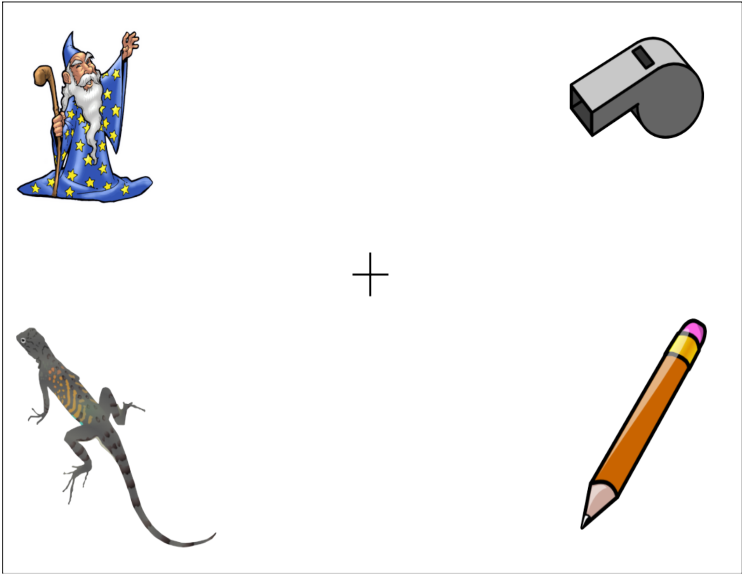
What You See is What You Get

A Closer Look at Bias in the Visual World Paradigm

Collin Nolte

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”

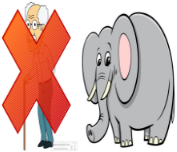
Often can not be observed directly

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

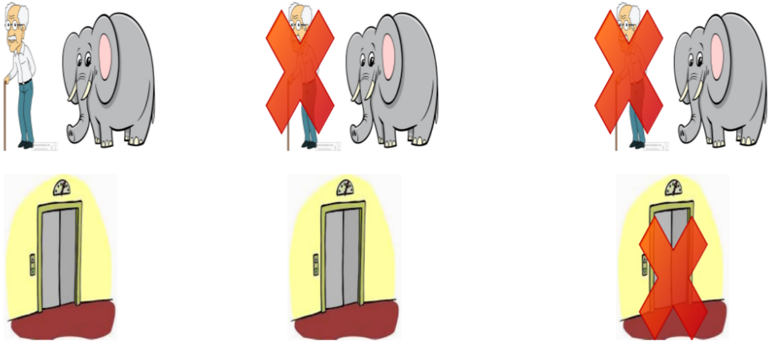
el

el → ele



el → ele → elephant

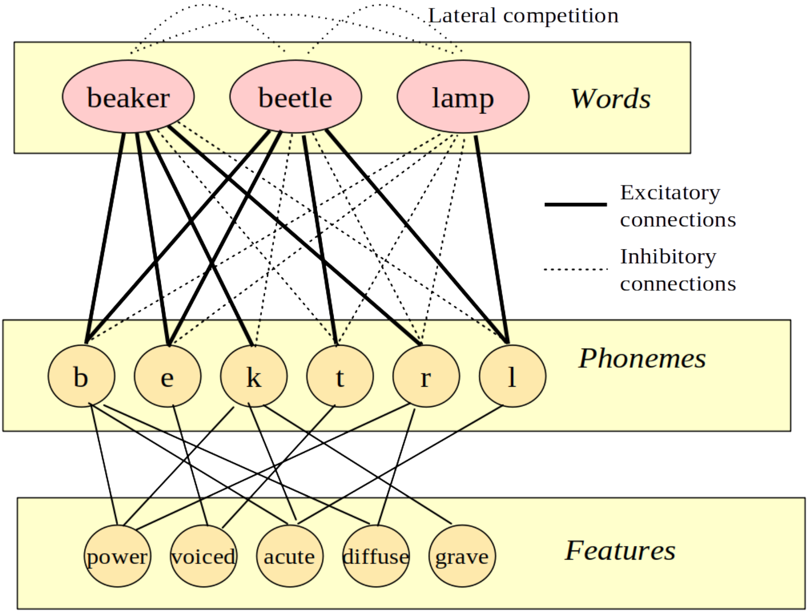


How does this evolve in time?

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

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

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



TRACE (McClelland & Elman, 1986)

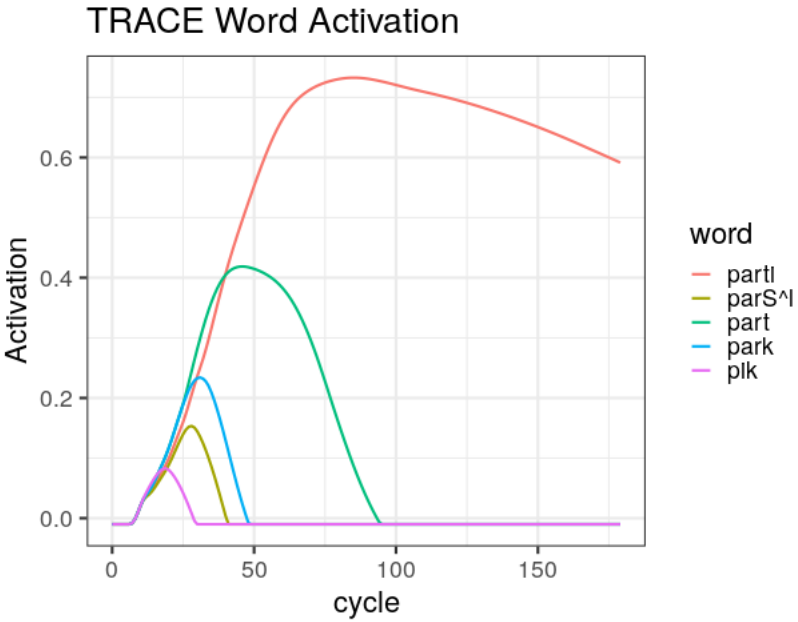


Figure 1: gave up on reordering the legend

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?

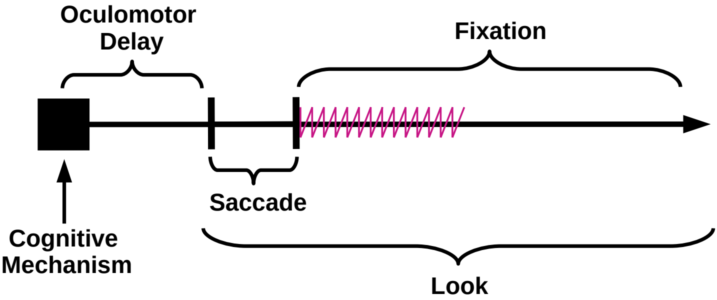
Cognitive activation is not something that can be measured directly

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

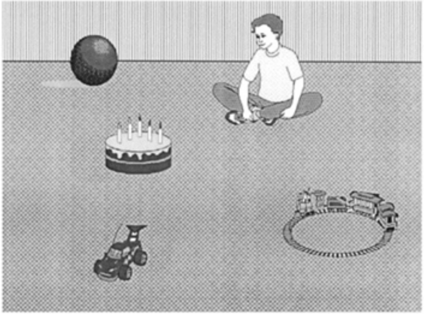
Visual World Paradigm introduced in 1995

Eyetracking software in conjunction with spoken sentence

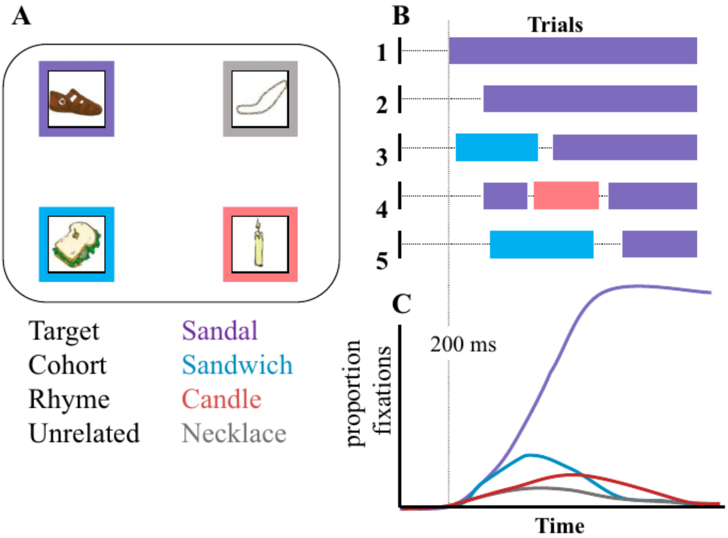
"The boy will move the cake"

How do we go from this to word recognition?

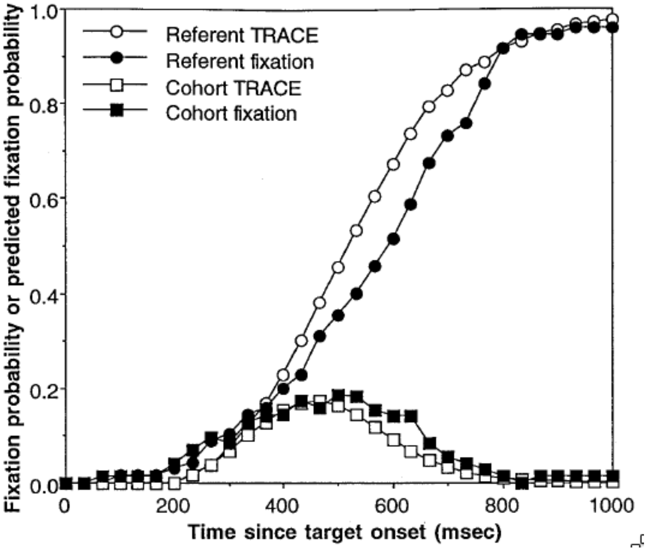
talk about differential eye tracking with ambiguity, etc (maybe use that image instead)



VWP Trials


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

Original study



So how does this relate to VWP

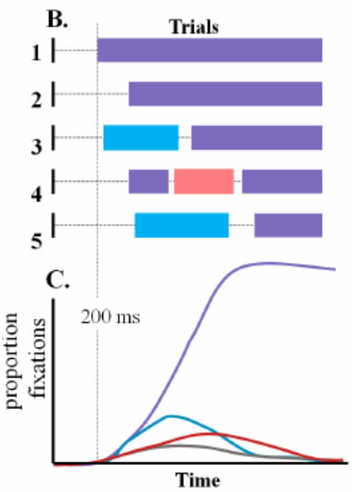
To make the problem more tractable, curves given a (usually) parametric form, $f_\theta(t)$ or $f(t|\theta)$

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

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

and find

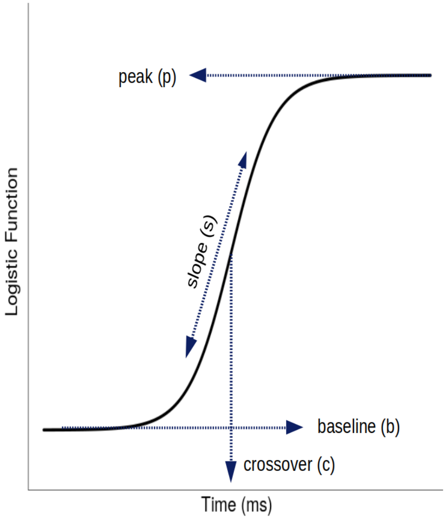
$$\hat{\theta} = \underset{\theta}{\text{argmin}}\, \mathcal{L}(f_\theta, y)$$



Parametric Function

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

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



Issues

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,

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

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

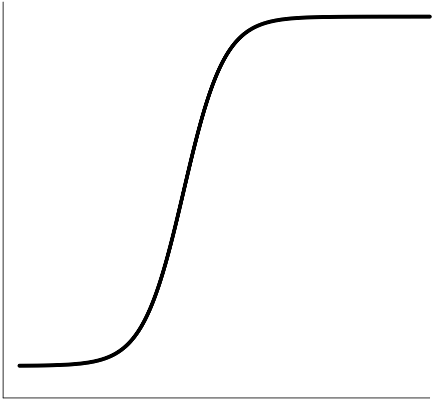
Added observation bias arises from the conflation of two distinct (though likely correlated) processes: the decision to initiate an eye movement to a particular place and the duration of a fixation

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

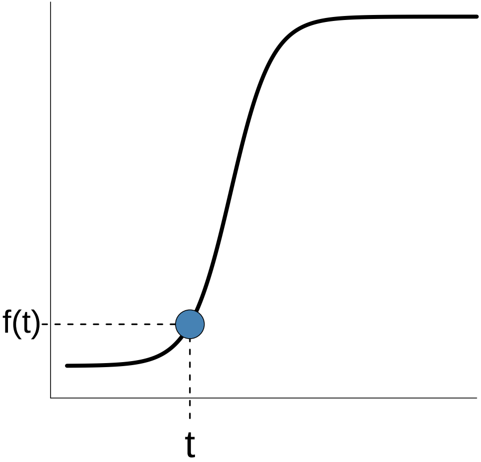
At some time t, a saccade is launched, and we know from length of saccade until *at least* refractory period for fixation, it is impossible for our eyes to go anywhere else

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

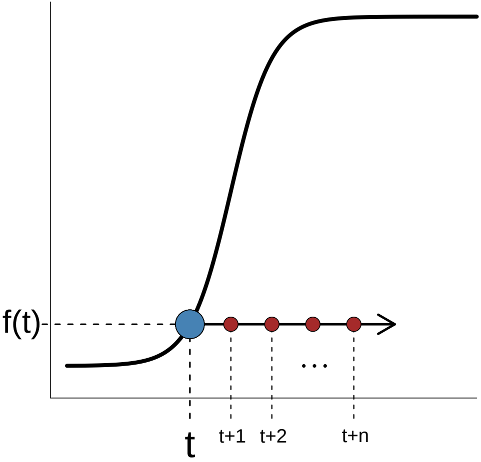
Activation curve



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

$$s_j \sim Bern(f_\theta(t_j))$$

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,

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

bdots

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

Assume activation can be modeled $f(t|\theta)$, with subject-specific θ_i

Introduce mechanics for fixation and oculomotor delay to demonstrate both added and delayed observation bias

Each subject will perform 300 simulations of a VWP trial, with 1,000 total subjects

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

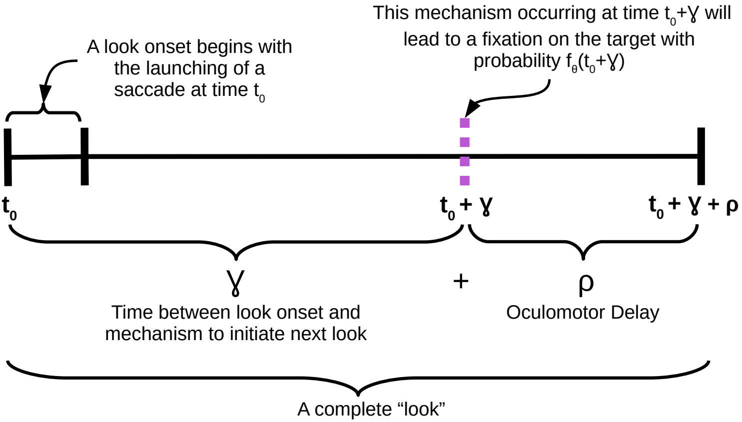
Simulation – Single Trial

Will need to fill in with exposition, don't want dense text on slide

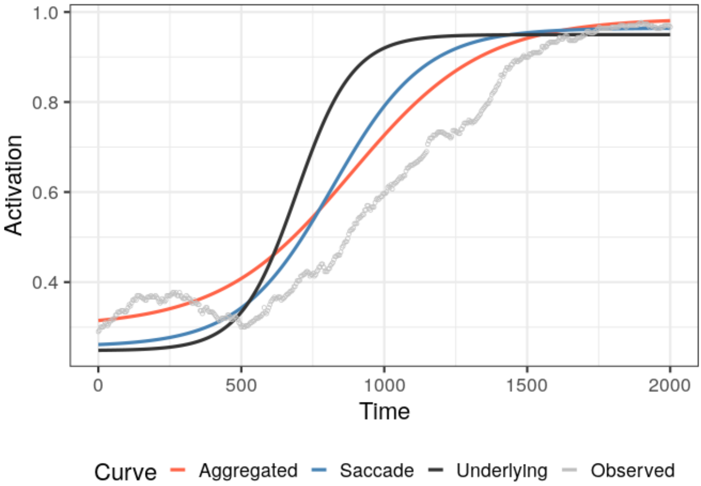
1. Look initiated at t_0, persisting for at least duration γ
2. At $t_0 + \gamma$, look towards target with probability $f(t_0 + \gamma|\theta)$
3. This is followed by oculomotor delay, ρ
4. At $t_0 + \gamma + \rho$, current look ends and next is immediately initiated

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

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



Simulation (N = 300)



	Aggregate	Saccade	Underlying
MISE	5.04	1.77	0.00

Ok, so where from here?

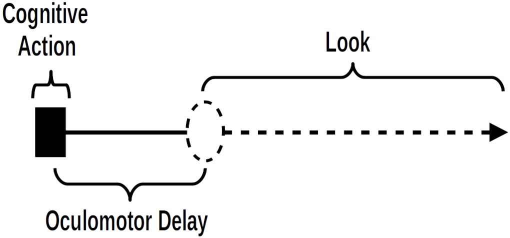
- bdots
- Simulation for eyetracking/physiology
- Extending the model (number of saccades, search patterns, etc.,)
- Oculomotor delay

Oculomotor delay

Though we talk about saccades and fixations, what we are *actually* interested in is this latent cognitive mechanism

It happens in our head first and then our eyes move. This delay, typically around 200ms, is random, and can bias our estimates

We will call the length of an oculomotor delay $\rho(t)$



Oculomotor delay, cont.

A saccade observed at time t_j is likely a sample from the activation curve f_θ at some point prior to t_j. We might then consider our saccades to be

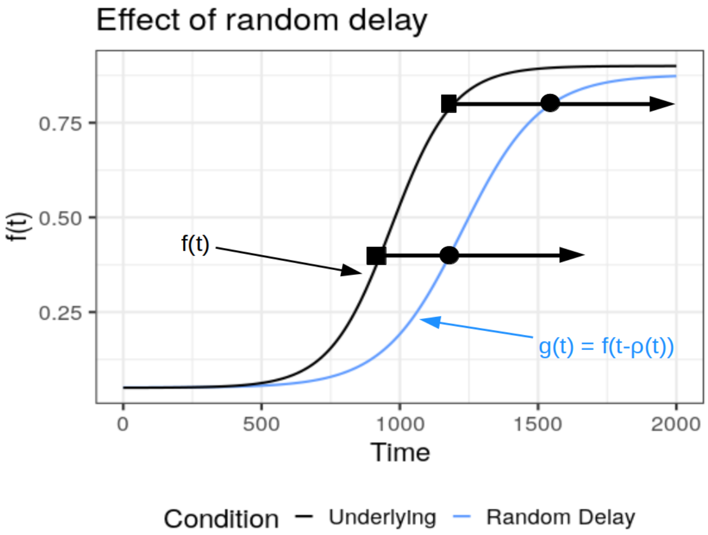
$$s_j \sim Bern[f_\theta(t_j - \rho(t_j))],$$

where $\rho(t)$ represents our oculomotor delay. It may be the case that:

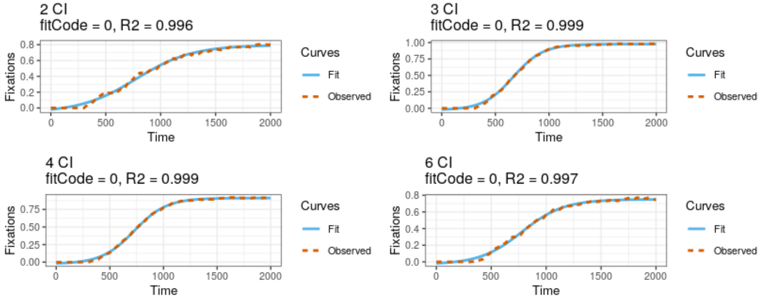
1. $\rho(t)$ is a constant function (including 0)
2. $\rho(t)$ is a random variable, independent on the value of t
3. $\rho(t)$ is a random variable, dependent on t and possibly other aspects of the trial

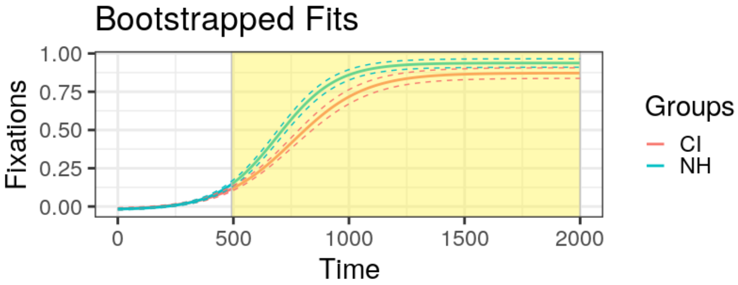
For clarity, then, we might call $f_\theta(t)$ the (latent) activation curve, with $g_\theta(t) = f_\theta(t - \rho(t))$ our (observed) saccade curve

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
- Saccade 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 eyetracking 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 **Fixation Curves in the Visual World Paradigm** 2020(?)

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