

Phonological Chain Shifts During Acquisition: Evidence for Lexical Optimization^{*}

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1. Introduction

Phonological chain shifts are a well-documented phenomenon in children during language acquisition. Chain shifts are challenging for current theories of phonology because they are opaque: an interaction between two phonological generalizations where one generalization is not surface true due to the application of the other. Based on diary studies of the phonological development of a child, between the ages of 1;0 and 2;0, I propose an account for chain shifts of this sort by showing that both generalizations are not active at the same time and therefore do not reflect a true synchronic opaque grammar. Rather, I show that these examples are due to lexical inertia (Menn & Stoel-Gammon, 1993), the phenomenon whereby older words are resistant to change even after a phonological generalization is no longer active. I formalize this through the use of lexicon optimization (Prince & Smolensky 1993/2002), where the underlying form of a lexical item is assigned to its surface form.

This analysis serves three functions. First, it presents an account of chain shifts during language development without introducing additional formal mechanisms, as has been suggested by others (Dinnsen & Barlow, 1998; Dinnsen & McGarrity, 2004; Dinnsen, O'Connor & Gierut, 2001; Jesney, 2007; Vanderweide, 2006). Second, it provides evidence for multiple stages of lexicon optimization, a component of OT often ignored in work on learning algorithms. Finally, it highlights the importance of considering the age of a word and when it was acquired when examining the synchronic phonological system of children. So, instead of simply examining a corpus of what a child does and does not say at a particular stage in development, the present findings suggest that eliciting new words is crucial in establishing the children's phonological grammar since older words may simply reflect the remnants of phonological generalization no longer active.

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2. Opaque Chain Shifts

Chain shifts have been identified as a subject of interest in children's speech since some of the earliest modern diary studies. In Smith's (1973) reporting of Amahl's speech development and Macken's (1980) subsequent analysis, the following chain shift was identified at 2;2 to 2;11 years of age:

- (1) Chain shift in Amahl's phonological development (age 2;2-2;11):

Stopping (all contexts):

a) [pʌdl] 'puzzle'

b) [pɛntl] 'pencil'

Velarization (before liquids):

c) [pʌgl] 'puddle'

d) [bɔkl] 'bottle'

Chain shift: /z/→[d], /d/→[g], /z/↔[g]

Another example is a child in Dinnsen & Barlow's (1998) study of normally developing and disordered child learners:

- (2) Chain shift in Subject 33 (age 5;4):

/s/→[θ]:

a) [θʌn] 'sun'

b) [duθ] 'juice'

/θ/→[f]:

c) [fʌm] 'thumb'

d) [bæf] 'bath'

Chain shift: /s/→[θ], /θ/→[f], /s/↔[f]

In (1), the first set of items reflects stopping of fricatives and the second set reflects the velarization of alveolar stops before liquids. The theoretical challenge comes from the observation that the stopped fricatives in (1a,b) remain alveolar despite being followed by a liquid. If velarization in (1c,d) reflects some sort of perceptual or articulatory difficulty with pre-liquid alveolars, there seems to be no explanation to account for why *puzzle* is not pronounced [pʌgl], with the underlying alveolar fricative surfacing as a velar stop.

In (2), there is a formally similar system of generalizations where /s/→[θ] and /θ/→[f]. Crucially, the [θ] in (2a,b) do not end up as [f] despite the perceptual or articulatory difficulty associated with [θ] reflected by its replacement by [f] in (2c,d). So, if the child is able to articulate the [θ] in [θʌn], why not the [θ] in *thumb*? Myriad other examples of chain shifts are discussed in Jesney (2007).

In the present study, I transcribed the speech of a typically developing child, M, between the ages of 1;0 and 2;0. This consisted of two observation periods a week lasting

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approximately one to two hours. The child interacted with adults, other children, and myself during these periods. Recordings were made so that a second trained phonetician could verify the transcriptions where possible. While some of the transcription could not be verified because of poor recording quality, all of the examples cited herein were verified. The entire transcription – verified and not - was used for the calculations in section 4, however.

These transcriptions included a number of chain shifts similar to the above. For example, at two years of age M produced the following forms:

(3) Chain shift in M (age 2;0):

Velarization

a) [kʌk] ‘talk’

b) [kæk] ‘cat’

Word-initial stopping

c) [tak] ‘sock’

d) [tʌn] ‘sun’

The two phonological processes, velarization and stopping, are similar to those in (1), though the contexts are slightly different. And again, the same complex pattern of interaction emerges. In (3c,d) alveolars surface despite the supposed constraint against them reflected in (3a,b). Indeed, a word-level chain shift occurs in (3c) where the child pronounces the word *sock* as [tak] despite apparently not being able to articulate this form for the actual word *talk* (3a). How, then, can a formal system express what child M can and cannot say and correctly derive the appropriate forms in (3)?

This problem can be formalized using surface-based approaches to phonology, such as Optimality Theory (OT; Prince & Smolensky, 1993). In OT surface forms reflect the optimal resolution of ranked constraints. The following abbreviated constraint evaluation would appropriately produce the form in (3a):

(4) OT constraint ranking for *talk*

/tak/	*COR	REDUCE	ID[PLACE]	ID[LOW]
(a) → kʌk			*	*
(b) tʌk	*!			*
(c) tak	*!	*!		

This tableau serves to establish the relative ranking of a markedness constraint against coronals (*COR) and a faithfulness constraint maintaining major place (ID[PLACE]). The precise context sensitivity of the coronal constraint can involve a number of factors, including the presence of a velar (see Pater, 1998), but for present purposes the blanket constraint against coronals is adequate. Also, the vowel change observed is immaterial.

When considering the tableau for the form in (3c), the *COR»ID[PLACE] ranking in (4) become problematic:

(5) OT constraint ranking for *sock*

/sak/	*COR	*[+CONT]	ID[PLACE]	ID[CONT]
(a) ⊗ tak	*!		*	*
(b) ←kak			*	*
(c) sak		*		

In (5), an incorrect form (5b) is selected as optimal, with the correct form (5a) ruled out because of the alveolar stop. Chain shifts of this sort, and their corresponding constraint ranking paradoxes, mirror the class of opaque chain shifts found in adult natural languages (Kirchner, 1996), except none follow this particular pattern of velarization and stopping, likely due to the different set of articulatory and perceptual constraints on children (Inkelas & Rose, 2007). In all cases, the common problem lies in reconciling the constraint ranking motivating an alternation (as in (4)) with the non-alternation in similar surface-forms (5). I argue that for *these* chain shifts, the solution lies not in an amendment to OT, or an additional set of constraints, but rather in a change in underlying representation.

3. Lexical Inertia and Children's Underlying Representations

The key to understanding this example lies in another set of forms and a more careful analysis of the different stages of development in the children's speech:

(6) Stages of the *s>t>k* chain shift in M's speech

	<u>Stage 1(1;0-1;4)</u>	<u>Stage 2(1;4-1;7)</u>	<u>Stage 3(1;7+)</u>
a) <i>cookie</i>	kʊ.ki	kʊ.ki	kʊ.ki
b) <i>talk</i>	kʌk	kʌk	tʌk
c) <i>sock</i>	n/a	tak	tak
d) <i>table</i>	n/a	tej.bo	tej.bo

Stage one reflects velarization, stage two reflects fricative stopping and the chain shift above and in stage three, the chain shift is resolved as the velarization disappears, and *talk* is articulated with a [t]. Crucially, the existence of the chain shift is predicated on the velarization generalization being active at stage two. The newly acquired word *table* shows that this is not the case, however, as it is correctly articulated with a [t]. Therefore, only the stopping generalization is synchronically active at this stage, and no chain shift is present.

What to make, then, of the initial [k] in *talk*? If the consonant place constraints in (4) were reversed to reflect a non-active velarization generalization, as is suggested by the form [tejbo], then the optimal form for *talk* would be [tʌk]. Note that the evaluation in (4) uses the adult form as the underlying form, an assumption made for generative phonology frameworks in general (Smith, 1973) and OT in particular (e.g Demuth, 1996; Gnanadesikan, 1996; Goad, 1996; Smolensky, 1996). This is based, in part, on the

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observation that children's receptive vocabulary develops far faster than their production ability. This allows there to be a single lexicon supporting both production and perception.

In OT, however, the principle of lexicon optimization posits that the underlying form is set to match the optimal surface form in a phonological grammar. So, for example, while /k^hæt/, /kæt^h/ and /kæt/ all yield the surface form [k^hæt] in a grammar with syllable-initial aspiration, the underlying form established by the grammar for *cat* is /k^hæt/. Few, if any, theories of OT acquisition address the question of when lexicon optimization occurs and the lexicon established, relying on the adult UR assumption and the question of how this adult UR is generated via lexicon optimization is generally not articulated.

This is particularly problematic in light of the fact that grammatical constraints may be perceptual and not only articulatory (Ohala, 1993). For example, the sonority sequencing principle (SSP) is argued to reflect the increasing difficulty of hearing a stop followed by a glide, liquid, nasal and then stop (Blevins, 2003; Steriade, 1999;) and consequently, children simplify onsets to be less marked with respect to the SSP (e.g. *please* as [piz] or [pwiz]; Barlow & Gierut, 1999; Gnanadesikan, 1995). If this high-ranking constraint reflects perceptual difficulty, the UR for these children should be /piz/ or /pwiz/ and not the adult form, which is mis-produced because it is misheard.

This approach also fails to capture the long-observed phenomenon of lexical inertia (Menn & Stoel-Gammon, 1993) where older words are more resistant to changes in production. The form [kʌk] in (6b) can be understood as an instance of lexical inertia in light of the correct /t/→[t] in (6d). So, the correct articulation of the *t* in *table* in stage two of development reflects a change in production from stage one, while the legacy [k] in [kʌk] is emblematic of a resistance to change. (This is not a velar context effect – the same is found for words such as *tv* [ki.bi] and *tail* [ke.ow].)

While amendments to OT learning algorithms have been suggested to account for this (e.g. Tessier, *this volume*), the solutions are centered on lexical exceptions and require the storage of additional 'precocious' forms marked as errors. This does not capture the wide-spread commonality of this phenomenon, and does not utilize the existing OT architecture; they are fixes specific to this issue.

Instead, this phenomenon can be addressed by adopting a theory of acquisition that uses the concept of lexicon optimization. If we adopt repeated stages of lexicon optimization, we can account for lexical inertia in general, and the above chain shift in particular.

If, at stage one, the learner goes through a stage of lexicon optimization, her UR for *talk* will be set to /kʌk/. This eliminates the evidence for the /t/→[k] generalization in stage two, and the constraint evaluations for (6b) and (6c) in stage two are unproblematic:

(6) OT constraint ranking for *talk*

/kʌk/	ID[PLACE]	*COR
(a) → kʌk		
(b) tʌk	*!	*

(7) OT constraint ranking for *sock*

/sak/	ID[PLACE]	*[+CONT]	*COR	ID[CONT]
(a) → tak			*!	*
(b) kak	*			*
(c) sak		*		

Subsequently, as more correct tokens of *talk* are heard, without the high-ranked *COR constraint active, lexicon optimization sets the UR to [tak] at stage three.

4. Measuring Inertia

In this section, I show that this phenomenon is not relegated to just the above set of transcribed examples, but is reflective of the entire developing lexicon. To do so, I introduce the notion of WORD-AGE, which measures how long a child has had a word in her productive lexicon. This can serve to assess whether the production of surface [k] for adult [t] at a particular stage for particular words is a case of inertia. If the words that show this change at a particular stage are older than those that are correctly articulated as [t], then the alternation can be said to reflect inertia as opposed to still being active. Then the existence of a true synchronic chain shift can be assessed based on whether there is a point at which the two generalizations are active at the same time.

The measure for word-age used here is simply the difference between the present time and the time the word was first uttered according to transcripts. A more complete measure would also incorporate frequency and be based on the entire productive vocabulary of a child. Also, the focus here is on voiceless obstruents. Including voiced would yield a more comprehensive measure, but complicate matters since their production could also include other variable. The simpler measure is sufficient for present purposes here, however.

To determine whether a given alternation is present in M's productive lexicon at any one point, all of the word tokens containing the relevant segment in the adult form are extracted. They are then categorized as to whether they are correctly articulated, or reflect the alternation. For each category, the average age of all of the words is calculated. The results are shown in Table 1.

The table shows that from 12 to 22 months of age, M's overall lexicon reflects velarization and at around 16 months we see some correctly articulated coronals. At 18 months, continuing on through 22 months, while the number of correctly articulated coronals increases, we still see words showing the velarization. This reflects the well-known variability in children's speech. Crucially, we see the average word-age increasing

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as well, to the point where, at 22 months, only one word is still pronounced with a velar, *teeth* [kik], which is one of the earliest-acquired coronal words (~13 months of age, hence the 9.0 word-age: 22-13=9). These data suggest that the synchronic ban on coronals disappears around 18 months of age.

M's Age	12		14		16		18		20		22	
	WA	n										
<i>k</i>	0.5	5	1.2	18	1.6	34	2.9	51	4.4	62	6.9	71
[k]	0.5	5	1.2	18	1.6	34	2.9	51	4.4	62	6.9	71
<i>t</i>	0.8	12	1.8	24	1.7	44	2.1	49	3.9	68	6.7	73
[k]	0.8	12	1.8	24	1.8	41	3.9	18	6.1	10	9.0	1
[t]	0.0	0	0.0	0	0.2	3	1.0	31	3.5	58	6.7	72
<i>s</i>	0.0	0	0.7	6	1.7	8	2.3	38	4.3	42	7.1	41
[t]	0.0	0	0.0	0	0.0	1	0.9	20	4.2	41	0.0	0
[s/f]	0.0	0	0.7	6	1.9	7	3.9	18	7.1	1	7.1	41
Total	0.7	17	1.4	48	1.7	86	2.4	138	4.2	172	6.9	185

Table 1: Word-age (WA) of all transcribed words in M's productive lexicon between 12 and 22 months of age that reflect (non)-alternations of interest. The top column headings indicate M's age. Each row with the segment in italics indicates the word-age (WA) and number of tokens (n) of all words containing that segment in adults' pronunciation. Each row with a phone indicates the WA and n of all words articulated with that phone when the adult representation is the segment above in italics. The first row shows all adult-/k/ words, the second shows all adult-/k/ words articulated as [k], the third row shows all adult-/t/ words, the fourth row shows all adult-/t/ words articulated as [k], and so on.

For fricative stopping, the data actually show early correct production of fricatives up until about 18 months, where stopping progresses to the point of targeting nearly all words at 20 months. At 22 months, correct production resumes.

If stopping begins at around 18 month and velarization ends at around 16 months, counts then the word-age of tokens from this time period serves to assess whether there is a synchronic opaque relationship. At 18 months, 31 out of 49 tokens are correctly articulated as alveolar, and the relative word-age of tokens undergoing velarization is 3.9 as compared 1.0 for correctly articulated alveolars. This is highly suggestive that an observed velarization is an effect of lexical inertia. At 16 months velarization is present (41 of 43 tokens) and only beginning to disappear (word-age of velarized words is only 1.8 months). At this point, however, only one of eight words reflects stopping, So, the periods when there is synchronic velarization of new words and synchronic fricative stopping do not overlap. Therefore, there is no synchronic chain shift.

5. Conclusion

While M's production data show what looks to be examples of an opaque chain shift, a more careful analysis shows this not to be the case. The apparent chain shift is an

instance of lexical inertia, whereby the production of a word reflects the remnants of articulatory and perceptual constraints no longer active.

This is demonstrated by showing that there was no point at which both constraints were active for new words. All words that showed velarization when stopping was active were words that had been acquired much earlier and subject to lexical inertia, while newly acquired words did not reflect velarization at this point in time. The degree to which a word may be subject to lexical inertia can be computed through the use of word-age. Word-age measures how long a word has been in a child's lexicon; here a rough measure of the difference between the first recorded utterance of a word and the present utterance is used. In the present example, all words still undergoing velarization when stopping began were words with a word-age of 3.9 months as compared to correctly articulated coronals with a word-age of 1.0 months.

This suggests a solution to opacity in children similar to that suggested by Sanders (2003) for Polish. The Polish lexicon reflects an opaque relationship between back vowel raising before homosyllabic voiced stops (e.g. *bul* 'ache, NOM.-SG.'; *bɔlə* 'ache, NOM.-PL.') and word-final devoicing (e.g. *klubɪ* 'clubs', *klup* 'club'). Some words reflect what appears to be an opaque relationship:

(8) Opacity in the Polish lexicon (taken from Sanders, 2003):

UR	Nom Sg.	Nom. Pl.	
/bɔb/	bup	bɔbɪ	'bean'
/rɔv/	ruf	rɔvɪ	'ditch'
/lɔd/	lut	lɔdɪ	'ice'

Sanders shows, however, that the vowel-raising alternation is no longer synchronically active for Polish speakers using a wug test. Primed with a plural nonce word like [smatɔgɪ], no Polish speakers responded with [smatuk] as the singular form; instead, they responded with [samtɔk]. So, the lexicon reflects the remains of an historical process of raised back vowels that no longer constitutes the grammar of Polish.

Similarly, for any hypothetical opaque relationship observed in child speech, the present findings suggest that a careful analysis of the synchronic grammar is necessary to definitively show opacity exists. In light of the fact that children's grammar changes so rapidly, experimentation, like wug tests, or an examination of only newly acquired words, becomes necessary, instead of sourcing a lexicon of several different elicitation sessions.

Lexical inertia can be formalized through within Optimality Theory through the use of multiple stages of lexicon optimization. Lexicon optimization is OT's way of establishing a lexicon by setting the underlying form of words based on the optimal surface form. For non-alternating forms, this simply consists of setting a UR equivalent to the SR. If this is done for words when a particular phonological generalization is active, then these words will exhibit lexical inertia until UR is reset again based on correctly perceived examples of a word. This ultimately requires a dual model of the

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lexicon – one for perception and one for articulation – as outlined in Menn (1976), and a mechanism for one influencing the other.

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