**INTRODUCTION**

**Goal:** To model fixation patterns and individual differences in the Visual World using a simple function with links to cognitive processing: time-delayed gamma functions sensitive to parser state (a function drawn from models of BOLD responses).

**Previous VWP models:** TRACE [1, 2], SRNs [3], dynamical systems [4], HMMs [5], and Growth Curve Analysis [6], against which we compare our model.

**Proposal:** Model time-evolving patterns for multiple objects using a time-delayed unimodal continuous function (e.g., gamma).

1. Processing of each syntactic region of interest ‘activates’ one object
2. Each region described by a gamma distribution; probabilities derived by normalization
3. Log likelihood is the (log) probability of the model as applied to individual trial data

**VISUAL WORLD PARADIGM DATA** (ATKINSON ET AL., 2013)

**Display:** The subject & 2 events, each with an associated object & instrument

**Critical items:** Temporarily ambiguous wh-questions following a story

1. (1) Can you tell me what Emily was eating during the cake?

**Predicted Eye Movements**

Anticipatory fixations on the relevant object during the verb region

- Presence of a verb predicts compatible object [7]; presence of a *wh*-filler predicts earliest possible integration location (active gap-filling [8-11])

Anticipatory fixations on the relevant instrument during the object / preposition region

Fixation on associated picture as referent is processed

**RESULTS**

<table>
<thead>
<tr>
<th>Method</th>
<th># of Parameters</th>
<th>Log Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma Model: 1000 samples</td>
<td>13</td>
<td>-19536.6 ± 2.6 (mean ± SD)</td>
</tr>
<tr>
<td>Growth Curve Analysis: quartic polynomials</td>
<td>29</td>
<td>-21494.2 (optimum)</td>
</tr>
<tr>
<td>Hierarchical Gamma Model: 1000 samples</td>
<td>13/participant + 15 hyperparameters</td>
<td>-17870.5 ± 17.8 (mean ± SD)</td>
</tr>
</tbody>
</table>

**INTERPRETATION & DISCUSSION**

**Gamma Model**

Syntactic regions of interest are used to predict fixations. Fixations during each region are modeled by region and by time bin (30ms) with the following gamma function (inspired by models of hemodynamic brain responses [12]):

\[ p(t) = \begin{cases} \frac{(t - (T_d + T_a))^{\alpha - 1}}{\Gamma(\alpha - 1)} \cdot \frac{e^{-(t - (T_d + T_a))}}{\lambda} & \text{for } t > (T_d + T_a) \\ 0 & \text{for } t \leq (T_d + T_a) \end{cases} \]

- \( \alpha \) = amplitude; \( n \) = shape of gamma; \( \lambda \) = rate of gamma
- \( T_d \) = onset of syntactic region, constants determined by model
- \( T_a \) = lag between word onset & behavioral response, set to 180ms

- represents time to plan & execute saccades [13]

**Distributions that activate the same item are summed.**

**Normalisation**

By-region values were converted to probabilities by bin using the Luce choice rule with a temperature parameter [14].

**Log Likelihood**

Probabilities applied to individual trial data according to the multinomial distribution. Parameters were sampled 1000 times with rStan [15].

**Hierarchical Model: Individual Differences**

Gamma parameters & temperature vary by participants (N = 27, 5 trials each)

\( \lambda_i \sim N(\mu_{\lambda}, \sigma_{\lambda}) \) for participant / & region / for region / for all regions

- Similar design for other gamma parameters

**Amplitude: Subject**

Log Mean & 95% HPD Interval by Subject

**Amplitude: Gap Prediction at Verb**

Log Mean & 95% HPD Interval by Subject

- Differences in **amplitude** in the **verb region** indicate varying degrees of active-gap filling (i.e., prediction of an object gap) OR action (i.e., fixation) based on that prediction.
- Differences in **amplitude** in the **subject region** indicate amount of interest in the subject as it is named.
- Comparison: subjects do not necessarily have consistent amplitudes across regions; (R² = 0.3, p > 0.1)

**REFERENCES**


