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

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1st Bayesian model of word knowledge acquisition → Model selects attentional and gaze displacements that maximize information gain, then updates word orthographic knowledge → Simulation results and comparison with behavioral data

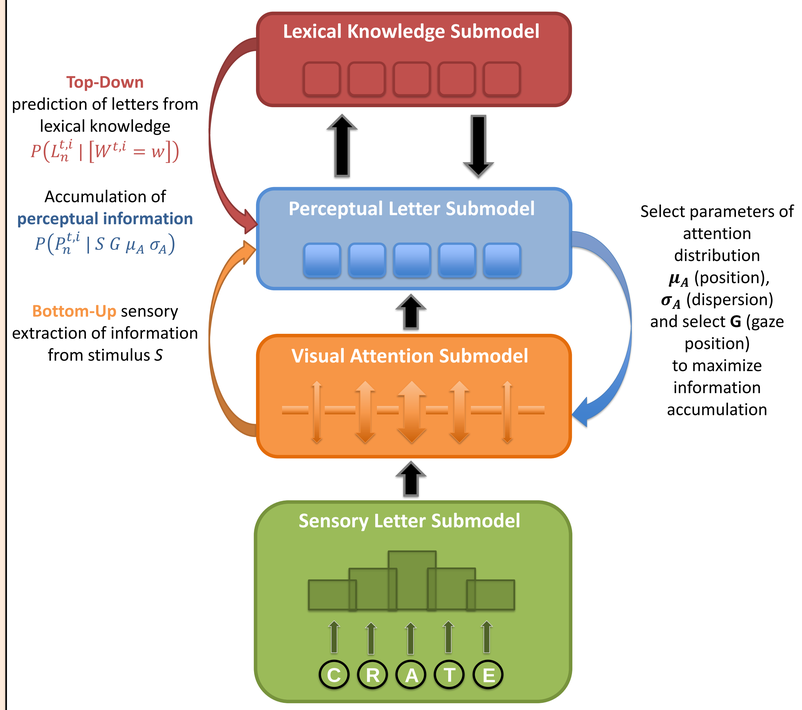
Context

Modeling word orthographic knowledge acquisition is one of the main current challenges. While many computational models simulate reading, word recognition, phonological transcoding or eye movement control in text reading, only one computational study (Ziegler, Perry, & Zorzi, 2014) has attempted to model the acquisition of word orthographic knowledge in children by proposing a dedicated model based on the Self-Teaching hypothesis (Share, 1995, 1999, 2004). This model postulates a fundamental role of phonological processing in the acquisition of word orthographic knowledge.

Our team has recently developed **BRAID, a new Bayesian model of word recognition** ("Bayesian word Recognition with Attention, Interference and Dynamics"), to simulate the performance of expert readers (Phénix, Valdois, & Diard, submitted; Ginestet, Phénix, Diard, & Valdois, submitted). **Here, we propose an extension of BRAID by implementing a mechanism for the acquisition of new orthographic knowledge** based on predictive calculations of visual-attention parameters.

Extension of the BRAID model for orthographic learning

BRAID is a hierarchical probabilistic model of visual word recognition composed of 4 submodels. We introduce a top-down dependency, so that contents of the perceptual letter submodel control the attentional parameters during orthographic learning.



To model orthographic learning, **we assume that visual attention and gaze displacements are chosen to optimize the accumulation of perceptual information** $P(P_n^{t,i} \mid S\ G\ \mu_A\ \sigma_A)$ about letters, so as to construct a new orthographic memory trace.

Goal: accumulate perceptual information efficiently in $P(P_n^{t,i} \mid S\ G\ \mu_A\ \sigma_A)$

Acquiring orthographic traces for new words

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

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

Top-Down word knowledge influence

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

Attentional and gaze displacements

We assume that visual attention parameters are controlled in order to efficiently obtain 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 fixation (measured as the expected entropy gain), modulated by an estimate of the motor cost of the attentional displacement:

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

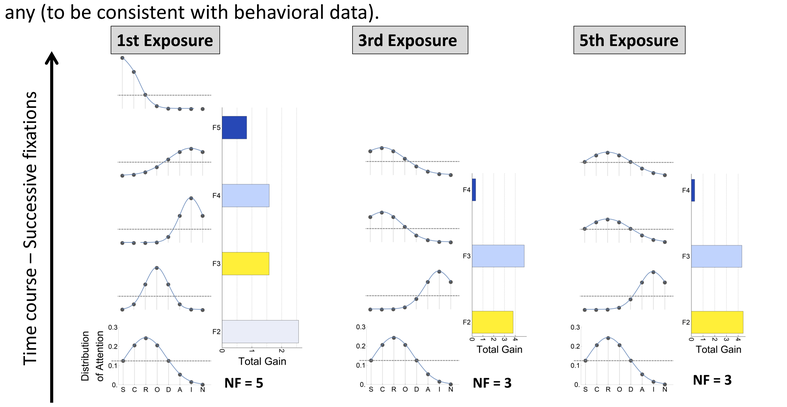
Prediction: Total gain maximization predicts human oculomotor behavior during orthographic (implicit) learning

Summary and discussion

- The BRAID model successfully performs orthographic learning of new words.
- The learning mechanism optimizes the accumulation of perceptual information. As a result, more fixations are required the first time a novel word is processed. After few exposures, word knowledge complements sensory decoding so that parallel processing becomes more efficient.
- Total Gain and the number of attentional fixations rapidly decrease with exposures inducing faster processing of new word, that is comparable to behavioral results.

Total Gain, Attention and Gaze Displacements over exposures

Illustration of learning the French pseudo-word "SCRODAIN" presented 1,3 or 5 times to the model. The position of the first fixation is set to the 3rd letter and fixation durations are set to 310 iterations for the 1st fixation and 230 iterations for the other fixations, if any (to be consistent with behavioral data).

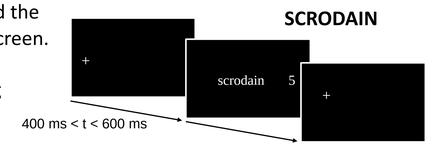


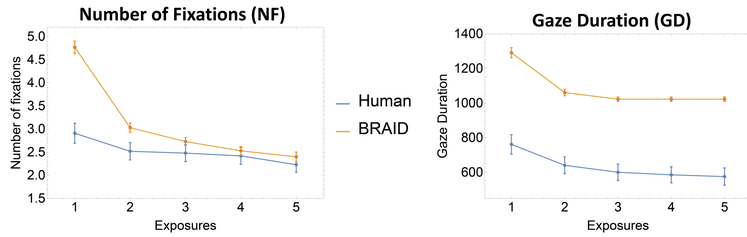
Simulation results: Total Gain decreases during a single exposure and NF rapidly decreases over exposures

Oculomotor measures during implicit learning: Simulated vs. Behavioral

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. The BRAID model simulated the learning of the same 30 PWs.





Result: NF and GD decrease over exposures in simulations as in behavioral data

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