BIASED LEARNING OF PHONOLOGICAL ALTERNATIONS BY 12-MONTH-OLD INFANTS
James White & Megha Sundara
PHONOLOGICAL ALTERNATIONS

- **Phonological alternation**: phonemes have variant surface forms depending on context.
  - American English: *pat* [pæt] \(\sim\) *patting* [pætn]

- Infants must learn the alternations of their native language during the language acquisition process.

- We know that they are at least able to do so by 12 months of age.¹

- **How do they learn these alternations?**

¹. White et al., 2008
BACKGROUND

- We still know little about **how** infants learn phonological alternations.

- We know that **statistical learning** is a powerful tool for the infant during the first year of life, used for:
  - Discriminating speech sounds
  - Phonotactic learning
  - Word segmentation
  - Presumably phonological alternations??

1. Maye et al., 2002; Anderson et al., 2003
2. Chambers et al., 2003
3. Saffran et al., 2006
BACKGROUND

Is statistical learning the only component?
- Are infants just looking for complementary distributions?

Unlikely:
- [h] and [ŋ] happen to be in perfect complementary distribution in English.
- But we probably don’t want to say they are alternating variants of the same category.¹

Is this learning constrained in some way?

¹. see Peperkamp et al., 2006 for similar examples
BACKGROUND

- Previous work has shown that phonological learning is constrained by biases:
  - People find some patterns harder to learn (or less plausible) than others.\(^1\)
  - Sometimes people make assumptions during learning that extend beyond what is available in their input.\(^2\)

- Most of the work on biases in phonological learning has been conducted with adults.
  - We still know relatively little about biases in infant phonological learning.\(^3\)

- We need a test case.

1. Moreton, 2008; Hayes et al., 2009; Skoruppa et al., 2011; Hayes & White, in press
2. Wilson, 2006; Finley & Badecker, 2008
**Test Case: Saltatory Alternations**

What is a saltatory alternation?
- Phonological alternation that “jumps over” a non-alternating, intermediate sound.¹
- From Latin *saltus* ‘leap’. Also called “leapfrogging.”²
- Example from Campidanian Sardinian³:
  - $p \rightarrow \beta/ V __$, but $/b/$ remains unchanged

\[
\begin{align*}
[p\text{̄}i] &\rightarrow [s:u \beta\text{̄}i] \quad \text{‘the bread’} \\
[b\text{̄}u] &\rightarrow [s:u b\text{̄}u] \quad \text{‘the wine’}
\end{align*}
\]

- This is a productive process that happens at other places of articulation as well.

---

¹ White, under revision  
² Minkova, 1991  
³ Bolognesi, 1998
Saltatory alternation

- Example from Campidanian Sardinian:
  -\( p \rightarrow \beta/\ V \_\), but /b/ remains unchanged

\[ [p\acute{\text{i}}] \rightarrow [\text{s:u } \beta\acute{\text{i}}] \text{ ‘the bread’} \]
\[ [b\acute{\text{u}}] \rightarrow [\text{s:u } b\acute{\text{u}}] \text{ ‘the wine’} \]

1. Bolognesi, 1998
Saltatory alternation

- Example from Campidanian Sardinian:
  - \( p \rightarrow \beta \) \( V \_ \), but /b/ remains unchanged

\[
\begin{align*}
[p{\text{\textae}}] & \rightarrow [s:u \beta{\text{\textae}}] \text{ ‘the bread’} \\
[b\_u] & \rightarrow [s:u b{\text{\textae}}u] \text{ ‘the wine’}
\end{align*}
\]

1. Bolognesi, 1998
**Saltatory Alternation**

- Example from Campidanian Sardinian:¹
  - $p \rightarrow \beta/ V \_\_\_, but /b/ remains unchanged

\[ [p\text{\textcolor{red}{\vphantom{i}}\textcolor{red}{\i}}] \rightarrow [s:u \beta\text{\textcolor{red}{\vphantom{i}}\textcolor{red}{\i}}] \quad \text{‘the bread’} \]
\[ [b\text{\textcolor{red}{\vphantom{i}}\textcolor{red}{\i}}] \rightarrow [s:u b\text{\textcolor{red}{\vphantom{i}}\textcolor{red}{\i}}] \quad \text{‘the wine’} \]

1. Bolognesi, 1998
**Saltatory Alternation**

- Example from Campidanian Sardinian:\(^1\)
  - \(p \rightarrow \beta/ V \_\), but /b/ remains unchanged

\[
\begin{align*}
[p\text{i}] & \rightarrow [s:u \beta\text{ai}] \quad \text{‘the bread’} \\
[b\text{iu}] & \rightarrow [s:u b\text{iu}] \quad \text{‘the wine’}
\end{align*}
\]

\(2\) feature changes

1. Bolognesi, 1998
SALTATORY ALTERNATION

- Example from Campidanian Sardinian:
  - p → β/ V __, but /b/ remains unchanged

[p’ai] → [s:u β’ai] ‘the bread’
[bũ] → [s:u bũ] ‘the wine’

1 feature difference
2 feature changes

1. Bolognesi, 1998
WHY FOCUS ON SALTATORY ALTERNATIONS?

- Researchers have long noted that phonological alternations between dissimilar sounds are less common cross-linguistically.¹

- Alternations usually follow the principle of minimal modification – if you are going to alternate, you should make the smallest change possible.²

¹ Trubetzkoy, 1939
² Steriade, 2001/2008
**Saltatory alternations = excessive modification**

- Saltatory alternations are striking counterexamples to the principle of *minimal modification*:
  - Involve dissimilar sounds (multiple feature changes).
  - They represent *excessive modification* – other possibilities exist that would require less extreme changes.
  - *Intuitively*: Why change $p \rightarrow \beta$ when $[b]$ is closer to $[p]$ and legal?
    - or-
      If you go to the trouble of changing $p \rightarrow \beta$, why not also change $b \rightarrow \beta$?
  - Due to this characteristic, some phonological theories predict saltatory alternations should not exist at all.\(^1\)

---

SALTATORY ALTERNATIONS = EXCESSIVE MODIFICATION

- Saltatory alternations are striking counterexamples to the principle of minimal modification:
  - Involve dissimilar sounds (multiple feature changes).
  - They represent excessive modification – other possibilities exist that would require less extreme changes.
  - Intuitively: Why change $p \rightarrow \beta$ when $[b]$ is closer to $[p]$ and legal?
    - or-
      If you go to the trouble of changing $p \rightarrow \beta$, why not also change $b \rightarrow \beta$?
  - Due to this characteristic, some phonological theories predict saltatory alternations should not exist at all.¹

- If alternations between dissimilar sounds are less common (in general), saltatory alternations appear to be especially uncommon.

Adults are biased against saltatory alternations when learning an artificial language.¹

- When learning potentially saltatory alternations, they assume intermediate sounds change without evidence in the input.
  - E.g., Learn: p → v, Assume: b → v
- Even with explicit evidence, they find saltatory alternations harder to learn.

¹ White, under revision
Main points of today’s talk

- 12-month-old infants, like adults, exhibit a bias against saltatory alternations.

- One plausible basis for such behavior is a bias based on the similarity of the alternating sounds.
EXPERIMENT OVERVIEW

- White, Peperkamp, Kirk, & Morgan (2008):
  - **Train:**  \[ p \rightarrow b \quad \text{or} \quad f \rightarrow v \]
  - **Test:**  \[ p \rightarrow b \quad \text{and} \quad f \rightarrow v \]
  - **Result:** Differentiated test items depending on training.
EXPERIMENT OVERVIEW

- White, Peperkamp, Kirk, & Morgan (2008):  
  - **Train:**  
    \[ p \rightarrow b \quad \text{or} \quad f \rightarrow v \]  
  - **Test:**  
    \[ p \rightarrow b \quad \text{and} \quad f \rightarrow v \]  
  - **Result:** Differentiated test items depending on training.

- Current study:  
  - **Train:**  
    \[ p \rightarrow v \quad \text{or} \quad t \rightarrow z \]  
  - **Test:**  
    \[ b \rightarrow v \quad \text{and} \quad d \rightarrow z \]  
  - **Prediction:** If infants are like adults, differentiate test items depending on training.
METHOD

- Visual Fixation procedure

1. Werker et al., 1998
METHOD

- Participants:
  - 36 twelve-month-olds (18 per condition)
  - Monolingual English input
METHOD

- Participants:
  - 36 twelve-month-olds (18 per condition)
  - Monolingual English input

- 2 phases: Exposure phase & Test phase
EXPOSURE PHASE

- Repeating phrases of function word + content word
  - E.g., na voli...rom timu...rom zimu...rom panu...na timu...na voli...
  - 2 function words (na or rom); 8 content word pairs
- 3 trials, 45 sec each (total of 135 sec)
- Not infant controlled
- 2 conditions: Potentially Saltatory and Control
- 2 exposure groups – Labials Alternating or Coronals Alternating (half randomly assigned to each)
**Exposure Groups**

### Potentially Saltatory

<table>
<thead>
<tr>
<th>Labials Alternating</th>
<th>Coronals Alternating</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>rom poli</code></td>
<td><code>rom poli</code></td>
</tr>
<tr>
<td><code>na voli</code></td>
<td><code>rom voli</code></td>
</tr>
<tr>
<td><code>rom poli</code></td>
<td><code>na poli</code></td>
</tr>
<tr>
<td><code>na voli</code></td>
<td><code>na voli</code></td>
</tr>
<tr>
<td><code>rom timu</code></td>
<td><code>rom timu</code></td>
</tr>
<tr>
<td><code>rom zimu</code></td>
<td><code>na zimu</code></td>
</tr>
<tr>
<td><code>na timu</code></td>
<td><code>rom timu</code></td>
</tr>
<tr>
<td><code>na zimu</code></td>
<td><code>na zimu</code></td>
</tr>
</tbody>
</table>
# Exposure Groups

## Potentially Saltatory

<table>
<thead>
<tr>
<th>Labials Alternating</th>
<th>Coronals Alternating</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>rom poli</em></td>
<td><em>rom poli</em></td>
</tr>
<tr>
<td><em>rom poli</em></td>
<td><em>na poli</em></td>
</tr>
<tr>
<td><em>na timu</em></td>
<td><em>na timu</em></td>
</tr>
<tr>
<td><em>rom timu</em></td>
<td><em>rom zimu</em></td>
</tr>
<tr>
<td><em>rom zimu</em></td>
<td><em>na zimu</em></td>
</tr>
</tbody>
</table>

**Alternating based on context:**
- [p] only after *rom*
- [v] only after *na*
**Exposure Groups**

### Potentially Saltatory

<table>
<thead>
<tr>
<th>Labials Alternating</th>
<th>Coronals Alternating</th>
</tr>
</thead>
<tbody>
<tr>
<td>rom poli</td>
<td>rom poli</td>
</tr>
<tr>
<td>rom poli</td>
<td>rom voli</td>
</tr>
<tr>
<td>rom timu</td>
<td>rom timu</td>
</tr>
<tr>
<td>na voli</td>
<td>na poli</td>
</tr>
<tr>
<td>na voli</td>
<td>na voli</td>
</tr>
<tr>
<td>rom timu</td>
<td>na zimu</td>
</tr>
<tr>
<td>rom timu</td>
<td>na zimu</td>
</tr>
<tr>
<td>na timu</td>
<td>na zimu</td>
</tr>
</tbody>
</table>

Contrastive: [t] and [z] after both *rom* and *na.*
**Exposure groups**

### Potentially Saltatory

<table>
<thead>
<tr>
<th>Labials Alternating</th>
<th>Coronals Alternating</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>rom poli</strong></td>
<td><strong>rom poli</strong></td>
</tr>
<tr>
<td><strong>na voli</strong></td>
<td><strong>na voli</strong></td>
</tr>
<tr>
<td><strong>rom poli</strong></td>
<td><strong>na poli</strong></td>
</tr>
<tr>
<td><strong>na voli</strong></td>
<td><strong>na voli</strong></td>
</tr>
<tr>
<td><strong>rom timu</strong></td>
<td><strong>rom timu</strong></td>
</tr>
<tr>
<td><strong>rom zimu</strong></td>
<td><strong>na zimu</strong></td>
</tr>
<tr>
<td><strong>na timu</strong></td>
<td><strong>rom timu</strong></td>
</tr>
<tr>
<td><strong>na zimu</strong></td>
<td><strong>na zimu</strong></td>
</tr>
</tbody>
</table>

Opposite pattern in this group.
**Exposure Groups**

### Potentially Saltatory

<table>
<thead>
<tr>
<th>Labials Alternating</th>
<th>Coronals Alternating</th>
</tr>
</thead>
<tbody>
<tr>
<td>rom poli</td>
<td>rom poli</td>
</tr>
<tr>
<td>na voli</td>
<td>rom voli</td>
</tr>
<tr>
<td>rom poli</td>
<td>na poli</td>
</tr>
<tr>
<td>na voli</td>
<td>na voli</td>
</tr>
<tr>
<td>rom timu</td>
<td>rom timu</td>
</tr>
<tr>
<td>rom zimu</td>
<td>na zimu</td>
</tr>
<tr>
<td>na timu</td>
<td>na zimu</td>
</tr>
</tbody>
</table>

### Control

<table>
<thead>
<tr>
<th>Labials Alternating</th>
<th>Coronals Alternating</th>
</tr>
</thead>
<tbody>
<tr>
<td>rom boli</td>
<td>rom poli</td>
</tr>
<tr>
<td>na voli</td>
<td>rom voli</td>
</tr>
<tr>
<td>rom boli</td>
<td>na poli</td>
</tr>
<tr>
<td>na voli</td>
<td>na voli</td>
</tr>
<tr>
<td>rom dimu</td>
<td>rom timu</td>
</tr>
<tr>
<td>rom zimu</td>
<td>na zimu</td>
</tr>
<tr>
<td>na dimu</td>
<td>na zimu</td>
</tr>
</tbody>
</table>
**Test Phase**

- Each trial = One novel pair of words repeated **without** *na* or *rom*
  - Thus, context no longer available at test – infants must map alternating forms onto same underlying forms.

- Within a given condition, infants received **same test trials**, regardless of Exposure Group
  - Potentially Saltatory: (trained on *[p] ~ *[v] or *[t] ~ *[z])
    - *buni/vuni, bagu/vagu, dilu/zilu, dari/zari*
  - Control: (trained on *[b] ~ *[v] or *[d] ~ *[z])
    - *puni/vuni, pagu/vagu, tilu/zilu, tari/zari*
  - Note: Half labials, half coronals

- Infant controlled
- 3 blocks, 4 trials each (12 total test trials)
- Order of test trials was counterbalanced across infants
**Experiment Overview**

- **Labials**
  - Potentially Saltatory: p, b, v
  - Control: t, d, z

- **Coronals**
  - Alternating Group
EXPERIMENT OVERVIEW

Potentially Saltatory

Control

Labials Alternating Group

p b v

t d z

Coronals Alternating Group

training  testing
EXPERIMENT OVERVIEW

Potentially Saltatory

Labials
Alternating Group

Coronals
Alternating Group

Control

training
testing

p b v
t d z
EXPERIMENT OVERVIEW

Potentially Saltatory Control

Labials Alternating Group

Coronals Alternating Group

Labials

Coronals
**EXPERIMENT OVERVIEW**

- **Potentially Saltatory**
- **Control**

### Labials
- Training: p, b → v
- Alternating Group: t, d → z

### Coronals
- Training: p, b → v
- Alternating Group: t, d → z
### Experiment Overview

<table>
<thead>
<tr>
<th>Potentially Saltatory</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Labials Alternating Group</strong></td>
<td></td>
</tr>
<tr>
<td>p</td>
<td>b → v</td>
</tr>
<tr>
<td>t</td>
<td>d → z</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Coronals Alternating Group</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>p</td>
</tr>
<tr>
<td>t</td>
</tr>
</tbody>
</table>
EXPERIMENT OVERVIEW

Potentially Saltatory

Labials
Alternating Group

Labials
Alternating Group

Coronals
Alternating Group

Control

Training

Testing

Labials

Coronals

35
**Experiment Overview**

**Potentially Saltatory**

Labials Alternating Group:
- p
- b
- v
- t
- d
- z

Coronals Alternating Group:
- p
- b
- v
- t
- d
- z

**Control**

- p
- b
- v
- t
- d
- z
**PREDICTIONS**

- Potentially Saltatory
- Control

Labials Alternating Group
- p
- b → v
- t
- d → z

Coronals Alternating Group
- p
- b → v
- t
- d → z

37

- training
- testing
PREDICTIONS

Labials Alternating Group

Coronals Alternating Group

[b] is intermediate between trained alternation; [d] is not.

Potentially Saltatory

Control
Predictions

[b] is intermediate between trained alternation; [d] is not.

[b] and [d] should be treated **DIFFERENTLY!!!**

**Labials Alternating Group**
- p
- t

**Coronals Alternating Group**
- p
- t

**Potentially Saltatory**
- b --\rightarrow v
- d --\rightarrow z

**Control**
Predictions

- [b] is intermediate between trained alternation;
- [d] is not.

[b] and [d] should be treated DIFFERENTLY!!

Labials Alternating Group
- p
- t

Coronals Alternating Group
- p
- t

Control
- b → v
- d → z

These should also be treated differently, but in the opposite way!
PREDICTIONS

[\textcolor{red}{{b}}] is intermediate between trained alternation; [\textcolor{blue}{{d}}] is not.

[b] and [d] should be treated DIFFERENTLY!!

\begin{itemize}
  \item [\textcolor{red}{{b}}] and [\textcolor{blue}{{d}}] should be treated DIFFERENTLY!!
\end{itemize}

Same test stimuli, but which sound is intermediate between the alternation depends on exposure.
→ Rules out item effects and effects based on specific sounds.
Predictions

[b] is intermediate between trained alternation; [d] is not.
[b] and [d] should be treated **DIFFERENTLY**!

Same test stimuli, but which sound is intermediate between the alternation depends on exposure.
→ Rules out item effects and effects based on specific sounds.

In fact: no significant differences found between exposure groups – so they are collapsed in the following results.
**PREDICTIONS**

Neither sound intermediate between alternating sounds. **No differences expected.**

![Diagram](image)

- **Potentially Saltatory**
  - Labials Alternating Group: p (t) → b (d) → v (z)
  - Coronals Alternating Group: p (t) → b (d) → v (z)

- **Control**
  - Labials Alternating Group: p (t) → b (d) → v (z)
  - Coronals Alternating Group: p (t) → b (d) → v (z)
SUMMARY OF PREDICTIONS

- Potentially Saltatory condition
  - Difference between Alternating place of articulation and Contrastive place of articulation.
  - Recall: the test items included in each of these comparison groups is different depending on exposure.
SUMMARY OF PREDICTIONS

- Potentially Saltatory condition
  - Difference between Alternating place of articulation and Contrastive place of articulation.
  - Recall: the test items included in each of these comparison groups is different depending on exposure.

- Control condition
  - No difference.
RESULTS

Mean looking time (s)

- Potentially Saltatory
- Control

Contrastive place
Alternating place

*
RESULTS

Sig. effect of Place ($p = .004$). Infants treated them differently, as predicted!!
RESULTS

Sig. effect of Place ($p = .004$). Infants treated them differently, as predicted!!

14/18 infants showing pattern
RESULTS

Sig. effect of Place ($p = .004$). Infants treated them differently, as predicted!!

14/18 infants showing pattern
RESULTS

14/18 infants showing pattern

8/18 infants showing pattern

Sig. effect of Place ($p = .004$). Infants treated them differently, as predicted!!

No difference in the control group!
**DISCUSSION**

- Difference between Contrastive and Alternating place of articulation, but **only** in the Potentially Saltatory case, as predicted.

- **Bottom line:**
  Difference in the Potentially Saltatory case but not in the Control case

  =

  Infants treated the saltatory alternations differently than the non-saltatory ones.
**DISCUSSION**

- Infant looking time was *shorter* when sounds were intermediate between *alternating sounds* than when intermediate between contrastive sounds.

- Why do we see this behavior?
  - Plausible explanation:

    - **Alternating place:**
    - **Contrastive place:**

    \[
    \begin{align*}
    p & \quad b \\
    v & \quad v
    \end{align*}
    \]
**DISCUSSION**

- Infant looking time was **shorter** when sounds were intermediate between **alternating sounds** than when intermediate between contrastive sounds.

- Why do we see this behavior?
  - Plausible explanation:
    - Alternating place: Learn p b v
    - Contrastive place:
**DISCUSSION**

- Infant looking time was **shorter** when sounds were intermediate between **alternating sounds** than when intermediate between **contrastive sounds**.

- Why do we see this behavior?
  - Plausible explanation:

```
Alternating place:  

Learn

p  b  v

Contrastive place:  

Assume
```
Discussion

- Infant looking time was **shorter** when sounds were intermediate between **alternating sounds** than when intermediate between contrastive sounds.

- Why do we see this behavior?
  - Plausible explanation:

![Diagram](attachment:diagram.png)
**DISCUSSION**

- Infant looking time was **shorter** when sounds were intermediate between **alternating sounds** than when intermediate between contrastive sounds.

- Why do we see this behavior?
  - Plausible explanation:

  ![Diagram](https://via.placeholder.com/150)

  **Alternating place:**
  - Learn
  - p ➔ b ➔ v
  - Assume

  **Contrastive place:**
  - Learn
  - t ➔ d ➔ z
  - Unclear
If dissimilar sounds alternate, 12-month-olds assume that more similar sounds are likely to alternate as well.

By doing so, they avoid having a saltatory alternation.

What is the source of this anti-saltation behavior?
**Discussion**

- **Conjecture:** Anti-saltation preference is due to a bias based on the principle of *minimal modification*:
  - Learners are tacitly aware of the relative perceptual similarity between pairs of sounds, based on experience (Steriade’s P-map).
  - **Minimal modification bias:** Alternations between perceptually dissimilar sounds considered less likely than those between more similar sounds.
  - Modeling the acquisition of alternations with a prior (i.e., soft bias) based on this principle does a good job of predicting the anti-saltation effect in adults.

---

1. Steriade, 2001/2008  
2. White, 2012; see also the modeling in Wilson, 2006
CONCLUSIONS

- 12-month-old infants learn novel alternations in a biased way.
  - Like adults, they apparently assume alternations will not be saltatory.

- This study provides evidence that the anti-saltation bias seen in adults\(^1\) is also active during child language acquisition.

- A plausible basis for the anti-saltation bias is a more general bias that prefers alternations with minimal modification.

---

1. White, under revision
THANK YOU

Acknowledgments:

- We would like to thank Bruce Hayes, Sharon Peperkamp, Kie Zuraw, Pat Keating, and audiences at the UCLA phonetics and phonology seminars for helpful discussion.
- Thanks also to Victoria Thatte, Chad Vicenik, Robyn Orfitelli, and undergraduate RAs in the UCLA Language Acquisition Lab.
- This work was funded by an NSF grant to the second author.
REFERENCES