CUES, OPACITY AND THE PUZZLE-PUDDLE-PICKLE PROBLEM

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In child language, interacting error patterns often result in opaque forms. One well-known example is the puzzle-puddle-pickle problem (Macken, 1980). In this example, Amahl (Smith 1973) at age 2;2 - 2;11, pronounces puzzle ([pʌzl̩]) words as puddle ([pʌdl̩]) words. Puddle ([pʌdl̩]) words are pronounced as pickle ([pʌgl̩]) words, while pickle ([pɪkl̩]) words are realized correctly. Amahl later (age 3;9) correctly pronounces puzzle and puddle words, but pronounces pickle ([pɪkl̩]) words) as puddle ([pɪtl̩]) words. This paper discusses the importance of examining the learnability of proposed OT analyzes of child language data and develops a demonstrably learnable account of the puzzle-puddle-pickle problem.

§1 examines the learnability of opaque forms using local constraint conjunction. §2 and §3 develop an alternate account of puzzle-puddle-pickle problem using fixed constraint hierarchies. §2 gives the perceptual basis of the analysis, while §3 implements the analysis in a harmony-as-faithfulness (Howe & Pulleyblank, 2004) framework. §4 gives the overall conclusions.

1. Learnability & Opacity in OT

This section examines the learnability of Dinnsen et al's (2001) OT analysis of the puzzle-puddle-pickle problem. Following Macken (1980), Dinnsen et al account for the puzzle-puddle-pickle problem using two acquisition stages: Early and Later. It is in the Early Stage that Amahl's error patterns yield a chain shift: target coronal fricatives are realized as coronal stops, while target coronal stops are realized as dorsal stops. What makes this a chain shift is that target coronal fricatives are not realized as dorsal stops. In the Later Stage, overgeneralization occurs when pickle words are realized as puddle words, but puzzle and puddle words are realized correctly.

In accounting for these patterns, Dinnsen et al use the markedness constraints in (1a) and the faithfulness constraints in (1b).

(1)	a.	*FRIC	Avoid fricatives
		*dl	Avoid coronals before liquid consonants
		*gl	Avoid velars before liquid consonants
	b.	IDENT (manner)	Corresponding segments must be identical in terms of manner features.
		IDENT (place)	Corresponding segments must be identical in terms of place features.
		LC	Corresponding segments must be identical in terms of either place or manner features.

Actes du congrès annuel de l'Association canadienne de linguistique 2006.
Proceedings of the 2006 annual conference of the Canadian Linguistic Association.

Dinnsen et al demonstrate that the constraints in (1) and their rankings as shown below in (2) are able to arrive at the desired outputs in each acquisition stage.

(2) Early Stage: LC, *FRIC, *dl, >> *gl >> ID (manner), ID (place)
Later Stage: LC >> ID (manner), *gl >> *dl, *FRIC, ID (place)

However, as learning in OT involves the learner demoting markedness and/or faithfulness constraints using positive evidence available in the input data, any OT analysis of child language data must consider the process of constraint demotion itself and not just the rankings necessary to yield observed patterns. The remainder of this section applies the constraint demotion algorithm (Tesar & Smolensky, 2002) to the stages in (2) to determine whether or not the rankings in (2) are indeed learnable.

1.1 The Early Stage

Since the Early Stage occurs after constraint demotion has begun, it is first necessary to consider the rankings found in the initial state. Gnanadesikan (1995) proposes that markedness constraints are initially ranked above faithfulness constraints. The learner, therefore, begins with the ranking in (3).

(3) *FRIC, *dl, *gl >> LC, ID (manner), ID (place)

LC, however, is a conjoined constraint; it joins together faithfulness to manner (IDENT (manner)) and faithfulness to place (IDENT (place)).[1] Kirchner (1996) argues that conjoined constraints are ranked higher than the individual constraints comprising the conjoined constraint. This gives the ranking in (4).

(4) *FRIC, *dl, *gl >> LC >> ID (manner), ID (place)

However, Dinnsen et al's analysis is not based on the above ranking. Given that in the Early Stage, LC is on the same stratum as the markedness constraints (see (2)), Dinnsen et al's analysis must begin with the initial ranking: LC,*FRIC, *dl, *gl >> ID (manner), ID (place). In their analysis, therefore, the conjoined *faithfulness* constraint functions as a *markedness* constraint.

Next consider whether learners can arrive at the ranking of the Early Stage from the initial ranking of the constraints. Note that since the goal here is to determine if learners can arrive at Dinnsen et al's proposed constraint rankings, I adopt Dinnsen et al's ranking of the initial state. The learning process is error-driven. That is, differences between the learner's output and the target (adult) grammar trigger a re-ranking of the constraints. As the tableau in (5) shows, only puzzle words are not realized as the adult form. It is this mismatch that activates the constraint demotion algorithm.

[1] This paper does not address outstanding issues with local constraint conjunction including what constraints can be conjoined, and what determines the domain of a conjoined constraint. See Padgett (2002) for a discussion of these issues.

(5) LC, *FRIC, *dl, *gl >> ID (manner), ID (place)[2]

		LC	*FRIC	*dl	*gl	ID (man)	ID (plce)
/pʌzl̩/	a. [pʌzl̩]		*	*!			
	b. ☞ [pʌdl̩]			*		*	
	c. [pʌgl̩]	*			*!	*	*
/pʌdl̩/	a. [pʌzl̩]		*	*!		*	
	b. ☞ [pʌdl̩]			*			
	c. [pʌgl̩]				*		*!
/pɪkl̩/	a. [pɪsl̩]	*	*!	*		*	*
	b. [pɪtl̩]			*			*!
	c. ☞ [pɪkl̩]				*		

Constraint Demotion operates on winner/loser pairs (Tesar & Smolensky, 2002). The winner is the adult form (in this example [pʌzl̩]), while the loser is the child's optimal form (in this example [pʌdl̩]). Data pairs are then subject to a process of marks cancellation, whereby any violations of the same constraint are eliminated. As shown in (6), the data pair [pʌdl̩]/[pʌzl̩] both violate *dl, which is then crossed out.

(6) [pʌdl̩]/[pʌzl̩]

Data Pairs	LC	*FRIC	*dl	*gl	ID (man)	ID (plce)
Loser: [pʌdl̩]			~~L~~		L	
Winner: [pʌzl̩]		W	~~W~~			

The remaining constraints are subjected to constraint demotion. Prince & Tesar (2004) propose that learners demote all constraints that prefer the loser (those that incur a 'W' mark) so that they are dominated by the highest ranking constraint that prefers the winner (those that incur an 'L' mark). Accordingly for [pʌdl̩]/[pʌzl̩], *FRIC is demoted below ID (manner). However, since ID

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[2] The conjoined constraint, LC, is only violated when both ID (manner) and ID (place) are violated.

(manner) and ID (place) occur on the same stratum, *FRIC is placed below both of these constraints giving the ranking in (7).

(7) LC, *dl, *gl >> ID (manner), ID (place) >> *FRIC

However, to arrive at Dinnsen et al's ranking for the Early Stage (see (2)), learners must demote *gl and not *FRIC. One possible solution to this problem is to reformulate *dl so that it prohibits coronal stops before liquids rather than all coronals. However, if this change is adopted, markedness constraints are not able to select a winner as the tableau in (8) shows.

(8) LC, *FRIC, *dl, *gl >> ID (manner), ID (place)

		LC	*FRIC	*dl	*gl	ID (man)	ID (plce)
/pʌzl̩/	a. ☞ [pʌzl̩]		*				
	b. [pʌdl̩]			*		*!	
	c. [pʌgl̩]	*			*!	*	*
/pʌdl̩/	a. [pʌzl̩]		*			*!	
	b. ☞ [pʌdl̩]			*			
	c. [pʌgl̩]				*		*!
/pɪkl̩/	a. [pɪsl̩]	*	*!			*	*
	b. [pɪtl̩]			*			*!
	c. ☞ [pɪkl̩]				*		

The task of selecting the optimal output is therefore deferred to the faithfulness constraints, and faithfulness constraints, by definition, select the most faithful candidate. Consequently, as shown in (8), child and adult forms are the same and no learning is needed.

This scenario can be avoided by adding a constraint such as *DORSAL (in addition to reformulating *dl). While puzzle and puddle words would still be realized as the adult form, pickle words would now be realized as puddle words. Such a mismatch would cause the learner to demote both *gl and *DORSAL to the bottom of the constraint hierarchy. This ranking (LC, FRIC, *dl >> ID (manner), ID (place) >> *gl, *DORSAL) is closer to that proposed for the Early Stage, and like the proposed ranking is able to yield the chain shift found in this stage. This solution, however, is still problematic as it continues to employ a conjoined faithfulness constraint that functions as a markedness constraint.

1.2 The Later Stage

Next consider if learners are able to arrive at the rankings proposed for the Later Stage. Again, I assume that learners begin with the ranking Dinnsen et al propose for the Early Stage. The tableau in (9) shows that this ranking yields the chain shift found in this stage: puzzle words are pronounced as puddle words, puddle words as pickle words, and pickle words are realized as the adult form.[3]

(9) LC, *FRIC, *dl >> *gl >> ID (manner), ID (place)

		LC	*FRIC	*dl	*gl	ID (man)	ID (plce)
/pʌzl̩/	a. [pʌzl̩]		*	*!			
	b. ☞ [pʌdl̩]			*		*	
	c. [pʌgl̩]	*			*!	*	*
/pʌdl̩/	a. [pʌzl̩]		*!	*		*	
	b. [pʌdl̩]			*!			
	c. ☞ [pʌgl̩]				*		*
/pɪkl̩/	a. [pɪsl̩]	*!	*	*		*	*
	b. [pɪtl̩]			*!			*
	c. ☞ [pɪkl̩]				*		

Again, the learning process is error-driven. Learning therefore results from two data pairs: [pʌdl̩]/[pʌzl̩] and [pʌdl̩]/[pʌgl̩]. The former data pair results in *FRIC being demoted below ID (manner), while the latter results in *dl being demoted below *gl. With these two demotions, learners arrive at the ranking in (10).

(10) LC >> *gl >> *dl >> ID (manner), ID (place) >> *FRIC

While this ranking is not exactly the same as what Dinnsen et al propose, the ranking is able to derive the overgeneralization of pickle words as puddle words. This is shown by the tableau in (11).

[3] It is worth noting that if, as discussed in the previous section, *FRIC is first demoted the resulting ranking (see (7)) cannot yield the chain shift that the ranking in (9) is able to yield.

(11) LC >> *gl >> *dl >> ID (manner), ID (place) >> *FRIC

		LC	*gl	*dl	ID (man)	ID (plce)	*FRIC
/pʌzl̩/	a. ☞ [pʌzl̩]			*			*
	b. [pʌdl̩]			*!		*	
	c. [pʌgl̩]	*!	*		*	*	
/pʌdl̩/	a. [pʌzl̩]			*	*!		*
	b. ☞ [pʌdl̩]			*			
	c. [pʌgl̩]		*!				
/pɪkl̩/	a. [pɪsl̩]	*!		*	*	*	*
	b. ☞ [pɪtl̩]			*		*	
	c. [pɪkl̩]		*!		*		

The ranking in (10), however, is problematic as it is not able to converge on the adult stage. Using the data pair [pɪtl̩]/[pɪkl̩], the learner demotes *gl below *dl giving the ranking LC >> *dl >> *gl >> ID (manner), ID (place) >> *FRIC. With this ranking, pickle words are realized correctly (the adult form), but puddle words are now realized as pickle words. This mismatch causes the learner to demote *dl below *gl, which then allows puddle words to be realized correctly, but pickle words to be realized as puddle words. This new mismatch now causes the learner to demote *gl below *dl, which then allows for the adult realization of pickle words but not puddle words. Essentially, the learner goes back and forth or 'thrashes' between the two rankings *dl >> *gl and *gl >> *dl, and consequently never converges on the adult grammar.

To summarize, when the internal workings of the constraint demotion algorithm are applied to the proposed rankings, serious problems are revealed. In particular, both the rankings proposed for the Early and Later Stages are not learnable as is the adult grammar. The next two sections outline an analysis using universally fixed constraint hierarchies that is based on the robustness of internal and contextual cues to place and manner, and which is learnable.

2. The Perceptual Basis of the Analysis

2.1 Acoustic Cues

This section outlines the acoustic cues to place and manner upon which the proposed perceptual analysis of the puzzle-puddle-pickle problem is based.

The acoustic cues to oral stops and fricatives, the only articulations of interest in this analysis, are summarized in (12).

(12) Summary of Cues to Stops and Fricatives

	Stops (oral)	**Fricatives**
Internal		
Manner	Attenuation	Fricative noise
Place	Duration of attenuation	Fricative noise spectrum
Contextual		
Manner	Noise Burst	
Place	F2 Transition Noise burst spectrum	F2 Transition

First consider internal cues to articulation, which are found in the closure, or onset phase, of a segment's articulation. Both attenuation and fricative noise are cues to manner of articulation. Attenuation is a cue to a stop articulation (Wright, 2004). Stops are articulated with a complete occlusion of the oral cavity which prevents air from escaping. This maximal degree of stricture creates an abrupt attenuation, or reduction, of energy at higher frequencies (Wright, 2004). The duration of this attenuation is a cue to place in a stop articulation. Fricative noise is a cue to a fricative articulation. Fricatives are articulated with a narrowing of the vocal tract that is sufficient to create a turbulent airflow that results in noise. The spectrum of fricative noise provides the listener with information regarding place in a fricative articulation.

Next consider contextual cues to manner and place. Contextual cues exist in the transition from one segment to the next, and occur in the offset, or release phase of a segment's articulation. For stops, contextual cues to manner are found in the noise burst that follows the sudden movement away from the oral constriction. This noise burst spectrum also provides the listener with information about the stop's place of articulation. In addition, F2 transitions that occur as the stop articulation is released into a vowel also provide the listener with information concerning its place of articulation. Similarly, F2 transitions provide listeners with information pertaining to the place of articulation in fricatives. Finally, it should be noted that fricative noise can also be considered a contextual cue; fricative noise continues through the offset phase. However, since the articulation of a fricative is not correlated with additional cues, I follow Wright (1999) in identifying fricative noise only as an internal cue.

Constraint hierarchies will be based on the strength, or robustness of the acoustic cues shown above in (12). This is discussed next.

2.2 Cue Robustness

Cue Robustness (Wright, 1999, 2001, 2004) refers to (a) the presence of strong acoustic cues, and (b) the presence of redundant acoustic cues. First consider the former. I propose that the presence of strong acoustic cues is correlated with internal cues to articulation. The strength of internal cues to manner is linked to differences in degree of stricture. Sounds articulated with a greater degree of oral stricture have weaker internal cues than do sounds articulated with a lesser degree of oral stricture. The complete oral constriction that is found in a stop articulation results in the absence of noise. In contrast, the lesser oral stricture found in a fricative articulation results in noise albeit aperiodic. Fricative noise, therefore, is a stronger cue to manner than is attenuation.

(13) fricative noise > attenuation

Recall that the cue to place in a stop is the duration of attenuation. Labials and coronals tend to have longer durations than do dorsals (Stathopoulos and Weismer, 1983). I argue that Internal cues to labial and coronal place in stops are more robust than cues to dorsal place in that a longer duration provides the listener with more time to identify place of articulation. For fricatives, internal cues to place are found in the fricative noise spectrum. For sibilant fricatives, this cue is sufficient for learners to identify place of articulation. In contrast, for non-sibilant fricatives, F2 transitions, a contextual cue, aid the listener in reliably identifying place (Ladefoged, 2001). Since sibilancy has no bearing on the analysis being developed here, it is sufficient to posit that internal cues to coronals are stronger than those to labial and dorsal articulations.[4] The robustness of cues to place in stops and fricatives is summarized in (14).[5]

(14)	Stops:	labial, coronal	>	dorsal
	Fricatives:	coronal	>	labial, dorsal

Next, consider cue redundancy. The presence of redundant cues ensures that the acoustic signal is sufficiently robust for the listener to recover and identify featural information in the noisy environments typical of speech. Stops have the strongest contextual cues, in that stops have redundant cues to their articulation. As was shown in (12), stops have both internal (attenuation) and contextual (noise burst) cues to their articulation. In contrast, fricatives only have internal cues to their articulation. There appears to be an inverse relationship between the robustness of internal and contextual cues. Articulations having stronger internal cues (fricatives) have weaker contextual cues, while articulations having stronger contextual cues (stops) have weaker contextual cues. As will be discussed in the next section, this inverse relationship has implications for the constraint system derived from cue robustness.

[4] There are, of course, other chain shifts that occur in the child language data (e.g. [s] -> [θ] -> [f]) for which sibilancy must be considered. This is left for future research.

[5] Note that it is possible to capture this difference in cue robustness using the acoustic features grave and diffuse. Labial and dorsal articulations generate a grave cue, while labial and coronal articulations generate a diffuse cue. Sibilancy can also be analyzed as having an enhancing effect on articulations that generate non-grave cues (Vanderweide, 2005).

3. A Re-Analysis of the Puzzle-Puddle-Pickle Problem

3.1 The Constraint Hierarchy

The re-analysis of the puzzle-puddle-pickle problem proposed in this section is based on universally fixed hierarchies of constraints. Within OT, such hierarchies can be used to derive implicational universals (i.e. A only if B), and are based on prominence scales such as those proposed in (13) and (14). Padgett (2002) argues that the constraint hierarchies projected from these scales also eliminate the need for local constraint conjunction. I show in this section that (1) a fixed constraint hierarchy can be used to account for the error patterns found in both the Early and Later Stages, and (2) that the re-rankings necessary to yield these patterns are learnable.

Recall from §1 that the locally conjoined constraint employed in Dinnsen et al's analysis conjoins together faithfulness to place and faithfulness to manner. The same effect can be achieved by aligning the internal cues to place with the internal cues to manner and implementing the resulting prominence scale using harmony-as-faithfulness.

As was shown in (14), internal cues to coronal place are stronger than cues to dorsal place.[6] Further, this is valid for both stops and fricatives. As well, fricatives have stronger internal cues to manner of articulation than do stops (see (13)). Finally, Padgett argues that what is more specific is universally more prominent than what is more general.[7] Taken together these proposals result in the prominence scale in (15a).

(15) a. Coronal (fricative) > Dorsal (fricative) > Fricative >
Coronal (stop) > Dorsal (stop) > Stop

b. ID_{COR} (fricative) >> ID_{DOR} (fricative) >> ID (fricative) >>
ID_{COR} (stop) >> ID_{DOR} (stop) >> ID (stop)

Howe & Pulleyblank (2004) argue that when prominence scales are perceptually motivated, they translate into universally fixed hierarchies of contextually specified *faithfulness* rather than markedness constraints. This gives the hierarchy of faithfulness constraints in (15b).

It is important to note that identity constraints apply to segments rather than features. Thus, the constraints in (15b) having the format ID_{PLACE} (manner) are violated when corresponding segments do not have the same place, regardless of whether the manner in the input segment is the same as its corresponding output segment. Similarly, constraints in (15b) having the format ID (manner) are violated when an output segment does not have the same manner as its corresponding input segment, regardless of any change to place. Some examples are shown in (16).

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[6] Labials are omitted as they have no bearing on the chain shift under consideration.

[7] For Padgett, prominence encompasses articulation, perception, and processing.

(16) I:

	/d/	/d/	/d/	/d/
I:	COR, STOP	COR, STOP	COR, STOP	COR, STOP
	|	|	|	|
O:	[d]	[z]	[g]	[x]
	COR, STOP	COR, FRIC	DOR, STOP	DOR, FRIC
	√√	√*	*√	**

/d/ -> [d] in being completing faithful does not violate either constraint. In contrast, /d/ -> [x] violates both ID_{PLACE} (manner) and ID (manner). Finally, /d/ -> [z] only violates ID (manner), while /d/ -> [g] only violates ID_{PLACE} (manner).

While faithfulness constraints are based on the strength of internal cues to articulation, markedness constraints prohibit against segments having weaker contextual cues. In this way, the markedness and faithfulness constraints together capture the robustness of internal and contextual cues to manner and place of articulation. The proposed markedness constraints, shown in (17), prohibit against any sound that is not a coronal. This follows from the inverse relationship that exists between the robustness of internal and contextual cues. Coronals in having the strongest internal cues to their articulation have the weakest contextual cues.

(17) a. *COR (fricative) Avoid coronal fricatives
b. *COR (stop) Avoid coronal stops

In addition to the markedness constraints shown in (17), Dinnsen et al's constraints against coronals and dorsals before liquids are still required. These are shown in (18). Note that (18a) has been reformulated to apply only to coronal stops rather than all coronals.

(18) a. *DL Avoid a coronal stop before a liquid consonant.
b. *GL Avoid a dorsal stop before a liquid consonant.

The remainder of this section presents a re-analysis of the error patterns observed in the Early and Later Stages.

3.2 A Re-Analysis of the Early Stage

Again, learners begin with markedness constraints ranked above faithfulness constraints. I propose that markedness constraints are ranked above the hierarchy of faithfulness constraints to which they pertain. This results in the hierarchy of constraints shown in (19).

(19) *COR (fricative) >> ID_{COR} (fricative) >> ID_{DOR} (fricative) >>
ID (fricative) >> *COR (stop), *DL, *GL >>
ID_{COR} (stop) >> ID_{DOR} (stop) >> ID (stop)

What is different from standard OT in this analysis is that the learner does not begin with all markedness constraints ranked above all faithfulness constraints. The ranking in (19) yields the chain shift found in the Early Stage. [8]

(20) *COR (fric) >> ID$_{COR}$ (fric) >> ID (fric) >>*COR (stop), *DL, *GL
>> ID$_{COR}$ (stop) >> ID$_{DOR}$ (stop) >> ID (stop)

		*COR (fric)	ID$_{COR}$ (fric)	ID (fric)	*COR (stop)	*DL	*GL
/pʌzl̩/	a. [pʌzl̩]	*!					
	b.☞ [pʌdl̩]			*	*	*	
	c. [pʌgl̩]		*!	*			*

		*COR (fric)	*COR (stop)	*DL	*GL	ID$_{COR}$ (stop)	ID (stop)
/pʌdl̩/	a. [pʌzl̩]	*!					*
	b. [pʌdl̩]		*	*!			
	c.☞ [pʌgl̩]				*	*	

		*COR (fric)	*COR (stop)	*DL	*GL	ID$_{DOR}$ (stop)	ID (stop)
/pɪkl̩/	a. [pɪsl̩]	*!				*	*
	b. [pɪtl̩]		*	*!		*	
	c.☞ [pɪkl̩]				*		

As the tableaux in (20) illustrate, puzzle words are realized as puddle words, puddle words as pickle words, and pickle words and pickle words.

Again, the learning process is error-driven. A mismatch between both puzzle words (realized as puddle words) and puddle words (realized as pickle words) cause the learner to re-rank constraints. Again, the process of constraint demotion is based upon data pairs. For (20), two data pairs are relevant: [pʌzl̩]/[pʌdl̩] and [pʌzl̩]/[pʌgl̩]. The constraints each of these data pairs violate are shown in (21).

[8] Only those constraints relevant to the input and output examples presented are shown in the remaining tableaux.

(21) a. [pʌzl̩]/[pʌdl̩]

Data Pairs	*COR (fric)	ID$_{COR}$ (fric)	ID (fric)	*COR (stop)	*DL	*GL
Loser: [pʌdl̩]			L	L	L	
Winner: [pʌzl̩]	W					

b. [pʌdl̩]/[pʌgl̩]

Data Pairs	*COR (stop)	*DL	*GL	ID$_{COR}$ (stop)	ID$_{DOR}$ (stop)	ID (stop)
Loser: [pʌgl̩]			L	L		
Winner: [pʌdl̩]	W	W				

Again, constraints that prefer the loser (those that incur a 'W') are demoted to below the first constraint that prefers the winner (those that incur an 'L'). I propose that only markedness constraints preferring the loser are demoted. Further, I propose that markedness constraints are demoted to below the first faithfulness constraint preferring the winner. So, for [pʌzl̩]/[pʌdl̩], *COR (fric) is demoted below ID (fric), and for [pʌdl̩]/[pʌgl̩], *COR (stop) and *DL are demoted below ID$_{COR}$ (stop). These two demotions give the ranking in (22).

(22) ID$_{COR}$ (fricative) >> ID$_{DOR}$ (fricative) >> ID (fricative) >>
*COR (fricative) >> *GL >> ID$_{COR}$ (stop) >>
*COR (stop), *DL >> ID$_{DOR}$ (stop) >> ID (stop)

The next section shows that the above ranking yields the patterns found in the Later Stage, and that the learner is able to converge on the adult grammar.

3.3 A Re-Analysis of the Later Stage

In the Later Stage, both puzzle and puddle words are realized as correctly (the adult form), but pickle words are overgeneralized and realized as puddle words. The tableaux in (23) illustrates that the ranking in (22) yields this pattern.

(23) ID_{COR} (fric) >> ID_{DOR} (fric) >> ID (fric) >> *COR (fric) >> *GL >>
ID_{COR} (stop) >> *COR (stop), *DL >> ID_{DOR} (stop) >> ID (stop)

		ID_{COR} (fric)	ID (fric)	*COR (fric)	*GL	*COR (stop)	*DL
/pʌzl̩/	a.☞ [pʌzl̩]			*			
	b. [pʌdl̩]		*!			*	*
	c. [pʌgl̩]	*!	*		*		

		*COR (fric)	*GL	ID_{COR} (stop)	*COR (stop)	*DL	ID (stop)
/pʌdl̩/	a. [pʌzl̩]	*!					*
	b.☞ [pʌdl̩]				*	*	
	c. [pʌgl̩]		*!	*			

		*COR (fric)	*GL	*COR (stop)	*DL	ID_{DOR} (stop)	ID (stop)
/pɪkl̩/	a. [pɪsl̩]	*!				*	*
	b.☞ [pɪtl̩]			*	*	*	
	c. [pɪkl̩]		*!				

Constraint demotion operates on the data pair [pɪkl̩]/[pɪtl̩], and results in the demotion of *GL below ID_{DOR} (stop). This gives the ranking shown in (24).

(24) ID_{COR} (fricative) >> ID_{DOR} (fricative) >> ID (fricative) >>
*COR (fricative) >> ID_{COR} (stop) >> *COR (stop), *DL >>
ID_{DOR} (stop) >> *GL >> ID (stop)

This ranking converges on the adult grammar: puzzle, puddle, and pickle words are all realized as the adult forms.

4. Conclusion

This paper has argued that consideration of the internal workings of the Constraint Demotion algorithm is crucial when proposing OT analyzes of the error patterns found in child language data. This paper has also developed an analysis of the puzzle-puddle-pickle problem that is learnable. Using universally fixed hierarchies of perceptually motivated constraints implemented in harmony-as-faithfulness, I have proposed that (1) learning occurs within a number of constraint hierarchies; (2) that within each hierarchy, learners begin with all markedness constraints ranked above all faithfulness constraints; (3) that within each hierarchy, learners demote markedness constraints below faithfulness constraints; and (4) that learning can occur within different hierarchies during a single stage of acquisition.

Overall, the analysis developed in this paper contributes to on-going research on the role of faithfulness in the acquisition of phonotactics.

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