# What You See is What You Get:

## A Closer Look at Bias in the Visual World Paradigm

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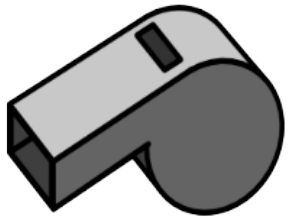
March 8, 2023



# Language and Cognition

The field is itself exceptionally broad, ranging from sentence processing, priming, reading, and word formation:

"trink" $\Rightarrow$ "trank" or "trinked"?

Troublesome when we commit too early:

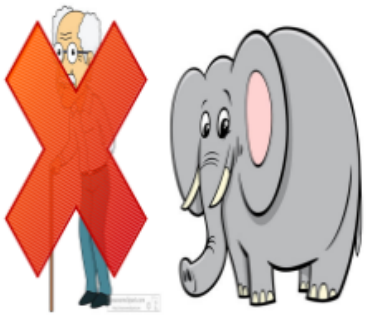
"The horse raced past the barn fell"

Often can not be observed directly

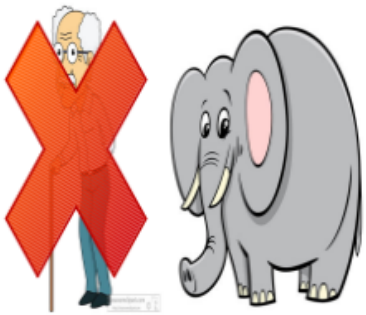
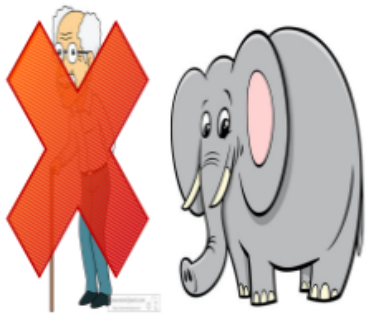
Limit focus to single word recognition

# el

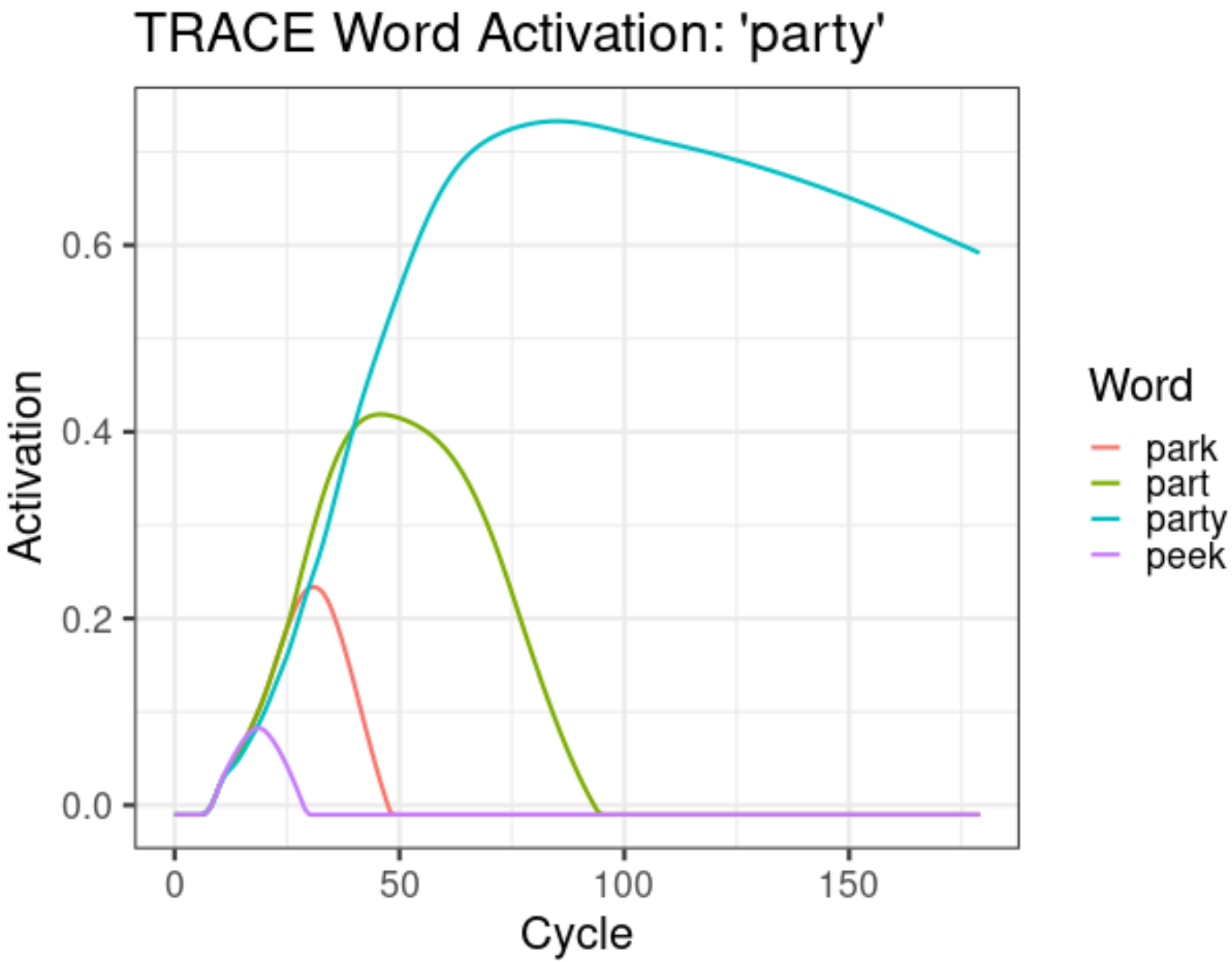
el → ele



el → ele → elephant




TRACE Word Activation: 'party'
Activation
0.0
0.2
0.4
0.6
0
50
100
150
Cycle
Word
park
part
party
peek

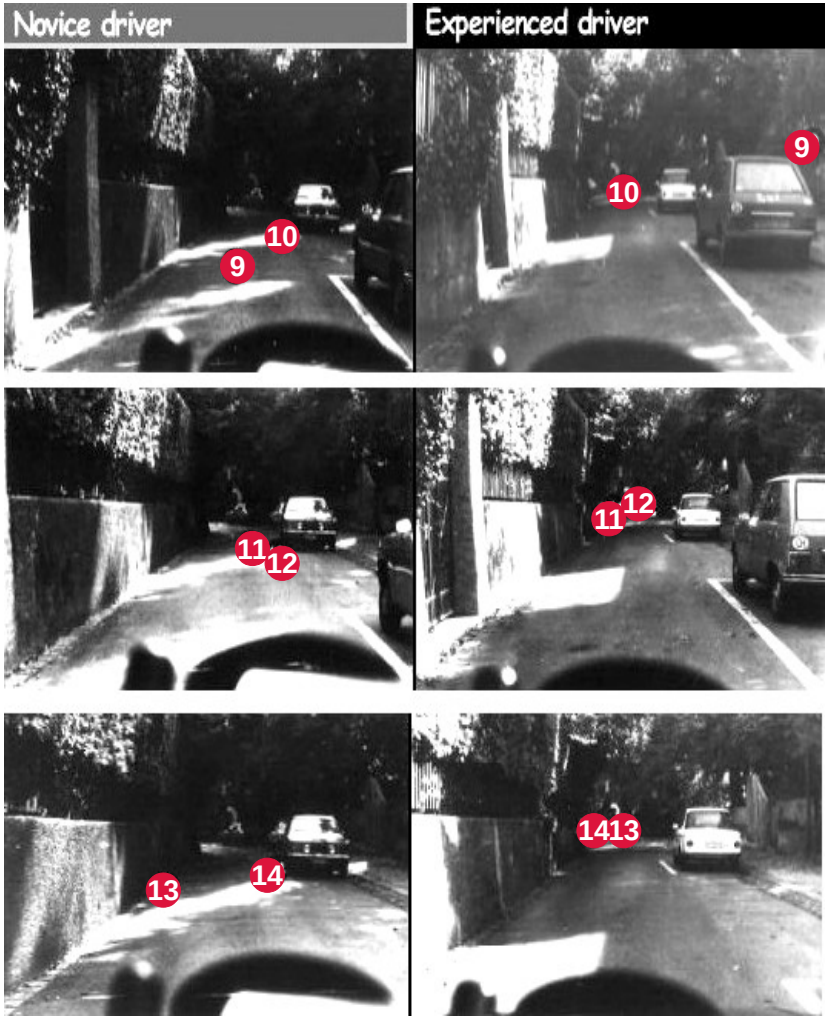
# Why do we care?

Typically interested in comparing activation between groups or conditions

- Normal Hearing (NH) vs Cochlear Implants (CI)
- Differentiating cognitive, specific, and non-specific impairments

How do we measure this?

# What's in a look?



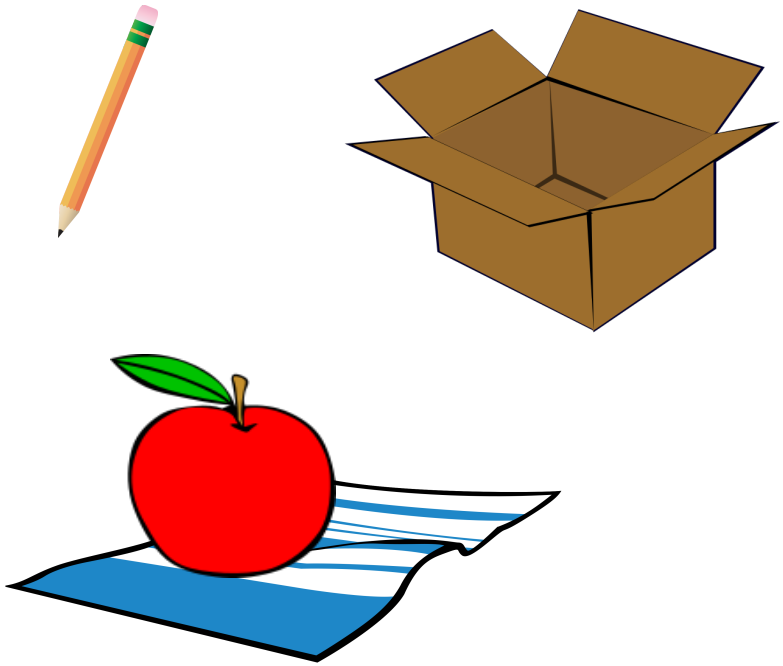

Cohen 1983

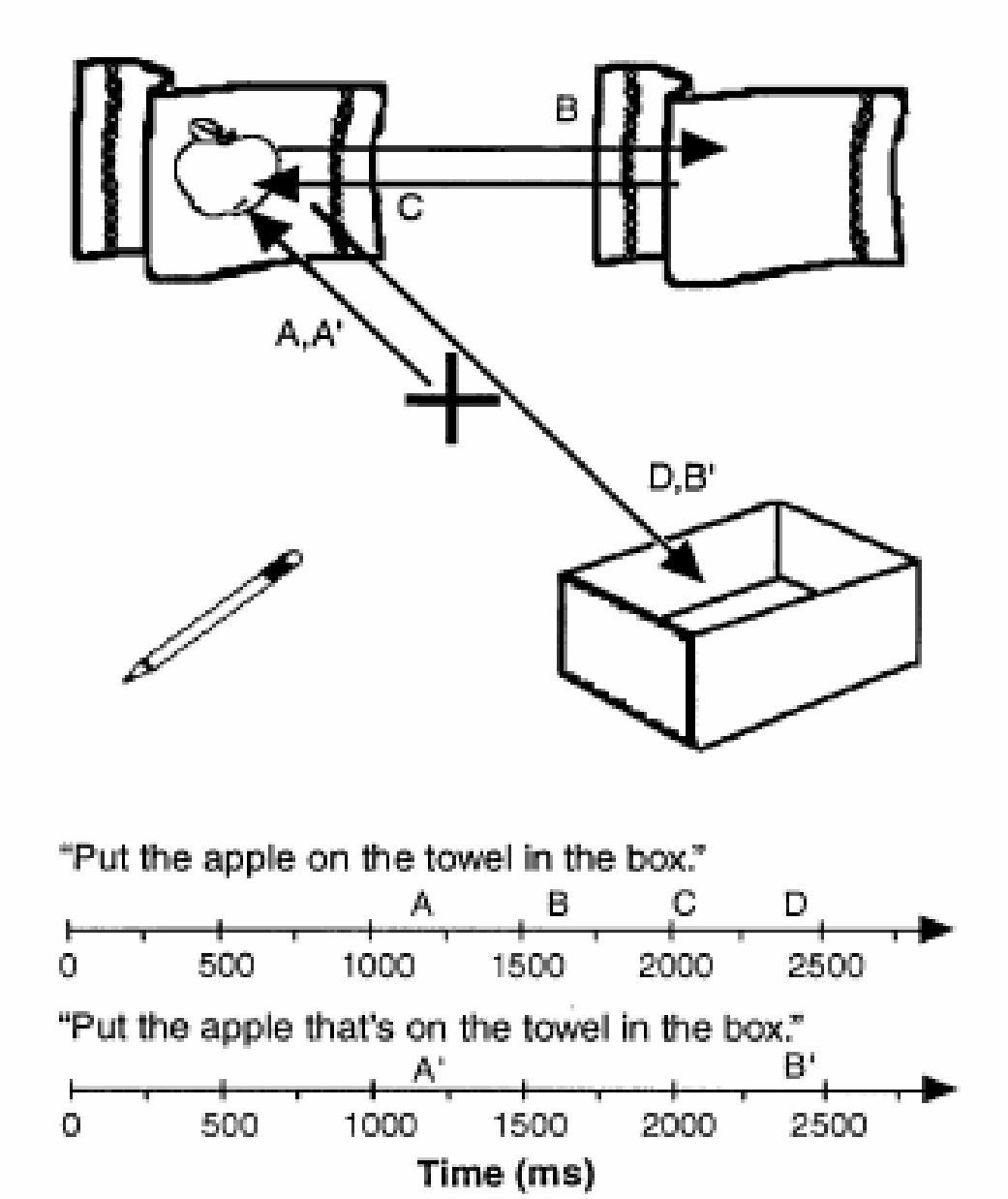
# Visual World Paradigm

Visual World Paradigm introduced in 1995

Eye-tracking in conjunction with spoken sentence

"Put the apple on the towel in the box"

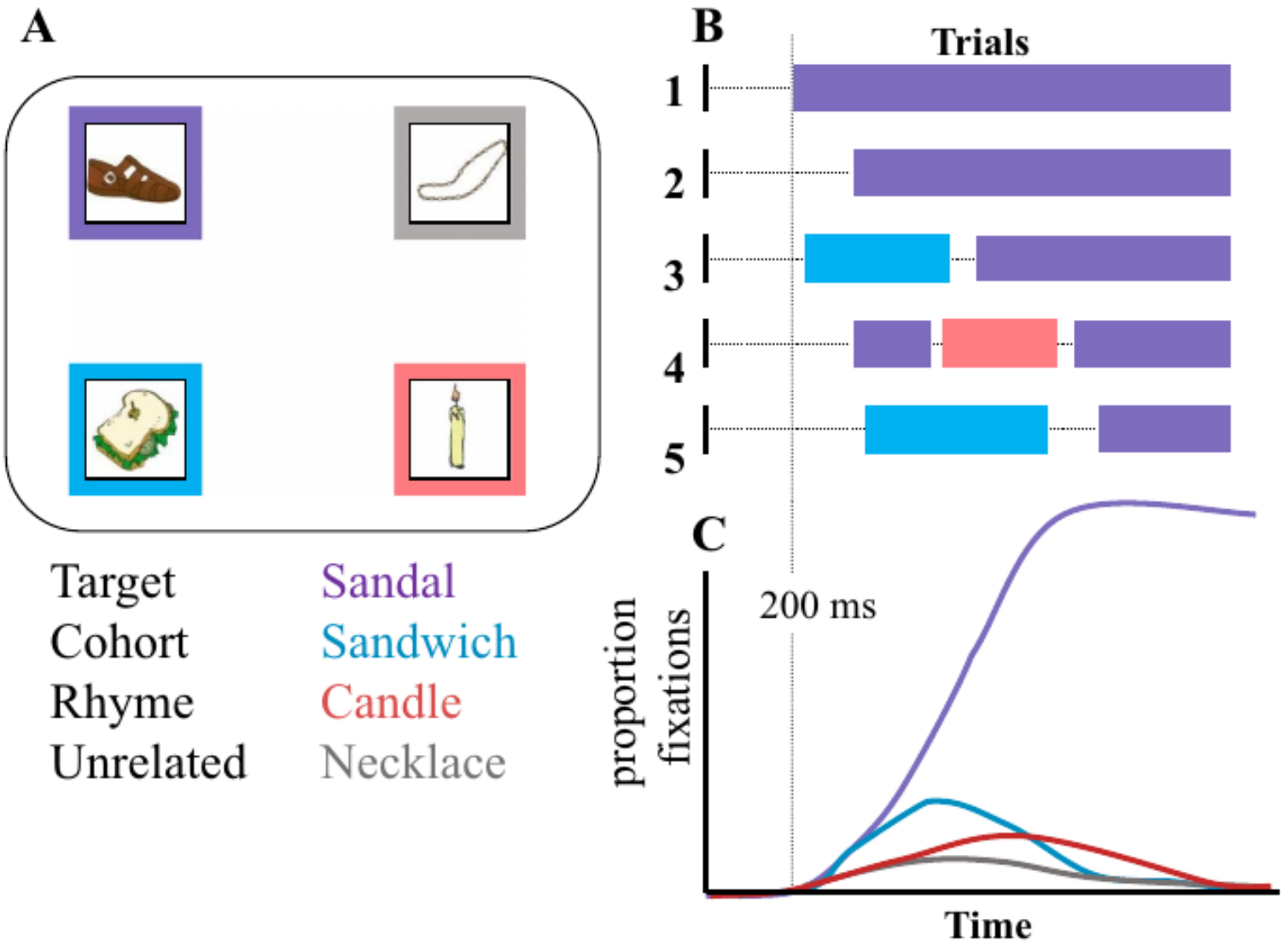



B
C
A,A'
D,B'
"Put the apple on the towel in the box."
A
B
C
D
0
500
1000
1500
2000
2500
"Put the apple that's on the towel in the box."
A'
B'
0
500
1000
1500
2000
2500
Time (ms)

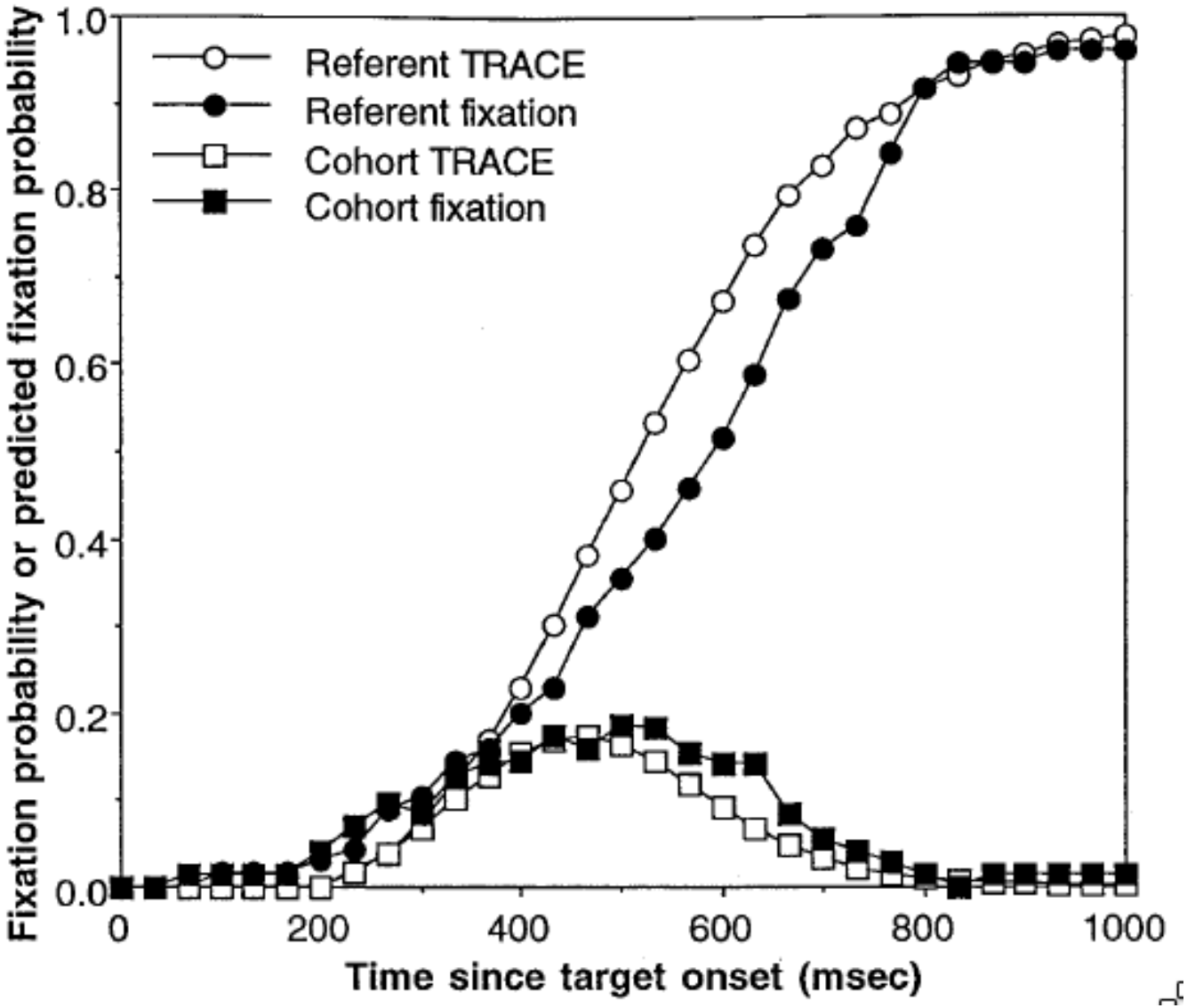
# Outline

- Eye-tracking and the VWP
- Methodology and Bias
- Simulation

# VWP Trials


A
Target
Cohort
Rhyme
Unrelated
Sandal
Sandwich
Candle
Necklace
B
Trials
1
2
3
4
5
C
200 ms
proportion fixations
Time

# Eye-tracking as activation



# So how does this relate to VWP

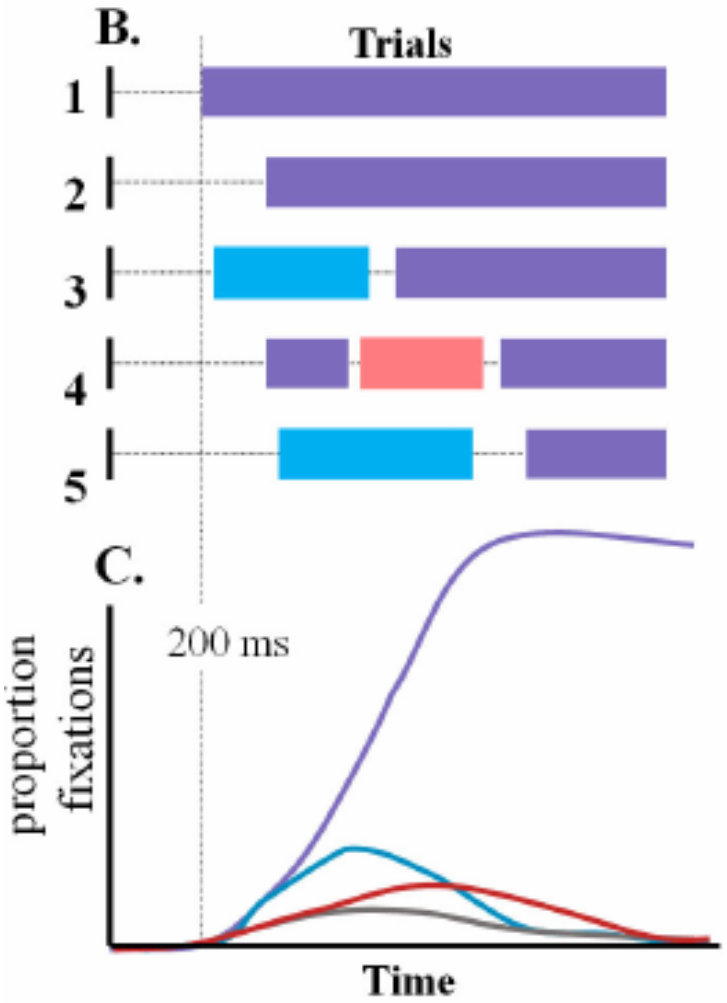
"Proportion of fixations" method

Letting $z_{jt}$ represent an indicator of fixation at time $t$ for trial $j = 1, \ldots, J$, we have empirical curve

$$y_t = \frac{1}{J} \sum_j z_{jt}$$

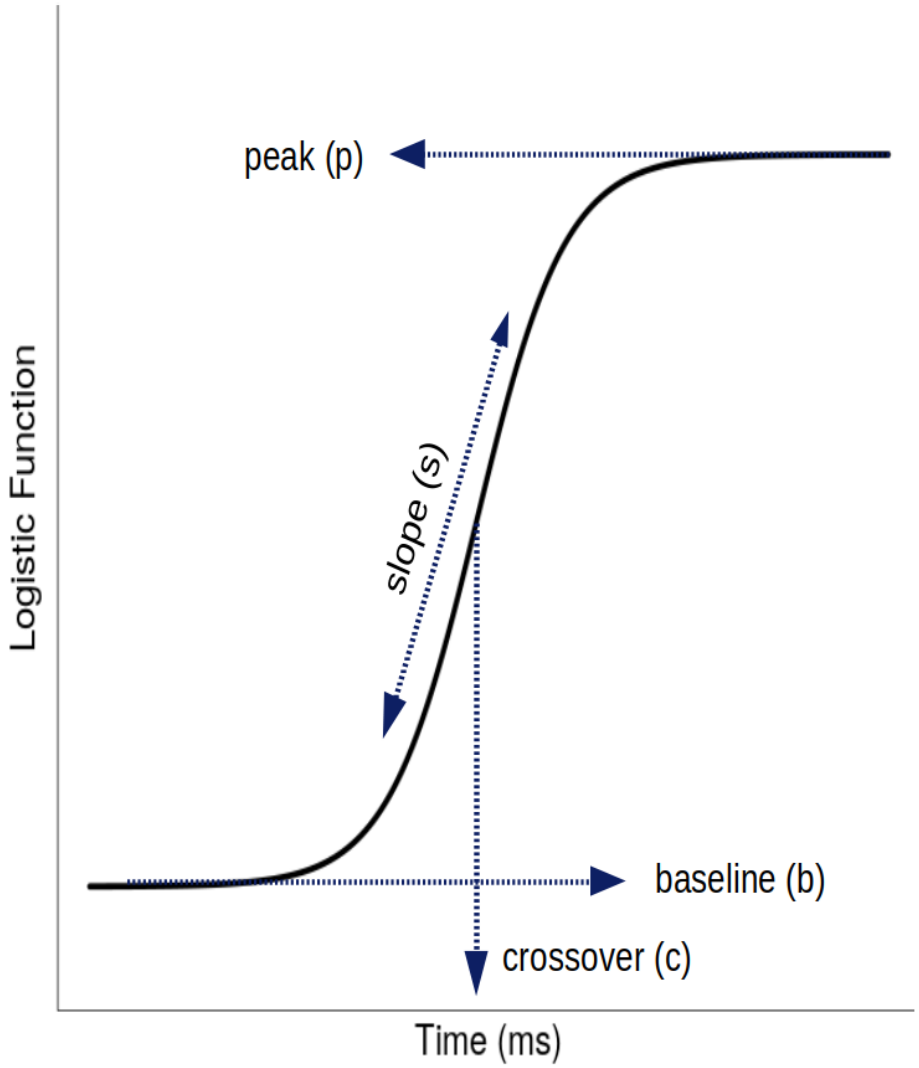
and find

$$\hat{\theta} = \underset{\theta}{\operatorname{argmin}}\, \mathcal{L}(f_\theta, y)$$



# Target – Logistic

$$f_\theta(t) = b + \frac{p-b}{1+\exp\left(\frac{4s}{p-b}(c-t)\right)}$$




Collin's dissertation
Proportion of Fixations Method


The next 20 slides
Proportion of Fixations Method

# Issues

"The default interpretation is greater fixation proportions indicate greater activation in the underlying processing system" (Magnuson 2019)

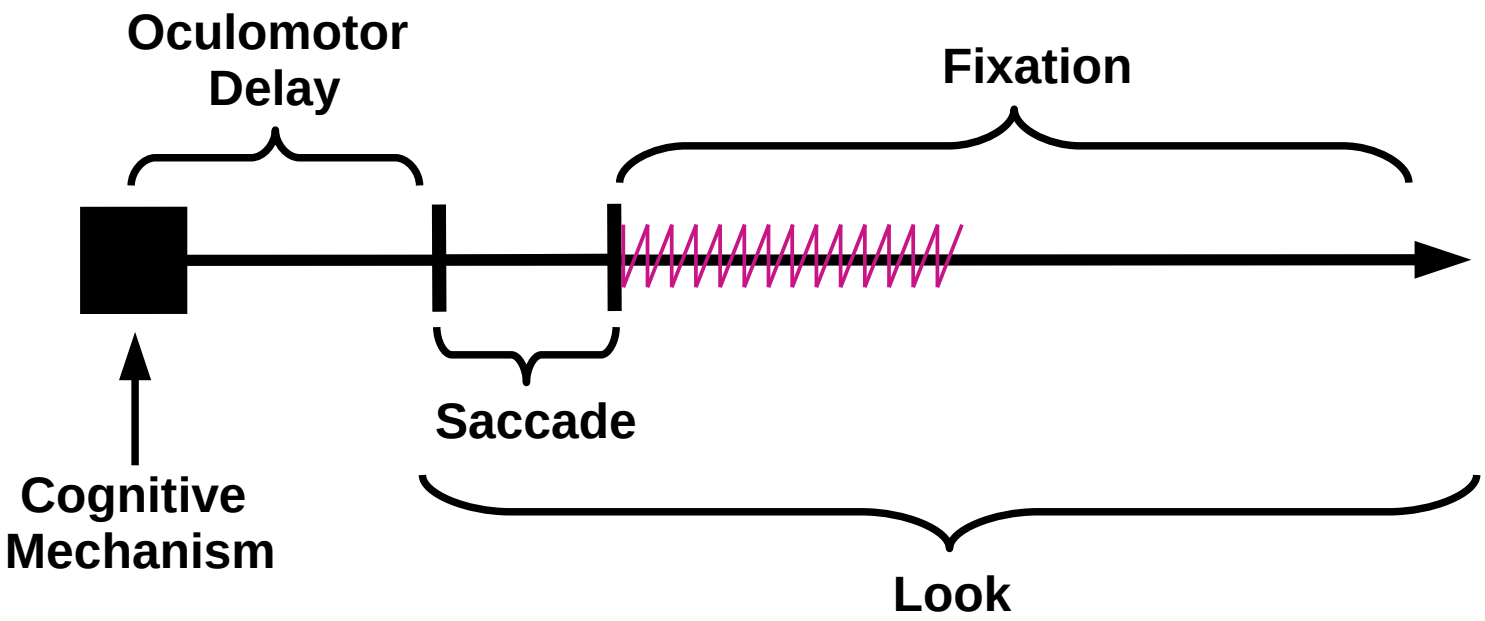
Specification of linking hypothesis

Despite visual similarities between the proportion of fixations and activation, there is an issue with the equivalence

$$y_{it} \equiv f(t|\theta_i).$$

Eye mechanics made up of distinct mechanisms that are differentially related to activation

# Visualizing Eye Mechanics

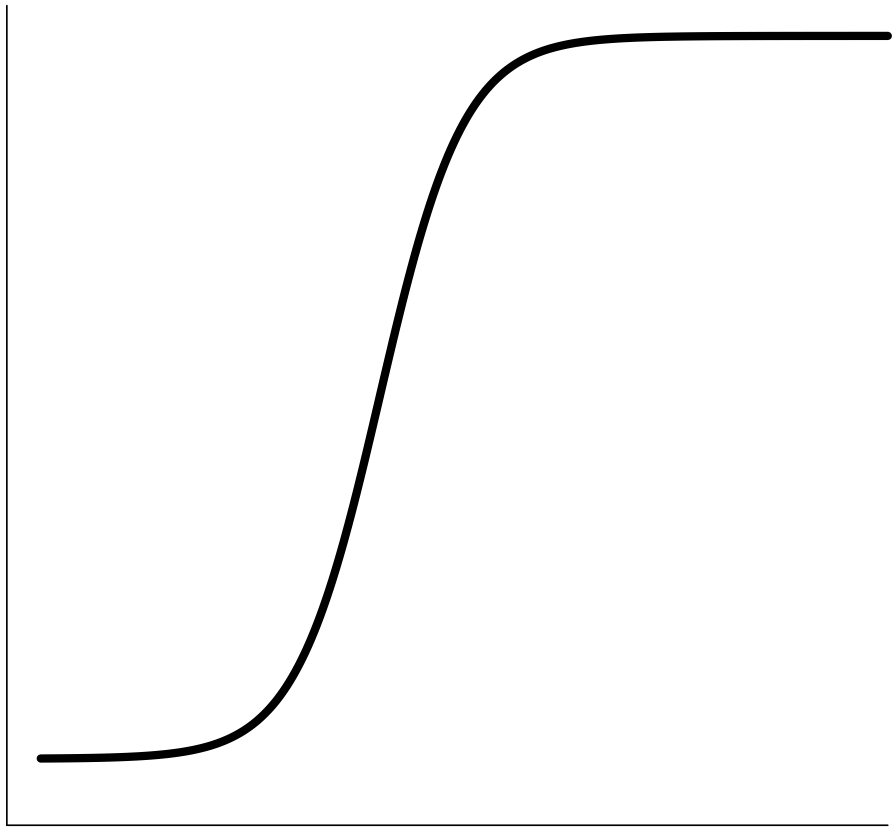


# Added Observation Bias

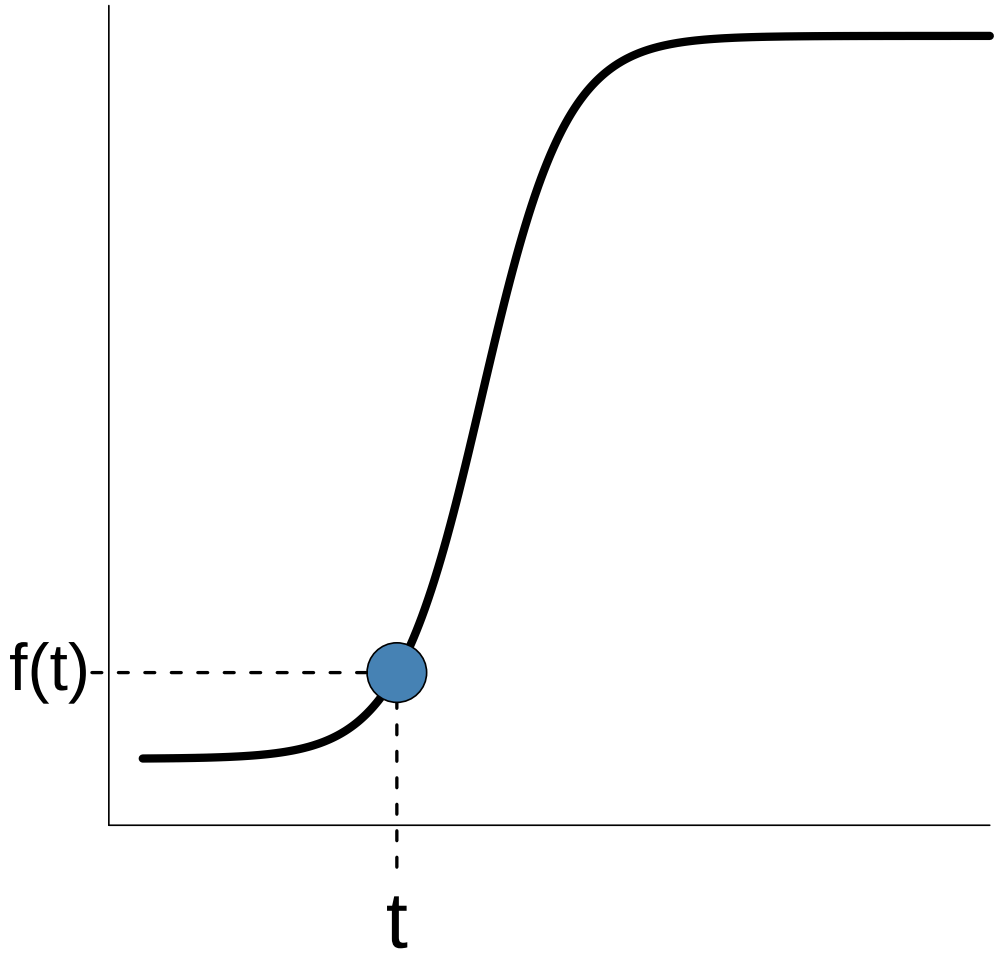
Added observation bias arises from the conflation of two distinct (though likely correlated) processes: the decision to initiate an eye movement to a particular place and the duration of a fixation

By including the entire length of the fixation as "observed" data relating to this process, we are both inflating the amount of data we have with data that is necessarily biased

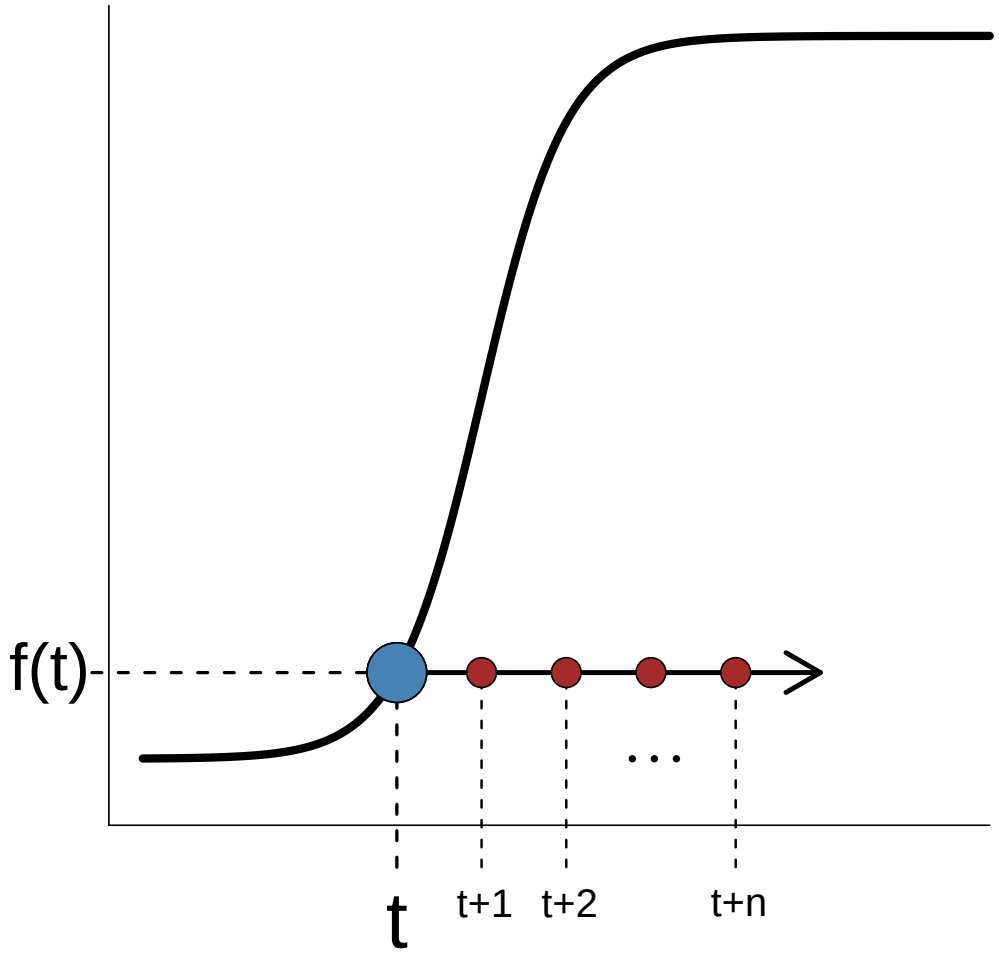
# Activation curve



# Onset of look



# ...followed by fixation



# Look Onset Method

Only the initial moment of look onset and its location, $s_k$, is considered relevant in the recovery of latent activation, where a look initiated at time $t_k$ follows

$$s_k \sim Bern\left[f\left(t_k|\theta\right)\right].$$

This gives us instead a set of ordered pairs, $\mathcal{S} = \{(s_k, t_k)\}_{k=1}^{K}$ rather than a time ordered vector of proportions

We are able to use an identical procedure as before,

$$\hat{\theta} = \underset{\theta}{\text{argmin}}\, \mathcal{L}(f_\theta, \mathcal{S})$$

# Delayed Observation

Between the cognitive mechanism and the initiation of look onset is a period of oculomotor delay, $\rho$

This gives distribution of look onset,

$$s_j \sim Bern\left[f\left(t_j - \rho\right)|\theta\right)\right].$$

It is "roughly" estimated to be around 200ms, and this is typically accounted for by subtracting 200ms from observations

We show that varying degrees of randomness in this process and drastically impact error in recovery

# Simulation

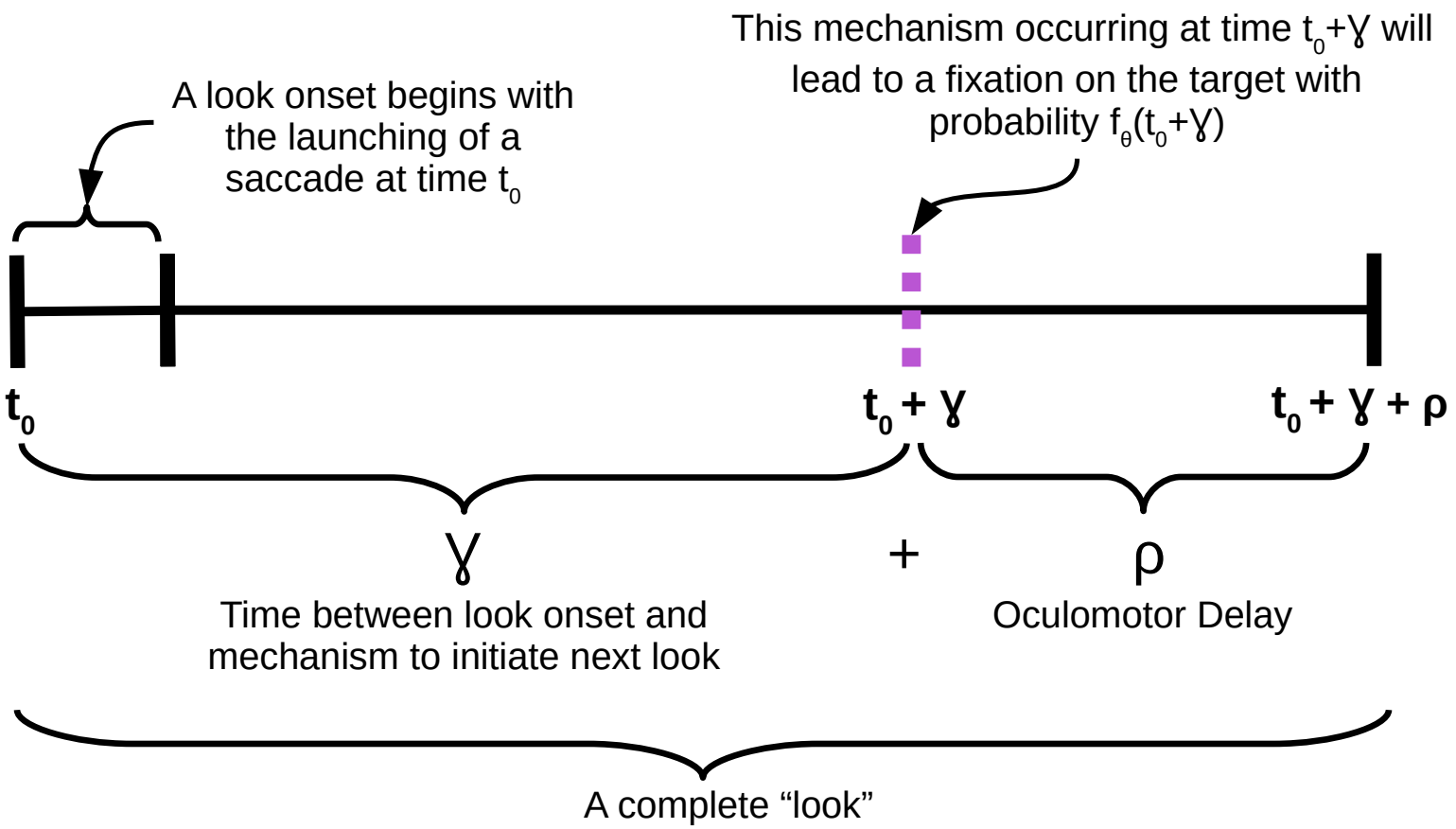
Create simulated VWP trials with eye mechanics oriented towards Target, the goal of recovering activation curve, $f(t|\theta)$

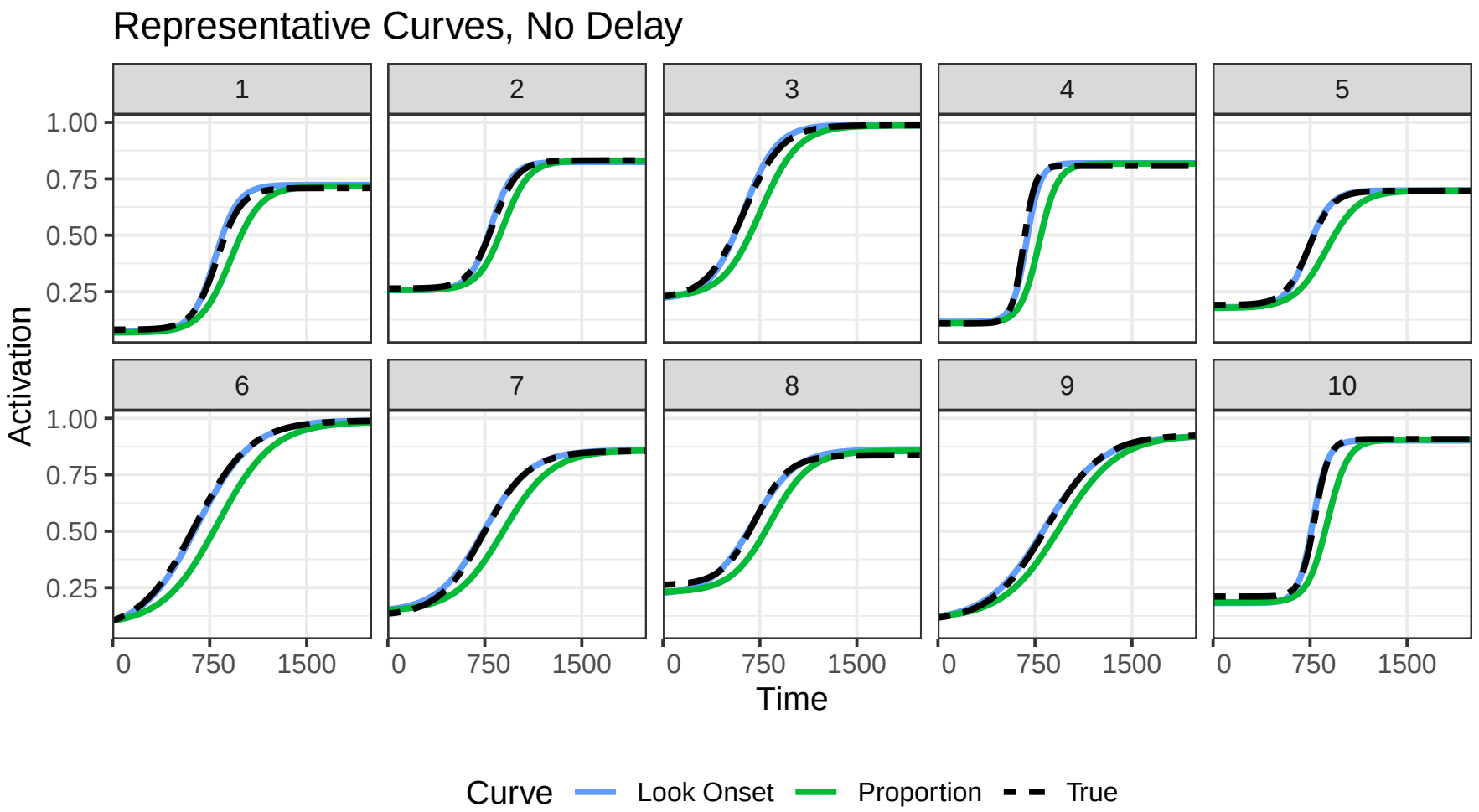
Each subject draws individual $\theta_i$ and performs 300 trials. 1,000 total subjects

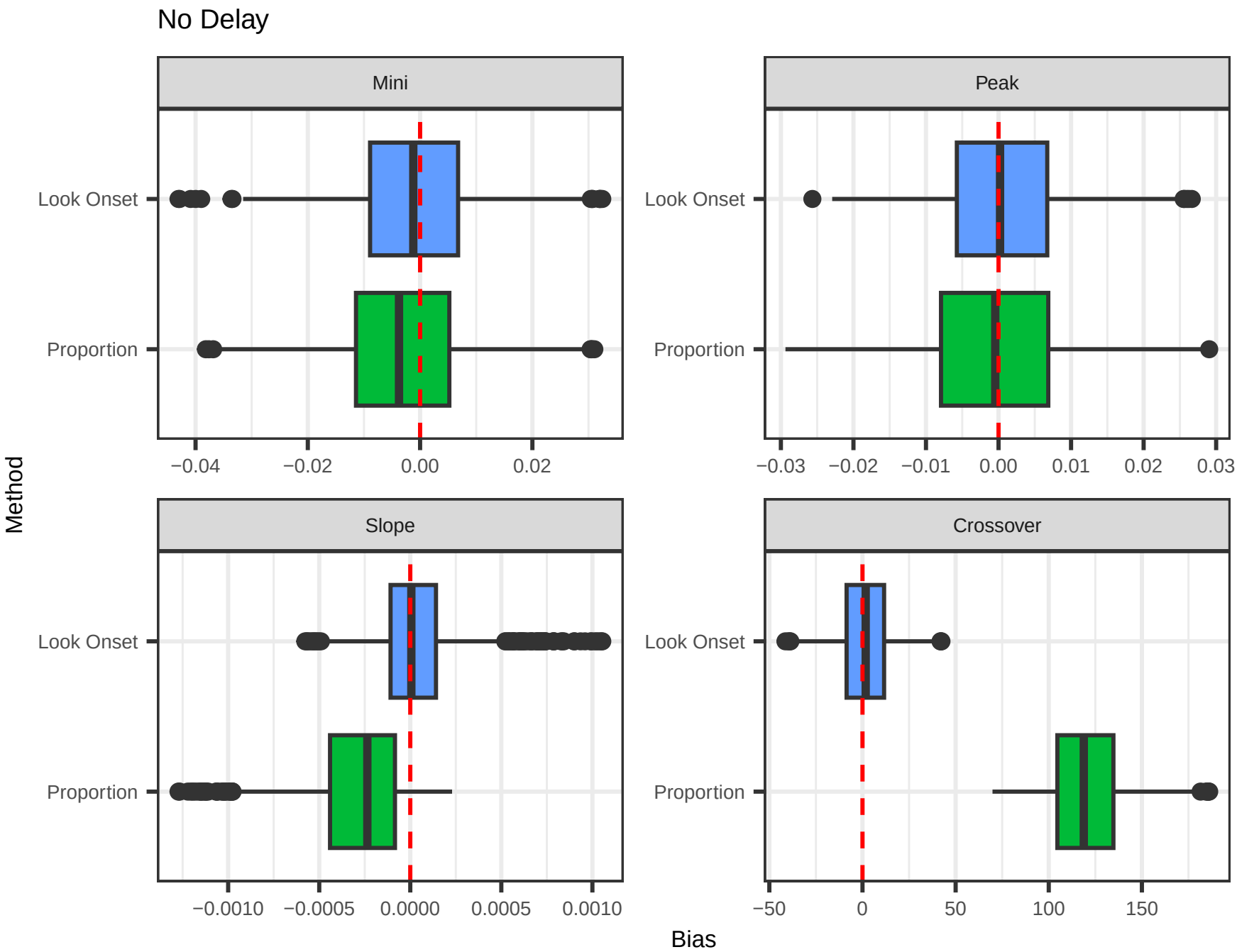
Estimate generating function using both methods

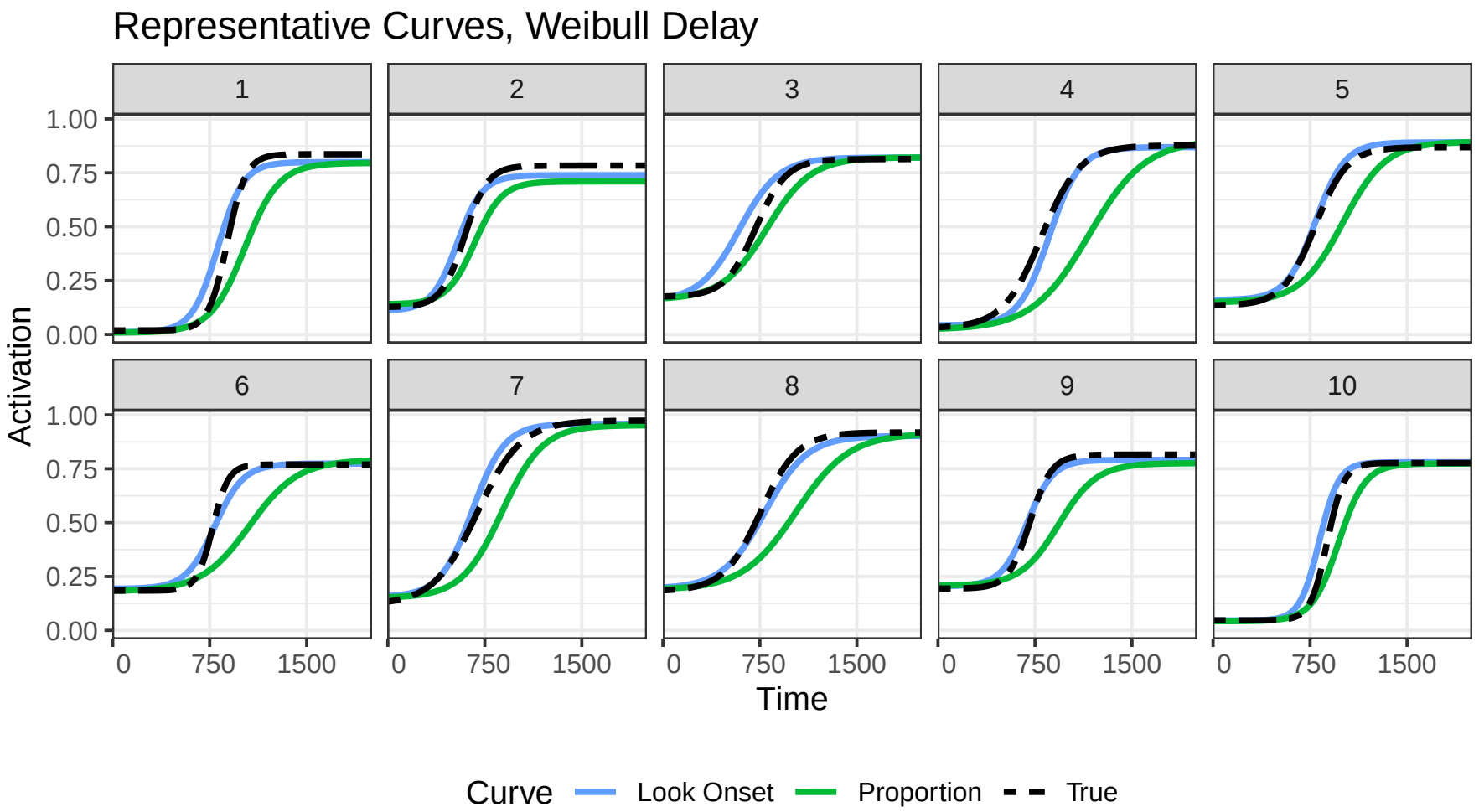
Metric for efficacy is MISE between generating and recovered curve

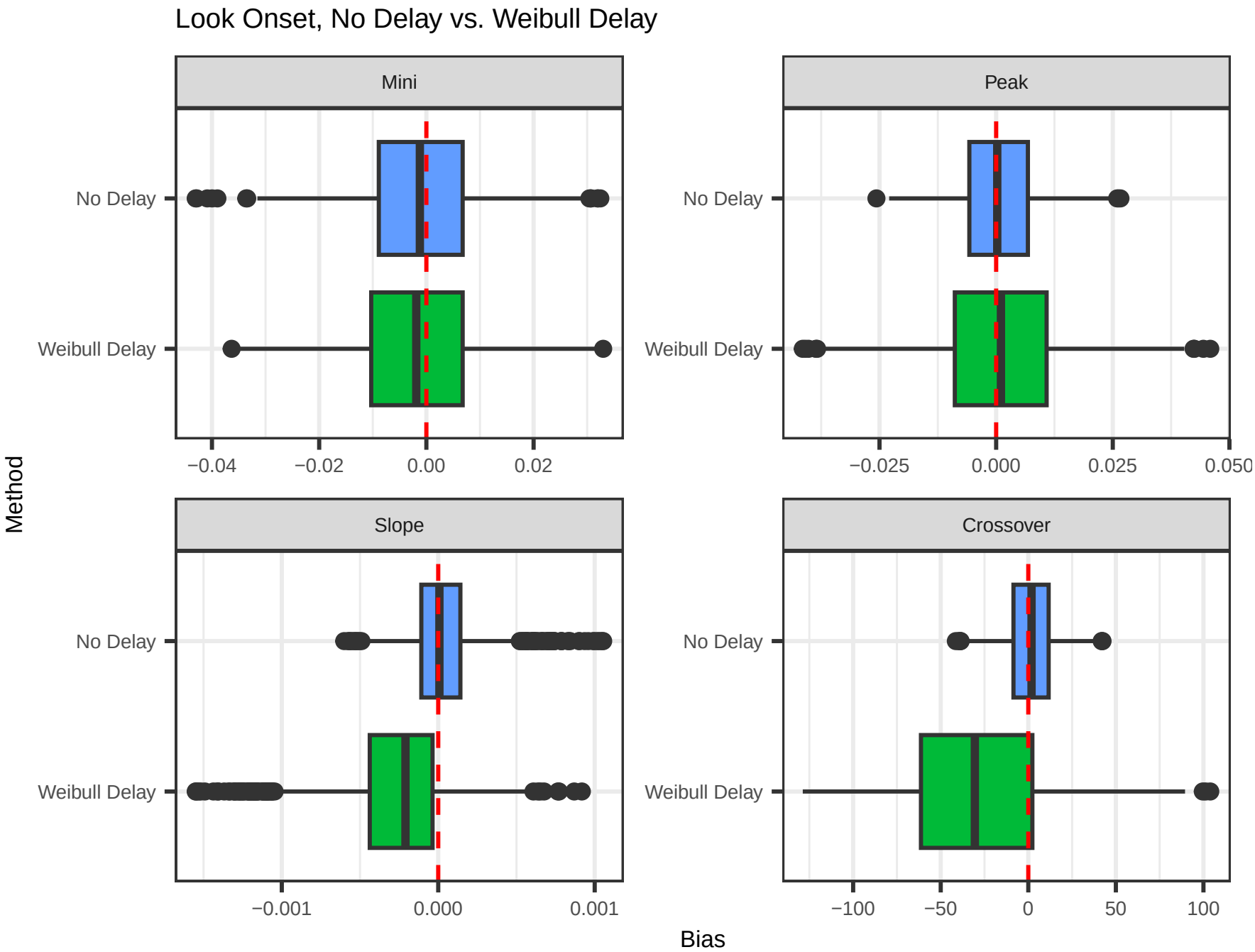
# Simulation Mechanics

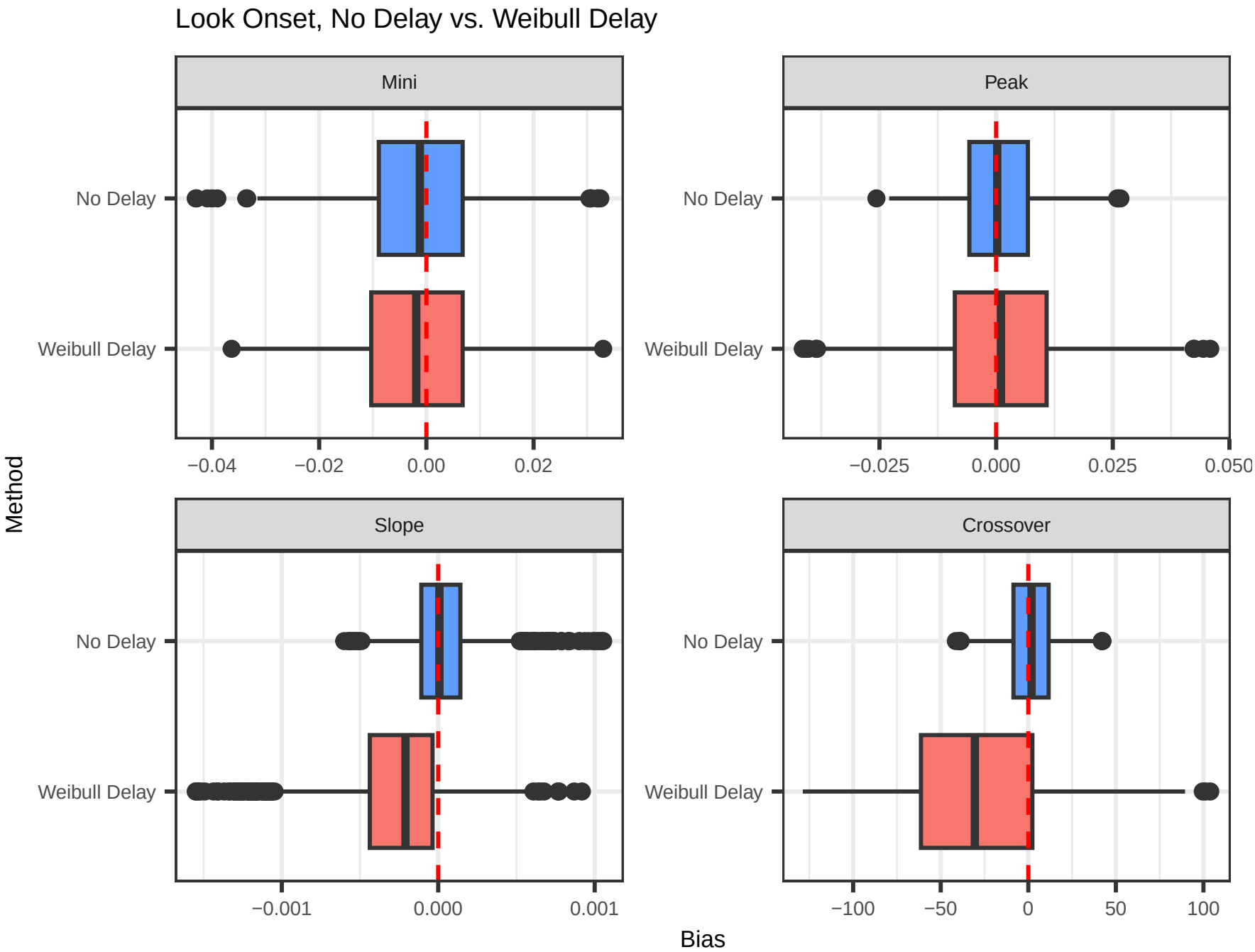


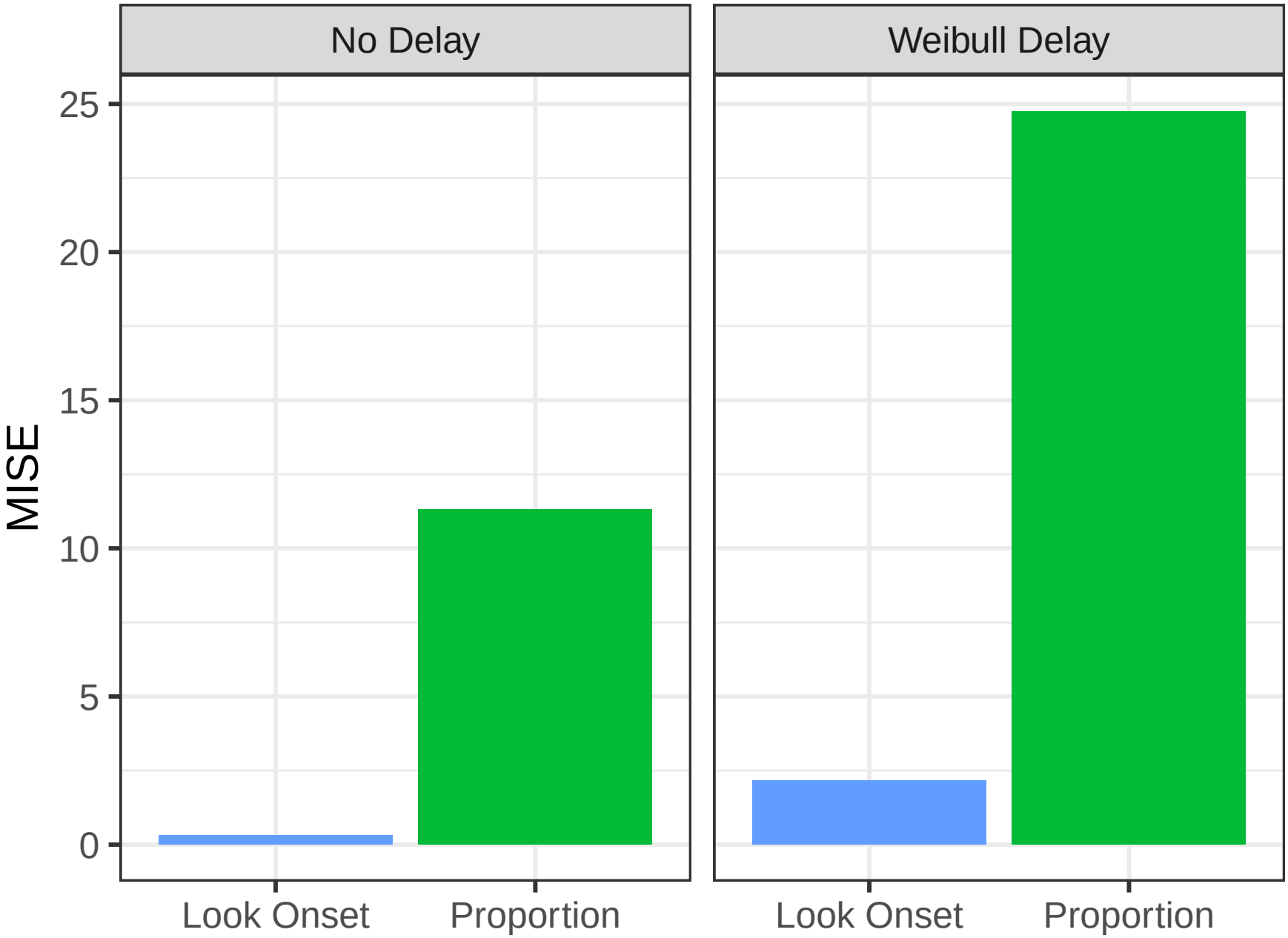

Representative Curves, No Delay
1
2
3
4
5
6
7
8
9
10
Activation
1.00
0.75
0.50
0.25
0
750
1500
Time
Curve
Look Onset
Proportion
True


No Delay
Mini
Peak
Slope
Crossover
Look Onset
Proportion
Method
Bias
−0.04
−0.02
0.00
0.02
−0.03
−0.02
−0.01
0.00
0.01
0.02
0.03
−0.0010
−0.0005
0.0000
0.0005
0.0010
−50
0
50
100
150


Representative Curves, Weibull Delay
1
2
3
4
5
6
7
8
9
10
Activation
1.00
0.75
0.50
0.25
0.00
0
750
1500
Time
Curve
Look Onset
Proportion
True


Look Onset, No Delay vs. Weibull Delay
Mini
Peak
Slope
Crossover
No Delay
Weibull Delay
Method
Bias
−0.04
−0.02
0.00
0.02
−0.025
0.000
0.025
0.050
−0.001
0.000
0.001
−100
−50
0
50
100

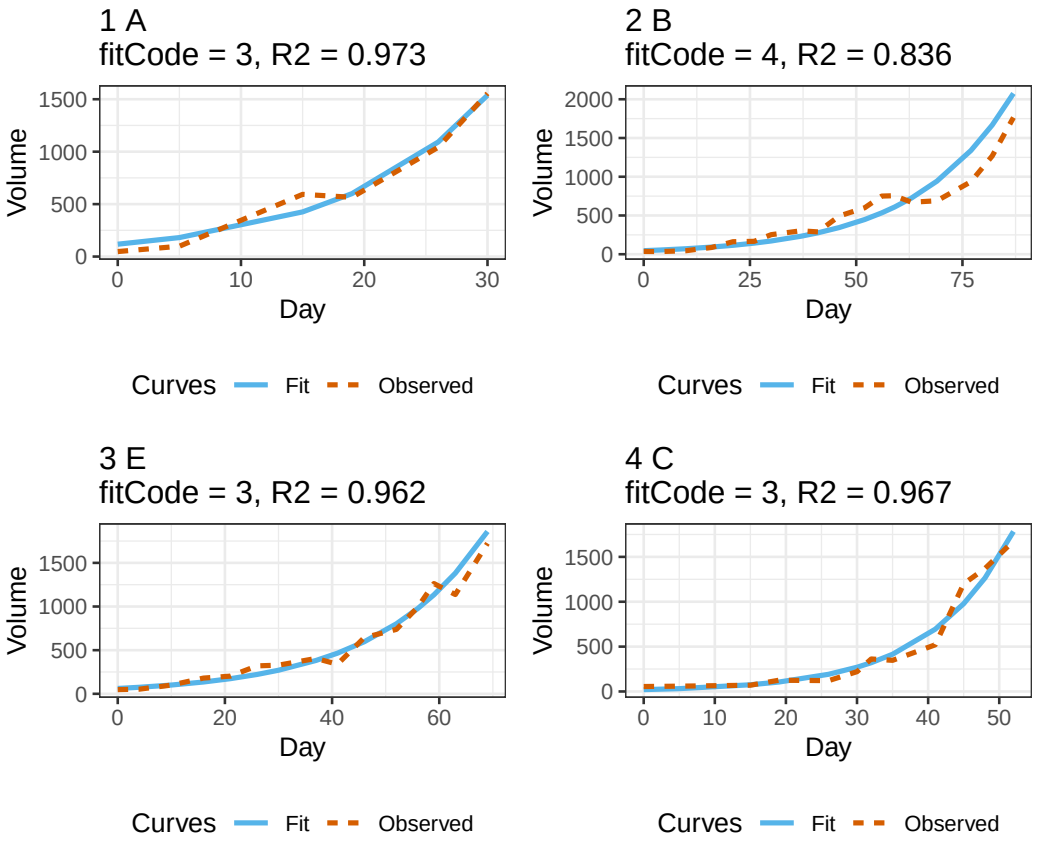

Look Onset, No Delay vs. Weibull Delay
Mini
Peak
Slope
Crossover
No Delay
Weibull Delay
Method
Bias
−0.04
−0.02
0.00
0.02
−0.025
0.000
0.025
0.050
−0.001
0.000
0.001
−100
−50
0
50
100

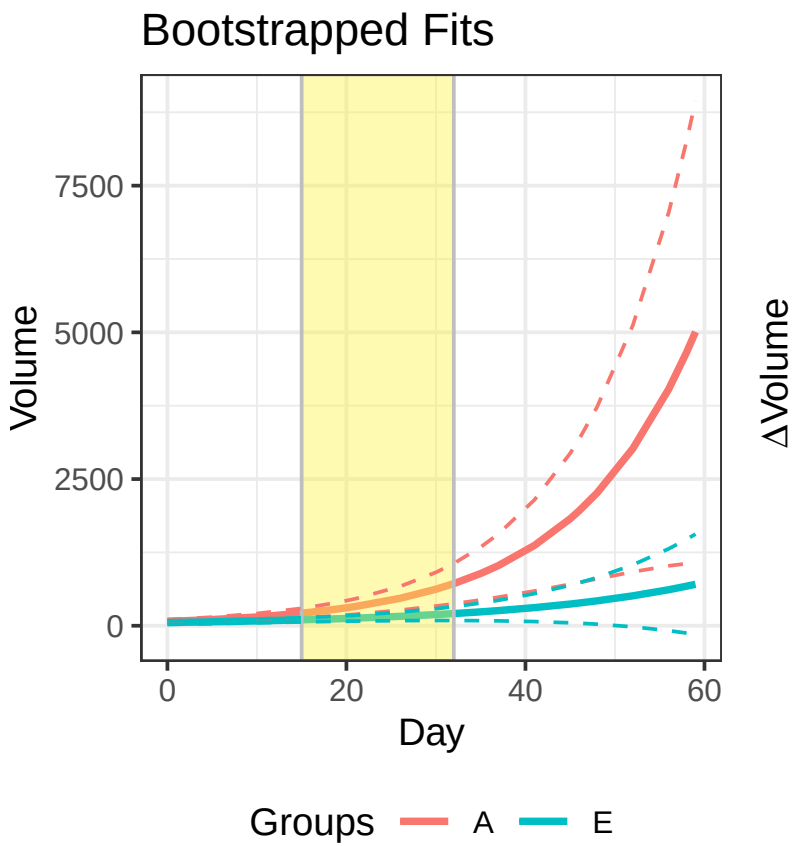

No Delay
Weibull Delay
MISE
25
20
15
10
5
0
Look Onset
Proportion
Look Onset
Proportion

# What else?

- Rewrote `bdots` package (thanks Seedorff)
- Expand and improve upon underlying methodology

# Bootstrapped differences in time series – `bdots`



thanks

# References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McMurray, Bob **I'm not sure that curve means what you think it means: Towards a [more] realistic understanding of the role of eye-movement generation in the visual world paradigm** 2022 *Psychonomic Bulletin & Review* p 1-45

Oleson, Jacob J; Cavanaugh, Joseph E, McMurray, Bob; Brown, Grant **Detecting time-specific differences between temporal nonlinear curves: Analyzing data from the visual world paradigm** 2017 *Statistical Methods in Medical Research*, Vol. 26, No. 6 p 2708-2725

Paul D. Allopenna, James S. Magnuson, Michael K. Tanenhaus **Tracking the Time Course of Spoken Word Recognition Using Eye Movements: Evidence for Continuous Mapping Models** 1998 *Journal of Memory and Language*, Vol. 38, Issue 4 p 419-439