What You See is What You Get:

A Closer Look at Bias in the Visual World Paradigm

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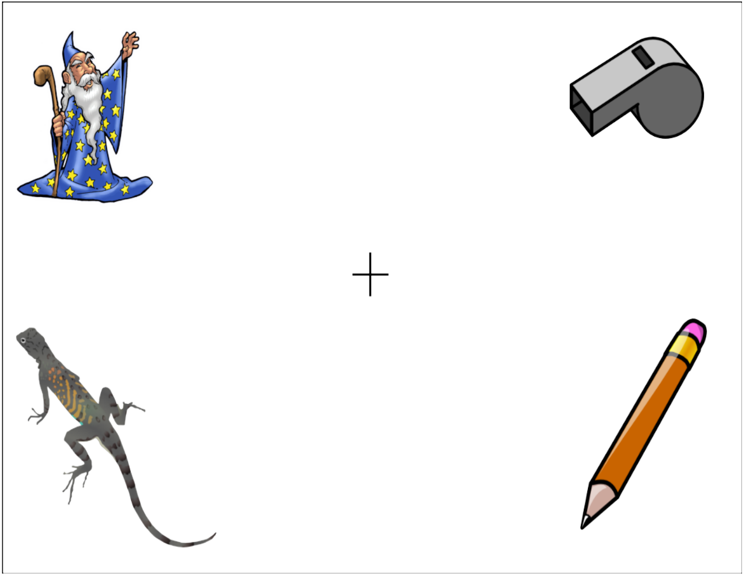
March 8, 2023



Outline

What is this talk going to be about?

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

Language and Cognition

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"

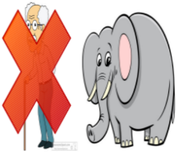
Often can not be observed directly

Limit focus to single word recognition start by introducing cohort model as an idea

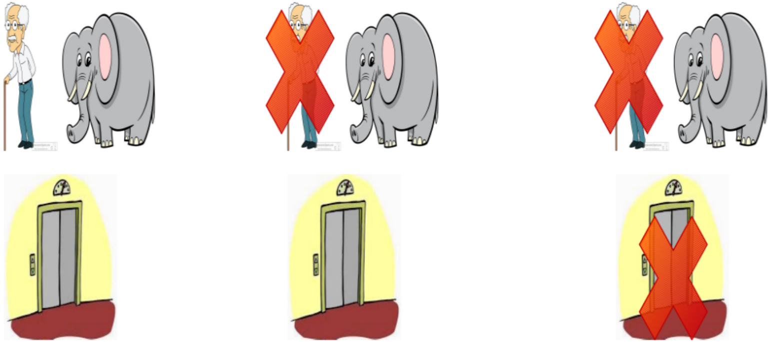
el

el → ele



el → ele → elephant



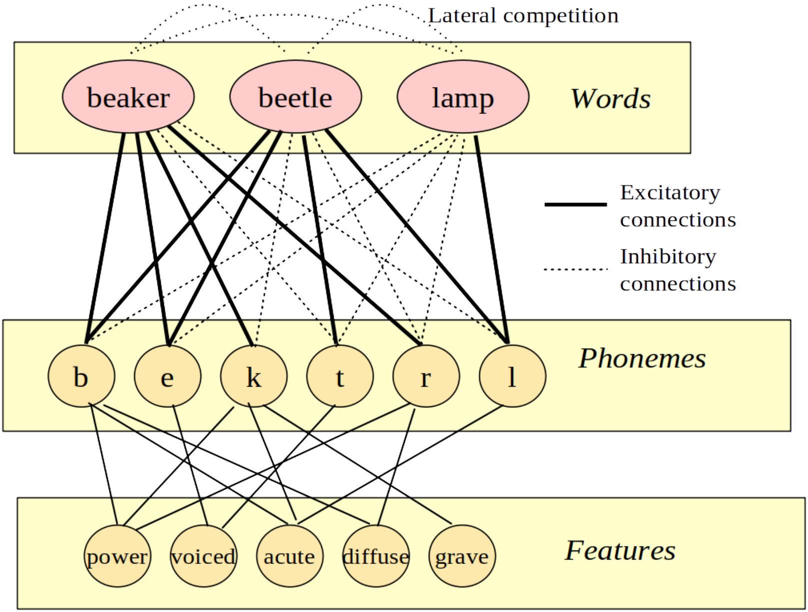
How does this evolve in time?

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 relies on information between levels, i.e., phonemes, words, etc.)
- Processes in real time along with network structure, accommodates competition
- Nodes, activation, and signal metaphors that motivate language used to describe it



TRACE (McClelland & Elman, 1986)

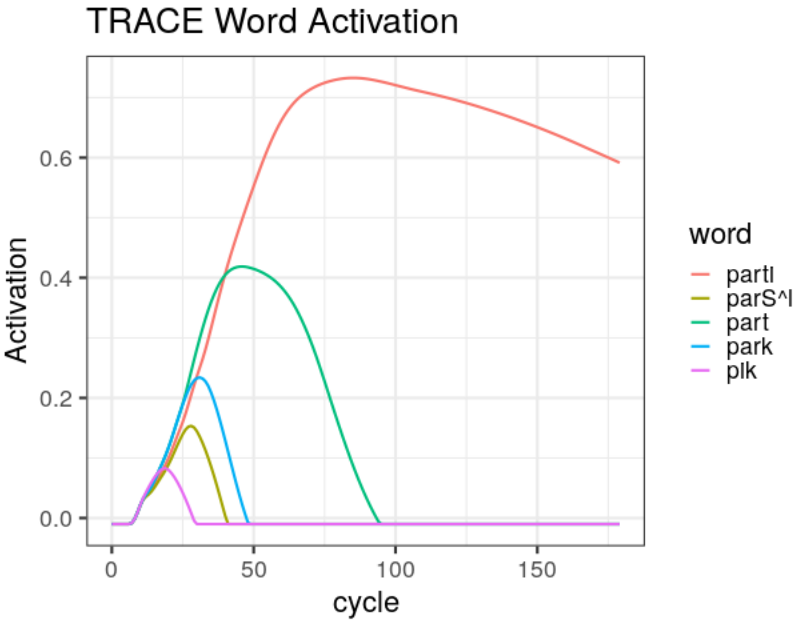


Figure 1: gave up on reordering the legend

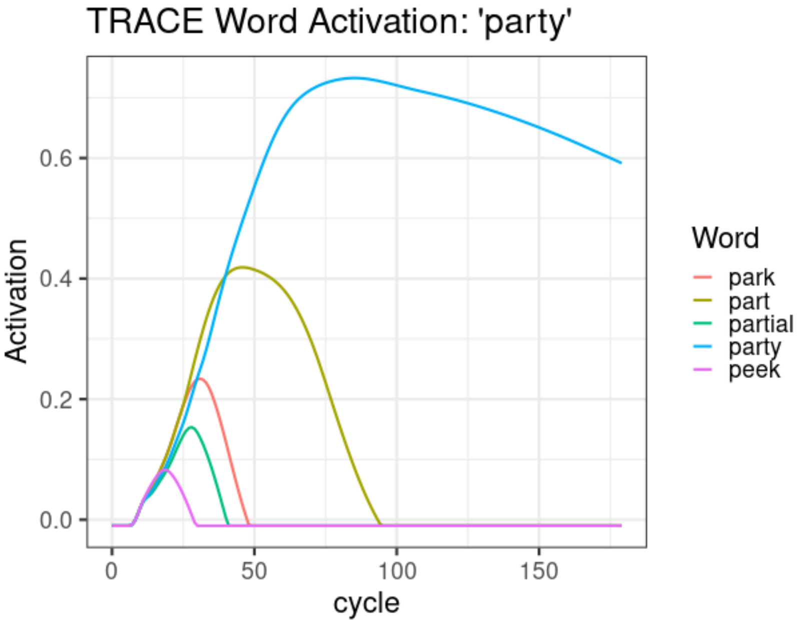


Figure 2: gave up on reordering the legend

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
comment that we will discuss bdots in more detail at end

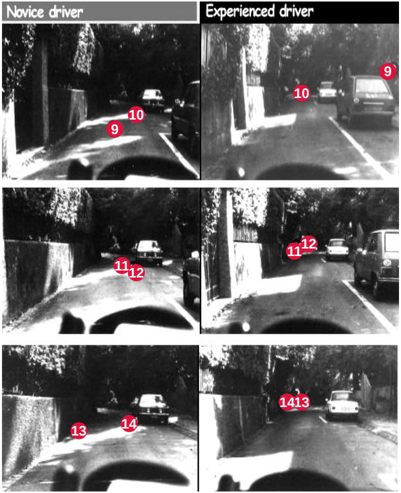
What's in a look?

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

What's in a look?

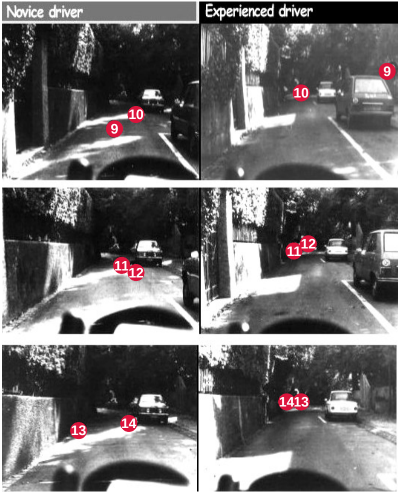
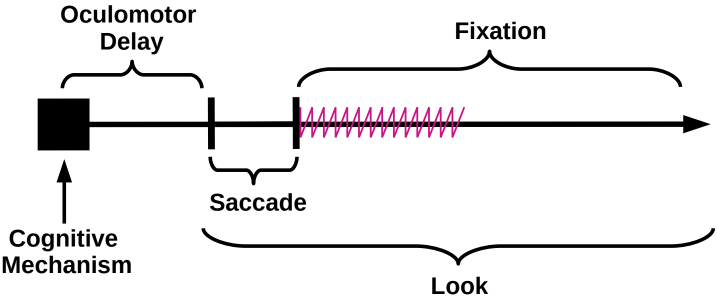


Figure 3: what it would look like without words

Visualizing Eye Mechanics



Visual World Paradigm

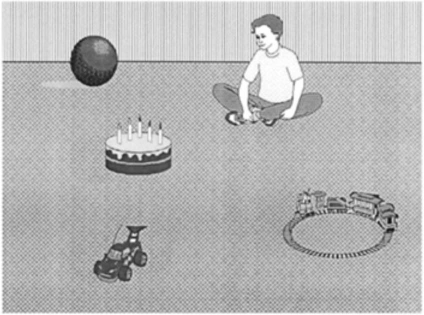
Visual World Paradigm introduced in 1995

Eye-tracking 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

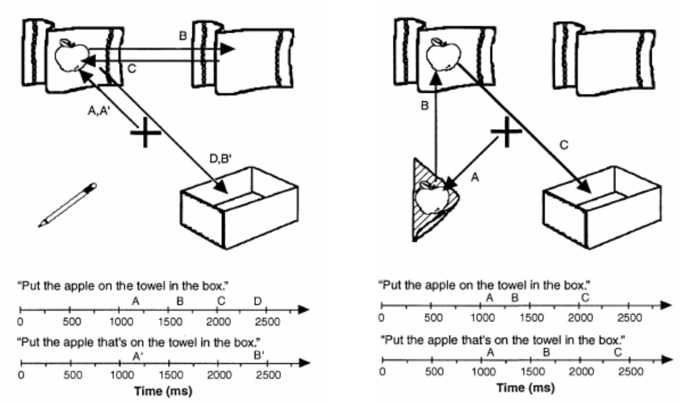
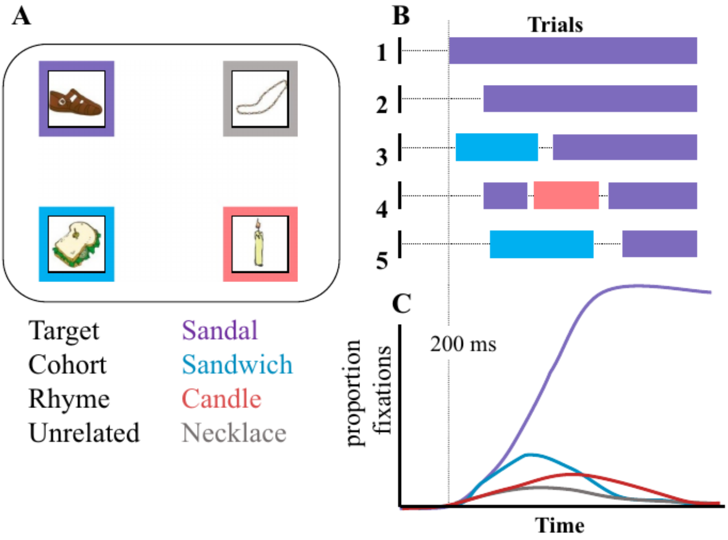
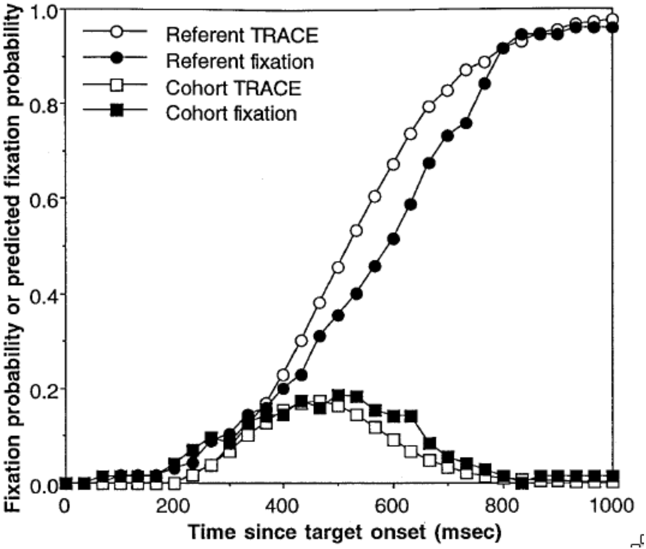


Figure 5: Differential eye response based on context and ambiguity

VWP Trials


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

Original study



So how does this relate to VWP

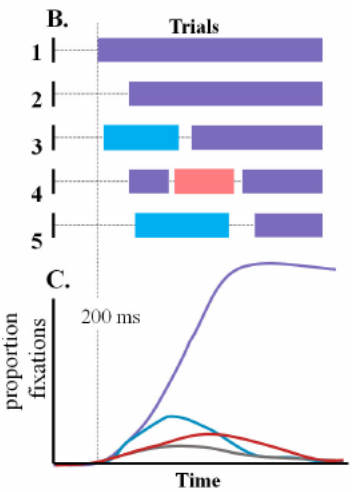
To make the problem more tractable, curves given a (usually) parametric form, $f_\theta(t)$ or $f(t|\theta)$

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

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

and find

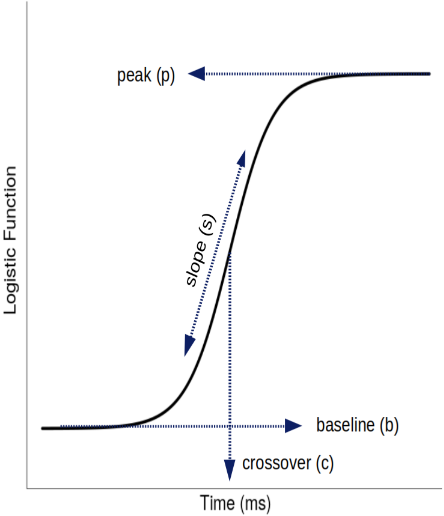
$$\hat{\theta} = \underset{\theta}{\operatorname{argmin}} \mathcal{L}(f_\theta, y)$$



Parametric Function

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

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



Linking hypothesis

Have used $f(t|\theta)$ as functional form for proportion of fixations, but relation to activation still implicit/undefined

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

Our primary proposal is that it is the underlying activation, rather than observed data, that should be modeled explicitly as $f(t|\theta)$

Issues

Actually, let's move delay observation bias until *after* look onset introduced since its unrelated, but relevant for sim

maybe move illustration of saccade/OM/fixation to immediately after this slide?

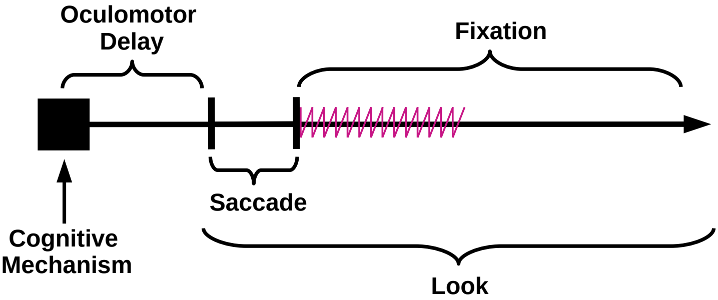
in light of this... Despite visual similarities between the proportion of fixations and activation, there is an issue with the equivalence

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

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

maybe don't specifically say anything here, save discussion for next slide then move on to added observation bias

Visualizing Eye Mechanics



Added Observation Bias

too many words

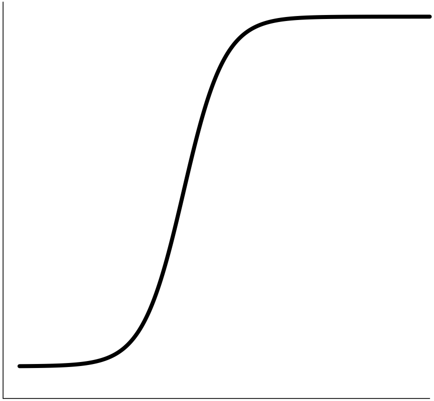
Added observation bias arises from the conflation of two distinct (though likely correlated) processes: the decision to initiate an eye movement to a particular place and the duration of a fixation

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

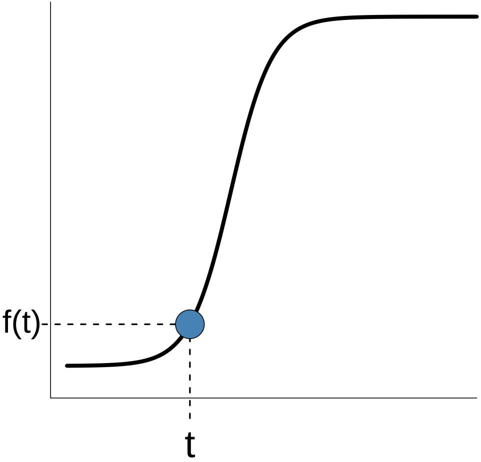
At some time t, a saccade is launched, and we know from length of saccade until *at least* refractory period for fixation, it is impossible for our eyes to go anywhere else

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

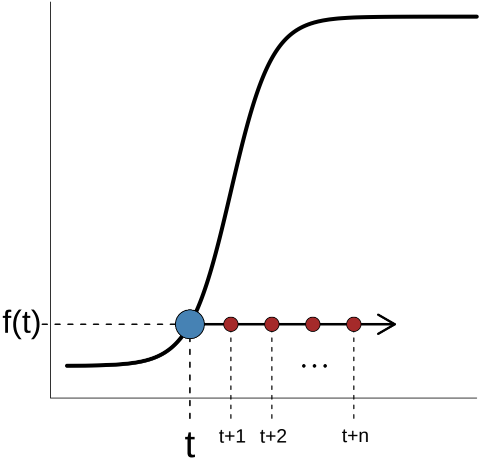
Activation curve



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

We propose 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

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

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,

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

Delayed Observation

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

This gives distribution of look onset,

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

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

Simulation

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

Each subject draws individual θ_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`

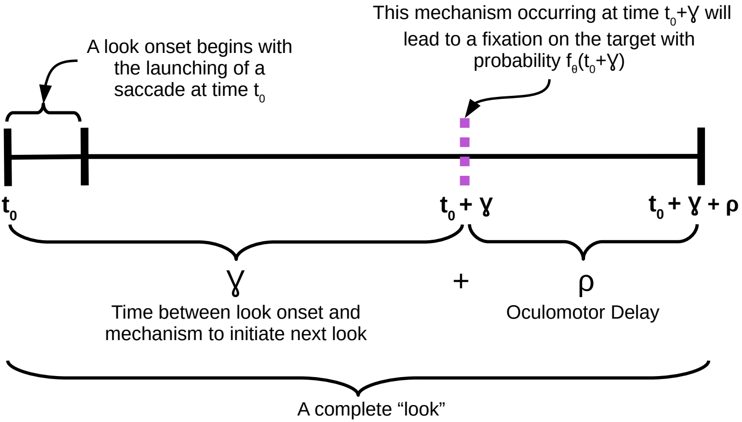
Simulation – Single Trial

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 γ
2. At $t_0 + \gamma$, look towards target with probability $f(t_0 + \gamma | \theta)$
3. This is followed by oculomotor delay, ρ
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 ρ

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



notes on results section

[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 γ 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

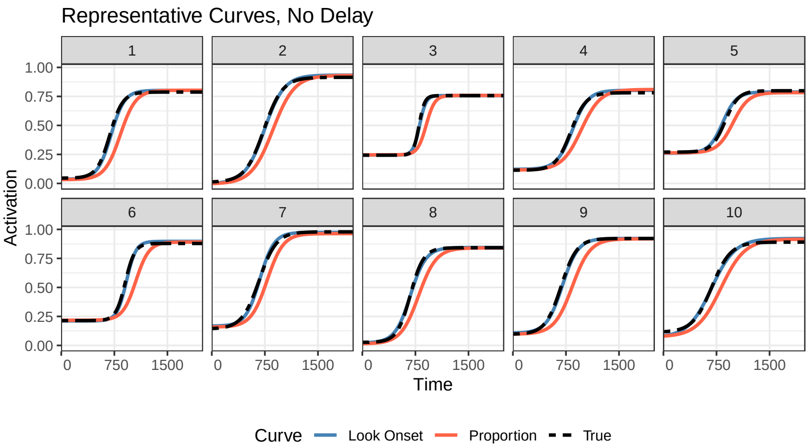


Figure 7: Representative curves with no oculomotor delay

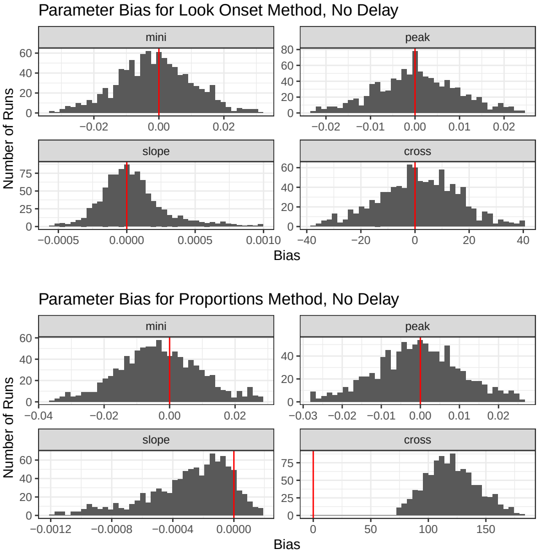


Figure 8: Parameter bias with no oculomotor delay

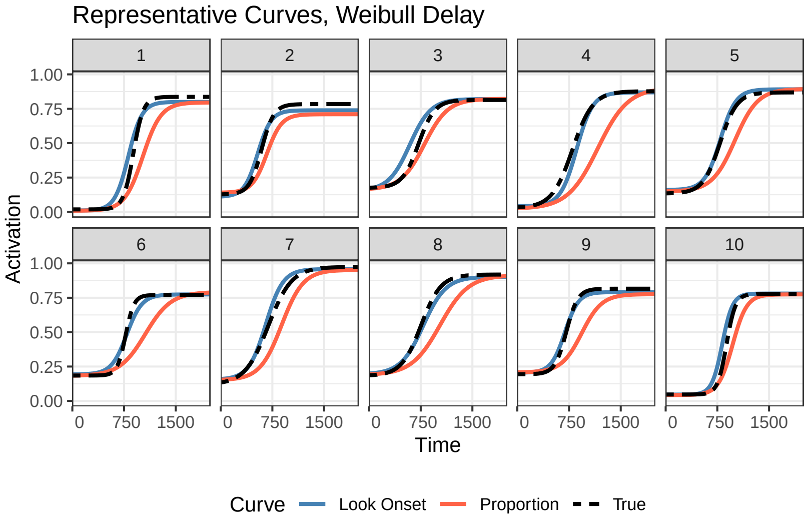


Figure 9: Representative curves with no Weibull delay

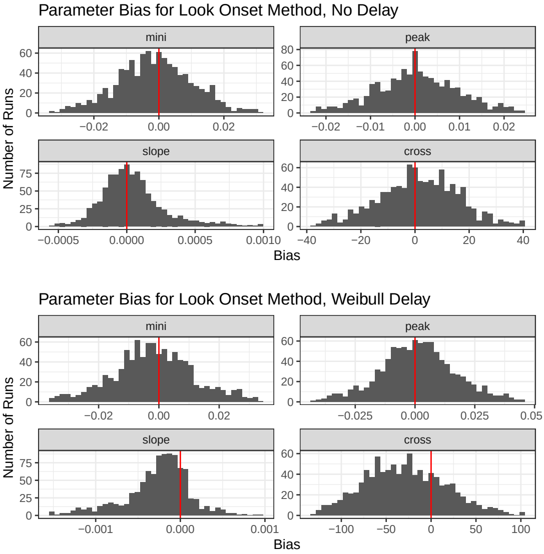


Figure 10: Parameter bias for look onset method

MISE

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

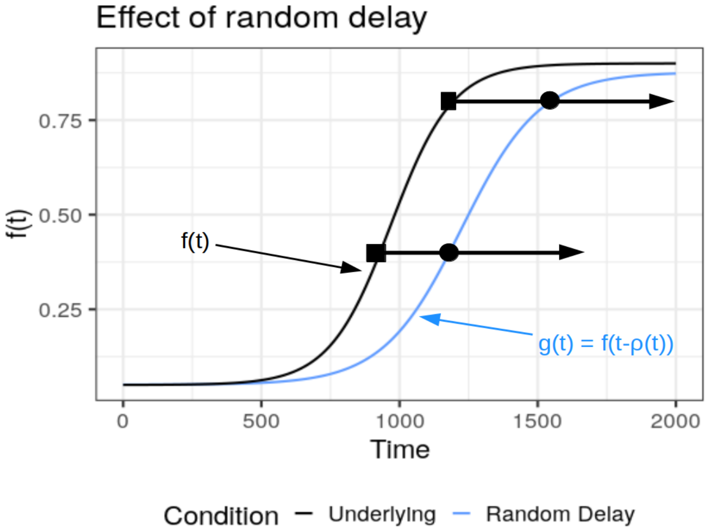
Table 1: Summary of mean integrated squared error across simulations

Where from here?

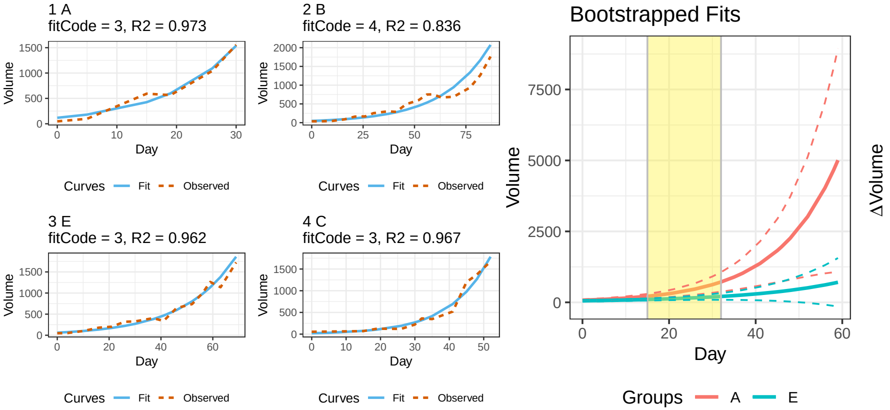
maybe elaborate on bdots *here*, what it can do, how it changed, etc.,. I also like the idea of talking a bit more about oculmotor delay (and I left that slide comparing curves after this), but its mostly theoretical time filler since I didn't actually do anything to address it

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

Impact of random delay



Bootstrapped differences in time series – `bdots`



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