18-month-olds compensate for a phonological alternation

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Context-dependent variation

• In word recognition, listeners are sensitive to phonetic detail\(^1,2\)
  • Sensitive to *degree* of mismatch between surface form and lexical representation\(^2\)

• However, some phonetic variation must be ignored in the process of word learning.
  • *Context-dependent phonological variation*

\(^{1}\text{e.g. [1] Swingley, 2009, [2] White & Morgan, 2008}\)
Tapping in American English

• Word-final /t/s and /d/s can surface phonetically as a tap (or flap), [ɾ]

• Most commonly occurs when the following word begins with an unstressed vowel e.g. again or in
  
  • E.g. bat again → [bæɾ#əɡɛn]

• Results in many-to-one mapping between legal surface forms and underlying lexical items - context-dependent, predictable
Previous work on phonological variation

• Voicing assimilation in French:\(^6\)
  • e.g. /bys dəvã/ → [byz dəvã]  \(bus\, devant\)
  • 2 year-old French-learning toddlers successfully compensate for native voicing assimilation in a preferential looking task with training
  • Also sensitive to context in which this process occurs

• But: 12 month-olds already successfully map surface \([r]\) to underlying /d/ in a segmentation study: \(padding\ → pad\)?

• Perhaps this ability is in place at an earlier age than 2 years?

Experiment Overview

• Do 18-month-old toddlers recognize familiar words produced with a surface tap in a word recognition task?

• Intermodal Preferential Looking Experiment[^8]
• Implemented using eye-tracking – SR Eyelink 1000 (Arm-mount)

• Experiment 1: Adults
• Experiment 2: 18-month-old toddlers

[^8]: Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987
Why 18 month-olds?

• Toddlers at 18-months of age can detect mispronunciations in coda position\(^1\)

• Toddlers at this age are also sensitive to the degree of mismatch between mispronunciations and target lexical representations:
  • In onsets\(^2\)
  • In codas\(^{10}\)

∴ 18 month-olds are sensitive to phonetic detail in coda position during word recognition

Visual set-up
(following White & Morgan, 2008)
General procedure

• Baseline Phase (4s)
  - Pair of images shown
  - No audio stimulus
  - Establish baseline preferences
    ↓
    Re-centered

• Test Phase
  - Same pair of images
  - Same location
  - Simultaneous presentation of audio
Target words

• Target words:
  • 6 /t/-final words: bat, cat, foot, plate, hat, boat
  • 6 /d/-final words: bed, slide, food, cloud, bread, bird
  • All picture-able words known by 18 month-old toddlers
  • 4 Non-words: lif, neem, bize, dape

• No target word is repeated twice in stop and tap condition: only 3 target words in each condition.

• Only half of the target words appeared in MP condition in each expt. group

• Words are embedded sentence-medially – an environment that makes processing difficult

Audio stimuli

- Recorded by phonetically-trained female native speaker of American English – IDS

- Recorded in two sentence frames:
  1. *Look for the X Sam lost!* (Expt. 1) or *Look for the X now!* (Expt. 2)
     - Context that favors stop production (= Stop condition)
  2. *Look for the X again!*
     - Context that favors tap production (= Tap condition)

- Stop and tap variants only presented in the frame that supports the alternation

- Mispronunciations (MP) and novel items were produced in both frames
Experiment 1: Adults

• 32 subjects (recruited from UCLA Psych Subject Pool)

• Native speakers of American English

• Trials were excluded if baseline fixation proportions < 10% or > 90%
  • Subjects excluded if more than half of their trials were not useable (n = 3)
Analysis I: Stop vs. Novel

• Difference score: %Test - %Baseline

• Baseline: Measured proportion of looks to target in 4 s phase

• Stop vs. Novel: Measured proportion of looks to target in a 2 second window from the start of the target word
Exp. 1: Results – Stop vs. Novel
Analysis II:
Stop vs. Tap vs. MP

- **Stop vs. Tap vs. MP**: Measured proportion of looks to target in a 2 second window from the **coda** of the target word
Exp. 1: Results – Stop, Tap and MP

![Graph showing difference scores for Stop, Tap, and Mispron conditions.](image)

- **Stop**: Blue bars with error bars indicating the difference score.
- **Tap**: Grey bars with error bars indicating the difference score.
- **Mispron**: Black bars with error bars indicating the difference score.

### Conditions
- **Condition**
  - Stop
  - Tap
  - Mispron

### Results
- **Stop**: ***
- **Tap**: n.s.
- **Mispron**: ***

### Statistical Significance

<table>
<thead>
<tr>
<th>Condition</th>
<th>Test</th>
<th>Baseline</th>
<th>Difference Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tap</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mispron</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Interim summary

• Adults recognize words equally well with stop and tap variants

• Adults accept mispronunciations as labels for target objects,
  • Not to the same degree as for stop and tap variants

• Gives us a baseline from which to compare the 18-month-olds
Experiment 2: 18 mo. Toddlers

- 38 English-learning toddlers (mean age: 18.2; range: 17.6: 20.2)

- Only included trials in which words were familiar to the child
  - Post-hoc questionnaire

- Trials were excluded if baseline fixation proportions < 10% or > 90%
  - Subjects excluded if more than half of their trials were not useable (n = 8)
Predictions from adult data

• Stop vs. Novel:
  • Look *more* to the target in **Stop condition** than **Novel condition**

• Stop vs. Tap vs. MP
  • Look *more* to the target in **Stop condition** than in **MP condition**
  • Look *more* to the target in **Tap condition** than in **MP condition**
  • Look *equally* to target in both **Stop** and **Tap conditions**
Exp. 2: Results – Stop vs. Novel

<table>
<thead>
<tr>
<th>Difference Score</th>
<th>%Test-%Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop</td>
<td>0.2</td>
</tr>
<tr>
<td>Novel</td>
<td>-0.1</td>
</tr>
</tbody>
</table>

Condition: Stop

Condition: Novel

* Significant difference
Exp. 2: Results – Stop, Tap and MP

Difference Score: %Test − %Baseline

-0.2
-0.1
0.0
0.1
0.2

Stop
Tap
Mispron.

Condition

n.s. $p = 0.18$
$p = 0.08$

$p = 0.18$

$p = 0.08$

n.s.
Effects of vocabulary?

• Why poor performance on stop trials (correct pronunciation)?

• This may be due to the sentence medial, pre-consonantal context
  • Cues to the segment might be obscured (e.g. weaker stop burst)

• Is the poor performance on stop trials attributable to a subset of the participants?

• Median split of production raw scores (CDI)
Exp. 2: Results – low CDI (Raw)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Stop</th>
<th>Tap</th>
<th>Mispron.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference Score: %Test−%Baseline</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>−0.1</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n = 19
Exp. 2: Results – high CDI (Raw)

Condition Difference Score: %Test − %Baseline

Stop Tap Mispron.

Exp. 2: Results

- CDI (Raw) Exp. 2

Results

- high

CDI (Raw)

- n.s.

- * p = 0.07

n = 19

Condition

Stop Tap Mispron.

Graph showing difference scores for Stop, Tap, and Mispronunciation conditions.
Exp. 2 Discussion

• Suggestive pattern: Tap > MP; Stop > MP
  • But only with toddlers with a high production score

• Tap = stop
  • 18 month-old toddlers are able to compensate online for tap variants

• Earlier than has been shown for voicing assimilation in French (Skoruppa et al., 2013a; Skoruppa et al., 2013b)

• 18 month-olds successfully detect mispronunciations in sentence-medial position (without training)
Conclusions

• Adults treat stop and tap variants for words equivalently.

• Strongly suggestive evidence that 18 month-olds have learned to compensate for tap variants of both /t/ and /d/ words as well.
  • Treat both stop and tap variants equivalently
  • Caveat: Only with toddlers with higher raw production CDI scores

• Future work:
  • How important is phonological context?
  • Is it item-specific? Can they generalize to novel words?
  • Continue testing
Acknowledgements

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  • Anya Mancillas

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• Henry Tehrani and Bryan Nguyen for technical assistance
Thank you!
References


## CDI Frequencies

<table>
<thead>
<tr>
<th>Target word</th>
<th>CDI comprehension freq. 16 months (%)</th>
<th>CDI production freq. 18 months (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[t]-words</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>hat</td>
<td>53.7</td>
</tr>
<tr>
<td>2</td>
<td>cat</td>
<td>51.2</td>
</tr>
<tr>
<td>3</td>
<td>boat</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>foot</td>
<td>41.2</td>
</tr>
<tr>
<td>5</td>
<td>bat</td>
<td>17.5</td>
</tr>
<tr>
<td>6</td>
<td>plate</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td>[d]-words</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>bird</td>
<td>67.5</td>
</tr>
<tr>
<td>2</td>
<td>bed</td>
<td>28.8</td>
</tr>
<tr>
<td>3</td>
<td>bread</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>food</td>
<td>16.3</td>
</tr>
<tr>
<td>5</td>
<td>cloud</td>
<td>12.5</td>
</tr>
<tr>
<td>6</td>
<td>slide</td>
<td>12.5</td>
</tr>
</tbody>
</table>

Comprehension frequency of target [t]- and [d]-words for 16-month-olds and production frequency for 18-month-olds.
# Mispronunciations

<table>
<thead>
<tr>
<th>/t/-words</th>
<th>/d/-words</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct Pron.</td>
<td>Mispronunciation</td>
</tr>
</tbody>
</table>
Closure duration

Closure duration

Duration (ms)

Frequency

0 1 2 3 4

0 20 40 60 80 100 120

Tap
Stop
# Vowel duration

<table>
<thead>
<tr>
<th></th>
<th>Tap</th>
<th>Stop</th>
<th></th>
<th>Tap</th>
<th>Stop</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>bat</strong></td>
<td>214</td>
<td>223</td>
<td><strong>bed</strong></td>
<td>128</td>
<td>203</td>
</tr>
<tr>
<td><strong>boat</strong></td>
<td>179</td>
<td>237</td>
<td><strong>bird</strong></td>
<td>229</td>
<td>389</td>
</tr>
<tr>
<td><strong>cat</strong></td>
<td>162</td>
<td>176</td>
<td><strong>bread</strong></td>
<td>192</td>
<td>311</td>
</tr>
<tr>
<td><strong>foot</strong></td>
<td>96</td>
<td>126</td>
<td><strong>cloud</strong></td>
<td>271</td>
<td>373</td>
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<tr>
<td><strong>hat</strong></td>
<td>137</td>
<td>202</td>
<td><strong>food</strong></td>
<td>158</td>
<td>297</td>
</tr>
<tr>
<td><strong>plate</strong></td>
<td>179</td>
<td>225</td>
<td><strong>slide</strong></td>
<td>225</td>
<td>274</td>
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<tr>
<td><strong>Mean</strong></td>
<td><strong>161</strong></td>
<td><strong>198</strong></td>
<td><strong>Mean</strong></td>
<td><strong>200</strong></td>
<td><strong>308</strong></td>
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