Continuous Developmental Change Can Explain Discontinuities In Word Learning

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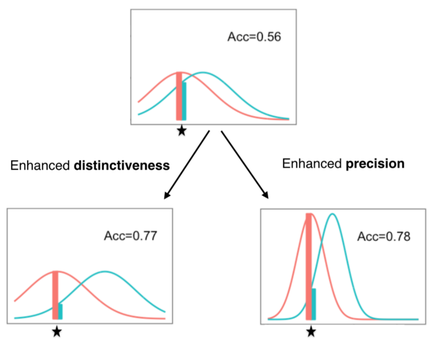
Introduction

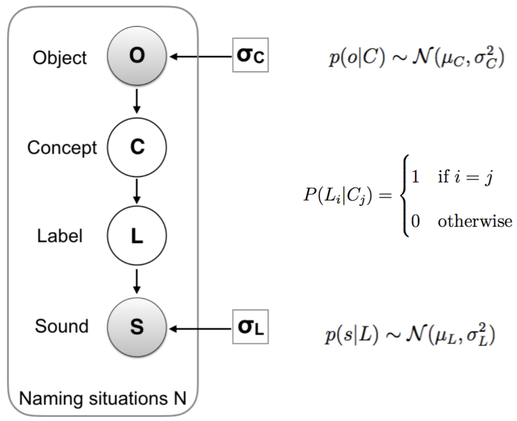
Cognitive development is often characterized in term of discontinuities[1,2], but these discontinuities can sometimes be apparent rather than actual. Computational models can help us understand how discontinuities may arise from continuous developmental change.

Case study in word learning: When and how do children become able to map minimal sound differences ("bin" vs. "din") to different meanings[3]? Early findings suggested a discontinuous developmental change around 17 years old, but later findings indicated that even younger infants show successful learning when the task is simplified or when more cues are available.[4,5,6]

Can a fully continuous model account for the findings? We represent a word as a probability distribution over the perceptual space (here in **red** and **green**). When the uncertainty of the representation is large relative to the distance between the stimuli (top panel), an instance of the red category (indicated with a star) could also be a plausible instance of the green category, hence the low recognition accuracy score. The accuracy increases when the stimuli are less similar (left panel), or when the representation are more precise (right panel)



Cognitive Model



$$p(o|C) \sim \mathcal{N}(\mu_C, \sigma_C^2)$$

$$P(L_i|C_j) = \begin{cases} 1 & \text{if } i = j \\ 0 & \text{otherwise} \end{cases}$$

$$p(s|L) \sim \mathcal{N}(\mu_L, \sigma_L^2)$$

leads to

$$P(o|s) = \frac{\sum_{C,L} P(s|L)P(o|C)P(L|C)}{\sum_o \sum_{C,L} P(s|L)P(o|C)P(L|C)}$$

instantiated as

From simple to complex

Model 1

Word learning is influenced by sound similarity but not by object similarity

σ_L only (one parameter)

$$P(o_T|s) = \frac{1}{1+e^{-\frac{\Delta s^2}{2\sigma_L^2}}}$$

Prediction 1

Model 2

Sound and object similarity influence word leaning equally

$\sigma_L = \sigma_C = \sigma$ (one parameter)

$$P(o_T|s) = \frac{1+e^{-\frac{\Delta s^2+\Delta o^2}{2\sigma^2}}}{1+e^{-\frac{\Delta s^2+\Delta o^2}{2\sigma^2}}+e^{-\frac{\Delta s^2}{2\sigma^2}}+e^{-\frac{\Delta o^2}{2\sigma^2}}}$$

Prediction 2

Model 3

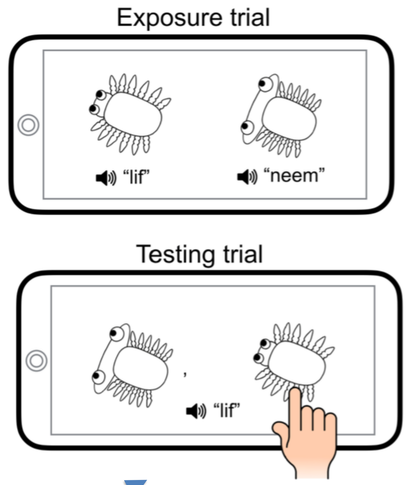
Sound and object similarity influence word leaning differently

$\sigma_L \neq \sigma_C$ (two parameters)

$$P(o_T|s) = \frac{1+e^{-\left(\frac{\Delta s^2}{2\sigma_L^2}+\frac{\Delta o^2}{2\sigma_C^2}\right)}}{1+e^{-\left(\frac{\Delta s^2}{2\sigma_L^2}+\frac{\Delta o^2}{2\sigma_C^2}\right)}+e^{-\frac{\Delta s^2}{2\sigma_L^2}}+e^{-\frac{\Delta o^2}{2\sigma_C^2}}}$$

Prediction 3

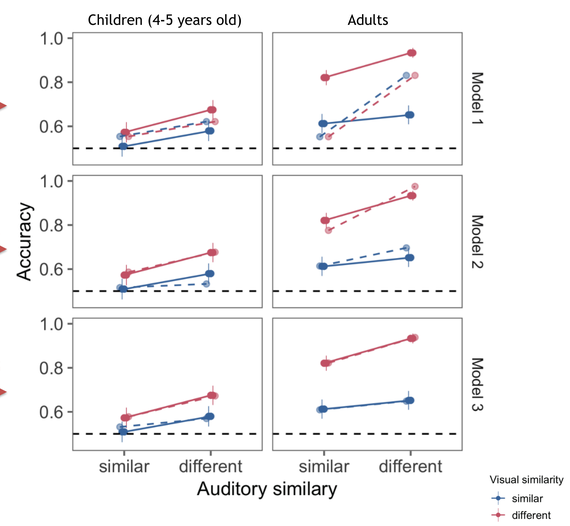
Task



predicts

human data

Results



Findings and conclusions

Developmental changes in word-object mappings can be characterized as a **continuous refinement in the precision of the probabilistic representations**. The model accounted for almost all the variance in both children and adult data even with minimal degrees of freedom.

While most previous research focused on the sound representation in analyzing the task, our work showed that the representation of the referent is equally important. Just like word learning is modulated by the phonological similarity of the form, **it is also modulated by the visual similarity of the semantic referents.**

We used a case from word learning as an example, but the same idea might apply to other aspects of cognitive development that are typically thought of as stage-like (e.g., acquisition of a theory of mind).

Computational models, such as the one proposed here, can help us investigate the extent to which discontinuities emerge due to genuine qualitative changes and the extent to which they reflect the granularity of the researchers' own measurement tools

References

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