameters in the diffusion model
- Fitting diffusion model parameters for ‘post-correct’ and ‘post-error’ trials indicated that post-error slowing is due to an increase in the threshold (‘boundary separation’), interpreted as ‘response caution’



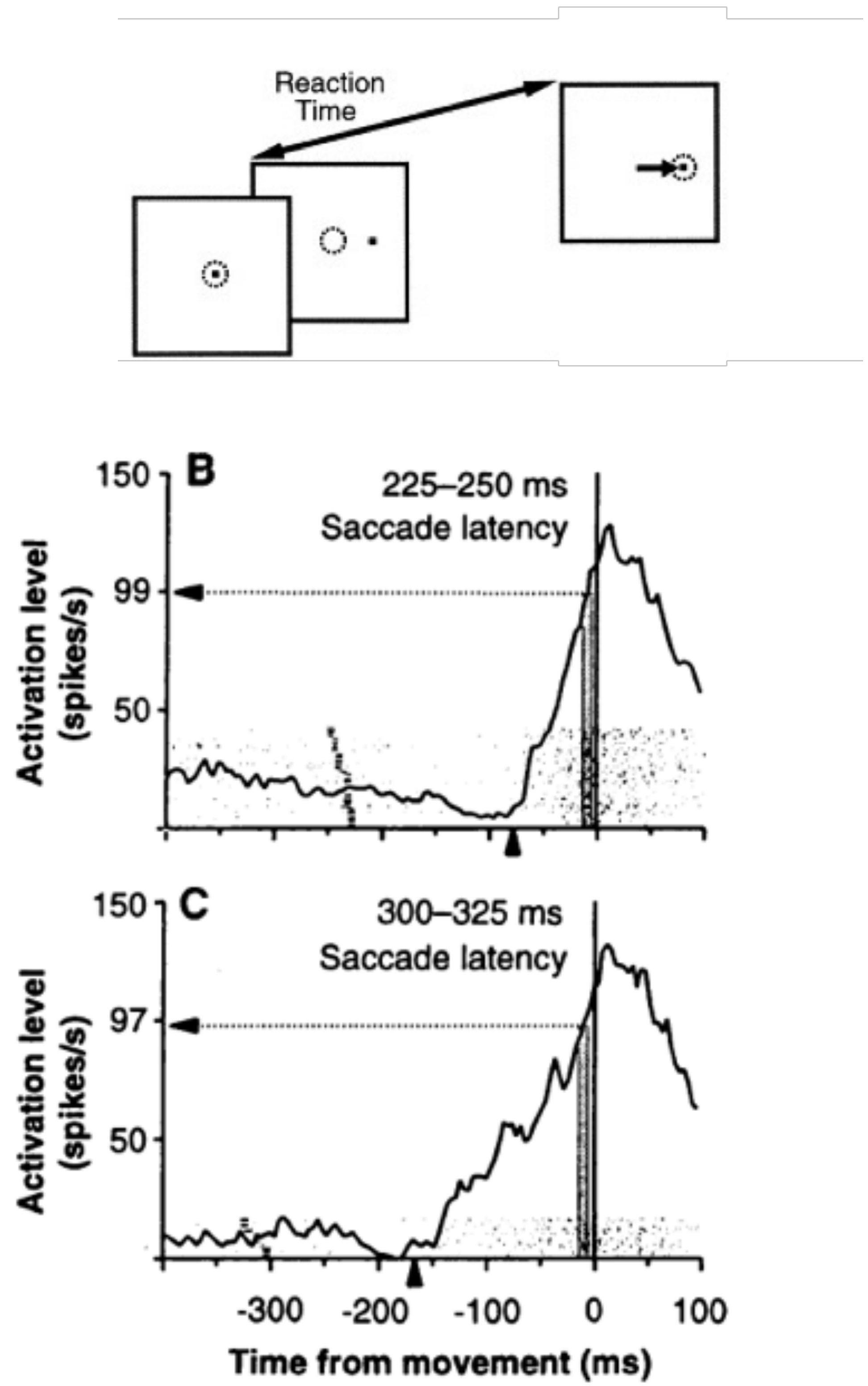


Dutilh, G., Vandekerckhove, J., Forstmann, B. U., Keuleers, E., Brysbaert, M., & Wagenmakers, E. J. (2012). Testing theories of post-error slowing. *Attention, Perception, & Psychophysics*, *74*, 454-465.

How are these models connected to neuroscience?

Neurophysiology of reaction time variability

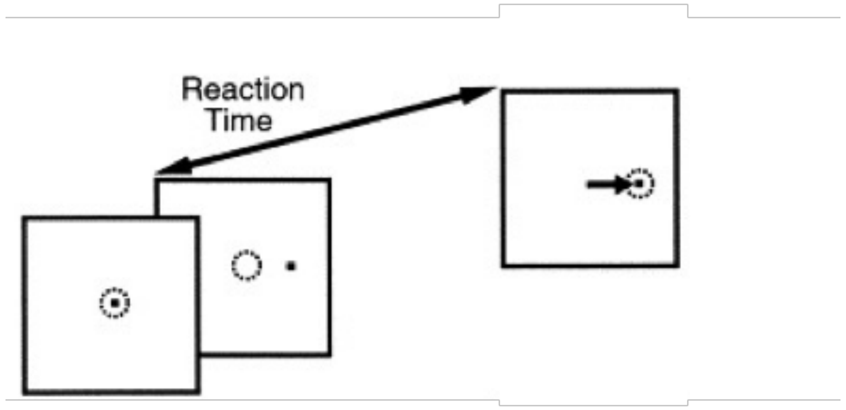
- Recordings in the frontal eye fields of monkeys performing a reaction time task
- Examination of neurons increasing their firing rate before saccades
- Neurons in the frontal eye field indicate that reaction times vary due to the drift parameter!

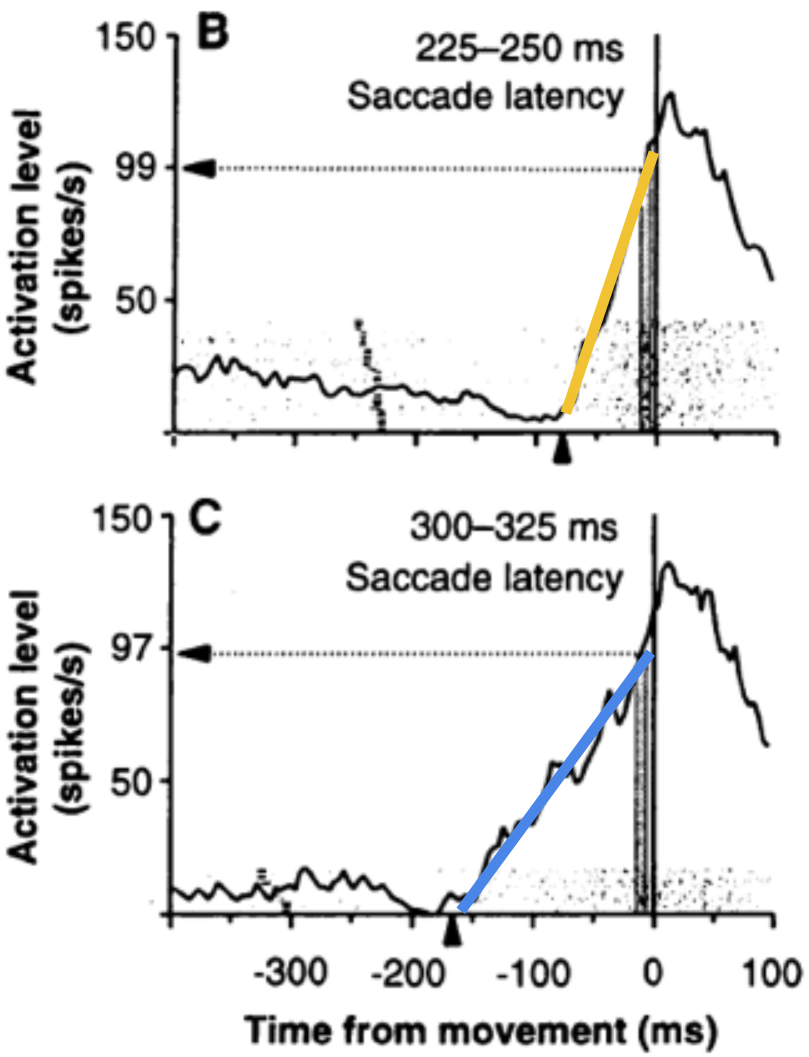


Hanes, D. P., & Schall, J. D. (1996). Neural control of voluntary movement initiation. Science, 274(5286), 427-430.

Neurophysiology of reaction time variability

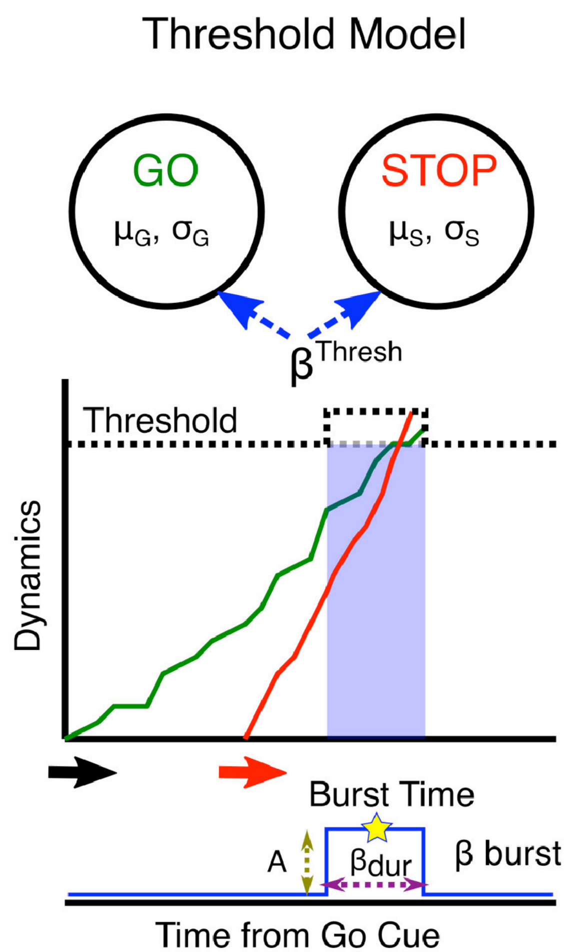
- Recordings in the frontal eye fields of monkeys performing a reaction time task
- Examination of neurons increasing their firing rate before saccades
- Neurons in the frontal eye field indicate that reaction times vary due to the drift parameter!

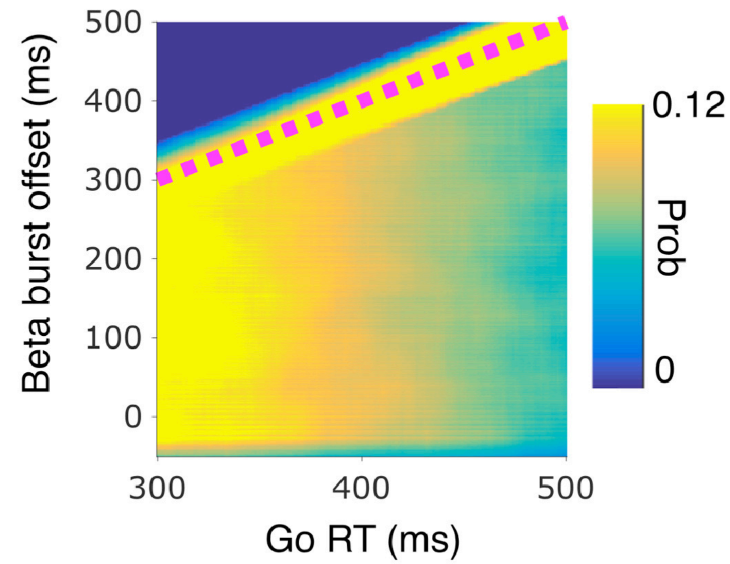




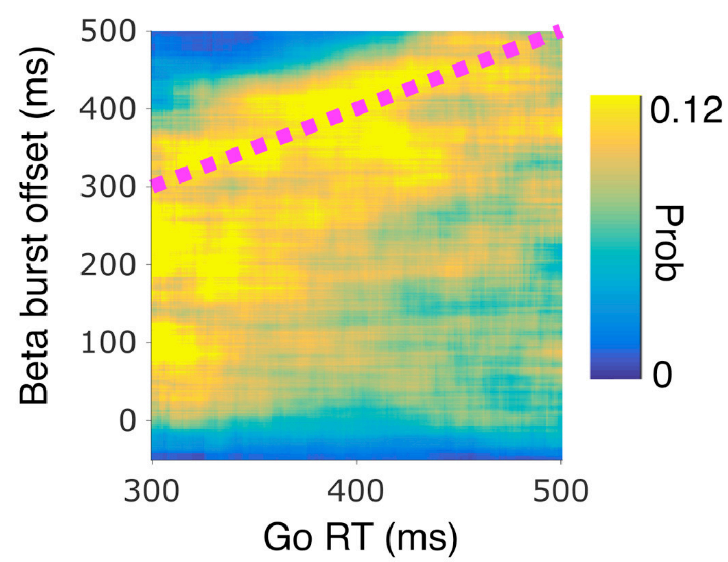
Hanes, D. P., & Schall, J. D. (1996). Neural control of voluntary movement initiation. Science, 274(5286), 427-430.

Beta oscillations can transiently increase decision thresholds





Model prediction



Human behaviour
(with EEG recordings)

Muralidharan, V., Aron, A. R., & Schmidt, R. (2022). Transient beta modulates decision thresholds during human action-stopping. NeuroImage, 254, 119145.

Summary

1. **Drift-Diffusion model and related models**
2. **Why are these models useful?**
3. **How can decision making be adapted?**
4. **How are these models connected to neuroscience?**

Next: Experimental Design