# Markov-Switching Models of Trial-level Pupil Dilation Time Courses



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### Introduction

- Pupil dilation indirectly reflects cognitive processing<sup>1</sup>
- Pupil deconvolution aims to recover cognitive events underlying the pupil dilation time course<sup>2-5</sup>
- Conventional deconvolution approaches<sup>2-5</sup> neglect trial and event-level variability in event onset and response
- To address this, we estimate event responses and perform the **deconvolution on the trial-level**

## **Conventional Deconvolution**

### Semi-Markov-Switching Pupil Models

Generalized Additive Mixed Models

Hidden semi-Markov Models

#### **Combining HsMMs and GAMMs to Perform Trial-level Deconvolution**





Cognitive events elicit a delayed pupil response. The sum of responses reflects the average observed time course.

### **Problems**

- Gamma Erlang functions<sup>2</sup> for all event responses
- Responses are constrained to be positive<sup>2-5</sup>, **negative dilation** values are modeled via drift<sup>3-4</sup> or offset<sup>5</sup>
- Events are recovered from average dilation time courses, neglecting **trial-level variability** in event onset<sup>2-5</sup>
- Gamma distributions
- experimental conditions
- per experimental condition

### **Preliminary Results**

#### **Testing sMs IR GAMMs via Lexical Decisions**



- 125 pseudo-words, 125 random strings, 250 words
- Google result count<sup>8</sup> was used as frequency measure for all stimuli

Frequency Effect on Response Times Random Strings Pseudo-words me) Words 9 15 20 10 Log(Google Frequency)

What can Trial-level Pupil Deconvolution reveal about the processing stages involved in LDs and the effect of **frequency** on these stages?

### Six Processing Stages are involved in LDs for Words and Non-words



**Early and late processing stages** are similar in duration for all word types. Visible duration differences between word types can only be observed in the **fourth stage**!

### Frequency and Word Type Effects on RTs are reflected in Stage Four



- Model appears to allocate first pupil response to stimulus onset on most trials • First robust word type and frequency interaction visible in stage 3 (< 200 ms)
- Stage four shows the most pronounced effects of word type and frequency
- The pattern in stage six is qualitatively quite similar to stage four

#### References

[1] Hess & Polt, "Pupil Size in Relation to Mental Activity during Simple Problem-Solving.", Science, 1964 [2] Hoeks & Levelt, "Pupillary dilation as a measure of attention: A quantitative system analysis.", Behav. res. meth. instrum. comput. [3] Wierda et al., "Pupil dilation deconvolution reveals the dynamics of attention at high temporal resolution.", PNAS, 2012

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### Discussion

- Model fit is not great, more complex random effects could help
- However, model seems to recover **plausible** processing stages
- Typical frequency and word type effects appear to originate mainly from the fourth stage ( $\sim$ 250 ms), so maybe this stage reflects a decision process?<sup>9-10</sup>

![](_page_0_Picture_44.jpeg)

penalty<sup>7</sup>