What You See is What You Get:

A Closer Look at Bias in the Visual World Paradigm

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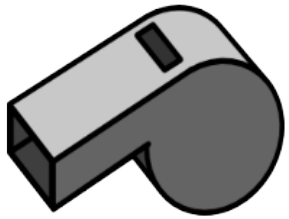
March 8, 2023



Language and Cognition

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

Troublesome when we commit too early:

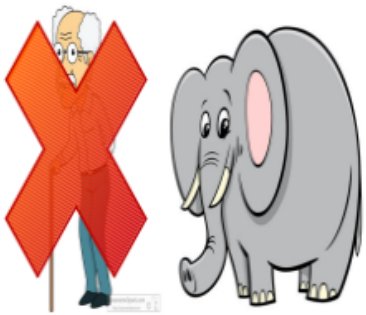
"The horse raced past the barn fell"

Often can not be observed directly

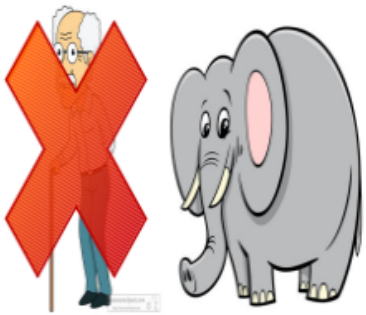
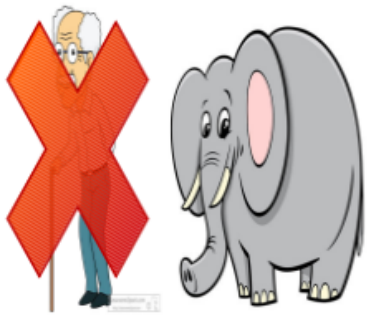
Limit focus to single word recognition

el

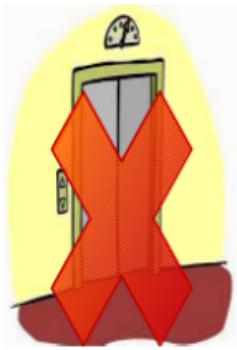
el → ele

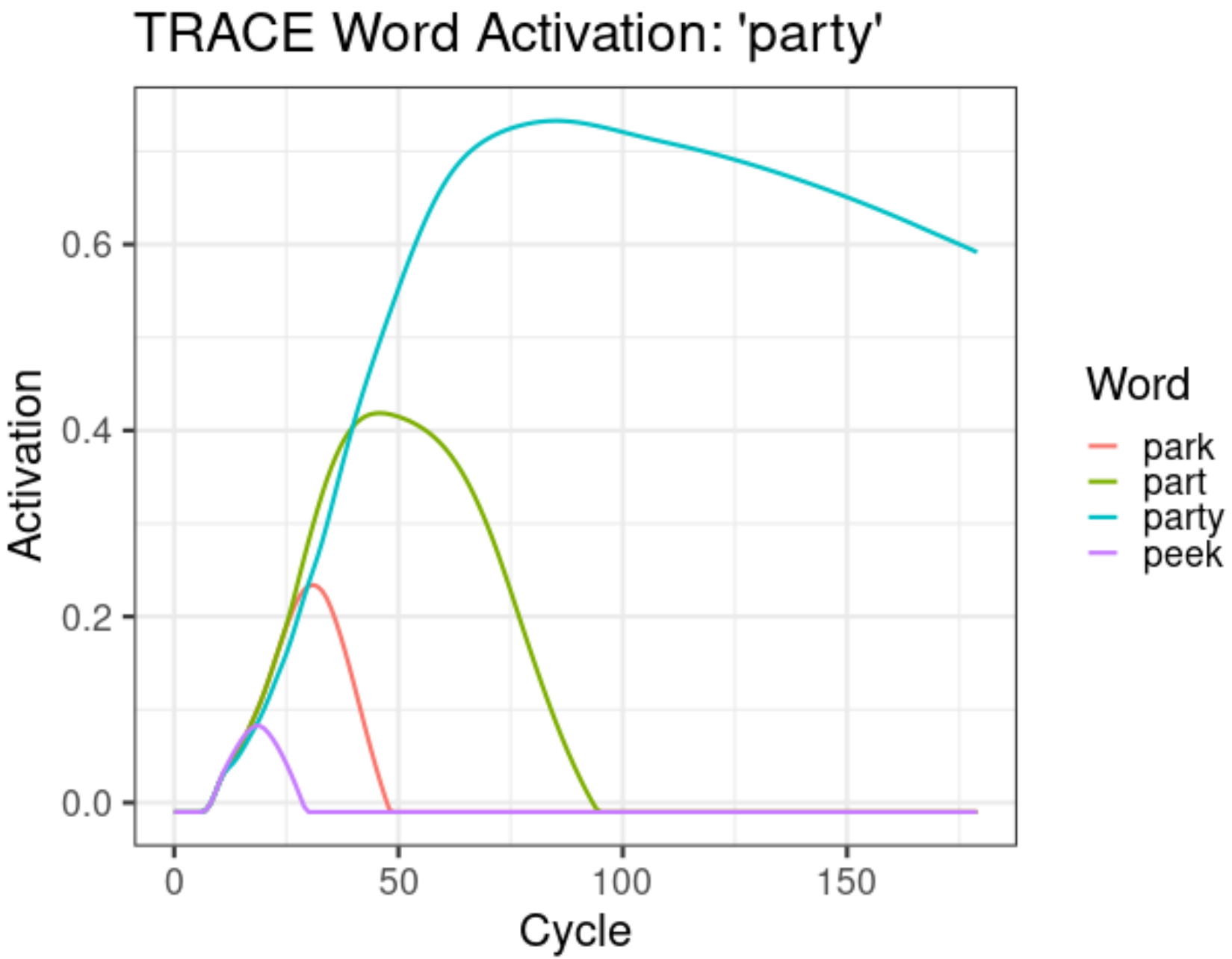


el → ele → elephant





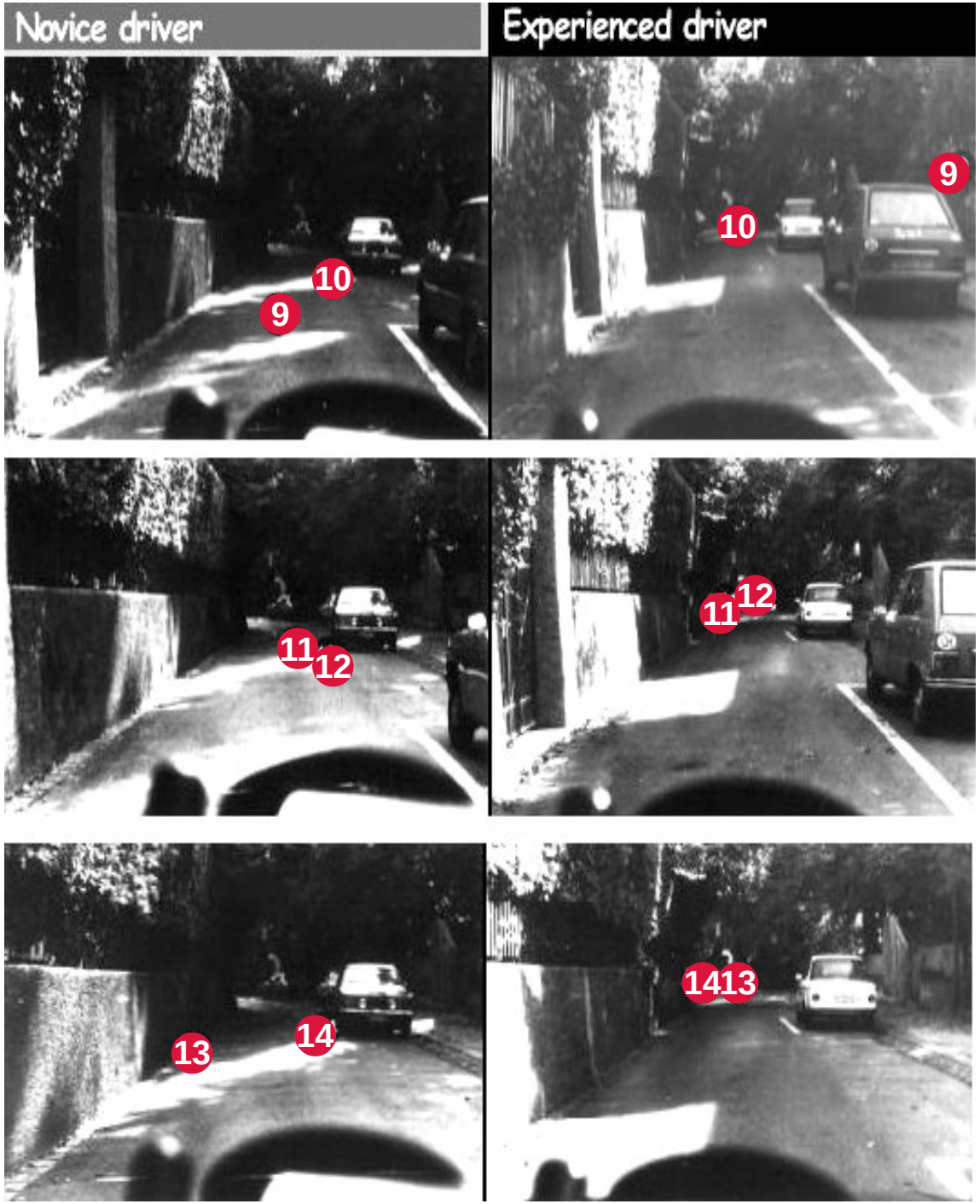

TRACE Word Activation: 'party'
Activation
0.0
0.2
0.4
0.6
0
50
100
150
Cycle
Word
park
part
party
peek

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?

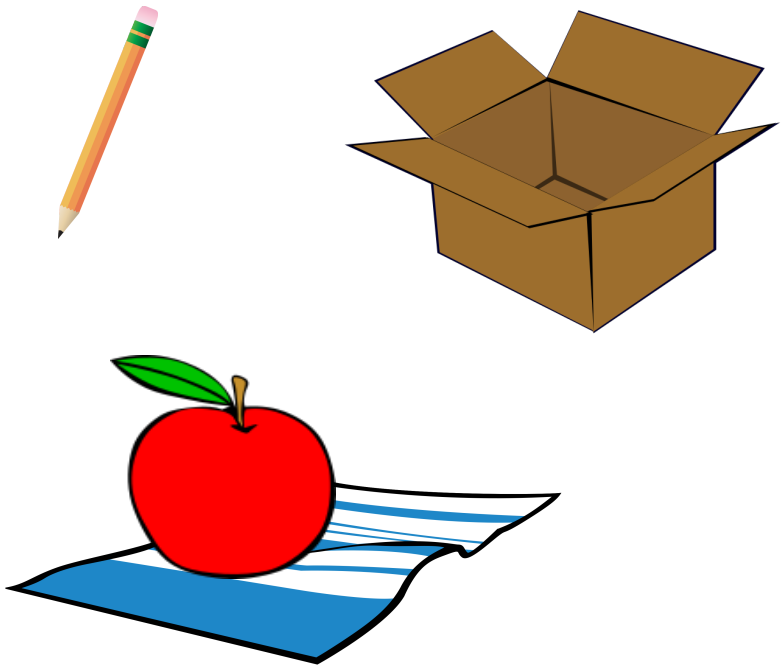

Novice driver
Experienced driver
9
10
10
9
11
12
11
12
13
14
14
13

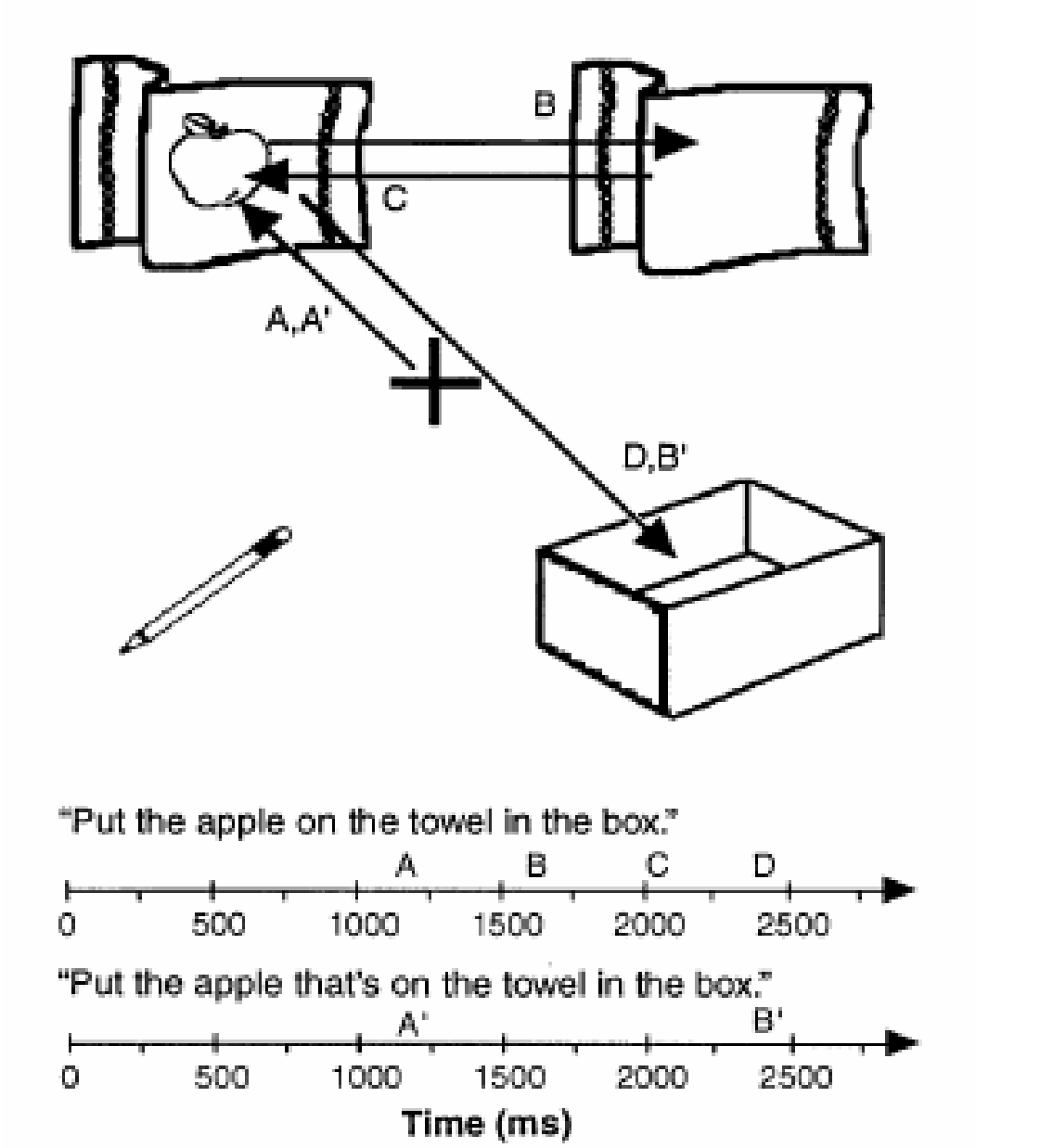
Visual World Paradigm

Visual World Paradigm (VWP) introduced in 1995

Eye-tracking in conjunction with spoken sentence

"Put the apple on the towel in the box"

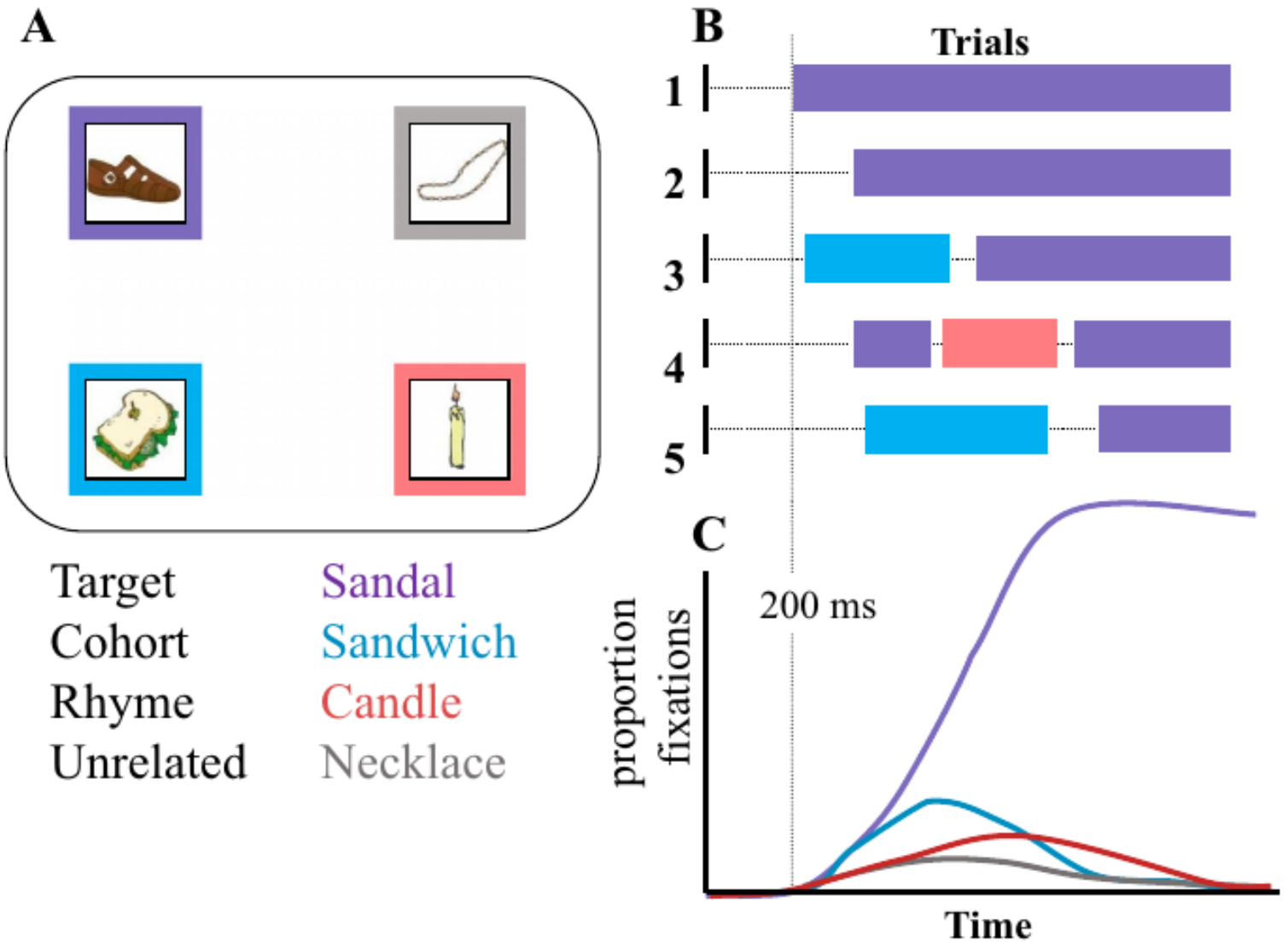



B
C
A,A'
D,B'
"Put the apple on the towel in the box."
A
B
C
D
0
500
1000
1500
2000
2500
"Put the apple that's on the towel in the box."
A'
B'
0
500
1000
1500
2000
2500
Time (ms)

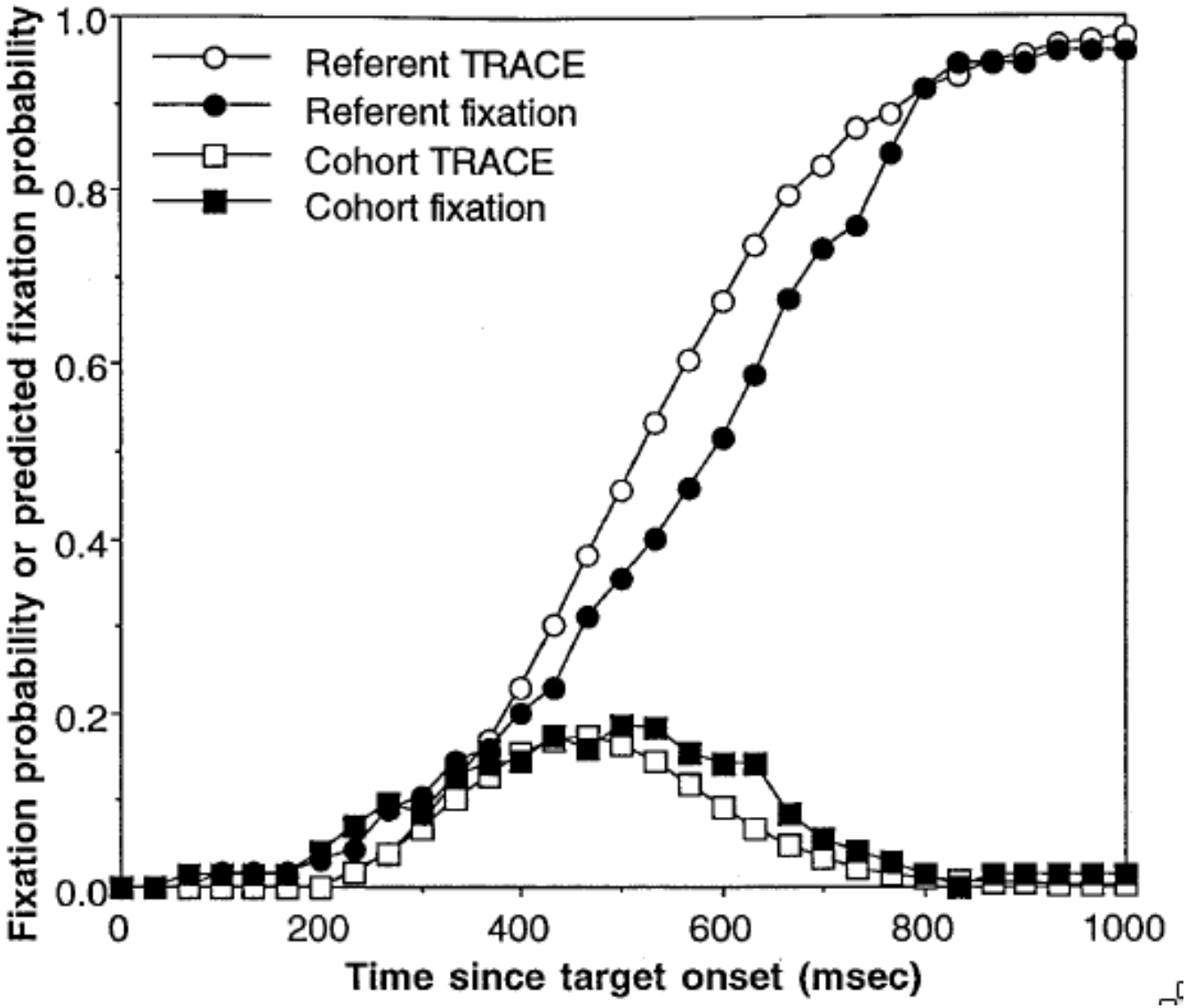
Outline

- Eye-tracking and the VWP
- Methodology
  - Proportion of Fixations
  - Bias
  - Look Onset Method
- 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

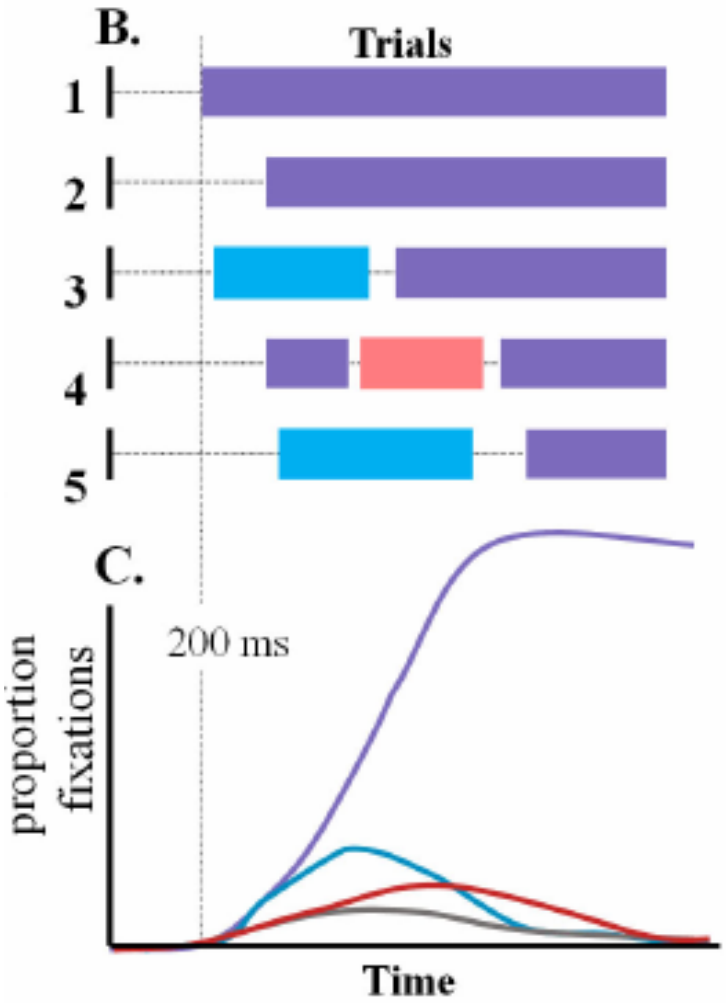
"Proportion of fixations" method

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

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



Proportion of Fixation Data

Fixation Trial Data

Trial	t	Target	Trial	t	Target
1	0	0	2	0	1
1	4	0	2	4	1
1	8	0	2	8	1
1	12	0	2	12	1
1	16	0	2	16	1
⋮	⋮	⋮	⋮	⋮	⋮
1	1596	1	2	1596	1
1	1600	1	2	1600	1

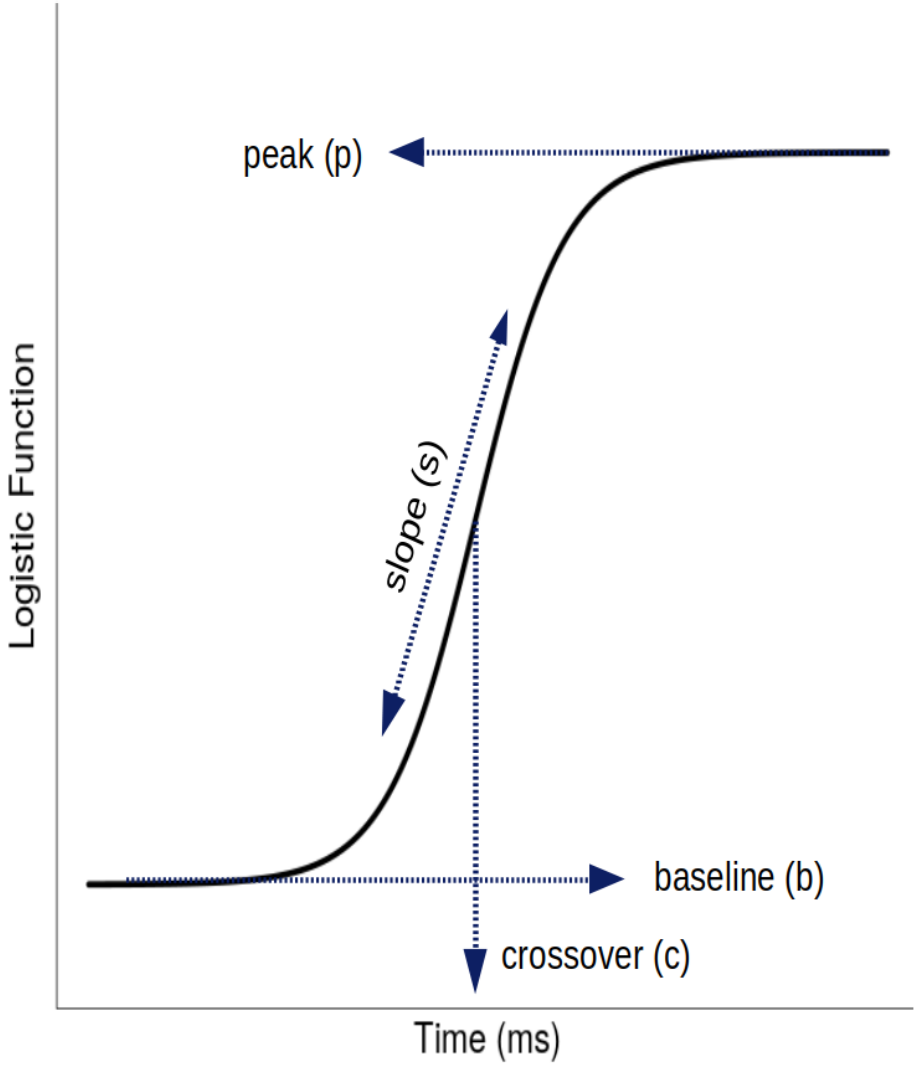
$\Rightarrow$

Proportion Data

t	Target
0	0.00
4	0.01
8	0.02
12	0.02
16	0.04
⋮	⋮
1596	0.91
1600	0.92

Target – Logistic

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



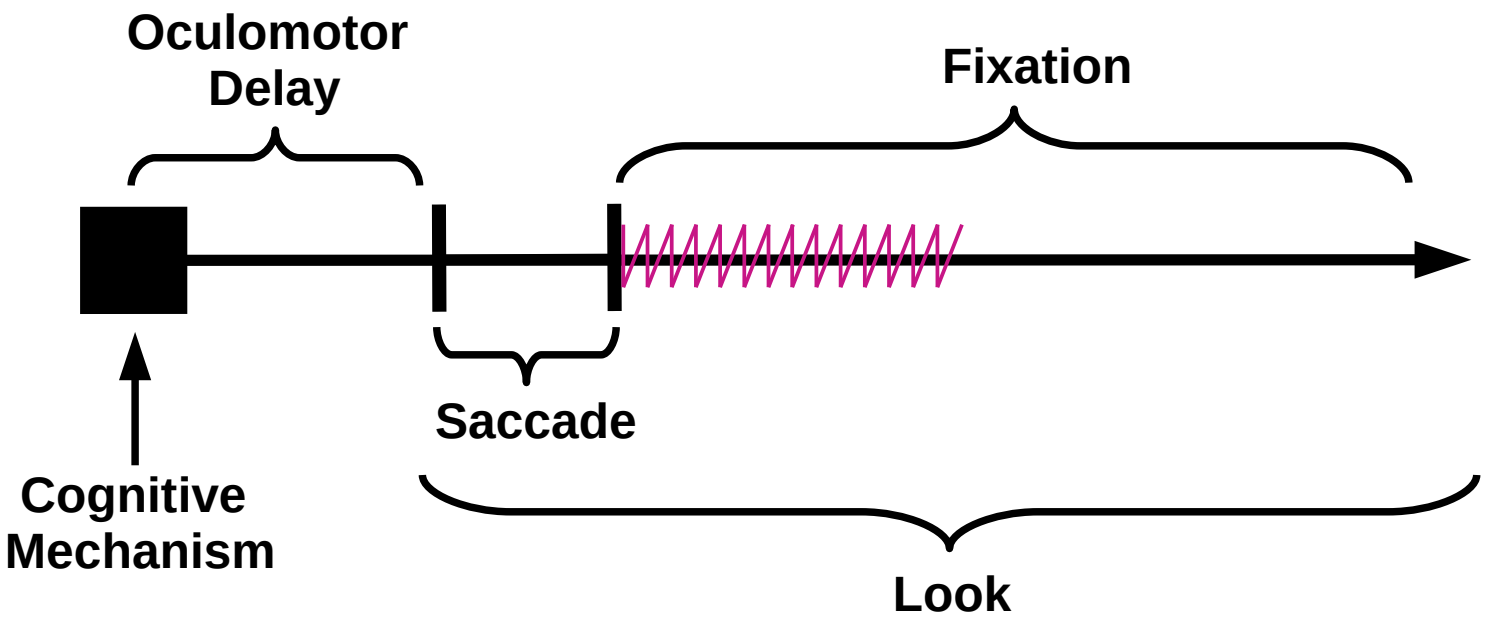

The next 20 slides
Proportion of Fixations Method

Issues

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

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

Visualizing Eye Mechanics



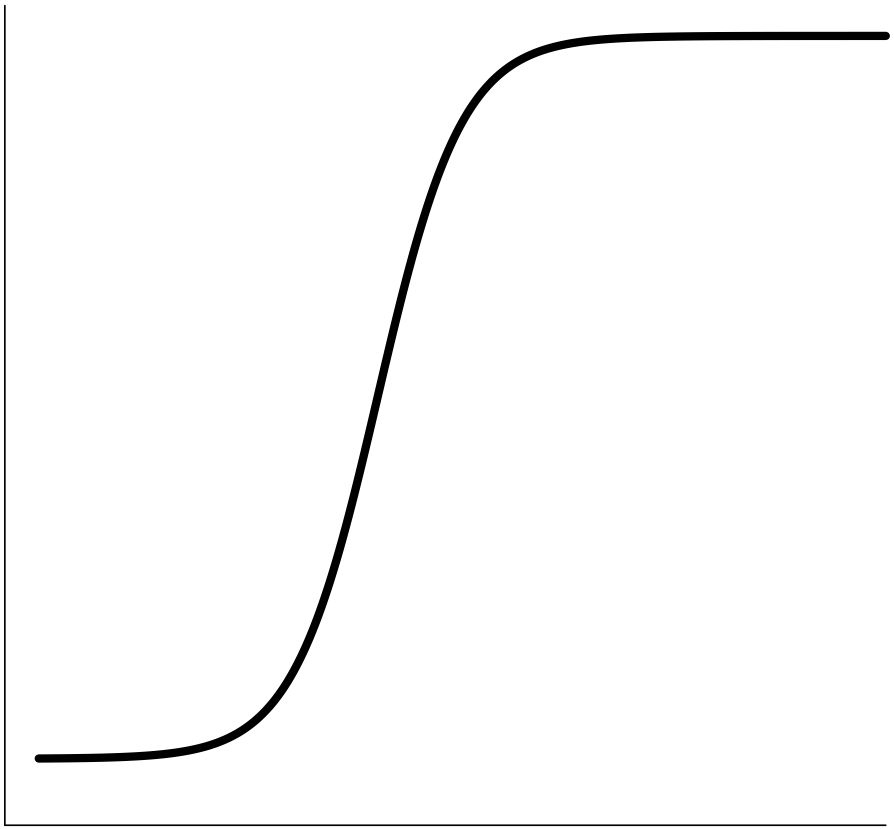
Added Observation Bias

There are two primary sources of bias to address

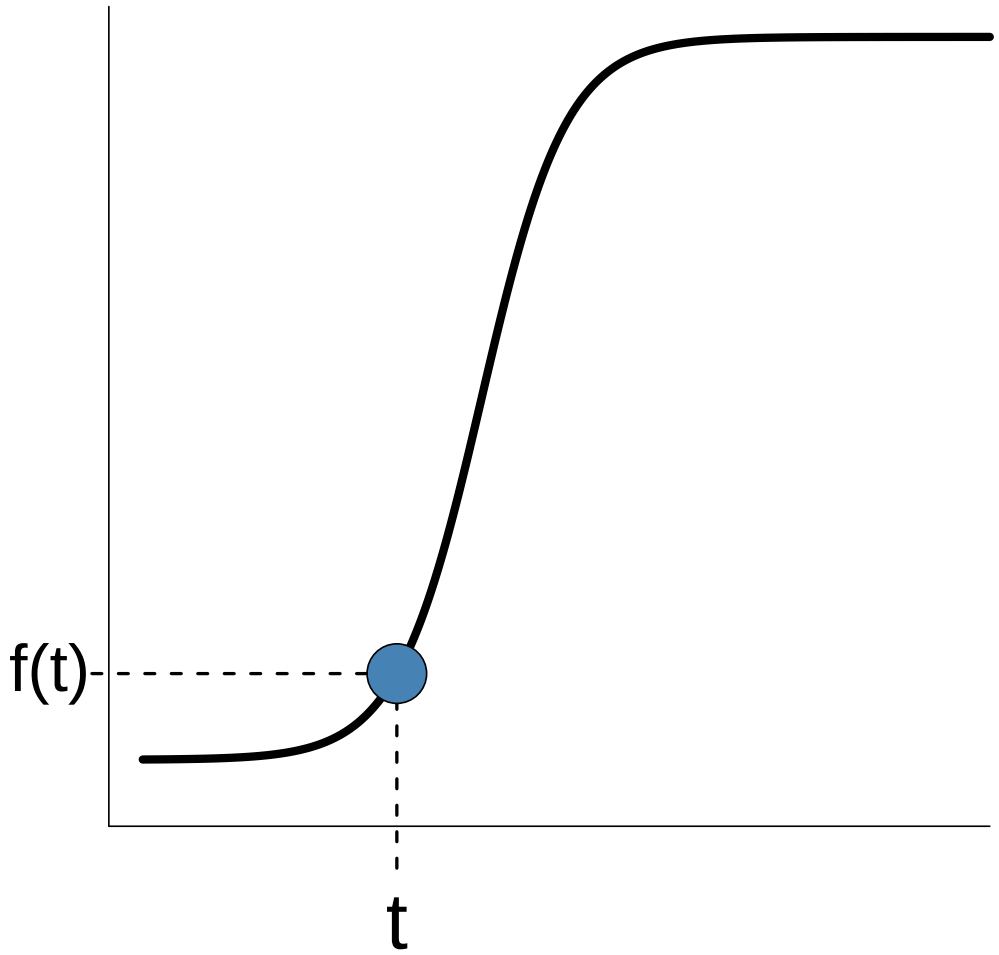
- Added observation bias
- Oculomotor delay

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

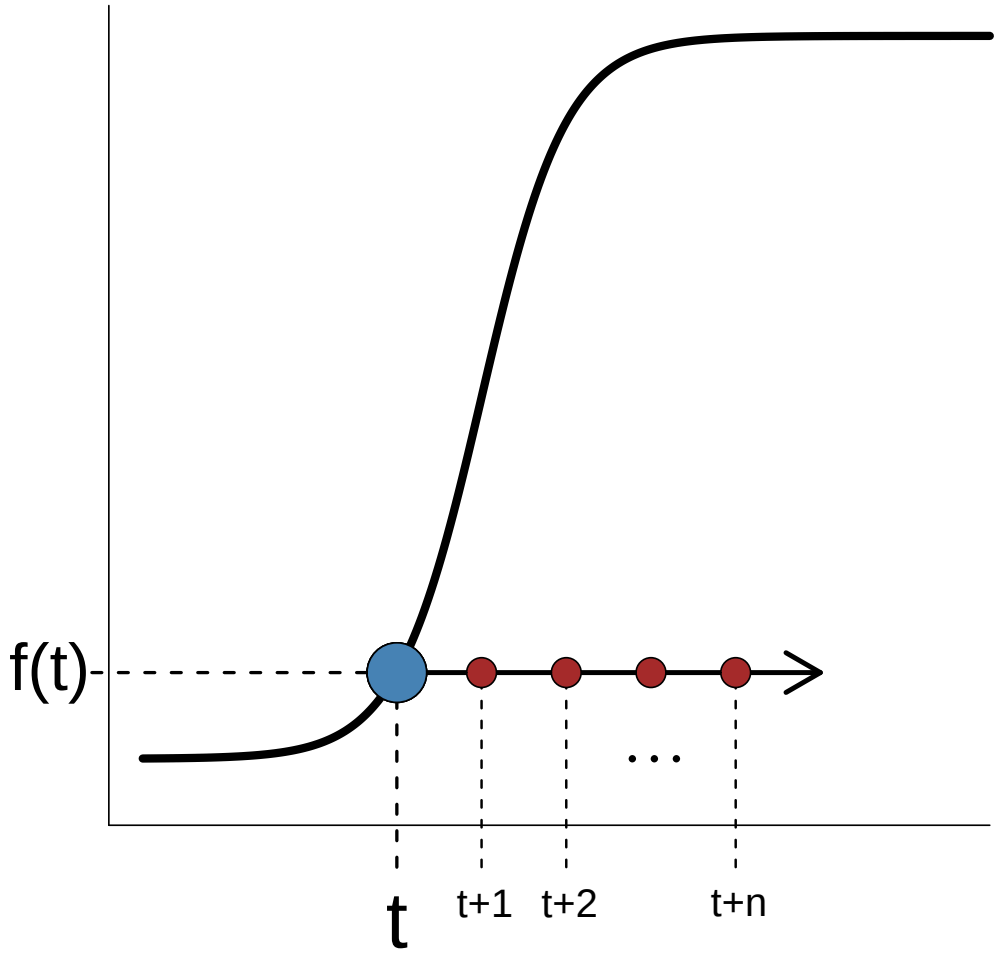
Activation curve



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,

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

Look Onset Data

Look Onset Data

t	Target
100	0
500	0
900	1
400	0
700	1
1400	0
⋮	⋮
800	0
1200	1

Proportion Data

t	Target
0	0.00
4	0.01
8	0.02
12	0.02
16	0.04
⋮	⋮
1596	0.91
1600	0.92

Delayed Observation

Between the cognitive mechanism and the initiation of look onset is a period of oculomotor delay, ρ

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 degree of randomness in this process have an impact in observed error and successful recovery

Simulation

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

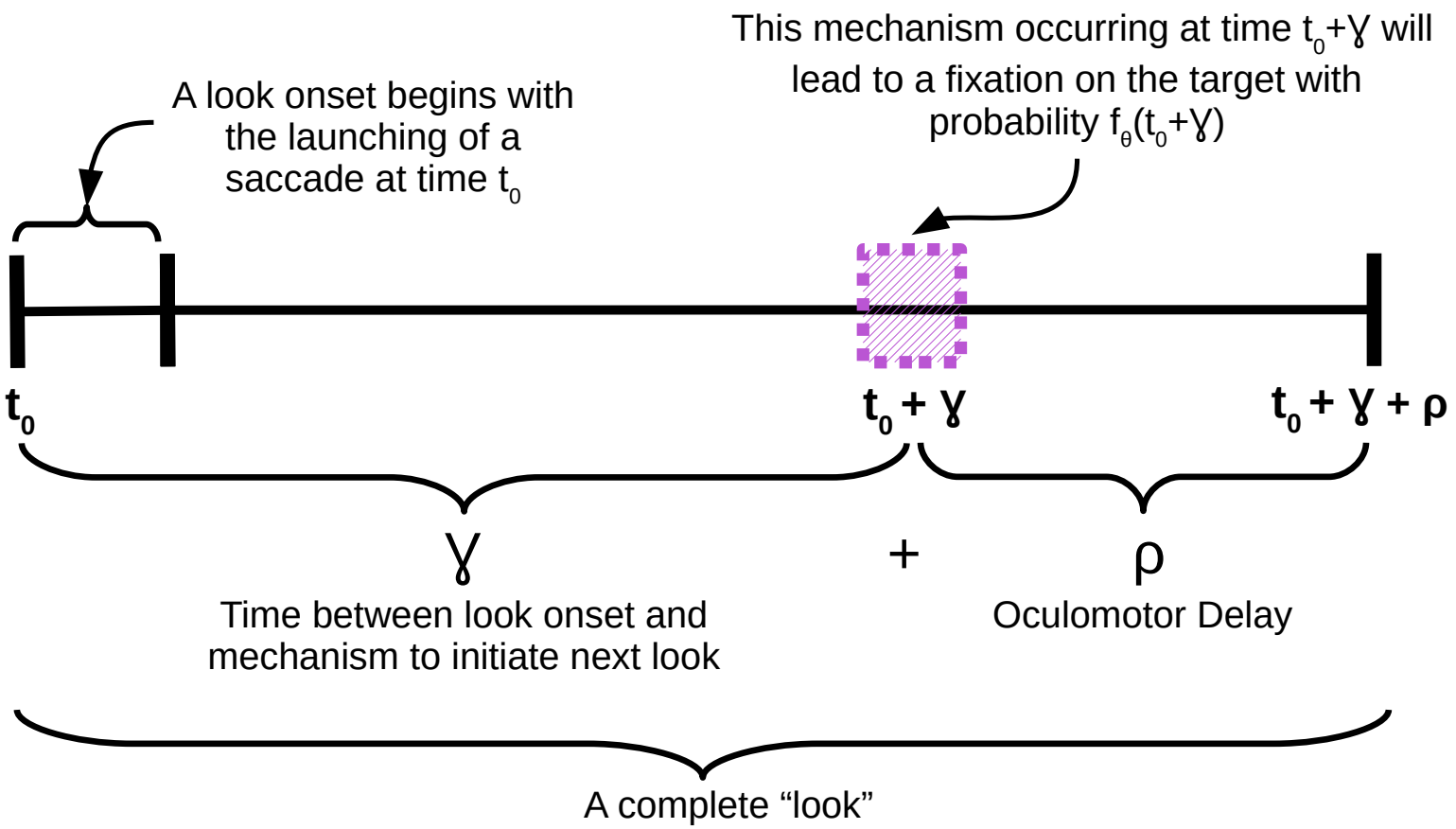
Each subject draws individual θ_i and performs 300 trials

1,000 total subjects

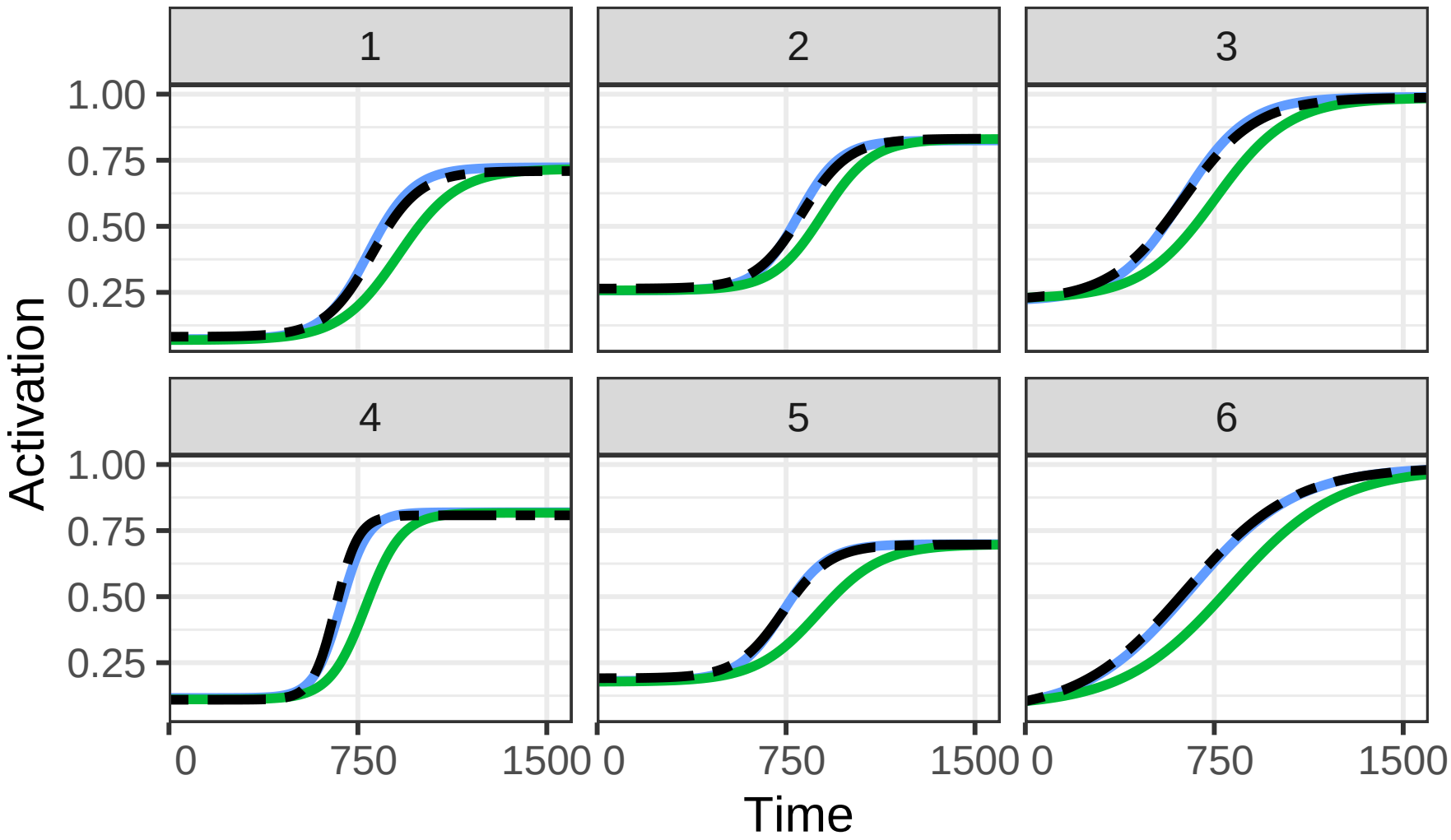
Estimate generating function using both methods

Metric for efficacy is MISE between generating and recovered curve

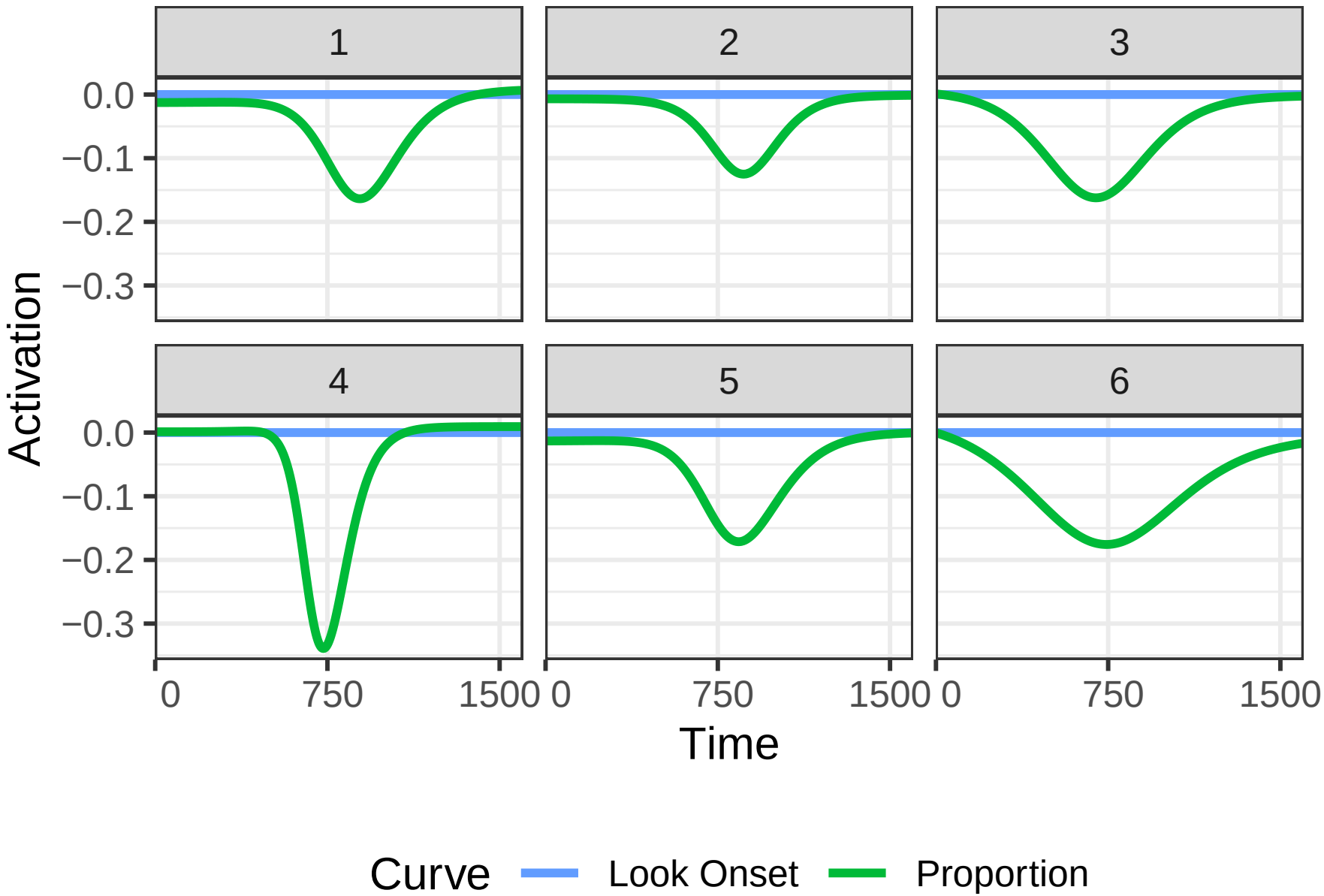
Simulation Mechanics

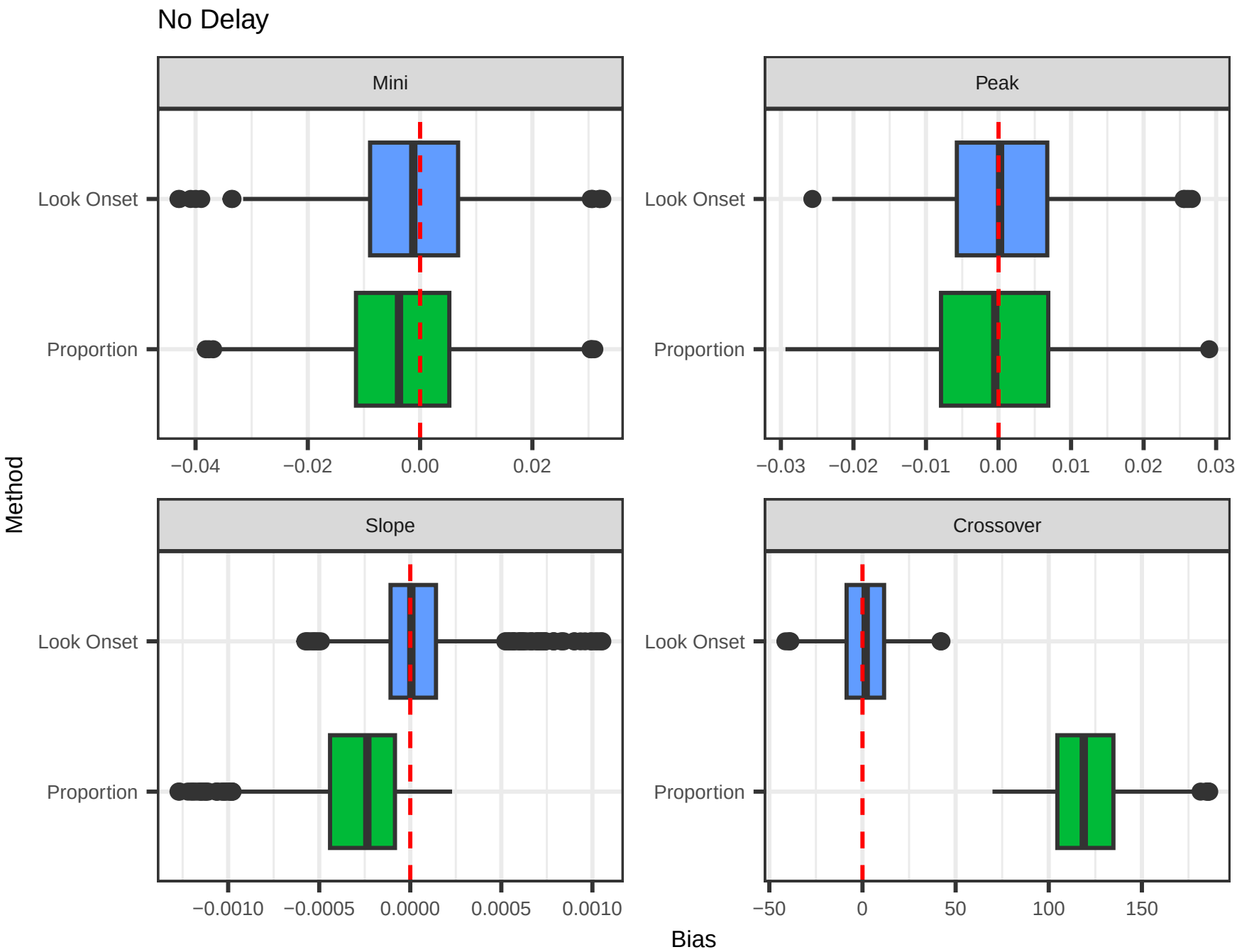


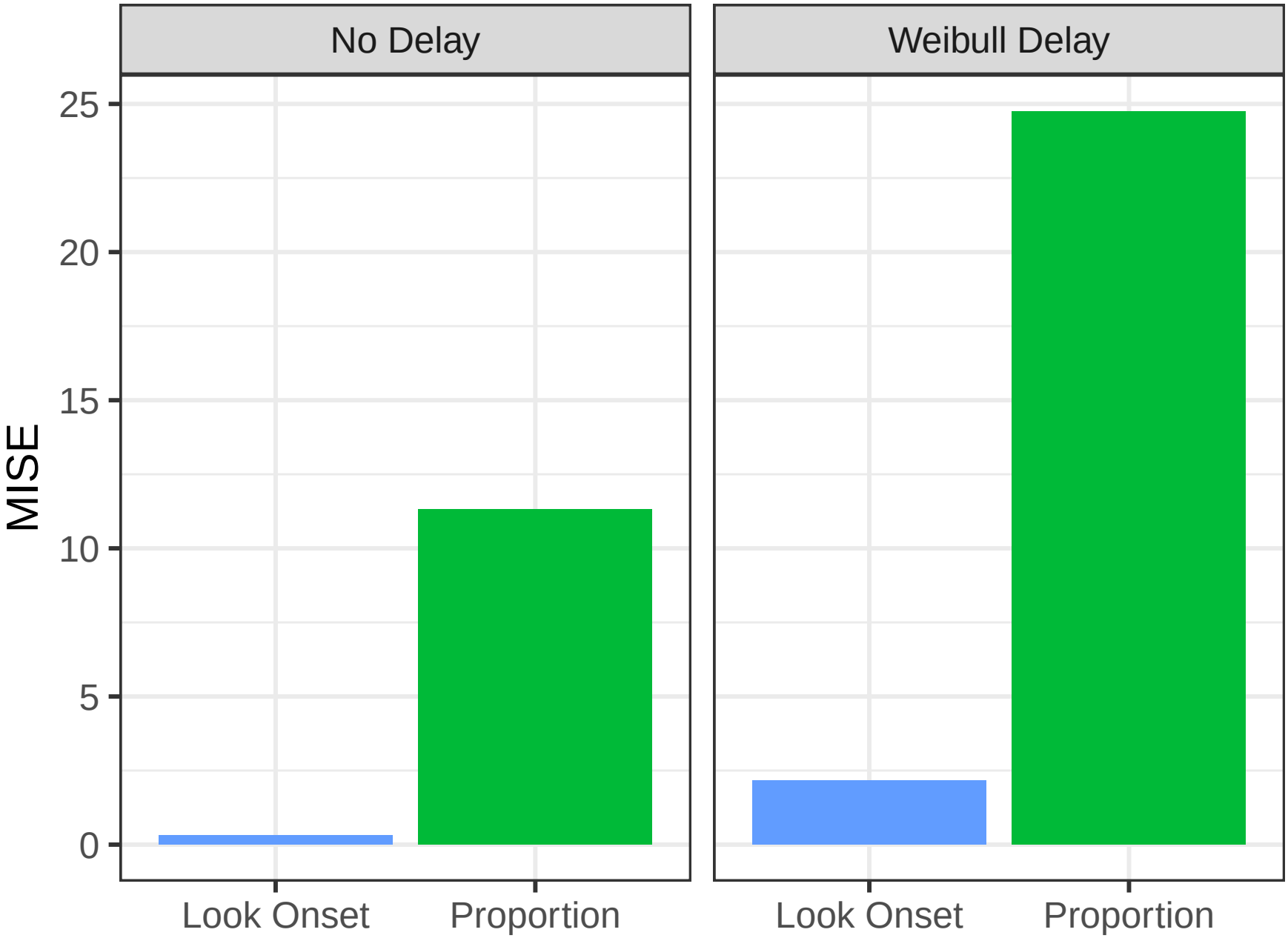
Representative Curves, No Delay



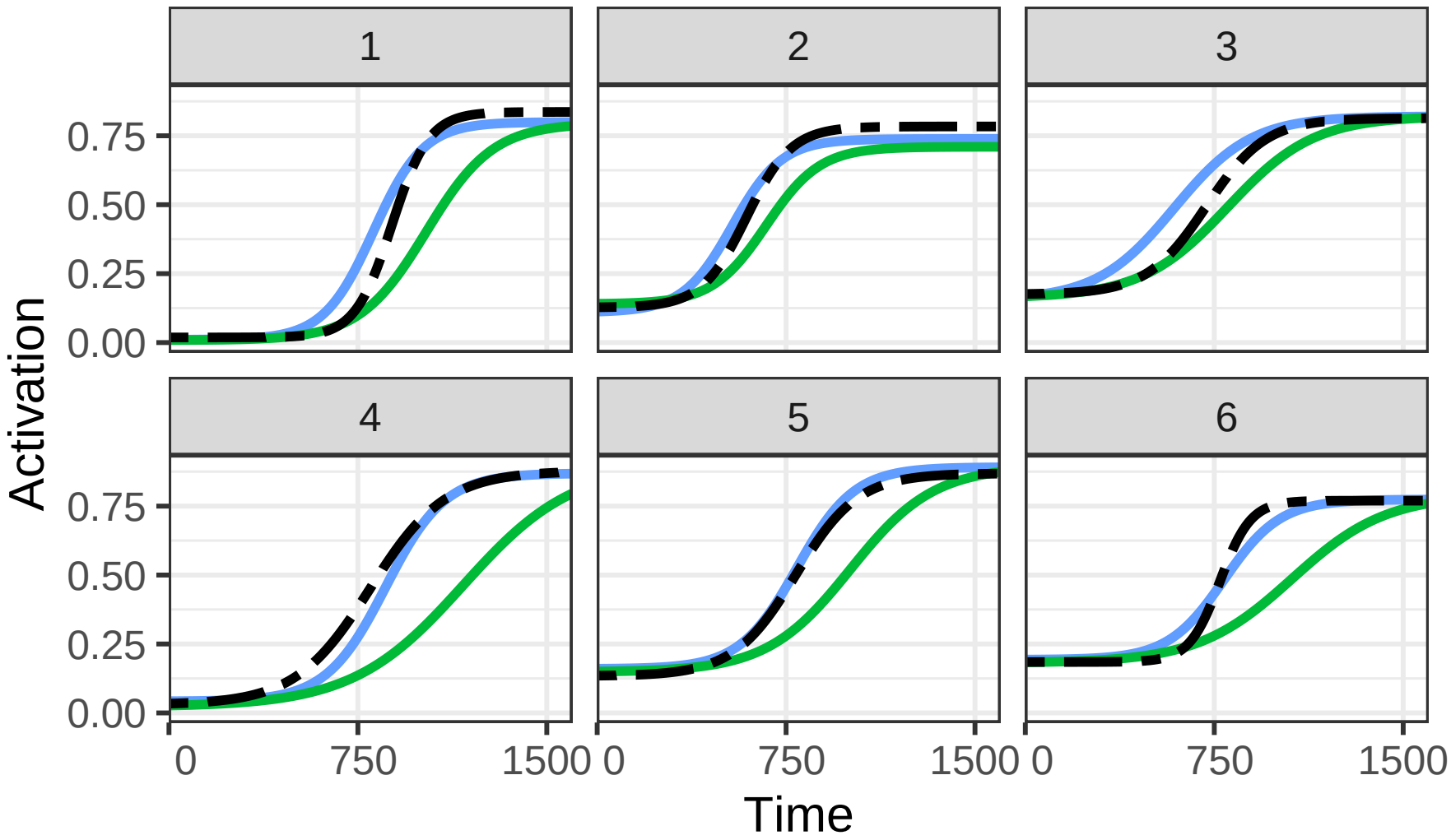
Representative Error Curves, No Delay



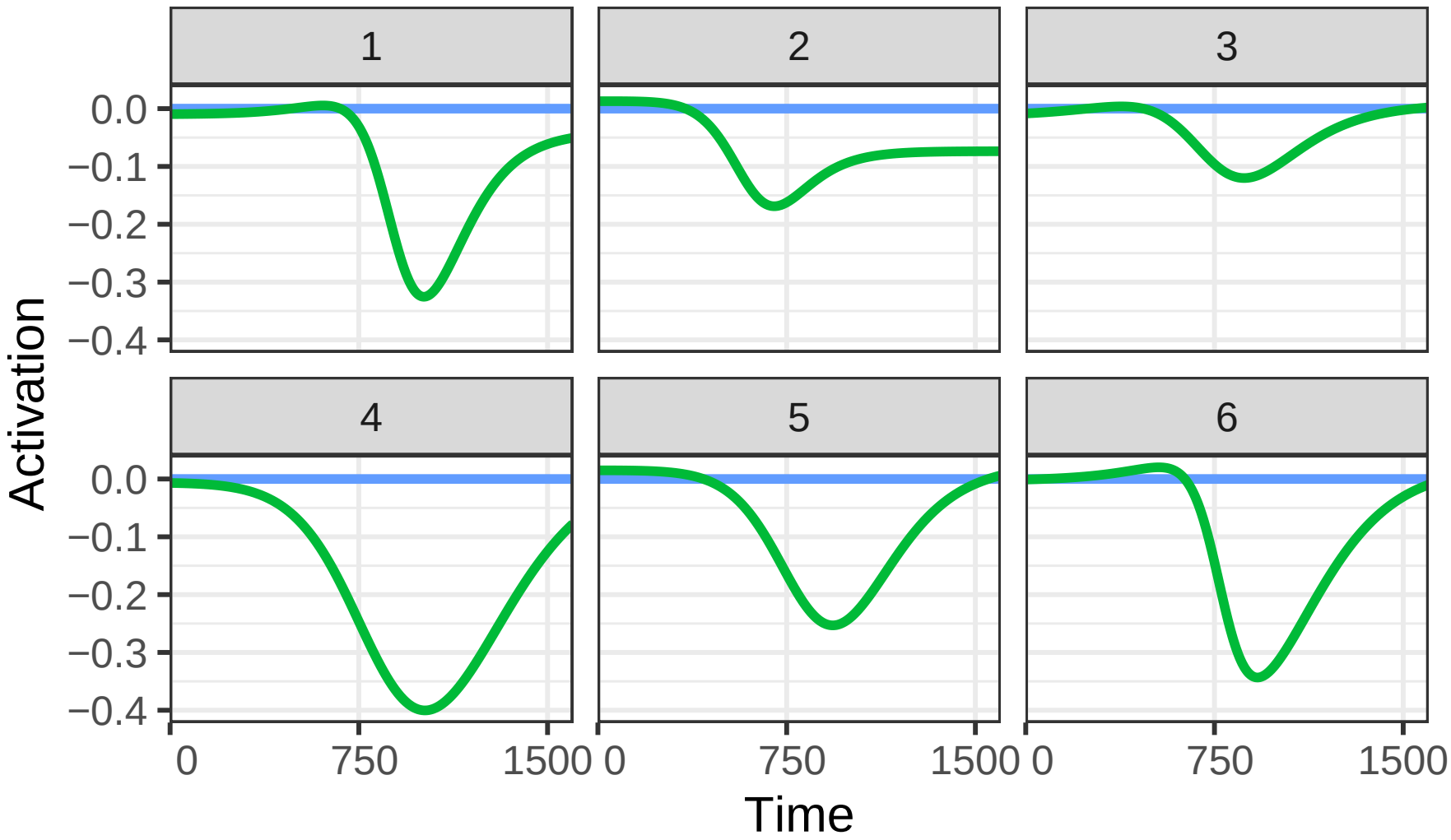

No Delay
Mini
Peak
Slope
Crossover
Look Onset
Proportion
Method
Bias
−0.04
−0.02
0.00
0.02
−0.03
−0.02
−0.01
0.00
0.01
0.02
0.03
−0.0010
−0.0005
0.0000
0.0005
0.0010
−50
0
50
100
150

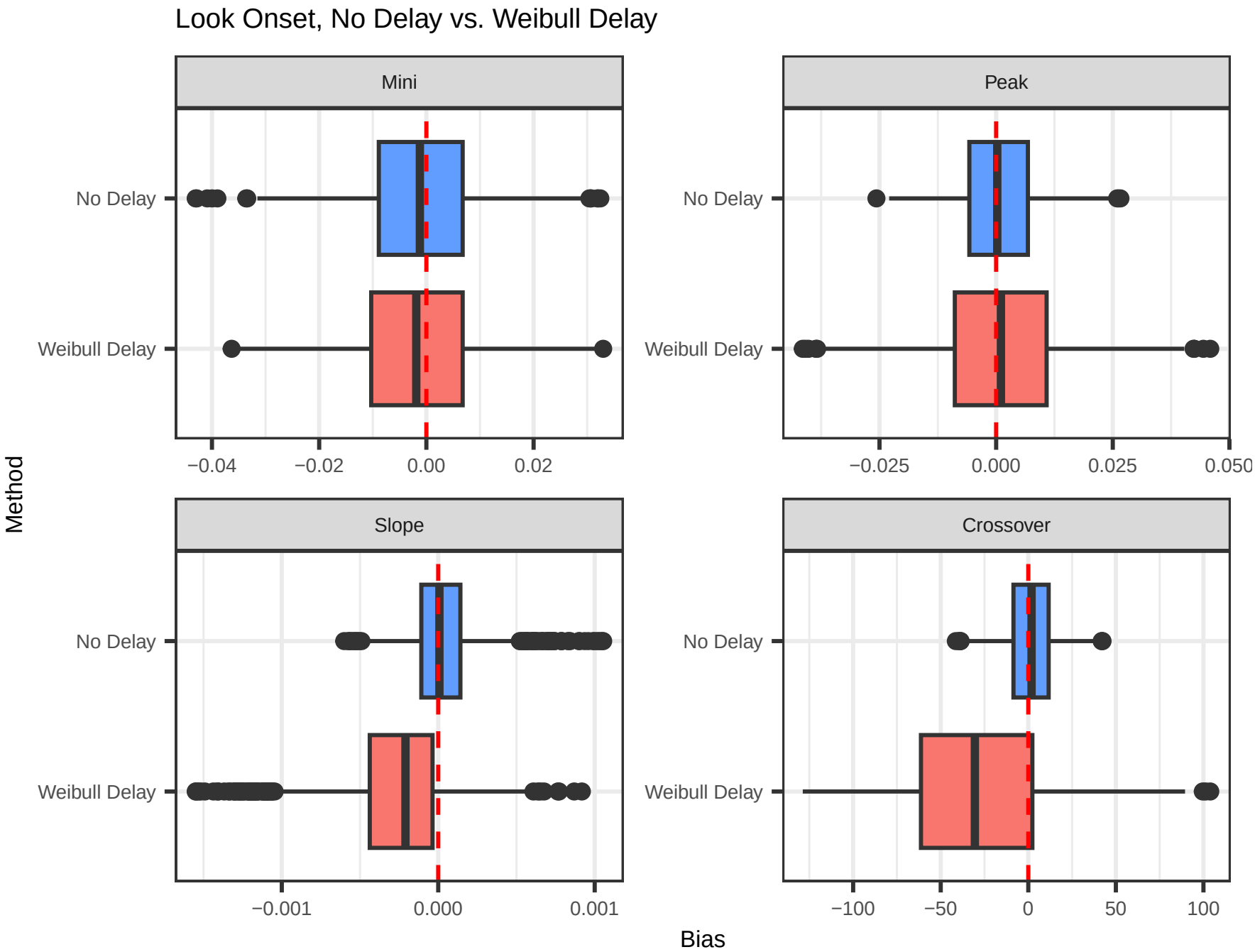

No Delay
Weibull Delay
MISE
25
20
15
10
5
0
Look Onset
Proportion
Look Onset
Proportion

Representative Curves, Weibull Delay



Representative Error Curves, Weibull Delay




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

What else?

`bdots` software

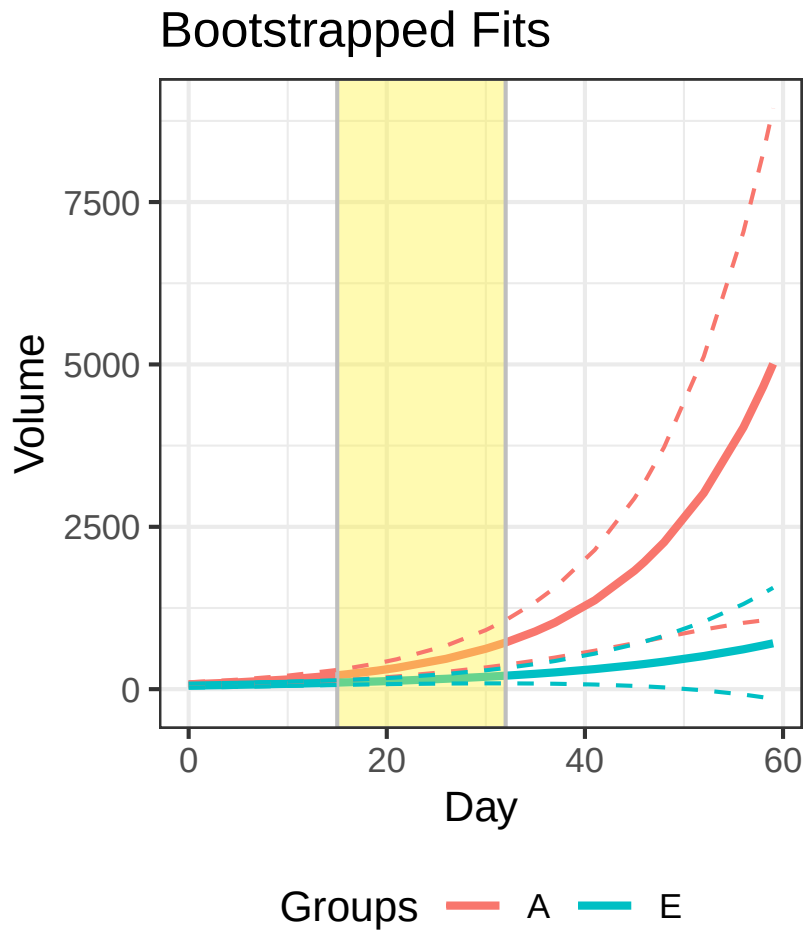
- Significant overhaul to interface
- Broad expansion of capabilities

Underlying methodology

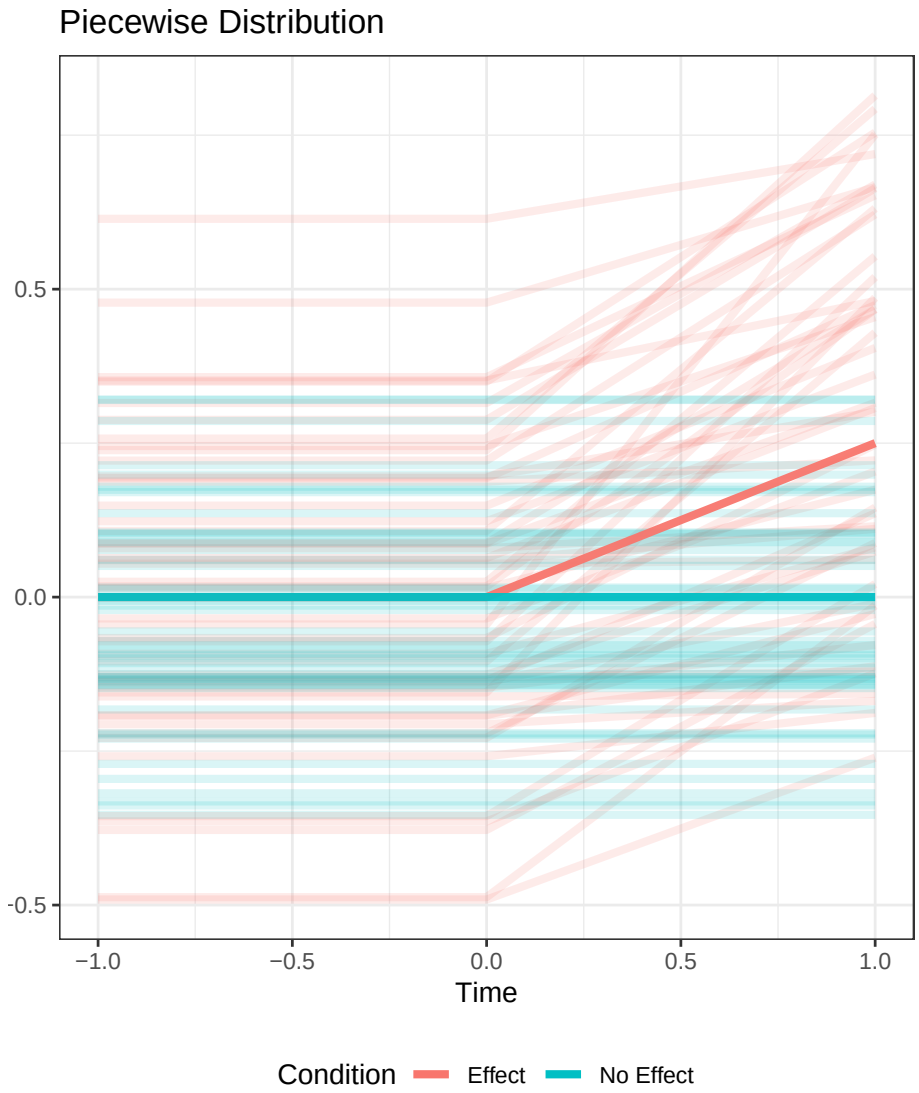
- Introduced two new methods
- Type I Error
- Power

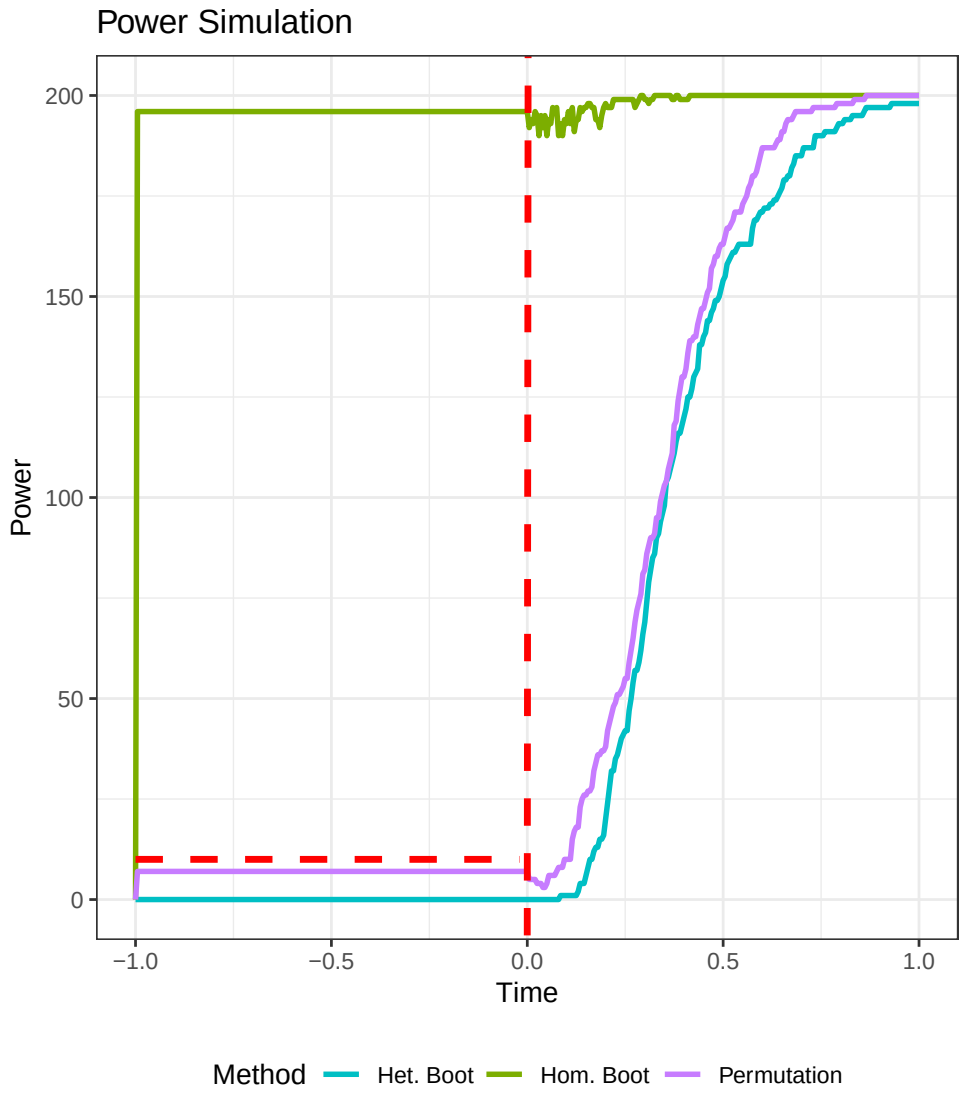
Bootstrapped differences in time series – bdots

```
fit <- bfit(data = dat,
            y = "Volume",
            subject = "ID",
            time = "Day",
            group = "Treatment",
            curveFun = expCurve())


boot <- bboot(Volume ~ Treatment(A, E),
              bdObj = fit)


plot(boot)
```



Methodology





thanks

References

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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