Motor-acoustic mappings shape child phonology: Evidence from a circular chain shift

Tara McAllister Byun\textsuperscript{1}  Adam Buchwald\textsuperscript{1}

\textsuperscript{1}New York University, Department of Communicative Sciences and Disorders
Child chain shifts

- A topic of perennial interest in the child phonology literature: **chain shifts** that appear to arise spontaneously in development (e.g., Dinnsen & Barlow, 1998; Jesney, 2007; Rose, 2009, Ettlinger, 2009; Dinnsen et al., 2011)

- Chain shift: Interacting phonological processes cause successive changes along some dimension (A → B; B → C)
  - e.g. *sun* → [θʌn], *thumb* → [θʌm] (Dinnsen & Barlow, 1998)
  - *puzzle* → [pʌdəl], *puddle* → [pʌdəl] (Smith, 1973; Jesney, 2007; Dinnsen et al., 2011)
Accounts of child chain shifts

▶ A case of **opacity**, i.e. phonological generalizations that are not surface-true.

▶ Problematic for constraint-based grammars:
  ▶ Why doesn’t the constraint that drives labialization in *thumb → [fʌm]* also apply in *sun → [θʌn]*?

▶ Performance limitations do not appear to offer a solution:
  ▶ If child is capable of producing *[θ]*, why does he/she not deploy it in the intended context?

▶ This talk will make the case that a *grammar that incorporates performance pressures* (motor, perceptual) can capture even highly problematic cases of chain shift.
  ▶ A-map model (McAllister Byun, Inkelas, & Rose, in press)
  ▶ Linked Attractor model (Menn, Schmidt, & Nicholas, 2009)
Circular chain shift?

- We present an apparent case of circular chain shift (A → B; B → A) in a child with minor phonological delay.
- Initial homorganic s-stop clusters were reduced (stick → [sɪk])
- But at the same time, [t] epenthesis converted initial coronal singletons to clusters (sick → [stɪk]).
- Not an easy phenomenon to capture in a formal grammar:
  - “The existence of a circular chain shift in which all links occur synchronically would present a problem for the OT doctrine of harmonic ascent...Moreton (1999) provides a formal proof showing that an OT grammar that admits only faithfulness and markedness constraints is incapable of modeling circular chain shifts” (Crowhurst, 2011)
- But hardly a straightforward performance phenomenon, either!
Case study

- “Wesley,” initially evaluated age 3;7
- Strong expressive and receptive language abilities
- History of mild speech delay
- Score on *Hodson Assessment of Phonological Patterns-3* fell 1.25 SD below mean for age
- Decreased intelligibility due to multiple phonological patterns.
Case study

- Velar fronting (all positions), palatal fronting (inconsistent)
  
  *I got to chew gum*

- Reduction of /s/-obstruent clusters in initial position

- Affected /st/, /sk/ clusters:
  
  - *stop and go*
  - *in the sky*

- But not /sp/ clusters:
  
  - *a spoon*
Exploratory therapy sessions

- Multiple oppositions (Williams, 1993, 2000, 2003) approach targeting /s/-/st/-/sk/ contrasts

- Session 1: Initially unable to imitate clusters.
  - store

- Later in Session 1: Able to produce clusters with cueing, inconsistently.
  - Good SLP!

- But also started to insert stops in singleton fricative contexts.
  - Bad SLP!
Exploratory therapy sessions

- Session 2: More accurate cluster productions, but more stop insertion with singleton targets as well.

Figure 1: Realization of cluster and singleton targets across treatment sessions
Exploratory therapy sessions

- Session 3: Produces clusters for singletons more often than for cluster targets.
- Session 4: Finally starting to resolve overgeneralization.

![Figure 2: Realization of cluster and singleton targets across treatment sessions](image-url)
A perceptual or representational problem?

- Perceptual testing: Forced-choice picture-pointing task in response to experimenter’s verbal model.
  - 10/10 correct responses for a /st/-/s/ minimal pair
  - 10/10 correct responses for a /st/-/sk/ minimal pair

- Wesley does perceive the /s/-/st/-/sk/ contrast.

- And he can map the perceived contrast to distinct stored lexical representations.
Covert contrast?

- Is the [st] that Wesley produces in error for target /s/ identical to the [st] that he produces for target /st/?
- Is the [s] that he produces for target /s/ identical to the [s] that he produces for target /st/?
- We measured minimal pairs *sick-stick* and *sir-stir* to look for covert contrast in Wesley’s output (Table 1).

<table>
<thead>
<tr>
<th>Target</th>
<th>Realized with [s]</th>
<th>Realized with [st]</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>sir</em></td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td><em>stir</em></td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td><em>sick</em></td>
<td>7</td>
<td>23</td>
</tr>
<tr>
<td><em>stick</em></td>
<td>7</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 1: Count of tokens realized with cluster versus singleton

- Measures included closure duration (surface [st] only), VOT (surface [st] only), fricative duration (all tokens).
Covert contrast?

- Underlying clusters (/st/ → [st]) did not differ significantly from derived clusters (/s/ → [st])
  - With respect to closure duration
  - With respect to VOT

Figure 3: Closure duration in true versus derived clusters

Figure 4: VOT in true versus derived clusters
Covert contrast?

- Similarly, no difference in fricative duration:
  - between underlying and derived singletons (/s/ → [s] versus /st/ → [s])
  - between underlying and derived clusters (/st/ → [st] versus /s/ → [st]).
- In short, no evidence of covert contrast.

**Figure 5:** Differences in fricative duration
Covert contrast?

- There was a significant difference in fricative duration between surface clusters and singletons, independent of underlying or derived status ($t = 4.4$, $df = 78$, $p < .0001$).
- Contrary to expectations from adult speech, [s] in surface cluster contexts was significantly longer than singleton [s].

Figure 6: Differences in fricative duration
Gestural coordination

- Wesley’s earliest [st] productions featured less than typical degree of coarticulatory overlap.
- Suggestive of difficulty with gestural coordination of multiple consonants (Davidson, 2006; Miozzo & Buchwald, 2012).
- Resembles gestural mistiming described in adult production of non-native clusters.

**Figure 7:** An articulatory-driven repair of a non-native consonant cluster sequence (image from Davidson, 2006)

- In homorganic clusters, sequence of slightly different movements of a single articulator may represent a particular articulatory challenge (Bates, Watson, & Scobbie, 2002).
If articulatory difficulty is the driving force behind Wesley’s cluster reduction, should we analyze these outputs as extragrammatical performance errors (Hale & Reiss 1998, 2008)?

No, there is a specific reason to reject this analysis:

1. In a $C_1C_2V$ cluster, there is tighter gestural coupling between $C_2$ and $V$ than $C_1$ and $V$ (Nam, Goldstein, & Saltzman, 2010).
2. In cases of cluster reduction as articulatory performance error, expect to observe reduction to $C_2$ (Miozzo & Buchwald, 2012).
An articulatory pressure, a phonological repair

So why does Wesley produce [sɪk] instead of [tɪk] for “stick”? Because the articulatory pressure interacts with other factors.

Goodness of perceptual match for adult target:
- /s/ is acoustically salient
- Reduction of /st/ to [t] is a greater perceptual deviation than reduction to [s]

Vacuous coalescence (/st, sk/ → [s]) addresses the articulatory challenge while achieving closer match for adult target.
Influence of motor learning on preferred repair

- What changed to allow the emergence (and overgeneralization) of the output in which both segments of the cluster were preserved?
  - Our contention: A change in the availability of a stable motor plan.
  - In the therapy setting, Wesley identified and stabilized the motor routine for cluster production with minimal gestural overlap.

- And due to recent practice, sometimes activated in non-target contexts.

- Overgeneralization to singleton targets interpreted as a performance error reflecting high level of activation of cluster motor routine.
Patterns in speech development and disorders can have transparent origins in phonetic performance factors...

...but they also demonstrably interact with perceptual and structural/representational factors.

The A-map model (McAllister Byun, Inkelas, & Rose, in press) aims to integrate performance pressures into the feature-based formalism that has been so successful in describing patterns/alternations in fully-developed phonologies.

The A-map in a nutshell:

- Stored knowledge about the reliability of different motor-acoustic mappings.
- Grammatical constraint favors candidates linked to a reliable plan.
- Dynamically updated; gain or loss of motor skill can be expressed within the grammar.
Assumptions

- Phonetic experience (inputs perceived, outputs produced) stored as episodic traces in multi-dimensional auditory-acoustic space.

- Phonological representations linked to phonetic detail (clouds of traces) via distinctive features in the analysis-by-synthesis framework (Halle & Stevens 1959, 1962; Poeppel, Idsardi & Wassenhove 2008; Kuhl et al. 2014).
Assumptions

- Motor plan executions generate a predicted outcome (efference copy) in addition to a perceptually encoded output.
- For speaker’s own output, both perceptually encoded trace and trace of efference copy are stored.

Figure 8: Clouds in speaker-transformed auditory-acoustic space representing the adult target (T), the child’s actual outputs (A), and efference copies representing the expected sensory consequences of planned outputs (E).
Metric of goodness of mappings

- When there is an error in motor planning or execution, there is divergence between perceptually encoded trace and trace of efference copy.
- For novel/complex motor plan, frequent errors yield larger mean distance between predicted and actual acoustic consequences.
- Indexed in the A-map.
Getting it into the grammar

- **PRECISE**: Penalize a candidate in proportion to the average distance between pairs of efference copies and actual outputs in the associated motor-acoustic mapping.
- Pressure favoring articulatory reliability exerted by **PRECISE** can come into competition with faithfulness to adult target.

![Figure 9:](image)

A. More faithful, less precise  
B. Less faithful, more precise
Conclusions

- Child phonology offers abundant evidence for links between motor and phonological development.
- An exemplar-based grammar that tracks motor-acoustic mappings:
  - Provides a direct mechanism to capture articulatory and perceptual pressures without abandoning the benefits of formalism;
  - Improves our ability to account for formally problematic phenomena like chain shift.
Thanks!

Any questions?

tara.byun@nyu.edu
buchwald@nyu.edu

Thanks to NIDCD (NIH R03DC012883).