

# What You See is What You Get

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

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What is this talk going to be about?

- Cognition/Activation
- Eyetracking and the VWP
- Methodology and Bias
- Future Directions

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

“trink”  $\Rightarrow$  “trank” or “trinked”?

Particularly troublesome when we commit too early:

“The horse raced past the barn fell”

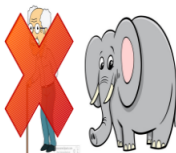
Often can not be observed directly

We are going to limit our focus today to single word recognition

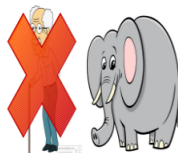
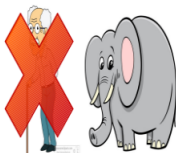
# el



el → ele



el → ele → elephant



# How does this evolve in time?

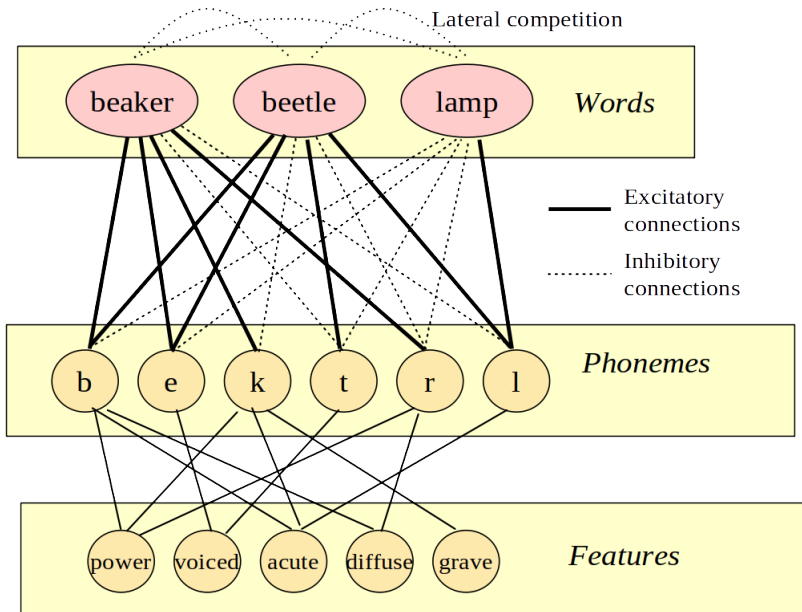
Continuous mapping models of word recognition account for variety of observed phenomenon

things like immediacy (hypothesis formed from earliest input), parallelism (multiple items activated, i.e., priming), graded activation (not all-or-nothing)

In particular, connectionist models of lexical access (such as TRACE):

- Network structure
- Processes in real time
- Nodes, activation, and signal





TRACE (McClelland & Elman, 1986)

# TRACE Word Activation

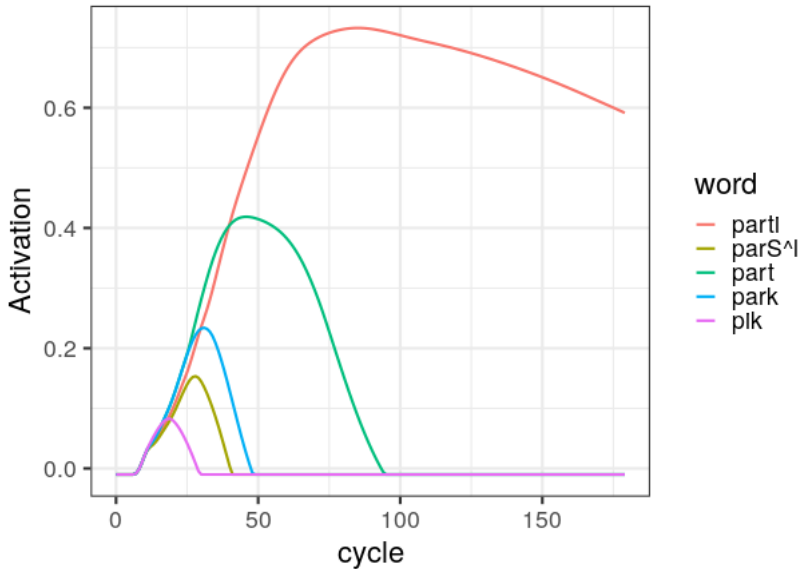


Figure 1: gave up on reordering the legend

# 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
- Phonological perceptions

Fortunately there is expertly written software to help accomplish this

# Ok, so how do we get access?

maybe make picture larger and  
remove all words?

Cognitive activation is not  
something that can be measured  
directly

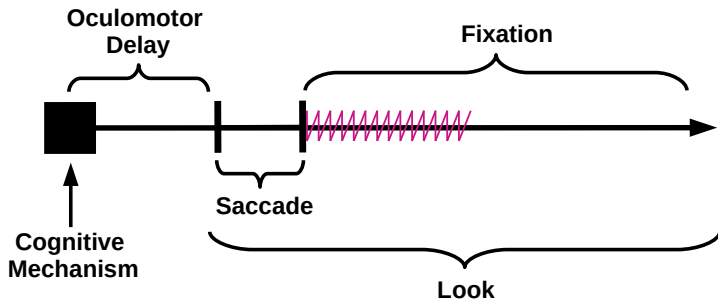
Our eyes reveal a terrifying  
amount of information about  
what we are considering

This has been empirically tested  
and confirmed in countless  
experiments



Cohen 1983

# Visualizing Eye Mechanics



# Visual World Paradigm

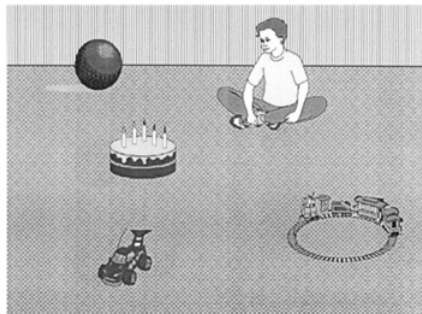
Visual World Paradigm  
introduced in 1995

Eyetracking software in  
conjunction with spoken sentence

“The boy will move the cake”

How do we go from this to word  
recognition?

talk about differential eye  
tracking with ambiguity, etc  
(maybe use that image instead)



# alt image for vwp

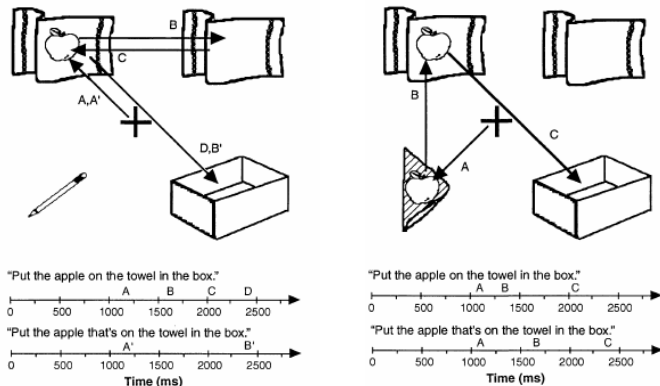
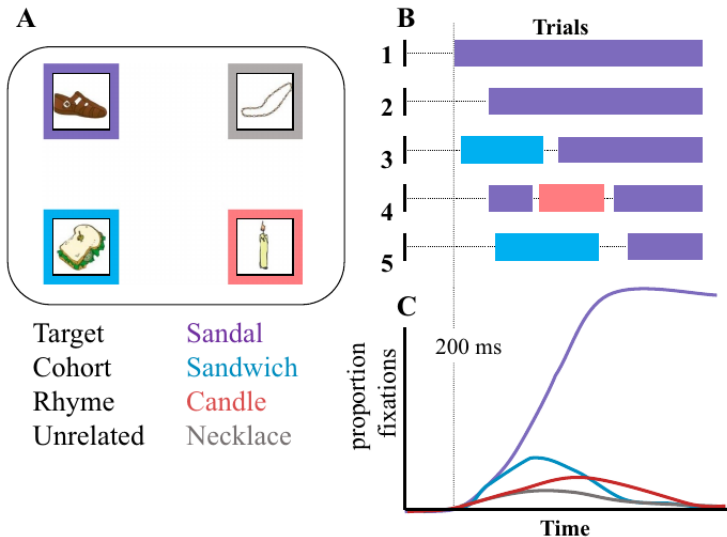


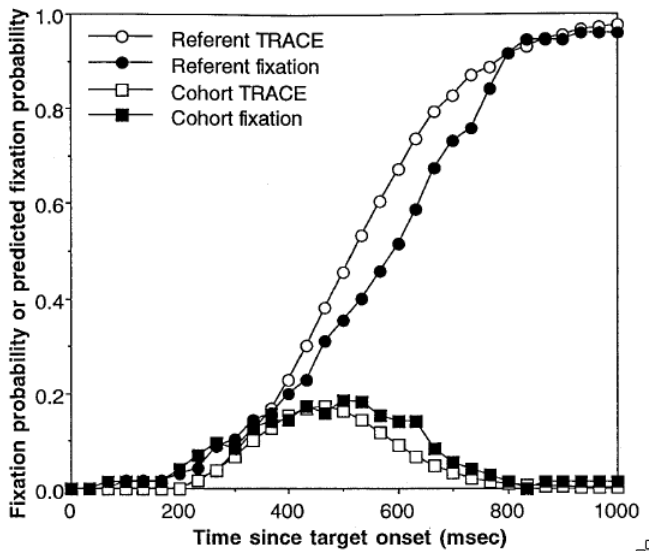
Figure 3: Differential eye response based on context and ambiguity

# VWP Trials





# Original study



# So how does this relate to VWP

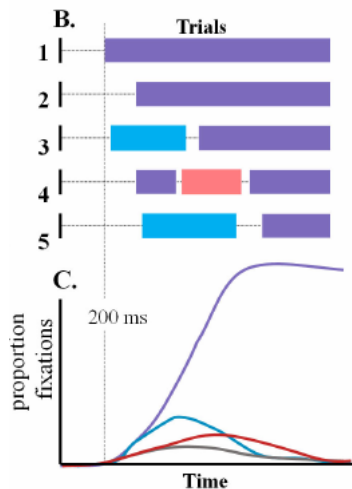
To make the problem more tractable, curves given a (usually) parametric form,  $f_{\theta}(t)$  or  $f(t|\theta)$

Letting  $z_{ijt}$  represent fixation at time  $t$  for trial  $j$ , we have empirical curve

$$y_{it} = \sum_j z_{ijt}$$

and find

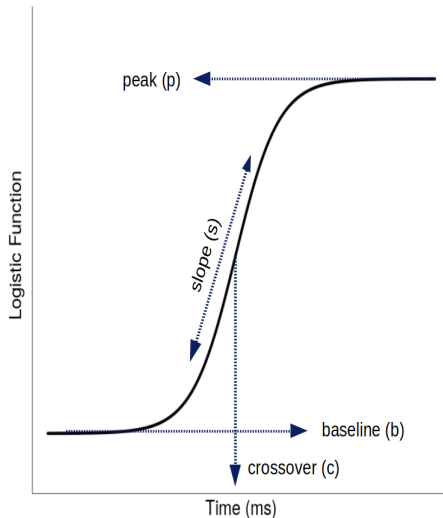
$$\hat{\theta} = \operatorname{argmin}_{\theta} \mathcal{L}(f_{\theta}, y)$$



# Parametric Function

Here, for example, is a four-parameter logistic function, typically used for the referent:

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



We are predominately interested in the recovery of a lexical activation function, though given visual similarities between the proportion of fixations and activation, we have the ostensible equivalence,

$$y_{it} \equiv f(t|\theta_i) \quad (1)$$

There are primarily two sources of biases inherent in this method which hitherto have been left unexamined:

1. Delayed observation bias/error
2. Added observation bias

(in reverse order because easier to explain plus its mostly an aside)

# Delayed observation bias

too many words

Delayed observation bias arises from the oculomotor delay between the cognitive process (of interest) and the first physiological response

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

Of course any actual bias would be the difference between the true value and the 200ms subtracted, but also has been no treatment as to the effect of randomness

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

# Added Observation Bias

too many words

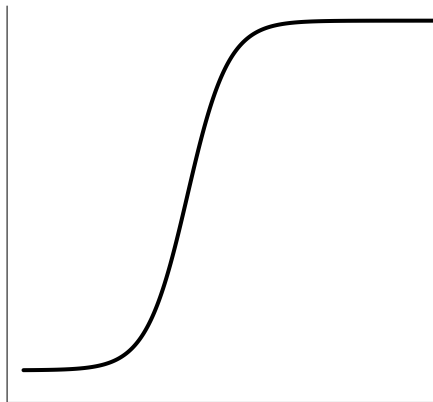
Added observation bias arises from the conflation of two distinct (though likely correlated) processes: the decision to initiate an eye movement to a particular place and the duration of a fixation

We are interested in the process that probabilistically determines the *location* of a fixation

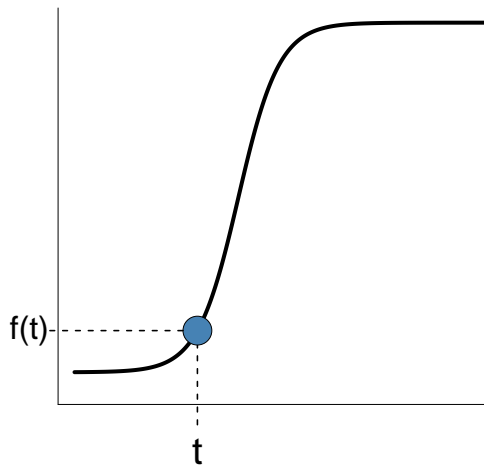
At some time  $t$ , a saccade is launched, and we know from length of saccade until *at least* refractory period for fixation, it is impossible for our eyes to go anywhere else

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

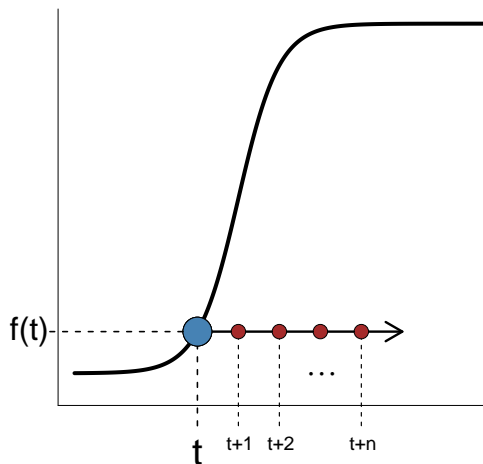


# Onset of look





...followed by fixation



# Look Onset Method

As the cognitive mechanism responsible for initiating an eye movement is probabilistically (allopenna) related to activation, we argue that the instance of a look onset is a more theoretically consistent and physiologically defensible observation to treat as relevant data

Under the look onset method, only the initial moment of look onset,  $s_j$ , is considered relevant in the recovery of latent activation, where a look initiated at time  $t_j$  follows

$$s_j \sim \text{Bern}(f_\theta(t_j))$$

This gives us instead a set of ordered pairs,  $\mathcal{S} = \{(s_j, t_j)\}$  rather than a time ordered vector of proportions

Fortunately, we are able to use nearly an identical procedure as before,

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

Should i talk about bdots somewhere? I don't think it needs its own slide. Mention bdots earlier then on previous slide be like oh yeah it can handle data from look onset as well

# Simulation

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

Each subject draws individual  $\theta_i$  from empirically determined distribution and will perform 300 trials. 1,000 total subjects

Metric for efficacy is MISE between generating function and recovered curve using `bdots`

# Simulation – Single Trial

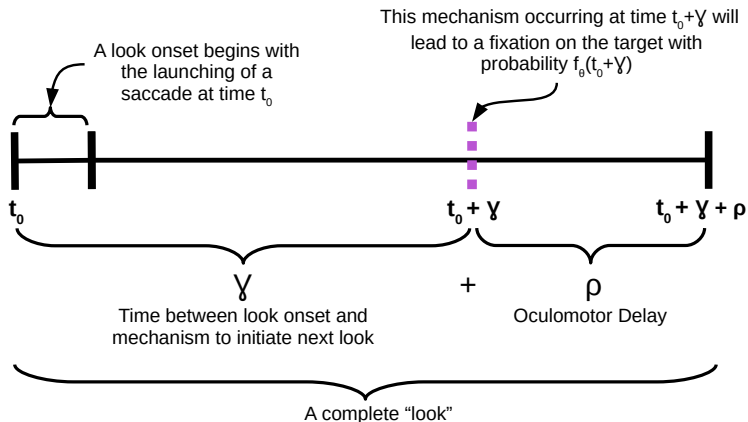
Will need to fill in with exposition, don't want dense text on slide  
Alternatively, I could just skip a slide like this all together and just explain in picture

1. Look initiated at  $t_0$ , persisting for at least duration  $\gamma$
2. At  $t_0 + \gamma$ , look towards target with probability  $f(t_0 + \gamma|\theta)$
3. This is followed by oculomotor delay,  $\rho$
4. At  $t_0 + \gamma + \rho$ , current look ends and next is immediately initiated

A trial begins at  $t = 0$  and continues until the cumulative duration of looks within trial exceeds 2000ms

would also say here or next slide we run three types with various distributions of  $\rho$

# Simulation (explain in words, could have less detail here)



[all meta commentary here, will delete slide]

Probably not necessary to include all simulations, I'll just choose two

I can make the proportion curves look as good or bad as I want by modifying the  $\gamma$  parameter. I don't think that's necessary here as I can comment as to why small changes make a large difference in subsequent analysis

For weibull delay, im only going to compare par bias for onset method against no delay since after the first sim there is really no reason to look at proportion method again

### Representative Curves, No Delay

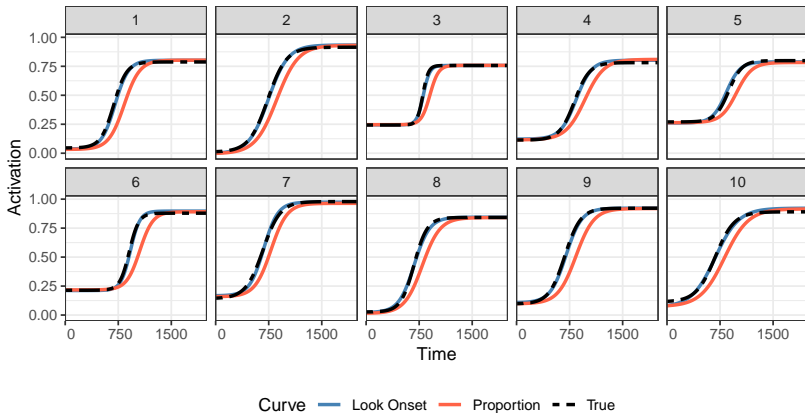
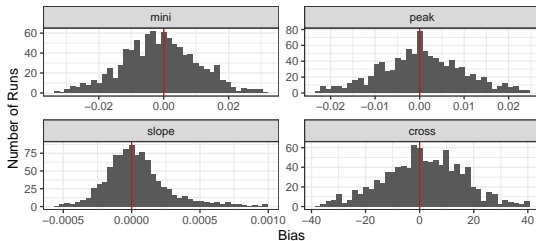


Figure 4: Representative curves with no oculomotor delay



### Parameter Bias for Look Onset Method, No Delay



### Parameter Bias for Proportions Method, No Delay

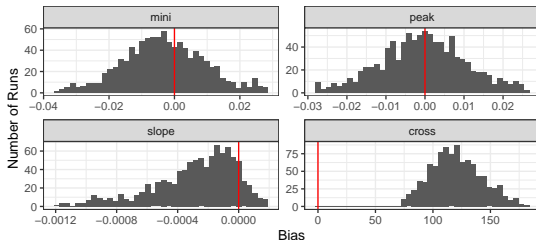


Figure 5: Parameter bias with no oculomotor delay

## Representative Curves, Weibull Delay

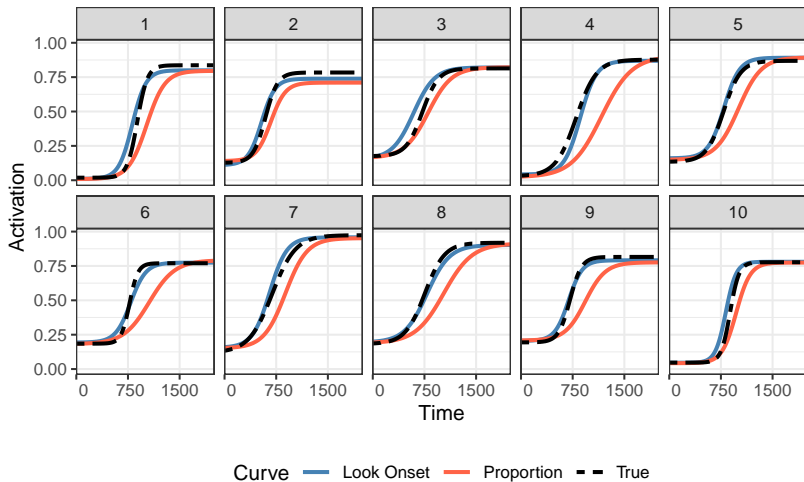
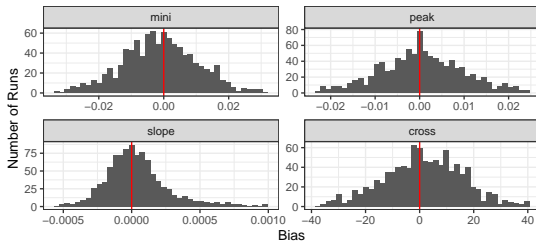


Figure 6: Representative curves with no oculomotor delay

### Parameter Bias for Look Onset Method, No Delay



### Parameter Bias for Look Onset Method, Weibull Delay

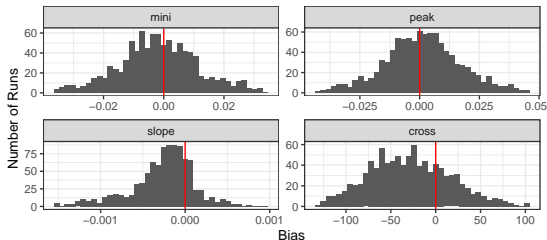


Figure 7: Parameter bias with no oculomotor delay

Method	Delay	1st Qu.	Median	3rd Qu.
Look Onset	No Delay	0.17	0.32	0.56
Look Onset	Weibull Delay	1.05	2.16	4.23
Proportion	No Delay	8.21	11.33	16.01
Proportion	Weibull Delay	15.27	24.75	38.14

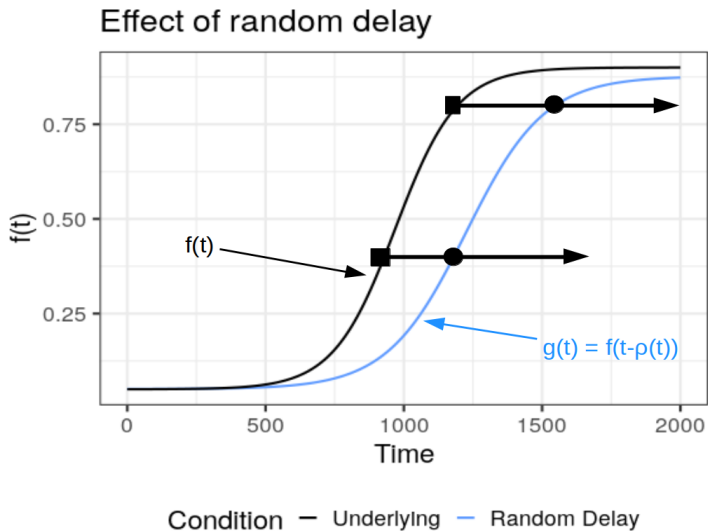
Table 1: Summary of mean integrated squared error across simulations

# Ok, so where from here?

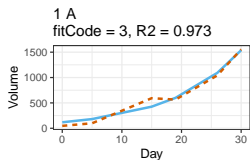
maybe elaborate on bdots *here*, what it can do, how it changed, etc.,. I also like the idea of talking a bit more about oculomotor delay (and I left that slide comparing curves after this), but its mostly theoretical time filler since I didn't actually do anything to address it

- bdots
- Simulation for eyetracking/physiology
- Extending the model (number of saccades, search patterns, etc.,)
- Oculomotor delay

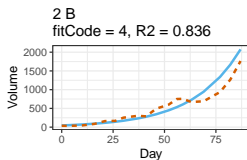
# Impact of random delay



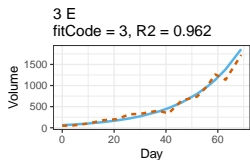
# Bootstrapped differences in time series – bdot s



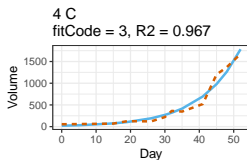
Curves — Fit - - - Observed



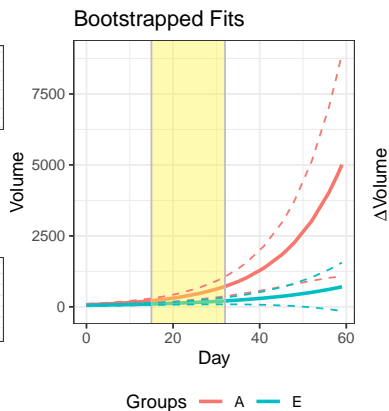
Curves — Fit - - - Observed



Curves — Fit - - - Observed



Curves — Fit - - - Observed



# Concluding remarks

What can we take away from this:

- VWP used to collect eye tracking data as proxy for word recognition
- Look onset method results in less bias in estimating generating curve
- Software and methodology to investigate these

And where are we going from here?

- Oculomotor delay
- Simulating eye tracking data (linking hypothesis)
- Expanding domain of `bdots`



# References

Magnuson, James S. **Fixations in the visual world paradigm: where, when, why?** 2019-09 *Journal of Cultural Cognitive Science*, Vol. 3, No. 2 Springer Science and Business Media LLC p. 113-139

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