Categorization and abstraction in perception

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Today’s goals

Our discussion today will touch on:

- Subcategorical detail in perception
- Acquisition of categories and distributional learning
This is Loki, an expert, probability-matching treat forager. He knew you do better finding treats if you know not just where they are, but how likely it is for a treat to be someplace. Tracking probabilities helps deal with uncertainty (i.e. where are the treats??).
Dealing with uncertainty is arguably a central problem in language processing. Do language users manage uncertainty about linguistic structure in the input like Loki managed uncertainty about treat locations?

- Do we track subcategorical (probabilistic) cues to linguistic categories?
- Do we exploit these cues in processing linguistic input?
- Do learners exploit ‘structured variation’ to discover categories in their experience?
⇒ **Eye-mind hypothesis** (Just & Carpenter, 1980): Eye movements (probabilistically) reflect contents of active attention (cf. Magnuson, 2019). A hypothesis about how cognitive events are related to observable measures is called a *linking hypothesis*. 
⇒ /bɛːɹ/ vs /pɛːɹ/ are (categorically) distinguished by voicing. But are listeners sensitive to subcategorical degree of voicing?
Distribution of VOTs by language

ENGLISH

SPANISH

THAI
Fig. 2. Identification curves (from mouse clicks) pooled across all subjects for the word and BP identification tasks. Shown is the proportion of trials in which the p-item was selected as a function of VOT.
Fig. 3. Mean proportion fixation to the competitor picture as a function of VOT. The left panel displays trials in which the subject responded /b/- (and the competitor was the p-item). The right panel displays trials in which the subject responded /p/- (and the competitor was the b-item). A clear gradient effect of VOT can be seen.
Fig. 7. Effect of VOT and time on fixations to the competitor. A clear gradient effect of VOT can be seen. Importantly, the effect of VOT is primarily on the duration of activation.
Key takeaways

- Lexical competitors activated as a gradient function of VOT: As you approach the category boundary, the activation of the competitor increases.

- Activation of the competitor was not short-lived: Competitors seem to remain active in proportion to their likelihood for upwards of a second after the ambiguous segment.

- McMurray et al’s hypothesis: Subcategorical distinctions are preserved and maintained by listeners to deal with ambiguity / uncertainty. Listeners track what VOTs make a good instance of /p/ or /b/ and exploit this information ‘online’ during language comprehension.

- **Example:** The /dʒ/ent in the fender/woods (Connine, Blasko & Hall, 1991).
Do we track subcategorical (probabilistic) cues to linguistic categories?

Do we exploit these cues in processing linguistic input?

Do learners exploit ‘structured variation’ to discover categories in their experience?
How do learners discover phonetic / phonological categories? Consider the target of acquisition: Languages vary not just in the number and character of phonetic / phonological categories, but also the fine phonetic details of those categories:
The conditioned head turn procedure

What do pre-verbal infants know about phonetic categories? The **conditioned head turn procedure** provides one tool. One standard use: Condition infants to turn their head and look at a ‘reinforcer’ when there is a change in a stream of speech stimuli (Werker et al., 1997).

![Diagram of the Conditioned Head Turn procedure](image_url)

Figure 1. A schematic diagram of the Conditioned Head Turn procedure.
How well can adult English speakers distinguish place of articulation in a /k’/ - /q’/ contrast (e.g. Thompson Salish)? Or in a /t/ - /t/ contrast (e.g. Hindi)?
Werker & Tees (1984)

What about infants?

**Infant Subjects Reaching Criterion on Hindi and Salish Contrasts**

<table>
<thead>
<tr>
<th>PERCENT</th>
<th>6-8 months</th>
<th>8-10 months</th>
<th>10-12 months</th>
<th>11-12 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hindi /tə/ vs /sə/</td>
<td>[Graph Data]</td>
<td>[Graph Data]</td>
<td>[Graph Data]</td>
<td>[Graph Data]</td>
</tr>
<tr>
<td>Salish /kɪ/ vs /qɪ/</td>
<td>[Graph Data]</td>
<td>[Graph Data]</td>
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</tr>
</tbody>
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**Cross-Sectional Data**

**Longitudinal Data**
Habituation paradigm

- Orient infant to visual display; play stimulus until looking time drops to pre-determined threshold (e.g. they ‘get bored’.
- At habituation, continue play same stimulus on same trials, or change stimulus on change trials.
- If infants detect a change, they will dishabituate and look more at the display. Increase in looking times for change trials compared to same trial baseline indicates discrimination.
Figure 4  English-hearing infants’ (at 4–5 months) looking time to same vs. change trials for the native [ma]–[na] and non-native [na]–[ŋa] contrasts. Error bars represent standard error.
Do learners exploit ‘structured variation’ to discover categories in their experience?

**Distributional learning:** A hypothesized learning procedure that leverages structured variation in the input to ‘infer’ the latent structure of the input. Common examples:

- The number of ‘peaks’ in a VOT distribution may signal number of voicing categories.
- Dips in transitional probability between syllables in a word may signal a word or morpheme boundary.
Table 1
Mean (SE) looking times for infants in each age group and familiarization condition on Alternating and Non-Alternating trials

<table>
<thead>
<tr>
<th></th>
<th>Alternating trials (s)</th>
<th>Non-Alternating trials (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 months Unimodal</td>
<td>4.85 (0.47)</td>
<td>4.53 (0.51)</td>
</tr>
<tr>
<td>8 months Unimodal</td>
<td>4.98 (0.63)</td>
<td>5.20 (0.56)</td>
</tr>
<tr>
<td>6 months Bimodal</td>
<td>5.66 (0.44)</td>
<td>6.41 (0.32)</td>
</tr>
<tr>
<td>8 months Bimodal</td>
<td>5.45 (0.52)</td>
<td>6.15 (0.56)</td>
</tr>
</tbody>
</table>

Novelty preference
Listeners recover abstract linguistic categories during perception...
... but are sensitive to, and maintain information about, subcategorical or probabilistic cues to those categories.
The distributional structure of the input may also be used by learners to detect hidden structure.