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Bayesian modeling of lexical knowledge in BRAID, a visual word recognition model

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1st Bayesian model of word knowledge acquisition

Context

Only a few computational studies (Ziegler et al., 2014; Pritchard et al., 2018) have implemented models of how children acquire lexical orthographic knowledge. These models implement the Self-Teaching hypothesis (Share, 1995, 1999, 2004), thus postulating that orthographic learning primarily relies on successful phonological decoding.

Evidence that visual information is gradually acquired during implicit orthographic learning (Joseph et al., 2014, 2018) and that visual attention span is related to orthographic knowledge acquisition (Ginestet et al., submitted) suggests that visual and attentional processing may further contribute to orthographic learning.

We extend BRAID, a Bayesian model of word recognition (Phénix et al., submitted; Ginestet et al., 2019), into BRAID-Learn, that models how new orthographic knowledge is acquired. Its main assumption is that visuo-attentional parameters are controlled so as to maximize the accumulation of information about letters of the stimulus.

Our simulations suggest that visual-attention processing is critical to acquire new orthographic knowledge.

The BRAID-Learn model: an extension of the BRAID model for orthographic learning

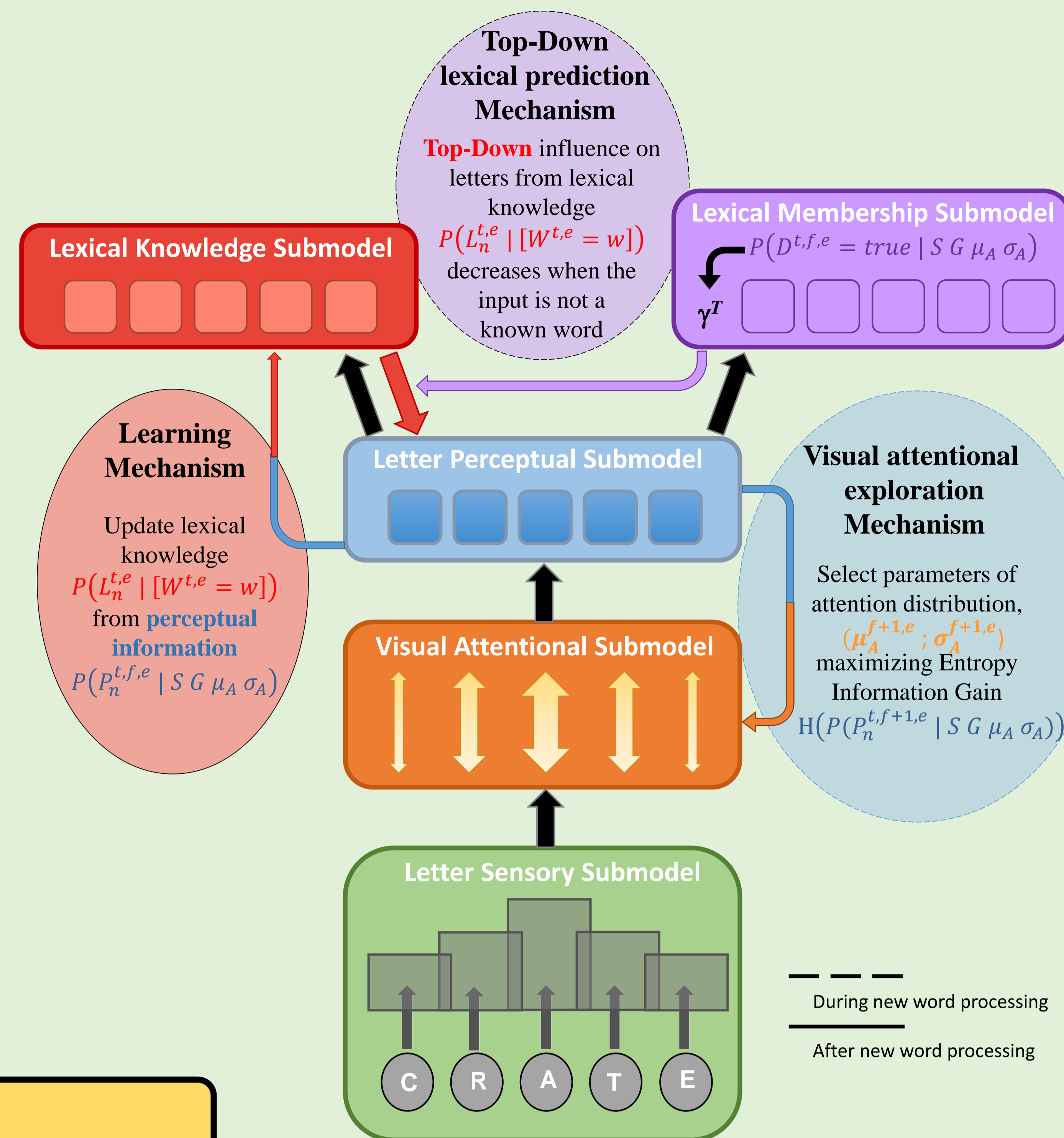
BRAID is a hierarchical probabilistic model of visual word recognition composed of 5 sub-models represented by colored rectangles on the Figure.

Hypothesis

LEARNING = efficient accumulation of perceptual information in $P(P_n^{t,e} | S G \mu_A \sigma_A)$

To model orthographic learning, we assume that:

- Visual attention and gaze displacements are chosen to optimize the accumulation of perceptual information about letters, so as to construct a new orthographic memory trace
- Perceptual representation results from bottom-up (sensory processing) and top-down (lexical prediction) influence
- Word familiarity modulates the amount of top-down lexical influence (e.g., for non-words, lexical prediction is irrelevant and should be suppressed)



Three mechanisms to model visuo-attentional exploration and learning

Top-Down Word Knowledge Influence

Knowledge about word letters influences perceptual traces $P(P_n^{t,e} | S G \mu_A \sigma_A)$. This influence is modulated by the probability that the stimulus presented is a known word or not (i.e., word familiarity).

Visual Attention and Gaze Displacements

Visual attention parameters are controlled so as to efficiently build perceptual traces. This is modeled by selecting the attentional parameter (μ_A ; σ_A) values that maximize a Total Gain (TG) measure (assuming gaze position G coincides with attentional focus position μ_A). TG characterizes the information gain obtained during each attentional focus (measured as the expected entropy gain), modulated by an estimate of the motor cost of the upcoming attentional displacement:

$$Total\ Gain = (1 - \alpha) \times Entropy\ Gain - \alpha \times Motor\ Cost$$

Acquiring orthographic traces for new words

In the model, word knowledge is represented by probability distributions about letters, $P(L_n^{t,e} | [W^{t,e} = w])$. Orthographic representation is learned and updated after each exposure, by integrating the current perceptual trace $P(P_n^{t,e+1} | S G \mu_A \sigma_A)$.

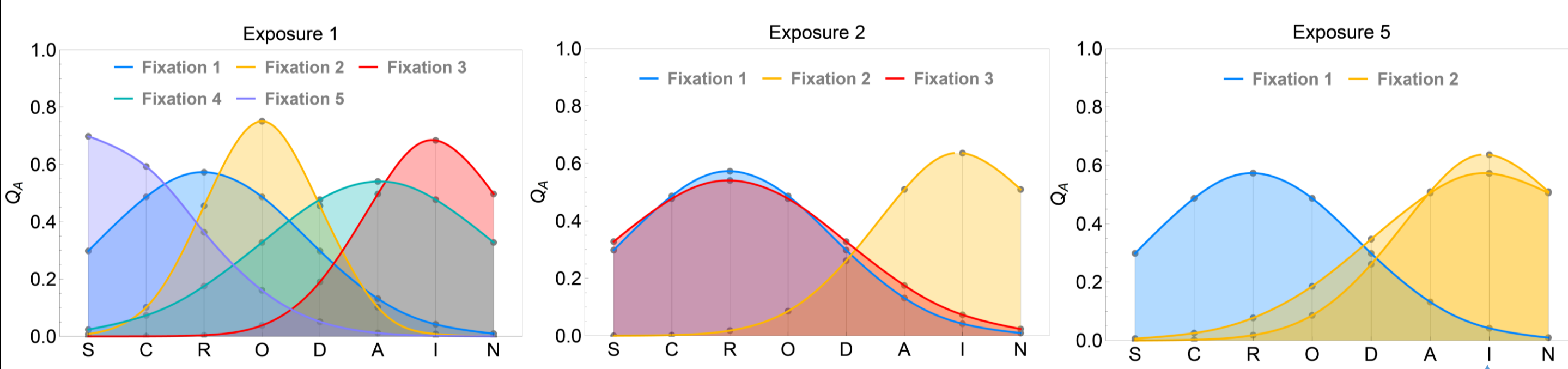
$$P(L_n^{t,e+1} | [W^{t,e+1} = w]) = \frac{P(L_n^{t,e} | [W^{t,e} = w]) \times e + P(P_n^{t,e+1} | S G \mu_A \sigma_A)}{e + 1}$$

Prediction: Controlling visuo-attentional parameters to maximize information gain predicts human oculomotor behavior during (implicit) orthographic learning

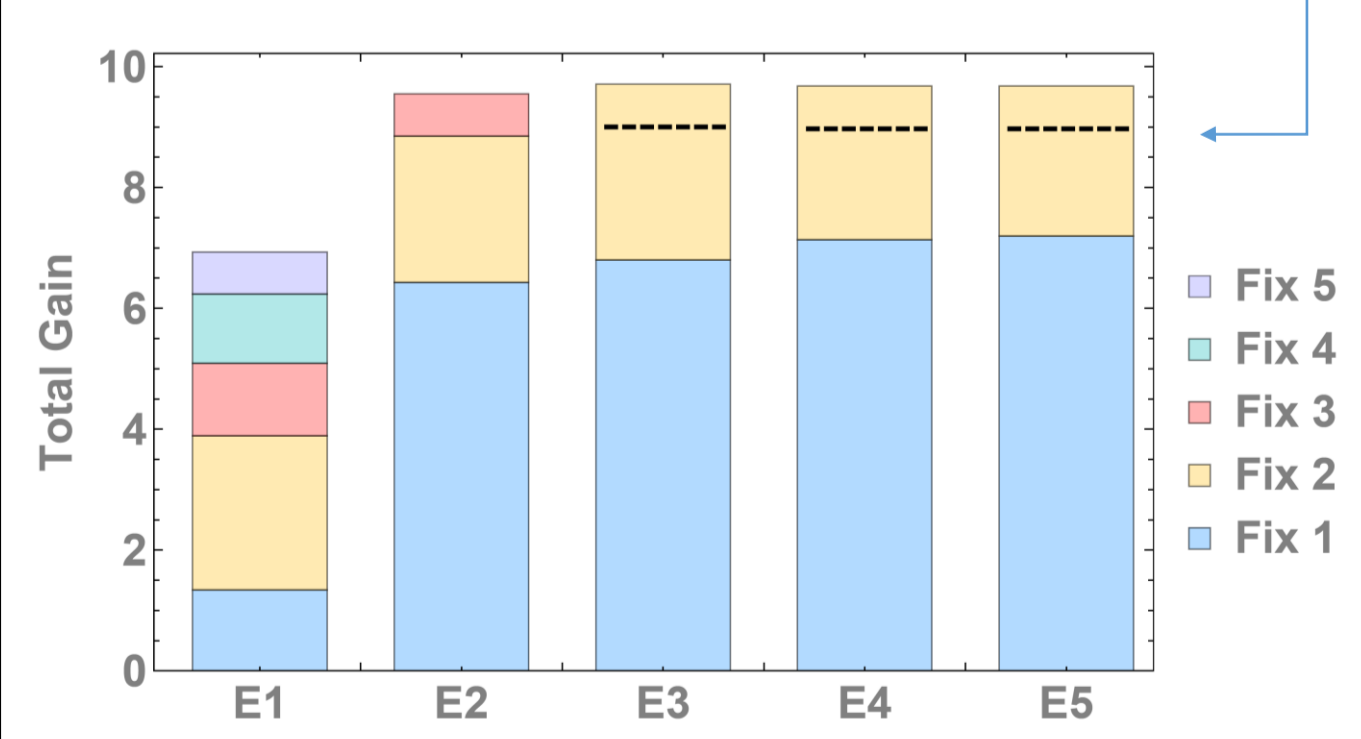
Simulation Results and Comparison with Behavioral Data

Total Gain, Attention and Gaze Displacements over exposures

Illustration of the learning process for the French pseudo-word "SCRODAIN" presented 5 times to the model.



Consecutive fixations at the same position are merged for analyses



Simulation results:

- Fixation number rapidly decreases over exposures
- Total Gain decreases during a single exposure
- Total Gain drastically increases for the first fixation between the 1st and the 2nd exposure (top-down effect)

Oculomotor measures during implicit learning:

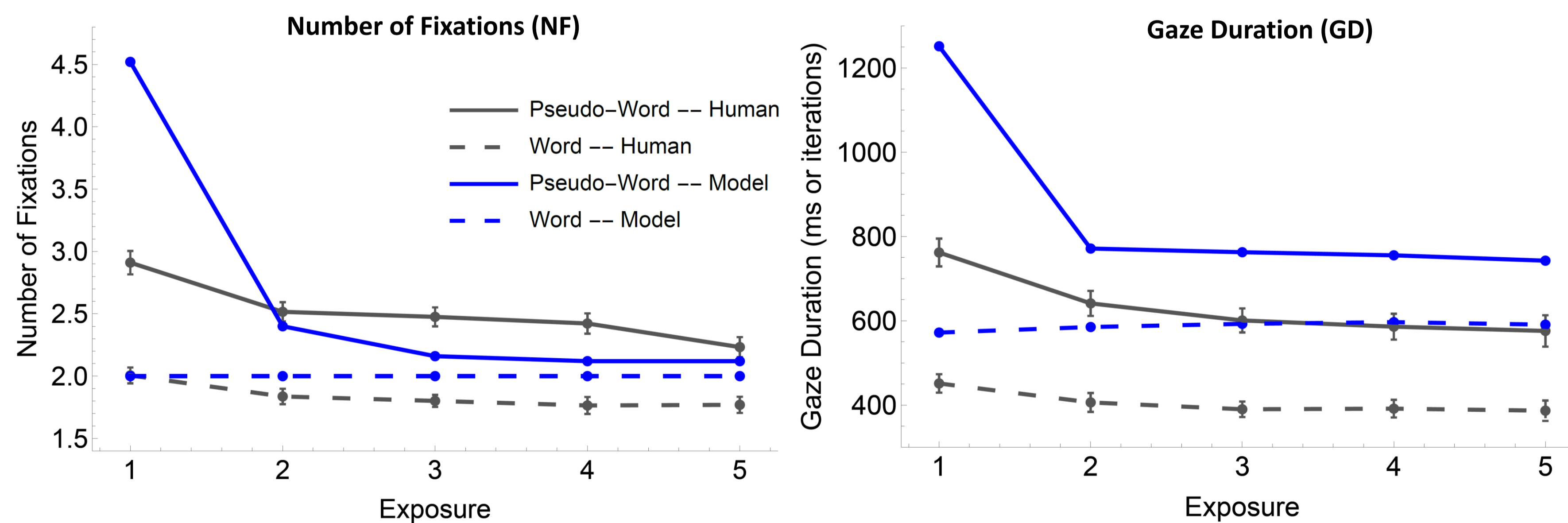
Model Simulation vs.

Behavioral data (Ginestet, Valdois, Diard & Bosse, sub.)

Material: Thirty "hermit" Pseudo-Words ($N_{avg} = 0$) of 8 letters, containing at least 2 ambiguous graphemes. All are orthographically legal in French.

Method: Participants had to read aloud the PW then the number displayed on the screen. PWs were presented 1, 3 or 5 times. We simulated the learning of the same 30 PWs using BRAID-Learn.

Results:



Summary and Discussion

✓ The BRAID-Learn model successfully performs novel word orthographic learning.

The learning mechanism optimizes the accumulation of perceptual information over time. As a result, more attentional shifts --thus fixations-- are required at the first encounter with the novel word. After a few exposures, the orthographic trace of the new word complements sensory decoding, which results in faster processing of the new word.

✓ The BRAID-Learn model qualitatively captures behavioral patterns of visuo-attentional behavior during implicit learning.

Visual attention is critical for novel word orthographic learning.

BRAID-Learn: a single framework that accounts for word recognition, orthographic learning and eye-movements during single word processing.

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