A PERCEPTUAL ANALYSIS OF CONSONANT CLUSTER REDUCTION

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This paper examines patterns of reduction in which children reduce a word initial consonant cluster of the form C_1C_2V by deleting either the first (C_1) or second (C_2) member of the cluster. §1 presents the data, and discusses previous accounts based on sonority and prosodic structure. §2 and §3 develop an alternate account of the reduction data given in §1. §2 gives the perceptual basis of the analysis, while §3 implements the analysis in OT (Prince & Smolensky, 1993/2004) using Harmony-as-Faithfulness (Howe & Pulleyblank, 2004). §4 gives the overall conclusions.

1. Analyzes based on Sonority and Prosodic Structure

The reduction of a consonant cluster to a single segment is a common phenomenon in child language (see Smith (1973), Fikkert (1994), Gnanadesikan (1995), Pater and Barlow (2003), Jongstra (2003a,b) among others). Children often reduce a consonant cluster by deleting either the first or second member of the cluster.[1] Some examples are shown in (1)

(1) a. C_1C_2 reduced to C_1

Child	Examples	
Gitanjali (Gnandesikan, 1995)	[kin] [piz] [fɛn]	<u>cl</u>ean <u>pl</u>ease <u>fr</u>iend
Leon (Fikkert, 1994)	[buːmə] [tɛi] [suːp]	<u>bl</u>oemen (flowers) <u>tr</u>ein (train) <u>sn</u>oep (sweet)

b. C_1C_2 reduced to C_2

Child	Examples	
Gitanjali	[gaj] [bɪw]	<u>sk</u>y <u>sp</u>ill
Jarmo (Fikkert, 1994)	[tuːf] [tyːs]	<u>st</u>oel (stool) <u>st</u>uk (piece)

[1] Children may also reduce a consonant cluster to a third segment comprised of features from the original members of the cluster. Such instances will not be considered in this paper.

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The data in (1a) is often accounted for using sonority: children retain the *least* sonorous member of the cluster (Fikkert (1994), Gnandesikan (1995), Gierut (1999), Pater & Barlow (2003) among others). If it is assumed that plosives are the least sonorant, then sonority can also account for the data in (1b). Children retain the plosive in words such as *spill*, but the fricative in words such as *friend*.

However in clusters consisting of /s/ followed by a sonorant, children may retain the *more* sonorant member of the cluster. This is shown in (2).

(2) Reduction to a Sonorant

Child	**Examples**
Amahl (Smith, 1973)	[lʌg] slug [mɔ:] small
Catootje (Fikkert, 1994)	[na:fɔ] snavel (bill) [la:pə] slapen (to sleep)

The deletion of /s/ in (2) can be accounted for if /s/ is analyzed as an appendix with the sonorant functioning as the head of the onset cluster (this analysis is proposed by Goad & Rose (2004)). Under this analysis, if it is assumed that children retain the head of the cluster, then /s/ is predicted to always delete.[2] Children, however, may also reduce /s/ sonorant clusters to the /s/ as the examples in (3) illustrate.

(3) Reduction to /s/

Child	**Examples**
Julia (Pater & Barlow, 2003)	[sip] sleep
Jarmo (Fikkert, 1994)	[sa:pə] slapen (to sleep)
Leon	[su:p] snoep (sweet) [se:w] snow (snow)

Goad and Rose (2004) account for the variation in (2) and (3) with two acquisition stages. In Stage One, children analyze /s/ as the head of the onset cluster, which is then retained on the basis of sonority. In Stage Two, children re-analyze /s/ as an appendix, which then deletes.

The variation observed in /s/ sonorant clusters is not restricted to just these clusters. The examples in (4) show that this same variation is also observed in plosive plus nasal and /f/ plus liquid clusters.

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[2] This analysis can also be applied to the data in (1b).

(4) Variation in Other Clusters

Child	Examples
Robin (Fikkert, 1994)	[kɪp] knip (cut) [nu:jə] knoeien (to make a mess)
Julia	[fɔgi] froggy
Catootje	[lœyt] fluit (flute)

Jongstra (2003a,b) proposes that children initially assign heads and appendices on the basis of sonority. For clusters that rise in sonority (e.g. /pl/, /tw/, /kn/, /sl/), the first member of the cluster is the head. For clusters that exhibit a sonority reversal (e.g. /sk/ and /sp/), the first member of the cluster is the appendix. Jongstra further proposes that children later re-assign the head from the first to the second member in clusters that do not form *good* onsets. Jongstra defines a *good* onset as one which has a sonority distance of three or more using the scale in (5).

(5) Vowels > Glides > /r/ > /l/ > Nasals > Fricatives > Plosives

Jongstra's two proposals result in a mix of stable and variable clusters. For the stable clusters (6a), the head (underlined) remains the same in both stages and will therefore always be retained.

(6) a. Stable Clusters: pl, pr, bl, br, tr, dr, kl, kr
tw
sk, sp

b. Variable Clusters: kn
sl, fl, χl
sm, sn

For the variable clusters (6b), the head is initially analyzed as the first member of the cluster and later as the second member. For these clusters, which segment children delete and which they retain is different in each stage.

Two problems can be identified with Jongstra's analysis.[3] First, her proposal requires that an appendix plus head representation be assigned not only to /s/ sonorant clusters but also to plosive plus nasal (e.g. /kn/) and fricative plus liquid (e.g. /fl/) clusters. She does not present any independent evidence justifying assigning an appendix initial representation to these clusters in particular the latter. Second, Jongstra proposes that the analysis of /s/ as an appendix in clusters such as /sp/ and /sk/ constitutes the positive evidence children need to re-analyze clusters similar in sonority from head-initial to head-final. /sp/ and /sk/ clusters, however, have a sonority distance of one not three. Jongstra does not discuss the type of evidence that children would need to re-analyze not only clusters having a sonority distance of one, but all clusters

[3] For a more detailed review of Jongstra's analysis see Vanderweide (2005).

having a sonority distance of less than three. Despite these problems, Jongstra's data clearly shows that variation in reduction patterns is not limited to /s/ sonorant clusters. Any account of children's reduction patterns must therefore attempt to explain this variation.

I propose that the stable and variable patterns of deletion in (6) follow from perceptibility, rather than from similarity in sonority.[4] My basic claim is that which member of a cluster children delete and which they retain is determined by comparing the perceptibility of the two possible resulting CV sequences (C_1V and C_2V). The CV sequence that is more perceptible is predicted to occur in children's outputs. Variation is predicted when (1) different types of cues decide between competing candidates in different stages of acquisition, and (2) when both CV sequences are equally perceptible. I begin by outlining the perceptual basis of the analysis.

2 A Perceptual Analysis

2.1 Acoustic Cues

The perceptibility of a CV sequence is based on the robustness of the internal and contextual cues to manner of articulation. Wright (2004) proposes three internal cues to manner. These are summarized in (7).

(7) Summary of Internal Cues to Articulation

Manner:	**Aperture:**	**Acoustic Cue:**
Oral Plosives	Oral: A_0 Nasal: N_0	Attenuation
Nasal Plosives	Oral: A_0 Nasal: N_{max}	Attenuation Nasal Formant
Fricatives	Oral: A_f	Fricative noise
Approximants	Oral: A_{max}	Formant Structure

I link the acoustic cues in (7) to the degree of stricture that occurs during the medial, or closure phase, of a segment's articulation. I follow Steriade (1992) in using oral aperture to represent differences in stricture. A complete occlusion of the oral cavity results in a minimal aperture (A_0). Since air is prevented from escaping, a minimal aperture creates an abrupt attenuation, or reduction, of energy at higher frequencies (Wright, 2004). As such, attenuation cues a plosive articulation. The presence or absence of nasal airflow is also a cue to a plosive articulation. I propose two degrees of nasal aperture. A minimal aperture (N_0) results when the velum is raised so that no air is permitted in the nasal passages. In contrast, a maximal aperture (N_{max}) is found when the velum is lowered so that air can flow through the nasal passages. This maximal aperture allows the vocal tract to resonate. Nasal formant structure, therefore, is

[4] The clusters /fr/ and /χr/ have been omitted from (6a). /sw/, /st/ and /sχ/ clusters have been omitted from (6b). I discuss these clusters further in §3.4.

a cue to a nasal plosive. In summary, attenuation cues both oral and nasal plosives, with nasal formant structure distinguishing nasal plosives from oral plosives.

A narrowing of the vocal tract sufficient to create a turbulent airflow results in an intermediate aperture (A_f). Fricative noise, therefore, is a cue to sounds (fricatives) articulated with an intermediate aperture. A maximal aperture (A_{max}) is present when the oral cavity is more open. This type of aperture results in an airflow that is free from turbulence, and allows the vocal tract to resonate. Formant structure, therefore, is a cue to sounds (approximants) articulated with a maximal oral aperture.

Next consider contextual cues. 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. Unlike internal cues, contextual cues to manner are found only in oral airflow. For plosives, contextual cues to manner are found in the noise burst that follows the sudden movement away from the oral constriction. According to Steriade (1992), a maximal oral aperture (A_{max}) occurs, as the oral constriction is released. The presence of this oral aperture is correlated with the presence of a noise burst. It should be noted that both fricative noise and formant structure can also be considered contextual cues; fricative noise and formant structure continues through the offset phase. However, since the articulation of either a fricative or an approximant is not correlated with additional cues, I follow Wright (1999) in fricative noise and formant structure solely as internal cues.

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. I propose that the strength of the internal cues to manner given in (7) can be linked to differences in degree of stricture. Essentially, sounds articulated with a continuous airflow have stronger internal cues to their articulation than do those lacking a continuous airflow.

First consider oral airflow. The absence of an oral airflow during the closure phase of a plosive's articulation is correlated with weak internal cues. This is because a complete oral constriction results in the absence of any noise. The implication, then, is that sounds articulated with a minimal oral aperture have weaker internal cues than do sounds articulated with a greater degree of oral aperture. This gives the ranking in (8a).[5]

[5] Note that the cues to formant structure are stronger than the cues to fricative noise. This is due to the recognizable pattern generated as a result of the regular repeating nature of periodic sounds. In contrast, aperiodic sounds such as fricatives lack this repeating patternI rank both formant structure and fricative noise, however, above attenuation, in that regardless of whether these cues are periodic or aperiodic, both are still stronger than the absence of sound.

(8) a. Oral Aperture: formant structure > attenuation
fricative noise

b. Nasal Aperture: nasal formant > attenuation

Next consider nasal airflow. The presence of an oral constriction in the articulation of a nasal creates anti-resonances which weaken the intensity of the nasal formants (Ladefoged (2001), Wright (2004)). The formant structure found in approximants is therefore a stronger internal cue that is the formant structure found in nasals. This gives the ranking shown above in (8b). Combining the ranking of oral and nasal aperture cues in (8) results in the hierarchy of internal cues shown in (9a). This is stated in terms of aperture in (9b).

(9) a. formant structure > nasal formant > attenuation
fricative noise

b. A_{max}, A_f > A_0 (N_{max}) > A_0 (N_0)

Finally, 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. Plosives have the strongest contextual cues, in that plosives have redundant cues to their articulation: plosives have both internal (attenuation) and contextual (noise burst) cues to their articulation. The next section implements the perceptual analysis developed in this section using Harmony-as-Faithfulness and shows how this analysis can derive the stable and variable patterns of reduction in (6).

3. Harmony-As-Faithfulness

3.1 Harmony and Constraint Hierarchies

Howe & Pulleyblank (2004) argue that when prominence scales are perceptually motivated as in (9), they translate into universally fixed hierarchies of contextually specified *faithfulness* rather than markedness constraints. Consequently, in a pre-vocalic context, faithfulness to approximants (A_{max}) and fricatives (A_f) is ranked higher than is faithfulness to nasals plosives (A_0 (N_{max})), which in turn is ranked higher than is faithfulness to oral plosives (A_0 (N_0)). This ranking is shown in (10)

(10) MAX (A_{max} / _V), MAX (A_f / _V) >>
MAX (A_0 (N_{max}) / _V) >> MAX (A_0 (N_0) / _V)

Under a Harmony-as-Faithfulness approach, markedness constraints are generally rather than contextually specified. In this analysis, markedness constraints prohibit against segments having weaker contextual cues. More specifically, markedness constraints (in (11)) prohibit against any sound that is not an oral plosive. This follows from the inverse relationship that exists between the robustness of internal and contextual cues: articulations having stronger internal cues (fricatives and approximants) have weaker contextual cues, while articulations having weaker internal cues (plosives) have stronger contextual cues. Oral plosives in having the weakest internal cues have the strongest contextual cues.

(11) a. *CONT (oral) — Avoid a consonant that is articulated with a continuous oral airflow.

b. *CONT (nasal) — Avoid a consonant that is articulated with a continuous nasal airflow.

The markedness constraints in (11) and the faithfulness constraints in (10) together capture the robustness of internal and contextual cues to manner of articulation. The remainder of this section derives the patterns of reduction found in child language beginning with plosive initial clusters.

3.2 Plosive Initial Clusters

I assume that in the initial state, markedness dominates faithfulness (Gnanadesikan (1995) and Smolensky (1996)). This gives the ranking in (12).[6]

(12) *CONT (oral), *CONT (nasal) >> MAX (A_f / _V)
>> MAX (A_0 (N_{max}) /_V) >> MAX (A_0 (N_0) /_V)

Inputs:	Outputs:	*CONT (oral)	*CONT (nasal)	MAX (A_{max} / _V)	MAX (A_0 (N_{max}) / _V)	MAX (A_0 (N_0) / _V)
PLV	a. ☞ PV			*		
	b. LV	*!				*
PGV	a. ☞ PV			*		
	b. GV	*!				*
PNV	a. ☞ PV				*	
	b. NV		*!			*

With this ranking, all plosive initial clusters will reduce to the plosive, the articulation with the strongest contextual cues.

Children later reduce plosive plus nasal (PN) clusters to the nasal. I argue that this reduction follows from the order in which children acquire the different manners of articulation. Fikkert (1994) showed that children learning

[6] Any constraints not pertaining to either the input or output candidates are omitted from all tableaux presented.

Dutch acquire oral plosives before they acquire nasal plosives. Children, therefore, will demote *CONT (nasal) before they demote *CONT (oral). This gives the ranking in (13). With this new ranking, plosive plus liquid (PL) and plosive plus glide (PG) clusters continue to reduce to the plosive. However for plosive plus nasal (PN) clusters, the nasal is now optimal in that it is more faithful to the input than is a CV sequence containing an oral plosive. This is shown by the tableau in (13).

(13) *CONT (oral) >>MAX (A_{max} / _V) >> MAX (A_0 (N_{max}) /_V) >> MAX (A_0 (N_0) /_V) >> *CONT (nasal)

		*CONT (oral)	MAX (A_{max} / _V)	MAX (A_0 (N_{max}) / _V)	MAX (A_0 (N_0) / _V)	*CONT (nasal)
PLV	a. ☞ PV		*			
	b. LV	*!			*	
PGV	a. ☞ PV		*			
	b. GV	*!			*	
PNV	a. PV			*!		
	b.☞ NV				*	*

It is important to note that the reduction of a PN cluster initially to the plosive and later to the nasal is not the result of changes to the child's perceptual abilities but rather follows from changes to the child's grammar.

3.3 Fricative Initial Clusters

3.3.1 Fricative+Plosive and Fricative+Nasal Clusters

As with plosive initial clusters, I assume that in the initial state markedness dominates faithfulness as shown by the following tableau.

(14) *CONT (oral), *CONT (nasal) >> MAX (A_f / _V) >> MAX (A_0 (N_{max}) /_V) >> MAX (A_0 (N_0) /_V)

		*CONT (oral)	*CONT (nasal)	MAX (A_f / _V)	MAX (A_0 (N_{max}) / _V)	MAX (A_0 (N_0) / _V)
FPV	a. FV	*!				*
	b. ☞ PV			*		
FNV	a. ☞ FV	*			*	
	b. NV		*	*!		

(14) illustrates that fricative plus plosive (FP) clusters reduce to the plosive. The optimality of CV sequences containing a plosive follows from markedness: plosives have the strongest contextual cues. In contrast, fricative plus nasal (FN) clusters reduce to the fricative. The optimality of the fricative follows from faithfulness: fricatives are more faithful to the input than are nasals. The implication here is that when the robustness of contextual cues is equal, the robustness of internal cues decides the optimal candidate.

Variation in FN clusters is also linked to acquisition order. Once children demote *CONT (nasal), contextual cues rather than internal cues decide the optimal candidate. This candidate is now the CV sequence containing the nasal. This is shown below in (15).

(15) *CONT (oral) >>MAX (A_f / _V) >> MAX (A_0 (N_{max}) /_V) >> MAX (A_0 (N_0) /_V) >> *CONT (nasal)

		*CONT (oral)	MAX (A_f / _V)	MAX (A_0 (N_{max}) / _V)	MAX (A_0 (N_0) / _V)	*CONT (nasal)
FPV	a. FV	*!			*	
	b. ☞ PV		*			
FNV	a. FV	*!		*		
	b. ☞ NV		*			*

Notice that variation in the reduction of PN and FN clusters occurs for different reasons. The initial reduction of PN clusters to a plosive follows from markedness, while the initial reduction of FN clusters to a fricative follows from faithfulness. The later reduction of these clusters to a nasal follows from markedness for FN clusters, but faithfulness for PN clusters. Each reduction, however, follows from perceptibility: faithfulness selects the candidate with the strongest internal cues, while markedness selects the candidate with the strongest contextual cues.

3.3.2 Fricative+Liquid Clusters

Unlike with the clusters discussed so far, neither faithfulness nor markedness can determine an optimal candidate for fricative plus liquid (FL) clusters. This is shown by the tableau in (16).

(16) *CONT (oral) >> MAX (A_f / _V), MAX (A_{max} /_V)

FLV	*CONT (cont)	MAX (A_f / _V)	MAX (A_{max} / _V)
a. ☞ FV	*		*
b. ☞ LV	*	*	

As shown in (16), both output candidates violate markedness constraints. Furthermore, since fricatives and approximants have the same perceptibility, no dominance relationship exists between MAX (A_f / _V) and MAX (A_{max} / _V). Faithfulness constraints can therefore also not select an optimal candidate.

According to Antilla (1997), the ranking of MAX (A_f / _V) and MAX (A_{max} / _V) can vary with respect to each other. If MAX (A_f / _V) is ranked above MAX (A_{max} / _V), CV sequences containing the fricative are optimal. If MAX (A_{max} / _V) is ranked above MAX (A_f / _V), CV sequences containing a liquid are now optimal. The tableaux in (17) illustrate these two possibilities.

(17) a. *CONT (oral) >> MAX (A_f /_V) >> MAX (A_{max} / _V)

FLV	*CONT (oral)	MAX (A_f / _V)	MAX (A_{max} / _V)
a. ☞ FV	*		*
b. LV	*	*!	

b. *CONT (oral) >> MAX (A_{max} / _V) >> MAX (A_f /_V)

FLV	*CONT (oral)	MAX (A_{max} / _V)	MAX (A_f / _V)
a. FV	*	*!	
b. ☞ LV	*		*

Children may freely rank MAX (A_f / _V) and MAX (A_{max} / _V) with respect to each other. Consequently, children may first have the ranking in (17a) and at a later stage the ranking in (17b). It is also possible that children may initially have the ranking in (17a), and later the ranking in (17a). Fikkert's data supports this prediction, as the examples from Jarmo in (18) show.

(18)	Jarmo	[lɪnʉ]	vlinder (butterfly)	(2;2.27)
		[sɪnʉ]		(2;4.1)
		[laːpə]	slapen (to sleep)	(2;3.9)
		[saːpə]		(2;3.9)

Jarmo initially reduces FL clusters to the liquid, and later to the fricative. Notice that for the word *sleep*, Jarmo, at age 2;3.9, reduces this cluster to either the liquid or the fricative. Such variation is consistent with Antilla's (1997) proposal that a different ranking for constraints lacking a dominance relation can be chosen each time an input candidate is submitted to the grammar.

3.4 Other Clusters

/st/, /sw/, /sχ/, and /fr/ and /χr/ clusters are all somewhat problematic for the analysis developed in this paper and require more research. First consider /st/ clusters. Under the analysis presented here, these clusters are predicted to be stable in that they should always reduce to the plosive. However, according to Jongstra's data, these clusters are variable. This variation may be linked to place of articulation, with the later reduction of this cluster to /s/ following from the greater perceptibility of cues to a coronal articulation in strident fricatives in comparison to plosives.

/sw/ clusters, for the same reasons as the FL clusters discussed in §3.3.2, are predicted to be variable. According to Jongstra's data, however, these clusters are stable. It may be that the reduction of this cluster to /s/ follows from the weaker contextual cues to a glide in comparison to liquids pre-vocalically. Similarly, /sχ/ clusters are predicted to be variable since /s/ and /χ/ have the same oral aperture. More data is needed to determine if the same type of variation exists in children's outputs for these clusters as it does for /sl/ clusters. Finally, /fl/ and /χr/ cluster both require more research.

4. Conclusion

Overall, the analysis of reduction patterns presented in this paper provides an alternate account to those based on sonority either alone or in conjunction with those based on prosodic structure. This alternate analysis proposes that children reduce consonant clusters to the more perceptible member as defined by the child's current constraint rankings. When markedness constraints dominate faithfulness constraints, clusters reduce to the segment having the strongest contextual cues pre-vocalically. During this stage of acquisition, the effects of Harmony-as-Faithfulness are obscured. When markedness constraints cannot decide a candidate or when markedness constraints have been demoted, clusters reduce to the segment having the strongest internal cues. The effects of Harmony-as-Faithfulness now become apparent.

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