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

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# 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 $\rightarrow$ B; B $\rightarrow$ C)
  - e.g. *sun* $\rightarrow$ [θʌn], *thumb* $\rightarrow$ [fʌm] (Dinnsen & Barlow, 1998)
  - *puzzle* $\rightarrow$ [pʌdəl], *puddle* $\rightarrow$ [pʌgəl] (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 $\rightarrow$ B; B $\rightarrow$ A) in a child with minor phonological delay.
- Initial homorganic s-stop clusters were reduced (*stick* $\rightarrow$ [sɪk])
- But at the same time, [t] epenthesis converted initial coronal singletons to clusters (*sick* $\rightarrow$ [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.

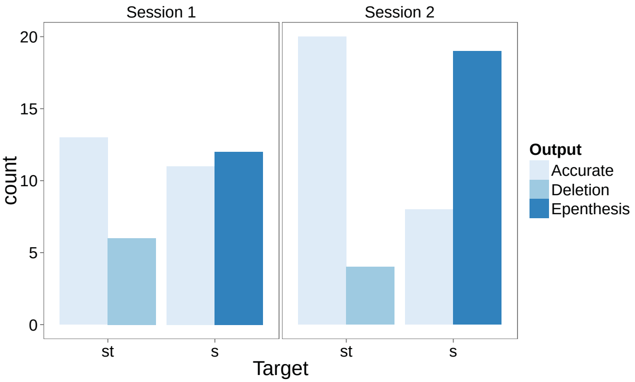



Figure 1: Realization of cluster and singleton targets across treatment sessions

# Exploratory therapy sessions

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

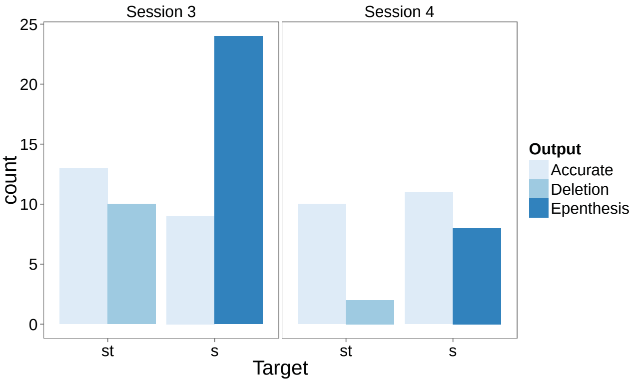



Figure 2: Realization of cluster and singleton targets across treatment sessions

# 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).

| **Target** | **Realized with [s]** | **Realized with [st]** |
|---|---|---|
| *sir* | 4 | 10 |
| *stir* | 2 | 12 |
| *sick* | 7 | 23 |
| *stick* | 7 | 12 |

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

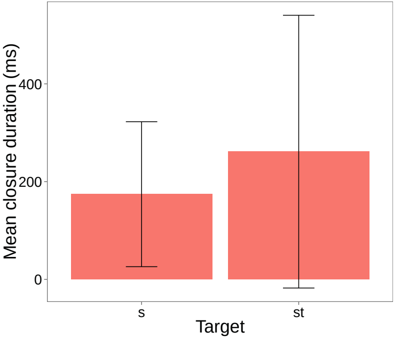



Figure 3: Closure duration in true versus derived clusters

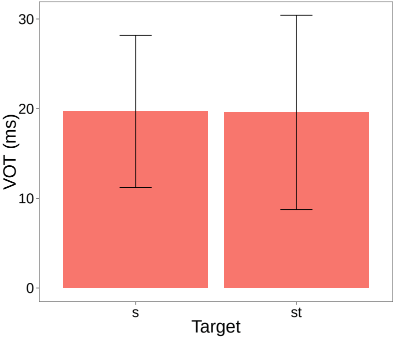



Figure 4: VOT in true versus derived clusters

# 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.

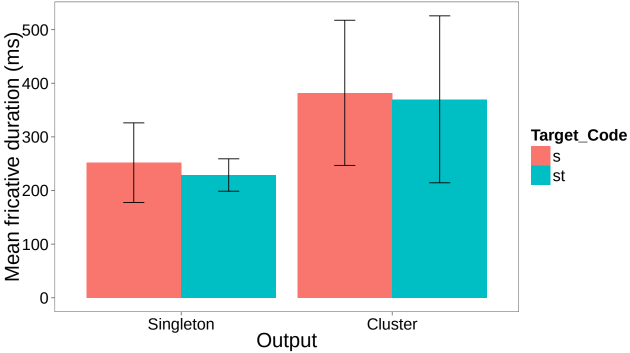



Figure 5: Differences in fricative duration

# 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].

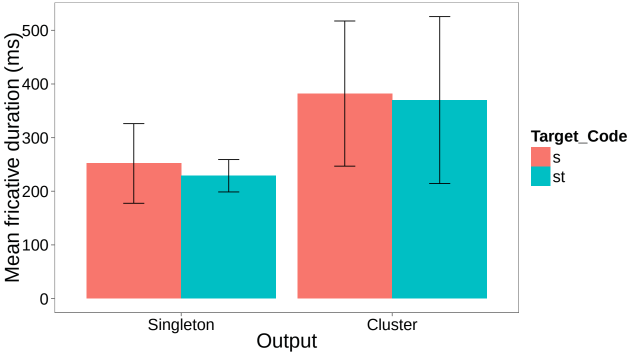



Figure 6: Differences in fricative duration

# 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.

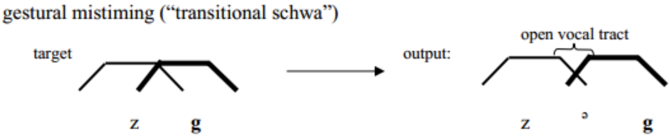



Figure 7: An articulatory-driven repair of a non-native consonant cluster sequence (image from Davidson, 2006)

- In homorganic clusters, sequence of slightly different movements of a single articulator may represent a particular articulatory challenge (Bates, Watson, & Scobbie, 2002).

# An articulatory pressure, a phonological repair

- 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:
  - 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).
  - 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/ $\rightarrow$ [s]) addresses the articulatory challenge while achieving closer match for adult target.

# Influence of motor learning on preferred repair

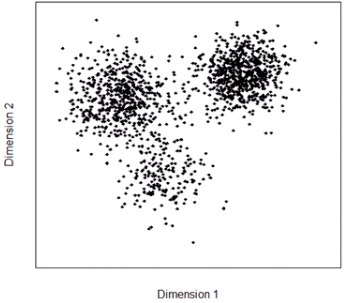
- What changed to allow the emergence (and overgeneralization) of the output in which both segments of the cluster were preserved?
  - Our contention: A change in the availability of a stable motor plan.
  - In the therapy setting, Wesley identified and stabilized the motor routine for cluster production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

# Modeling the motor-grammar interface

- 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.

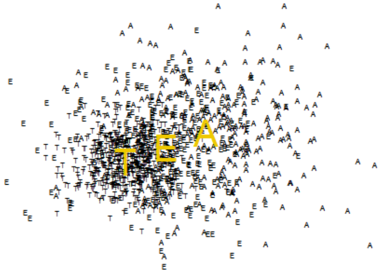
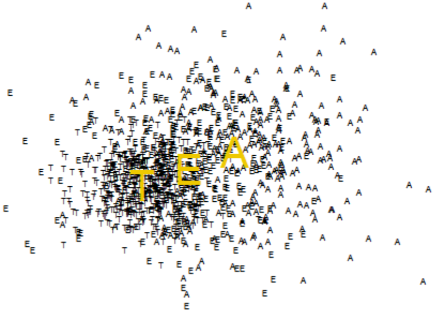



Figure 8: Clouds in speaker-transformed auditory-acoustic space representing the adult target (T), the child's actual outputs (A), and efference copies representing the expected sensory consequences of planned outputs (E).

# 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.

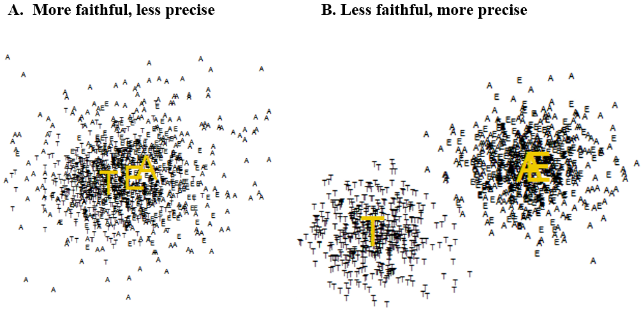



Figure 9:

# 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?

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