Typology and Variation in Child Consonant Harmony
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1. Introduction
Consonant harmony is a pervasive process of child phonology in which non-adjacent consonants assimilate in major place of articulation. Some examples of velar harmony are given below from a child learning American English (Trevor; Compton and Streeter 1977, Pater 1997):

(1) **Trevor’s velar harmony**

<table>
<thead>
<tr>
<th>Example</th>
<th>Word</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>[gɔɡ]</td>
<td>dog</td>
<td>1;5.14</td>
</tr>
<tr>
<td>[kɔk]</td>
<td>coat</td>
<td>1;5.18</td>
</tr>
<tr>
<td>[kæɡ]</td>
<td>cat</td>
<td>1;3.4</td>
</tr>
<tr>
<td>[ɡɪɡu:]</td>
<td>tickle</td>
<td>1;7.26</td>
</tr>
<tr>
<td>[ɡʌɡ]</td>
<td>bug</td>
<td>1;5.18</td>
</tr>
<tr>
<td>[kʌk]</td>
<td>cup</td>
<td>1;5.13</td>
</tr>
<tr>
<td>[ɡɪɡu]</td>
<td>pickle</td>
<td>1;9.2</td>
</tr>
</tbody>
</table>

There has been considerable discussion of the absence of long-distance assimilation of this type cross-linguistically. Equally remarkable however, are ways that the typology of non-local child place assimilation parallels the cross-linguistic typology of local place assimilation.

(2) **Typological generalizations on place assimilation**

a. If non-coronals are targets of assimilation, then so are coronals.

b. If progressive assimilation occurs, then so does regressive.

The following generalization is only possible in child language:

(3) **Typological generalization on consonant harmony**

If harmony applies across non-homorganic vowels, it applies across homorganic vowels as well.
The data in (1) illustrate the fact that Trevor's consonant harmony instantiates the full range of possible harmony patterns – the implicator of each generalization is attested as well as the implicatum. However, in its final stage, at age 2;2, Trevor's consonant harmony is evidenced in only the most limited form – regressive assimilation across back vowels to coronal targets (i.e. only the implicata):

(4) **The final stage of Trevor's consonant harmony**
    a. [aː ɡɛː ɪt ɡrʌk] *I get it truck* 2;2.1
    b. [fiːd ɡʌks] *feed ducks* 2;2.3
    c. [haiː ɡɔɡ # tæːvʊɾ ɡɔd 3uː] *Hi dog–Trevor hold you* 2;2.10

As well as in developmental changes in the application of harmony, we find reflections of the typological generalizations in frequencies of variant forms in Trevor's consonant harmony patterns.

(5) **Generalizations on Trevor's variable consonant harmony**
    a. Coronals are targets of harmony as frequently or more frequently than non-coronals (at any given point in his development).
    b. Regressive harmony occurs as frequently or more frequently than progressive harmony.
    c. Harmony occurs across homorganic vowels as frequently or more frequently than across non-homorganic vowels.

Such correlations between typology and variation strongly suggest that the same constraints are at work in both domains (i.e. variation is structured, not random). We posit a small set of ranked and violable constraints to account for the typological generalizations and developmental stages, and show that partial orderings of this set of constraints (Anttila 1997, Anttila & Cho 1998) yields frequencies of variation that align with those attested in Trevor’s data.

The presentation in outline: 2 Quantifying variation in Optimality Theory, 3 Method, 4 Influence of the target, 5 Directionality, 6 Influence of the intervening vowel, 7 The stages in summary, 8 Conclusions.

2. **Quantifying variation in Optimality Theory**

OT assumes that a grammar consists of ranked, violable constraints. A fully ranked grammar, given an input, can only produce one winning output candidate (Prince & Smolensky 1993).

(6)

<table>
<thead>
<tr>
<th>/ɡzrt/</th>
<th>ONSET</th>
<th>DEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. [?ɡzrt]</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>b. [ɡzrt]</td>
<td>*!</td>
<td></td>
</tr>
</tbody>
</table>

In order to get variation in the outputs of a grammar, one can assume instead
that some constraints in the grammar can be unranked with respect to each other (Anttila 1997, Anttila & Cho 1998).

(7) **Anttila 1997**: the factorial typology of a stratum of unranked constraints determines the proportions of variation in their effects.

At any given output evaluation time, a total ranking is randomly generated that is compatible with the partially ranked grammar, and the output form is selected according to this full ranking. By normal principles of probability, variant output forms will stand in proportions to each other equal to the proportions of fully ranked instantiations of the grammar that select them.

(8) **Factorial typology of a grammar with two unranked constraints**

a. grammar: \(A >> B, C >> D\)

b. \(A >> B >> C >> D\): selects candidate (a) (50% of the time)

c. \(A >> C >> B >> D\): selects candidate (b) (50% of the time)

Candidate (a) will win when \(B >> C\), and (b) when \(C >> B\).

<table>
<thead>
<tr>
<th></th>
<th>/UR/</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>[SR₁]</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>b.</td>
<td>[SR₂]</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

It often occurs that several rankings favor the same output form. In a grammar with three unranked constraints, if two of the six rankings below favor a particular output, then it is predicted to appear 33% of the time; if three rankings, then 50%, and so on.

(9) **Factorial typology of a grammar with three unranked constraints**

a. grammar: \(A >> B, C, D >> E\)

b. \(A >> B >> C >> D >> E\)

c. \(A >> B >> D >> C >> E\)

d. \(A >> C >> B >> D >> E\)

e. \(A >> C >> D >> B >> E\)

Candidate (a) will win only when constraint \(B\) outranks both \(C\) and \(D\) (in two of the six instantiations, or 33% of the time) candidate (b) will win the rest of the time (in four instantiations, or 66% of the time).

<table>
<thead>
<tr>
<th></th>
<th>/UR/</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
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<td>a.</td>
<td>[SR₁]</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>b.</td>
<td>[SR₂]</td>
<td>*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For applications of unranked constraints to variation in phonological development, see Demuth (1997) and Curtin (2000), on frequency of variation in syntactic acquisition, see Legendre *et al.* (1999).
3. Method

In pursuing an OT analysis of phonological acquisition and variation, we assume that the process of acquisition consists of a series of different rankings of the same universal constraints (modulo some possible maturational changes in constraints, as in our AGREE).

(12) Phonological development
a. initial state / earliest infant grammar: \( M_1, M_2, M_3 >> F_1, F_2, F_3 \)
b. final state / adult grammar: \( F_2, F_1 >> M_3 >> F_3 >> M_1, M_2 \)

The constraints, and fixed rankings, we posit for consonant harmony are the following:

(13) Consonant harmony constraints
a. AGREE-L >> AGREE-R
b. FAITHLAB, FAITHDOR >> FAITHCOR
c. NO-GAP

Initially, the markedness constraints dominate the faithfulness constraints (Faithfulness applies according to the standard acquisitional assumption that Input \( \approx \) Adult surface form).

(14) Initial state: markedness over faithfulness
AGREE-L >> AGREE-R, NOGAP >> FAITHLAB, FAITHDOR >> FAITHCOR

In the final state, in which consonant harmony is absent, faithfulness outranks markedness:

(15) Final state: faithfulness over markedness
FAITHLAB, FAITHDOR >> FAITHCOR >> AGREE-L >> AGREE-R, NOGAP

The intermediate rankings of these constraints yield predicted developmental stages (see Levelt and van de Vijver to appear), and variational frequencies. Our aim was to determine the extent to which these stages and frequencies match those attested in the application of velar harmony in longitudinal data from one child.

The data (Compton and Streeter 1977, Pater 1997):

(16) The data
a. American English learning child (San Francisco area)
b. Diary-style transcribed data collected by mother, a speech pathologist trained in phonetic transcription of child speech, at frequent, but non-regular intervals
c. Placed in a computerized database
d. For the period under study, (~2;2), there is a total of 9641 transcribed utterances.

We extracted all of the initially stressed adult forms from the glosses of the shape $C_1(C)V_1(C)C_2(C)(V)(C)$, where the following applied:

(17) **Restrictions on the data**

a. $C_1$ and $C_2$ are both oral stops  
b. Either $C_1$ or $C_2$ is a velar  
c. $V_1$ is stressed

We eliminated other word types to eliminate factors other than those under study (e.g. the manner of the target or trigger, stress placement).

We divided the words into 8 classes, based on the place of $C_1$ and $C_2$, and whether $V_1$ was front or back ($T$, $K$, $P$ = coronal, velar, labial consonant, $O$ = back vowel, $I$ = front vowel):

(18) **Word classes**

a. KOP  
b. KIP  
c. KOT  
d. KIT  
e. POK  
f. PIK  
g. TOK  
h. TIK

To get a first approximation of the stages of Trevor’s development, for each of the 8 word types we measured the proportion of harmonized vs. non-harmonized forms attested in the period up to 1;5, and each individual month through 2;3.

We then defined more fine-grained stages that more closely matched the changes in the application of harmony, and constructed grammars to model the attested frequency of harmony in these stages.

4. **The influence of the target**

4.1 **Typological account**

As the constraint motivating consonant harmony, we assume an *AGREE* constraint (cf. Lombardi 1999, Bakovic 2000) that has a broader domain than the adult version.

(19) **Versions of AGREE**

a. *AGREE*: consonants in domain D must agree in place specification.  
b. *child domain*: word  
c. *adult domain*: string-adjacency (i.e. consonant clusters)

One could also derive consonant harmony from constraints assumed to be active in adult grammars (e.g. Goad 1997), but this leads to prediction of unattested patterns for adult languages.

Resistance of different places of articulation to assimilation accounted
for by ranking of AGREE w.r.t. faithfulness constraints

(20) **Place faithfulness constraints**

a. \( \text{FAITH(LAB), FAITH(DOR), FAITH(COR)} \)

b. \( \text{FAITHX: input place feature X is preserved in the output.} \)

For the generalization that assimilation of non-coronals implies that of coronals, we posit a fixed ranking (Kiparsky 1994; cf. Jun 1995):

(21) **The place faith hierarchy**

\( \text{FAITH(DOR), FAITH(LAB) >> FAITH(COR)} \)

The ranking of Faith(Dor) and Faith(Lab) will determine whether labials assimilate to velars, or vice versa. Child typology provides evidence of both rankings.

(22) **Evidence for both labial dominance and velar dominance**

- **Labial-to-velar assimilation:** Menn (1971), Stoel-Gammon (1996), Pater (1997)
- **Velar-to-labial assimilation:** Cruttenden (1978), Gnanadesikan (to appear), Macken (1995)

To illustrate the factorial typology produced by the permutation of AGREE with the constraints in this hierarchy, we will use the FAITHDOR >> FAITH-LAB ranking motivated for Trevor.

(23) **The interaction of AGREE with the place faith hierarchy**

a. \( \text{AGREE >> FAITH(DOR) >> FAITH(LAB) >> FAITH(COR)} \)

labials and coronals assimilate to velars

b. \( \text{FAITH(DOR) >> AGREE >> FAITH(LAB) >> FAITH(COR)} \)

labials and coronals assimilate to velars

c. \( \text{FAITH(DOR) >> FAITH(LAB) >> AGREE >> FAITH(COR)} \)

only coronals assimilate to velars

d. \( \text{FAITH(DOR) >> FAITH(LAB) >> FAITH(COR) >> AGREE} \)

no assimilation

This matches the coronal/non-coronal implication. Since the changes in the patterns produced depend on the ranking of AGREE with respect to FAITHLAB and FAITHCOR, we will leave FAITHDOR out of further discussion, assuming that it always dominates FAITHLAB.

The following tableaux illustrate a grammar that targets both labials and coronals for assimilation.

(24)

<table>
<thead>
<tr>
<th>/dak/</th>
<th>AGREE</th>
<th>FAITH(LAB)</th>
<th>FAITH(COR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. [gak]</td>
<td></td>
<td></td>
<td>*</td>
</tr>
</tbody>
</table>
b. \([d\Delta k]\)  *!

(25) 

<table>
<thead>
<tr>
<th></th>
<th>/b\Lambda g/</th>
<th>AGREE</th>
<th>FAITH(LAB)</th>
<th>FAITH(COR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>[g\Lambda g]</td>
<td></td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>b.</td>
<td>[b\Lambda g]</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The next two tableaux are valid for a grammar that targets only coronals.

(26) 

<table>
<thead>
<tr>
<th></th>
<th>/d\Delta k/</th>
<th>FAITH(LAB)</th>
<th>AGREE</th>
<th>FAITH(COR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>[g\Delta k]</td>
<td></td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>b.</td>
<td>[d\Delta k]</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(27) 

<table>
<thead>
<tr>
<th></th>
<th>/b\Lambda g/</th>
<th>FAITH(LAB)</th>
<th>AGREE</th>
<th>FAITH(COR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>[g\Lambda g]</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b.</td>
<td>[b\Lambda g]</td>
<td></td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

4.2 Developmental reranking

Developmental prediction of typological account:

(28) Developmental prediction

Labials may stop assimilating before coronals, but coronals will never stop assimilating before labials.

To abstract from the effects of directionality, and the intervening vowel, we can contrast two word types: POK and TOK. The following is a month-by-month analysis of POK and TOK words.

(29) Percent harmonized forms by month

<table>
<thead>
<tr>
<th></th>
<th>TOK</th>
<th>POK</th>
<th>TOK</th>
<th>POK</th>
</tr>
</thead>
<tbody>
<tr>
<td>~1;5</td>
<td>96%</td>
<td>100%</td>
<td>1;11</td>
<td>100%</td>
</tr>
<tr>
<td>1;6</td>
<td>100%</td>
<td>94%</td>
<td>2;0</td>
<td>71%</td>
</tr>
<tr>
<td>1;7</td>
<td>100%</td>
<td>97%</td>
<td>2;1</td>
<td>67%</td>
</tr>
<tr>
<td>1;8</td>
<td>93%</td>
<td>96%</td>
<td>2;2</td>
<td>34%</td>
</tr>
<tr>
<td>1;9</td>
<td>100%</td>
<td>97%</td>
<td>2;3</td>
<td>6%</td>
</tr>
<tr>
<td>1;10</td>
<td>100%</td>
<td>59%</td>
<td>2;4</td>
<td>0%</td>
</tr>
</tbody>
</table>

At 1;11, labials have ceased to be targets (except for one instance of bug as [g\Lambda g] at 2;1), while coronals continue to undergo assimilation. At 2;4, consonant harmony has been eliminated entirely. Thus, we have evidence for all three grammars predicted by the typological account (see further Pater 1997):

(30) Grammars predicted and attested
Stage 1: AGREE >> FAITH(LAB) >> FAITH(COR)
Stage 2: FAITH(LAB) >> AGREE >> FAITH(COR)
Stage 3: FAITH(LAB) >> FAITH(COR) >> AGREE

4.3 Variation as unranked constraints

Variational prediction of typological account:

(31) **Variational prediction**
Coronals may assimilate with greater frequency than labials, but labials will never assimilate with greater frequency than coronals.

Grammars producing place-specific variation in harmony:

(32) **Grammars producing place-specific variation**

a. FAITH(LAB), AGREE >> FAITH(COR)
b. FAITH(LAB) >> AGREE, FAITH(COR)

Predicted frequencies of variation with these grammars:

(33) **Predicted frequencies of variation**

a. POK 50%  TOK 100%
b. POK 0%  TOK 50%

Variational stages and actually attested frequency of harmony:

(34) **Attested frequencies of variation**

a. 1;9.19 – 1;10.15  POK 50%  TOK 100%
b. 2;0.8 – 2;2.17  POK 0%  TOK 51%

Evidence of variation from (34a):

(35) Evidence of variation during 1;9.19–1;10.15

a. [kʌɡ] plug 1;9.27
e. [bʌk] book 1;10.2
b. [pʌɡ] plug 1;9.28
f. [ɡuɡ] book 1;10.2
c. [pʌɡ] plug 1;10.2
d. [kʌɡ] plug 1;10.2

don’t want it—down?

Evidence of variation from (34b):

(36) Evidence of variation during 2;0.8–2;2.17

a. [trʌk] truck 2;1.5
b. [krʌk] truck 2;1.5
c. [mama tek it # aut # fiː] Mama take it out 2;1.14
don waːn it # dauːn] don’t want it—down?
Before each of these variational stages, the relevant type of harmony applied consistently, and after, hardly at all; see section 7 for data.

Including variation, we have now seen 5 stages (gaps in dates are due to absence of data):

(37) **Stages in Trevor’s development seen so far**

a. **Stage 1 (~1;9.2):** AGREE >> FAITH(LAB) >> FAITH(COR)
   assimilation of coronals and labials

b. **Stage 2 (1;9.19–1;10.15):** FAITH(LAB), AGREE >> FAITH(COR)
   assimilation of coronals, variable assimilation of labials

c. **Stage 3 (1;11.1–2;0.3):** FAITH(LAB) >> AGREE >> FAITH(COR)
   assimilation of coronals, no assimilation of labials

d. **Stage 4 (2;0.8–2;2.17):** FAITH(LAB) >> AGREE, FAITH(COR)
   variable assimilation of coronals, no assimilation of labials

e. **Stage 5 (2;2.23~):** FAITH(LAB) >> FAITH(COR) >> AGREE
   no assimilation

5. **Directionality**

5.1 **Typological account**

5.1.1 **Approach 1: Positional faithfulness**

If progressive assimilation is blocked by a specific faithfulness constraint, only regressive assimilation occurs. Examples: Jun (1995) and Lombardi (1999) use onset-specific faithfulness to block assimilation from coda to onset (see also Beckman 1998 and Bakovic 2000 on positional faithfulness and assimilation). Obviously, a direct adoption of this approach won't work, since the target of child assimilation is often an onset!

We can therefore posit a constraint ANCHOR-RIGHT that enforces faithfulness to segments closer to the right edge over segments closer to the left edge.

(38) **ANCHOR-RIGHT:** the underlying place of the rightmost consonant is preserved in the output.

No ranking of AGREE and ANCHOR-R produces strictly progressive harmony:

(39) **Factorial typology of AGREE with ANCHOR-RIGHT**
a. AGREE >> ANCHOR-R: *bidirectional harmony*

b. ANCHOR-R >> AGREE: *only regressive harmony*

In combination with the Place Faithfulness hierarchy, the following patterns result:

(40) **Interaction of ANCHOR-RIGHT with AGREE and place faith**

a. AGREE >> ANCHOR-R, FAITH(LAB) >> FAITH(COR)
   *bidirectional assimilation targeting labials and coronals*

b. ANCHOR-R >> AGREE >> FAITH(LAB) >> FAITH(COR)
   *regressive assimilation targeting labials and coronals*

c. FAITH(LAB) >> AGREE >> ANCHOR-R >> FAITH(COR)
   *bidirectional assimilation targeting coronals*

d. FAITH(LAB) >> ANCHOR-R >> AGREE >> FAITH(COR)
   *regressive assimilation targeting coronals*

5.1.2 Approach 2: Fixed ranking

Another approach is to have separate constraints driving progressive and regressive assimilation (see e.g. McCarthy 1997, Walker 1998), with a fixed ranking between them.

(41) **Direction-specific AGREE constraints**

a. AGREE-LEFT: any consonant preceding a Dorsal consonant is Dorsal.

b. AGREE-RIGHT: any consonant following a Dorsal consonant is Dorsal.

c. **fixed ranking**: AGREE-LEFT >> AGREE-RIGHT

(42)

(43)

Under this account, strictly regressive assimilation results when FAITH is ranked between AGREE-L and AGREE-R:

(44) **Interaction between FAITH and the AGREE hierarchy**

a. AGREE-L >> AGREE-R >> FAITH: *bidirectional harmony*

b. AGREE-L >> FAITH >> AGREE-R: *regressive harmony*

In addition, because of the possibility of ranking FAITH(LAB) between the two AGREE constraints, the factorial typology is slightly richer (see (45b)).

(45) **Interaction between the place faith and AGREE hierarchies**

a. AGREE-L >> AGREE-R >> FAITH(LAB) >> FAITH(COR)
   *bidirectional assimilation targeting labials and coronals*

b. AGREE-L >> FAITH(LAB) >> AGREE-R >> FAITH(COR)
regressive assimilation targeting labials and coronals
progressive assimilation targeting only coronals
c. AGREE-L >> FAITH(LAB) >> FAITH(COR) >> AGREE-R
regressive assimilation targeting labials and coronals
d. FAITH(LAB) >> AGREE-L >> AGREE-R >> FAITH(COR)
bidirectional assimilation targeting only coronals
e. FAITH(LAB) >> AGREE-L >> FAITH(COR) >> AGREE-R
regressive assimilation targeting only coronals

Tableaux illustrating directional difference in place blocking (see McCarthy 1997 and Walker 1998:51 for similar analyses of crosslinguistic cases in which blocking is direction-specific).

(46)  
<table>
<thead>
<tr>
<th>/POK/</th>
<th>AGREE-L</th>
<th>FAITH(LAB)</th>
<th>AGREE-R</th>
<th>FAITH(COR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. əɾ [KOK]</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>b. [POK]</td>
<td></td>
<td></td>
<td>*!</td>
<td></td>
</tr>
</tbody>
</table>

(47)  
<table>
<thead>
<tr>
<th>/KOP/</th>
<th>AGREE-L</th>
<th>FAITH(LAB)</th>
<th>AGREE-R</th>
<th>FAITH(COR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. əɾ [KOP]</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>b. [KOK]</td>
<td></td>
<td></td>
<td>*!</td>
<td></td>
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</tbody>
</table>

(48)  
<table>
<thead>
<tr>
<th>/TOK/</th>
<th>AGREE-L</th>
<th>FAITH(LAB)</th>
<th>AGREE-R</th>
<th>FAITH(COR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. əɾ [KOK]</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>b. [TOK]</td>
<td></td>
<td></td>
<td>*!</td>
<td></td>
</tr>
</tbody>
</table>

(49)  
<table>
<thead>
<tr>
<th>/KOT/</th>
<th>AGREE-L</th>
<th>FAITH(LAB)</th>
<th>AGREE-R</th>
<th>FAITH(COR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. əɾ [KOK]</td>
<td></td>
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<td></td>
<td>*</td>
</tr>
<tr>
<td>b. [KOT]</td>
<td></td>
<td></td>
<td>*!</td>
<td></td>
</tr>
</tbody>
</table>

5.2 Developmental reranking

Developmental predictions of both typological accounts:

(50) Progressive assimilation may end before regressive assimilation, but never the reverse.

Developmental prediction of fixed ranking account:

(51) Progressive assimilation may cease to target non-coronals before regressive assimilation does, but never the reverse.

When we compare the KOT words to the TOK words, and the KOP words to the POK words, we do find that progressive assimilation ends much earlier than regressive.
Percent harmonized forms by month

<table>
<thead>
<tr>
<th></th>
<th>TOK</th>
<th>KOT</th>
<th>POK</th>
<th>KOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>~1;5</td>
<td>96%</td>
<td>100%</td>
<td>100%</td>
<td>47%</td>
</tr>
<tr>
<td>1;6</td>
<td>100%</td>
<td>100%</td>
<td>94%</td>
<td>0%</td>
</tr>
<tr>
<td>1;7</td>
<td>100%</td>
<td>100%</td>
<td>97%</td>
<td>0%</td>
</tr>
<tr>
<td>1;8</td>
<td>93%</td>
<td>92%</td>
<td>96%</td>
<td>0%</td>
</tr>
<tr>
<td>1;9</td>
<td>100%</td>
<td>45%</td>
<td>97%</td>
<td>0%</td>
</tr>
<tr>
<td>1;10</td>
<td>100%</td>
<td>11%</td>
<td>59%</td>
<td>0%</td>
</tr>
<tr>
<td>1;11</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>2;0</td>
<td>71%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>2;1</td>
<td>67%</td>
<td>0%</td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td>2;2</td>
<td>34%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>2;3</td>
<td>6%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>2;4</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

These data suggest four stages:

(52) **Percent harmonized forms by month**

(53) **Stages of place-specific and direction-specific assimilation**

a. ~1;5: bidirectional assimilation targeting labials and coronals
b. 1;6 - 1;8: regressive assimilation targeting labials and coronals, progressive assimilation targeting only coronals
c. 1;9: regressive assimilation targeting labials and coronals
d. 1;11: regressive assimilation targeting only coronals

Since the stage described in (53b) cannot be dealt with under positional faithfulness, we adopt the fixed ranking analysis.

Because directional AGREE requires stating the trigger feature, this analysis has the added benefit of avoiding two problems of the general AGREE constraint for labial harmony:

(54) **Unsupported predictions of general AGREE**

a. Labial and velar harmony are predicted to cooccur: both occur when AGREE >> FAITH(COR), but are blocked when FAITH(COR) >> AGREE. This matches neither the crosslinguistic typology, nor Trevor's stages (his labial harmony ends at 1;9, before velar harmony).

b. The ranking AGREE, ANCHOR-R >> FAITH(LAB) predicts regressive assimilation in PVT words, e.g. [ded] bed. However, PVT words only ever exhibit progressive harmony in Trevor's data, i.e. [bep] bed (see further Werle 2000).

The stages of Trevor's development, abstracting from variation, are therefore now analyzed as follows (Stages 1-4 correspond to (53a.-d.), Stage 5 produces no harmony at all):

(55) **Current analysis of Trevor’s grammars by stages**

a. **Stage 1**: AGREE-L >> AGREE-R >> FAITH(LAB) >> FAITH(COR)
b. **Stage 2**: AGREE-L >> FAITH(LAB) >> AGREE-R >> FAITH(COR)
c. **Stage 3**: AGREE-L >> FAITH(LAB) >> FAITH(COR) >> AGREE-R
d. **Stage 4**: FAITH(LAB) >> AGREE-L >> FAITH(COR) >> AGREE-R
e. **Stage 5**: FAITH(LAB) >> FAITH(COR) >> AGREE-L >> AGREE-R
The only grammar for which there is no evidence is the one producing bidirectional assimilation that targets only coronals

(56) **Unattested grammar**

\[ \text{FAITH(LAB)} \gg \text{AGREE-L} \gg \text{AGREE-R} \gg \text{FAITH(COR)} \]

This grammar seems incompatible with the developmental path taken by Trevor; it is, however, attested in the stage of Amahl's development (Smith 1973) analyzed by Goad (1997).

5.3 **Variation as unranked constraints**

Variational prediction of the typological account:

(57) Regressive assimilation may apply with greater frequency than progressive assimilation, but never the reverse.

An example of regressive assimilation occurring with greater frequency occurs at the earliest stage of development, in which \text{FAITH(LAB)} and \text{AGREE-R} are unranked:

(58) **Variation through 1;5**

\begin{align*}
\text{a. } & \text{AGREE-L} \gg \text{AGREE-R}, \text{FAITH(LAB)} \gg \text{FAITH(COR)} \\
\text{b. } & \text{predicted} \\
\text{c. } & \text{attested } \sim 1;5 \\
& \begin{array}{cccc}
\text{TOK} & \text{KOT} & \text{POK} & \text{KOP} \\
\text{100\%} & \text{100\%} & \text{100\%} & \text{50\%} \\
\text{96\%} & \text{100\%} & \text{100\%} & \text{47\%} \\
\end{array}
\end{align*}

Data showing variation:

(59) **Evidence of variation during 1;5**

\begin{align*}
\text{a. } & [k\lambda p] \quad \text{cup} \quad 1;5.4 \\
\text{b. } & [k\lambda k'] \quad \text{cup} \quad 1;5.5 \\
\text{c. } & [k\lambda p] \quad \text{cup} \quad 1;5.5 \\
\text{d. } & [k\lambda k'] \quad \text{cup} \quad 1;5.6 \\
\end{align*}

Similarly, regressive assimilation of coronals occurs with nearly 100\% frequency while progressive assimilation is much less frequent.

(60) **Variation during 1;9.19–1;10.1**

\begin{align*}
\text{a. } & \text{AGREE-L} \gg \text{FAITH(LAB)} \gg \text{AGREE-R}, \text{FAITH(COR)} \\
\text{b. } & \text{predicted} \\
\text{c. } & \text{attested } 1;9.19–1;10.1 \\
& \begin{array}{cccc}
\text{TOK} & \text{KOT} & \text{POK} & \text{KOP} \\
\text{100\%} & \text{50\%} & \text{100\%} & \text{0\%} \\
\text{100\%} & \text{20\%} & \text{78\%} & \text{0\%} \\
\end{array}
\end{align*}
Data showing variation:

(61) **Evidence of variation during 1;9.19–1;10.1**

a. [ge:d] *good* 1;9.27  

b. [gε:g] *good* 1;9.27  

c. [ko:lq to:z] *cold toes* 1;10.1  

d. [ko:l] *cold* 1;10.1

Matching the grammars to the data is impeded somewhat here by the lack of data between 1;9.2–1;9.19 (Trevor was sick), which makes the transition seem somewhat abrupt.

(62) **Transition between 1;9.2 and 1;9.19**

<table>
<thead>
<tr>
<th></th>
<th>KOT</th>
</tr>
</thead>
</table>
| a. ~1;9.2 | 96% (26/27)  
| b. 1;9.19–1;10.1 | 20% (2/10)  

There is also by overlap between the periods of variation for progressive coronal and regressive labial assimilation — recall the stage we posited for variable labial assimilation.

(63) **Variable labial assimilation during 1;9.18–1;10.15**

<table>
<thead>
<tr>
<th></th>
<th>POK</th>
<th>TOK</th>
</tr>
</thead>
<tbody>
<tr>
<td>1;9.19–1;10.15</td>
<td>20%</td>
<td>100%</td>
</tr>
</tbody>
</table>

As regressive labial assimilation persists slightly longer, we posit the following stage as occurring after the one in (55) (more accurate would be to specify the date of reranking of each of the constraints).

(64) **Variation 1;10.2–1;10.15**

a. **AGREE-L, FAITHLAB >> AGREE-R >> FAITHCOR**

<table>
<thead>
<tr>
<th></th>
<th>TOK</th>
<th>KOT</th>
<th>POK</th>
<th>KOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>b. predicted</td>
<td>100%</td>
<td>0%</td>
<td>50%</td>
<td>0%</td>
</tr>
<tr>
<td>c. attested 1;10.2–1;10.15</td>
<td>100%</td>
<td>6%</td>
<td>29%</td>
<td>0%</td>
</tr>
</tbody>
</table>

6. **The intervening vowel effect**

6.1 **Typological account**

Levelt (1994) claims that consonant harmony in a corpus of Dutch acquisition (almost) always involves assimilation across an intervening homorganic vowel. Homorganicity defined as follows (following Lahiri and Evers 1991, see also Clements and Hume 1995):
(65) Consonant-vowel homorganicity (Levelt 1994)
   a. \([±\text{labial}]= [±\text{round}]\)
   b. \([±\text{dorsal}]= [±\text{back}]\)
   c. \([±\text{coronal}]= [±\text{front}]\)

Levelt questions whether consonant harmony as true consonant-to-consonant assimilation exists at all. However, as we have seen, data from the acquisition of English provide ample evidence of assimilation across non-homorganic vowels (see also Goad 1997, Menn to appear).

Stoel-Gammon (1996) discusses a case in which regressive velar harmony applies only with an intervening back vowel. As mentioned in the introduction, this is true of Trevor at 2;2:

(66) Velar harmony licensed by intervening back vowel
   a. \([aː\text{qe}ː\text{rt} \text{kræk}]\quad I\text{ get it truck} \quad 2;2.1\)
   b. \([\text{fiːd gəks}]\quad \text{feed ducks} \quad 2;2.3\)
   c. \([\text{haiː gəg} # \text{tæːvɔː hɔd 3uː}]\quad \text{Hi dog—Trevor hold you} \quad 2;2.10\)

(67) Velar harmony blocked by intervening front vowel
   a. \([\text{tekt}]\quad \text{take it} \quad 2;2.1\)
   b. \([\text{dʃənk rt}]\quad \text{drink it} \quad 2;2.15\)

Levelt (1994) reanalyzes consonant harmony as V-to-C assimilation. This predicts that back vowels alone trigger assimilation of coronals — we find only two putative examples in the corpus (vs. 157 instances of harmony for TOK words):

(68) Putative examples of back vowels spreading dorsality
   a. \([\text{ga}]\quad \text{top} \quad 1;1.7\)
   b. \([\text{ga}]\quad \text{top} \quad 1;1.12\)

Analysis:

(69) Analysis of intervening vowel effect
   a. AGREE demands feature sharing between consonants, rather than between any two segments (i.e. consonants or vowels).
   b. NOGAP (Itô, Mester and Padgett 1995) rules out feature linkages between consonants that exclude an intervening vowel.
   c. Dorsal features can only be shared by a back vowel.

The simplest approach under an OT analysis is to assume that NOGAP is a violable, rankable constraint, though it would be possible to construct an account that maintained strictly local spreading, and an inviolable NOGAP. The ranking AGREE >> NOGAP yields as Outputs for TOK and TIK:
Interaction between AGREE and NOGAP

a. AGREE >> NOGAP  
assimilation across back vowels  assimilation across front vowels  
/TOK/ → [KOK]  /TOK/ → [KIK]  
[DOR] [DOR]  [DOR] [DOR]

b. NOGAP >> AGREE  
assimilation across back vowels  no assimilation across front vowels  
/TOK/ → [KOK]  /TOK/ → [TIK]  
[DOR] [DOR]  [DOR] [DOR]

Given the fixed ranking between AGREE-L and AGREE-R, NOGAP can limit the effects of both regressive and progressive assimilation, or just progressive assimilation, but not regressive assimilation alone:

Interaction between NOGAP and AGREE-L >> AGREE-R

a. AGREE-L >> AGREE-R >> NOGAP  
bidirectional assimilation across back and front vowels

b. AGREE-L >> NOGAP >> AGREE-R  
regressive assimilation across back and front vowels  progressive assimilation only across back vowels

c. NOGAP >> AGREE-L >> AGREE-R  
bidirectional assimilation only across back vowels

6.2 Development as reranking

Developmental predictions of the typological account:

Developmental predictions of the typological account

a. Velar assimilation may last longer across back vowels than across front vowels, but never the reverse.

b. Regressive assimilation may last longer across back vowels than progressive assimilation, but never the reverse.

To assess whether prediction (73a) is borne out in Trevor's data, we can compare TOK and TIK, and POK and PIK words.

Percent harmonized forms by month

<table>
<thead>
<tr>
<th></th>
<th>TOK</th>
<th>TIK</th>
<th>POK</th>
<th>PIK</th>
<th>TOK</th>
<th>TIK</th>
<th>POK</th>
<th>PIK</th>
</tr>
</thead>
<tbody>
<tr>
<td>~1;5</td>
<td>96%</td>
<td>100%</td>
<td>100%</td>
<td>92%</td>
<td>1;11</td>
<td>100%</td>
<td>75%</td>
<td>0%</td>
</tr>
</tbody>
</table>
To check prediction (73b), we can compare TOK and TIK, and KOT and KIT words (no relevant data on progressive assimilation of labials).

(75) Percent harmonized forms by month

<table>
<thead>
<tr>
<th></th>
<th>TOK</th>
<th>TIK</th>
<th>KOT</th>
<th>KIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>~1;5</td>
<td>96%</td>
<td>100%</td>
<td>100%</td>
<td>16%</td>
</tr>
<tr>
<td>1;6</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>22%</td>
</tr>
<tr>
<td>1;7</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>1;8</td>
<td>93%</td>
<td>50%</td>
<td>92%</td>
<td>15%</td>
</tr>
<tr>
<td>1;9</td>
<td>100%</td>
<td>100%</td>
<td>45%</td>
<td>0%</td>
</tr>
<tr>
<td>1;10</td>
<td>100%</td>
<td>25%</td>
<td>11%</td>
<td>0%</td>
</tr>
</tbody>
</table>

(76) Developmental rankings of AGREE and NOGAP

a. ~1;8: AGREE-L >> AGREE-R >> NOGAP
   bidirectional assimilation across back and front vowels
b. 1;9–1;11: AGREE-L >> NOGAP >> AGREE-R
   regressive assimilation across back and front vowels
   progressive assimilation only across back vowels
c. 2;0–: NOGAP >> AGREE-L >> AGREE-R
   assimilation only across back vowels

6.3 Variation as unranked constraints

Variational prediction of the typological account:

(77) Velar assimilation across back vowels may occur with greater frequency than across front vowels, but never the reverse.

This prediction is met by the variation that occurs in the pronunciation of the KIT words from the outset. Since TIK words are unaffected by variation at this point, the following ranking is posited to last until KIT words stop assimilating:

(78) Posited ranking through 1;9.2
a. **AGREE-L >> NOGAP, AGREE-R**

b. *regressive assimilation across back and front vowels*

*progressive assimilation across back vowels*

*variable progressive assimilation across front vowels*

This is quickly followed by variation in regressive assimilation across front vowels (i.e. for TIK words):

(79) **Posited ranking during 1;9.19–2;1.26**

a. **AGREE-L, NOGAP >> AGREE-R**

b. *regressive assimilation across back vowels*

*variable regressive assimilation across front vowels*

*progressive assimilation only across back vowels*

Since this completes the account, we can now examine the numerical predictions and attested data in the context of the entire analysis.

7. **Summary: rankings, numerical predictions, and data**

The following are the grammars constructed on the basis of the evidence discussed above, and the periods that seem to best align with the grammars (as noted in 5.2, we do not posit overlapping periods, which would have allowed a slightly better data fit). The **AGREE** constraints are in boldface, to highlight their gradual demotion relative to the limiting constraints.

(80) **Rankings and periods of Trevor’s relevant grammars**

<table>
<thead>
<tr>
<th></th>
<th>Rankings</th>
<th>Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td><strong>AG-L &gt;&gt; AG-R, NOGAP, F(LAB) &gt;&gt; F(COR)</strong></td>
<td>– 1;5</td>
</tr>
<tr>
<td>G2</td>
<td><strong>AG-L &gt;&gt; F(LAB) &gt;&gt; AG-R, NOGAP &gt;&gt; F(COR)</strong></td>
<td>1;6 – 1;9.2</td>
</tr>
<tr>
<td>G3</td>
<td><strong>AG-L, NOGAP &gt;&gt; F(LAB) &gt;&gt; AG-R, F(COR)</strong></td>
<td>1;9.19 – 1;10.1</td>
</tr>
<tr>
<td>G4</td>
<td><strong>AG-L, NOGAP, F(LAB) &gt;&gt; F(COR) &gt;&gt; AG-R</strong></td>
<td>1;10.2 – 1;10.15</td>
</tr>
<tr>
<td>G5</td>
<td><strong>F(LAB) &gt;&gt; AG-L, NOGAP &gt;&gt; F(COR) &gt;&gt; AG-R</strong></td>
<td>1;11 – 2;0.3</td>
</tr>
<tr>
<td>G6</td>
<td><strong>F(LAB) &gt;&gt; AG-L, NOGAP, F(COR) &gt;&gt; AG-R</strong></td>
<td>2;0.8 – 2;1.26</td>
</tr>
<tr>
<td>G7</td>
<td><strong>F(LAB), NOGAP &gt;&gt; AG-L, F(COR) &gt;&gt; AG-R</strong></td>
<td>2;2.1 – 2;2.17</td>
</tr>
<tr>
<td>G8</td>
<td><strong>F(LAB), NOGAP &gt;&gt; F(COR) &gt;&gt; AG-L &gt;&gt; AG-R</strong></td>
<td>2;2.23 – 2;3.17</td>
</tr>
</tbody>
</table>

As the **AGREE** constraints are demoted, the predicted frequency of harmony for the various word types diminishes gradually:

(81) **Predicted variation by grammar and word type**

<table>
<thead>
<tr>
<th>KOP KIP KOT KIT POK PIK TOK TIK</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
<th>G5</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% 33% 100% 50% 100% 100% 100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>50% 100% 100% 100% 100% 100% 100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>50% 100% 100% 100% 100% 100% 100%</td>
<td>0%</td>
<td>0%</td>
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<td>0%</td>
<td>0%</td>
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<tr>
<td>0% 0% 0% 0% 0% 0% 0% 0% 0% 0% 0%</td>
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<tr>
<td>0% 0% 0% 0% 0% 0% 0% 0% 0% 0% 0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>
The following tables show the match between the predicted and attested frequencies. While the frequencies do not always agree perfectly, the predicted and attested relative frequencies of harmony across word types within a stage do always correspond.

(82) **Stage 1** (~1;5): **AGREE-L >> AGREE-R, NOGAP, F(L) >> F(C)**

<table>
<thead>
<tr>
<th></th>
<th>KOP</th>
<th>KIP</th>
<th>KOT</th>
<th>KIT</th>
<th>POK</th>
<th>PIK</th>
<th>TOK</th>
<th>TIK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>predicted</strong></td>
<td>50%</td>
<td>33%</td>
<td>100%</td>
<td>50%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>attested</strong></td>
<td>47%</td>
<td>—</td>
<td>100%</td>
<td>16%</td>
<td>100%</td>
<td>94%</td>
<td>96%</td>
<td>100%</td>
</tr>
</tbody>
</table>

(83) **Stage 2** (1;6–1;9.2): **AGREE-L >> F(L) >> AGREE-R, NOGAP >> F(C)**

<table>
<thead>
<tr>
<th></th>
<th>KOP</th>
<th>KIP</th>
<th>KOT</th>
<th>KIT</th>
<th>POK</th>
<th>PIK</th>
<th>TOK</th>
<th>TIK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>predicted</strong></td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
<td>50%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>attested</strong></td>
<td>0%</td>
<td>0%</td>
<td>96%</td>
<td>16%</td>
<td>98%</td>
<td>63%</td>
<td>98%</td>
<td>86%</td>
</tr>
</tbody>
</table>

(84) **Stage 3** (1;9.19–1;10.1): **AGREE-L, NOGAP >> F(L) >> AGREE-R, F(C)**

<table>
<thead>
<tr>
<th></th>
<th>KOP</th>
<th>KIP</th>
<th>KOT</th>
<th>KIT</th>
<th>POK</th>
<th>PIK</th>
<th>TOK</th>
<th>TIK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>predicted</strong></td>
<td>0%</td>
<td>0%</td>
<td>50%</td>
<td>0</td>
<td>100%</td>
<td>50%</td>
<td>33%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>attested</strong></td>
<td>0%</td>
<td>0%</td>
<td>6%</td>
<td>0%</td>
<td>29%</td>
<td>12%</td>
<td>100%</td>
<td>33%</td>
</tr>
</tbody>
</table>

(85) **Stage 4** (1;10.2–1;10.15): **AGREE-L, NOGAP, F(L) >> F(C) >> AGREE-R**

<table>
<thead>
<tr>
<th></th>
<th>KOP</th>
<th>KIP</th>
<th>KOT</th>
<th>KIT</th>
<th>POK</th>
<th>PIK</th>
<th>TOK</th>
<th>TIK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>predicted</strong></td>
<td>0%</td>
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<tr>
<td><strong>attested</strong></td>
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<td>6%</td>
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<td>29%</td>
<td>12%</td>
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(86) **Stage 5** (1;11.1–2;0.3): **F(L) >> AGREE-L, NOGAP >> F(C) >> AGREE-R**

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<tr>
<td><strong>predicted</strong></td>
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<td>8%</td>
<td>100%</td>
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(87) **Stage 6** (2;0.8–2;1.26): **F(L) >> AGREE-L, NOGAP, F(C) >> AGREE-R**

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<tr>
<td><strong>predicted</strong></td>
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<td>8%</td>
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(88) **Stage 7** (2;2.1–2;2.17): **F(L), NOGAP >> AGREE-L, F(C) >> AGREE-R**

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</thead>
<tbody>
<tr>
<td><strong>predicted</strong></td>
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<td><strong>attested</strong></td>
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Anttila’s (1997) theory of variation predicts that quantities of variation should be in small integer fractions: e.g. 100%, 66% (2/3), 50% (1/2), 33% (1/3), 25% (1/4). The data at some points do seem to show just this sort of variation. To model smaller frequencies (see e.g. Stage 8: TOK), and gradual declines in variation, either a much richer constraint set, or a richer model of variation, such as that of Boersma and Hayes (to appear), would be needed.

8. Conclusions
In this paper, we have proposed an account of the three typological generalizations on child velar harmony first noted by Stoel-Gammon (1996) (see also Dinnsen and O’Connor to appear on a typological generalization on manner harmony):

(90) Proposed constraints
a. directionality: AGREE-L >> AGREE-R
b. target place: FAITHLAB, FAITHDOR >> FAITHCOR
c. vowel blocking: NOGAP

We have also shown how this account of these basic generalizations yields further specific predictions (i.e. interaction of directionality with blocking effects of consonants and vowels). Most of the grammars predicted by the factorial typology of these constraints were seen to be attested in different stages of the application of consonant harmony in one child's longitudinal data. Predicted patterns of relative frequency of variation for the various word types were also shown to be instantiated in Trevor's data.

References


