

## Chapter 3: Place Assimilation\*

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## 1. Introduction

The present study is concerned with place assimilation in consonant clusters. In such assimilations, one of two neighbouring consonants takes on the place of articulation of another. This occurs, for example, in Diola-Fogny. In (1), /m/ takes on the velar place of the following /g/, becoming [ŋ]:

(1) ni+gam+gam      [niɡaŋɡam]      ‘I judge’ (Sapir 1965)

It is not difficult to derive place assimilation within the framework of previous theories such as classical generative theory, feature geometry, or underspecification theory. This is also true in Optimality Theory (Prince & Smolensky 1993). For instance, if there is a Markedness constraint of the type \*HETERORGANICCLUSTER, and Faithfulness constraints for place of articulation are ranked below it, then place assimilation will be derived, as shown below.

(2) A familiar Optimality-Theoretic analysis of place assimilation

input = / ni+gam+gam /	*HETERORGANICCLUSTER	MAX-PLACE
a. [niɡamɡam]	*!	
b. ↗ [niɡaŋɡam]		*

However, such an account leaves unanswered some crucial questions. One wonders, for instance, why languages should have a constraint like \*HETERORGANICCLUSTER in the first place—what is it about heterorganicity such that languages should so often avoid it? Moreover, positing a constraint like \*HETERORGANICCLUSTER does nothing to account for the interesting typological patterns that have been found to govern place assimilation (Mohanar 1993, Jun 1995, and below). These include the characteristically regressive direction of place assimilation, the greater propensity of nasals to undergo it, the greater propensity of coronals to undergo it, and the greater tendency of non-coronals to trigger it. These patterns are elaborated further below. Any reasonable theoretical account of place assimilation should account for these patterns, which are quite robust cross-linguistically.

In this article, I will lay out an approach to place assimilation that aims to achieve these goals. In my approach, there is no role for a constraint like \*HETERORGANICCLUSTER. Instead, place assimilation is treated as the consequence of interactions among constraints that have phonetic teleologies, both articulatory and perceptual. As a result, the cross-linguistic patterns mentioned above receive explanations that emerge from properties of human speech production and perception. The crucial basis of the explanation lies in asymmetries in the perceptibility of place of articulation in different segments and in different contexts.

The proposal described here represents a minor revision of ideas originally put forth in Jun (1995, 1996a). Subsequent work that has followed similar lines of inquiry includes

Steriade (1995, 2001), Myers (1997), and Boersma (1998).

## 2. Perception of place

There are many potential perceptual cues for phonological place contrasts. For instance, cues for place may be located in the formant transitions of adjacent vowels, in stop release bursts, and in fricative noise. Different consonant types have different cues, and the salience of the cues may be different. Accordingly, different consonant types vary in the degree of perceptibility of place contrasts. In addition, not all potential sources of perceptual cues for each segment type are available in actual speech; the cues may be present or absent (or weakened or enhanced) depending on the context. Such contextual variation in cue distribution is the focus of this section.

To begin, here is a brief overview of the most important place cues and their distribution; for more detailed discussion, see below, as well as Borden, Harris & Raphael (1994), Wright (1996, this volume) and Wright, Frisch & Pisoni (1996). Place cues may be either INTERNAL or TRANSITIONAL, depending on where the cues are located in time relative to the constriction of a consonant. Internal cues can be found during acoustic interval corresponding to the consonantal constriction, as in the frication noise of a fricative. Transitional cues are found during the period of coarticulation between a consonant and its neighbouring segments. The most important transitional cues are vowel formant transitions. In CV and VC sequences, articulators move from a consonantal position to a vocalic position

or vice-versa, changing the vocal tract shape. This shape is acoustically reflected in formant changes during the vowel offset (VC) or onset (CV). Thus, although the cues occur “during” the vowel, they serve as a major source of information concerning the place of articulation of the consonant.

Let us now consider what potential sources of place cues are available for each manner of articulation. Stops bear no cues for place during closure, but when adjacent to vowels induce formant transitions; many stops also possess a release burst, which results from the sudden venting of high intraoral pressure at release. Earlier studies of the perception of place in stops show that the release burst alone can provide salient place cues (Malécot 1958; Winitz, Scheib, and Reeds 1972). However, formant transitions, especially CV transitions, also provide a good source of place cues, and it is hard to determine the relative contribution of transitions and burst to the identification of place (Manuel 1991; Byrd 1992; Wright this volume; and others).

For fricatives, the spectrum of noise provides an internal place cue. The noise spectrum is highly reliable for the identification of the place in sibilant fricatives, but less so in nonsibilant fricatives (Wright et al. 1996). Thus, formant transitions on an adjacent vowel play an important role in the perception of nonsibilant fricatives, compared with sibilants.

Nasals are produced with complete oral closure just like stops, and bear cues in the formant transitions of neighbouring vowels similar to those of stops. Nasals lack bursts, but

have internal cues in the form of the nasal resonance (murmur) during the period of closure.

However, the nasal resonance cues are less reliable in identifying the place of a nasal than the vowel formant transition cues (Malécot 1956).

Unlike other consonants, approximants (liquids and glides) have a formant structure that serves as an internal cue. They also benefit from transition cues on the neighbouring vowels; typically, formants change fairly gradually in the transition between vowels and approximants.

The potential sources of consonant place cues just discussed are summarised below:

(3) Sources of consonant place cues

<i>segment types</i>	<i>Cue types</i>	
	<i>Internal</i>	<i>Transitional</i>
stops	none	CV, VC formant transitions, release burst
nasals	nasal resonance	CV, VC formant transitions
fricatives	frication noise	CV, VC formant transitions
liquids and glides	formant structure	CV, VC formant transitions

For present purposes, it is the *relative* perceptibility of consonants that is crucial. Below, I compare the perceptibility of consonants under four different conditions:

- (i) Comparison between preconsonantal consonants with different manner features (*target manner*)
- (ii) Comparison between preconsonantal consonants with different place features (*target place*)

(iii) Comparison between preconsonantal and prevocalic consonants (*target position*)

(iv) Comparison between consonants occurring before consonants with different place features (*trigger place*)

Variation in perceptibility in each condition will be seen to explain a number of patterns of assimilation.

## 2.1 Target manner

This section discusses the relative perceptibility of place cues in stops, nasals, fricatives, liquids and glides. For reasons that will be clear later on, I focus here on the effects of manner in consonants that occur as the first member of a consonant cluster; specifically, as  $C_1$  in  $V_1C_1C_2V_2$ . Consonants in this position often lack salient place cues; in particular, CV formant transitions are not available. In a  $V_1C_1C_2V_2$  sequence,  $V_2$  normally bears little information about  $C_1$  due to the intervening  $C_2$ ; the formant transitions in the onset of  $V_2$  will mostly have cues for  $C_2$ . In addition, when  $C_1$  is a stop, it is often unreleased due to overlap with  $C_2$  (especially when  $C_2$  is a nasal or obstruent) and thus lacks a release burst. Thus, the pattern of cues seen earlier in (3) is reduced in this context to (4):

(4) Sources of consonant place cues in pre-C position (esp. C<sub>2</sub> = a nasal or obstruent)

<i>Segment types</i>	<i>Cue types</i>	
	<i>Internal</i>	<i>Transitional</i>
stops	none	VC formant transitions
nasals	nasal resonance	VC formant transitions
fricatives	frication noise	VC formant transitions
liquids and glides	formant structure	VC formant transitions

The crucial comparison here will be between noncontinuants (stops and nasals) vs. continuants (fricatives and approximants) in preconsonantal position. The crucial point will be that noncontinuants suffer a proportionately greater disadvantage from occurring in this context, relative to continuants.

Stops in preconsonantal position lack prominent cues in the release burst and CV transitions. VC formant transitions may provide the only place cues for stops in this location; and as will be discussed below, cues in VC formant transitions are much less prominent than those in CV transitions. Therefore, perceptibility of the stop place is drastically reduced in preconsonantal position, compared to prevocalic position.

This drastic weakening of place cues is also true of the nasals. According to Kurowski & Blumstein's (1984) perceptual experiments, the nasal murmur and transitions surrounding the nasal release provide the most reliable place cues, but neither the murmur immediately preceding the release nor the transition immediately following the release provides a salient

place cue for the nasal by itself. Since in preconsonantal position, nasals are normally unreleased, and unreleased nasals lose the most prominent cues around the release, the perceptibility of nasals' place cues thus is drastically reduced in preconsonantal position.

In contrast, if the consonant occurring preconsonantly is a continuant, it maintains its internal cues in addition to the cues in the VC formant transitions. Thus even if a fricative or nonnasal sonorant overlaps with a consonant in C<sub>2</sub>, its place cues can be well preserved. A short period of non-overlapping frication at the beginning of a fricative, especially in the case of sibilants, can provide somewhat stable place cues. Thus, fricatives have more robust place cues than stops and nasals in preconsonantal position. Hura, Lindblom, & Diehl (1992) carried out perception tests to compare English fricatives, stops and nasals in confusability when occurring before a stop. Their results indicate that fricatives were less confusable than stops and nasals. Also, as discussed above, the critical place cues for glides and liquids are located in relatively gradual frequency changes. Especially in case of (English) liquids, the frequency changes may persist for much of the preceding vowel's duration. Such gradual changes can provide robust perceptual cues. In conclusion, continuant consonants—fricatives and nonnasal sonorants—have more robust place cues than stops and nasals when occurring as the first member of a consonant cluster.

Nasals and stops differ with respect to perceptibility of place information. Both suffer from a lack of release in preconsonantal position, but nasals have an additional handicap. In a

VN sequence, the vowel is characteristically nasalised, either throughout, or at least during the crucial period of the consonant transitions. Nasalised vowels are perceptually difficult in comparison with oral vowels, and their amplitudes are decreased by anti-formants (Johnson 1997). Thus, nasalised vowels are normally less distinct than oral vowels. This acoustic and perceptual difference between nasalised and oral vowels may lead us to assume that formant transitions of nasalised vowels are less distinct with respect to the place of the following consonant than those of oral vowels. In other words, nasals have less prominent place cues in the VC transitions than stops, suggesting the relative perceptibility of stops over nasals in preconsonantal position. This argument is consistent with results of the perception experiment by Hura et al. mentioned above: it was found that when occurring before a stop, stops were less confusable than nasals, although this difference was not statistically significant.

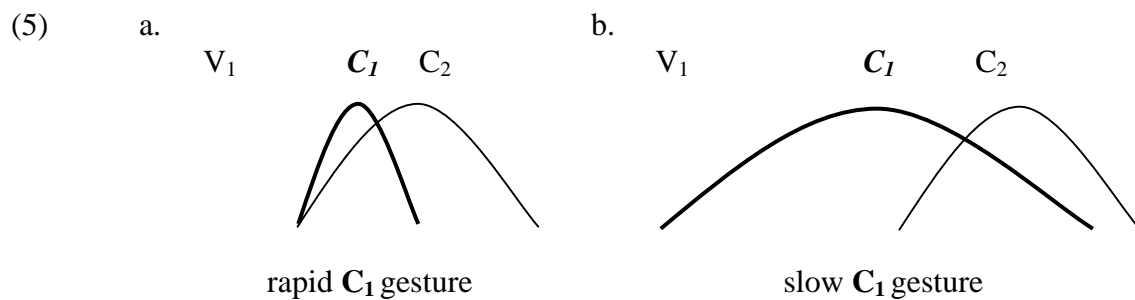
To summarise this section: in preconsonantal position, nasals have weaker place cues than stops, which in turn have weaker cues than continuants.

## 2.2 Target place

Consider the relative perceptibility of place cues of coronals, labials and velars when they are unreleased, occurring as the first member of a consonant cluster. Experimental evidence (Byrd 1994, citing Öhman 1967, Kuehn & Moll 1976, and Winitz et al. 1972) has established that a coronal, specifically [d], has perceptually weaker cues compared to noncoronals. This

weakness can be explained as follows (cf. Browman & Goldstein 1990, Kang 1999). Typically, the underlying gesture with which coronals are realised is articulated more rapidly. That is, tongue tip gestures are rapid and thus have rapid transition cues; whereas tongue dorsum and lip gestures are more sluggish and thus give rise to long transitions.

This has important consequences for the acoustic effects of articulatory overlap. Consider the difference between a longer and a shorter consonant articulation gesture, when the consonant occurs in preconsonantal position:



When the gesture for  $C_1$  is articulated rapidly, the formant transitions at the end of  $V_1$  will be affected not just by  $C_1$ , but also by the overlapping  $C_2$ . When the gesture for  $C_1$  is made slowly, however, the transitions in  $V_1$  will result almost entirely from  $C_1$ . Thus, a longer-gesture consonant in  $C_1$  (i.e. a velar or labial) will be rendered more identifiable by the preceding formant transitions than will a shorter-gesture consonant (such as a coronal).

The claim for the perceptual weakness of unreleased coronals relative to labials and velars is supported by results of Winitz, Scheib & Reeds's (1972) perception study of the identification of English voiceless stops. In this study, the release burst of a stop and 100

msec of the adjacent vowel were isolated from English mono-syllable words taken from running speech. When stop bursts alone, isolated from word-final VC sequences, were presented to subjects, alveolars were found to be most accurately identified. However, when 100 msec of a vowel segment preceding the stop was additionally employed, alveolars became least accurately identified. These results indicate not only that alveolars are the most confusable stops at the end of the word, but also that vowel transitions into an alveolar stop are least informative of its place of articulation. Consequently, the results support the claim that coronals have weaker place cues than noncoronals when they lack cues in the release burst.

Other results of Winitz et al.'s perception study may suggest an additional distinction among noncoronals. In the comparison between two perception tests, one employing stimuli with stop bursts alone and the other with stop bursts plus 100 msec of adjacent vowel, the accuracy of identification greatly improved for final velars compared to labials (some improvement) and alveolars (almost no improvement). My interpretation of these results is that vowel transitions into a velar stop are more informative of the stop's place of articulation than those for labials and coronals. If this interpretation is correct, velars have stronger place cues than coronals and labials when they are unreleased.

This difference may be attributed to an acoustic characteristic property of velars, i.e. compactness (Jakobson, Fant & Halle 1963). Velars can be characterised by a noticeable

convergence of F2 and F3 of neighbouring vowels. These two formants can form a prominence in the midfrequency range. As argued by Stevens (1989: 17-18), such a midfrequency prominence of velars can form a robust acoustic cue for place of articulation. Listeners do not have to know the exact target points of F2 and F3 transitions to identify velars; mere convergence of two formants will provide a sufficient cue, regardless of where the convergence occurs.

The general conclusion of this section is that place cues of unreleased dorsals are more perceptible than those of unreleased labials, which in turn are more perceptible than those of unreleased coronals.

### 2.3 Target position

This section concerns the relative perceptibility of consonants in prevocalic and preconsonantal positions. It has been shown in the literature (Bladon 1986; Manuel 1991; Ohala 1990, 1992 among others) that prevocalic or syllable-initial consonants are acoustically/perceptually stronger than preconsonantal or syllable-final consonants. In section 2.1, I related this claim to patterns of release: stops and nasals are released before vowels but typically unreleased before consonants, especially obstruents and nasals. Thus, in preconsonantal position, both stops and nasals have only weak place cues, losing the prominent release burst cues and cues around the nasal release, respectively.

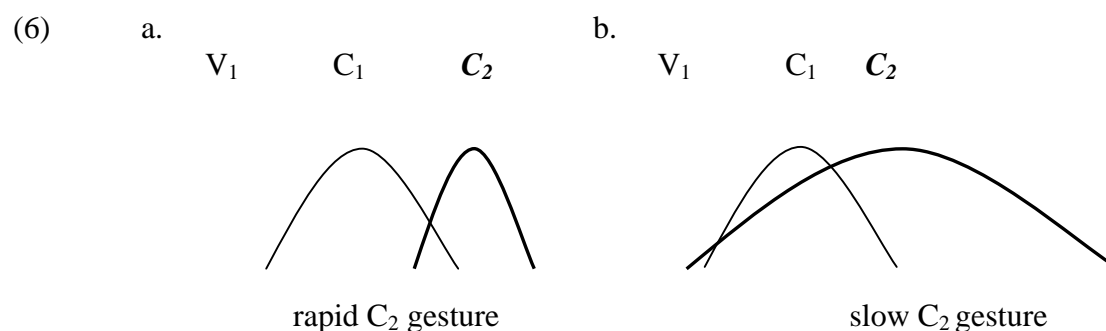
Another important factor is the relative perceptibility of CV and VC formant transitions.

Experimental results consistently show that CV transitions provide more prominent place cues than VC transitions (Repp 1978; Fujimura, Macchi, Streeter 1978; Wright 1996; Ohala 1990 and references cited therein). One possible explanation for this difference lies in the auditory response system (see Wright this volume; Côté 2000): the onset of the speech signal is emphasised compared to its offset. Because of this, CV transitions out of a consonant closure are effectively amplified, whereas VC transitions into a consonant closure are not.

Thus, for two reasons—patterns of release, and auditory system asymmetries— the place cues of a consonant are stronger in prevocalic position than in preconsonantal position.

#### 2.4 Trigger place

The perceptibility of place cues of  $C_1$  in a cluster  $C_1C_2$  also varies as a function of the place of  $C_2$ . Due to coarticulation, the formant transitions of  $V_1$  are affected by both  $C_1$  and  $C_2$ , although  $C_1$ 's influence is dominant (Byrd 1992, Zsiga 1992). Thus,  $C_2$  with different place features may obscure place cues of the  $C_1$  to differing degrees. I claim that this depends on the inherent velocity of the articulator involved in  $C_2$ : a slower gesture for  $C_2$  obscures the place cues for  $C_1$  more easily. The schematic representations in (6) can illustrate this point.



In (6a), a rapid  $C_2$  gesture (marked in bold) slightly overlaps with the preceding  $C_1$  gesture; so that  $C_2$ 's influence onto VC formant transitions would be minimal. Example (6b) illustrates that a slow gesture of  $C_2$  may begin even before the  $C_1$  gesture does; thus it will greatly obscure the VC transition cues to identification of the  $C_1$ . The slower the gesture for  $C_2$ , the greater this effect will be. As discussed above, coronals are characterised by rapid articulatory gestures, whereas noncoronals are characterised by slow gestures. From this, it follows that the place cues of  $C_1$  can be obscured more easily before noncoronals than coronals.

## 2.5 Summary

The four perceptibility scales proposed in this section are repeated below.

### (7) Perceptibility Scales for Place

- a. Target manner: [+cont]/\_\_C > [stop]/\_\_C > [nasal]/\_\_C
- b. Target place: unreleased dorsal > unreleased labial > unreleased coronal
- c. Target position: \_\_V > \_\_C
- d. Trigger place: \_\_coronal > \_\_noncoronal

It will be shown in section 4 that typological patterns of place assimilation follow from these perceptibility scales.

## 3. Typology

Place assimilation patterns display language-specific variability. However, the variability is not unconstrained; there are systematic gaps and asymmetries. This section discusses a data

survey, building on Mohanan (1993), which confirms this claim. The discussion below is based on data from Brussels Flemish, Catalan, Diola-Fogny, English, German, Hindi, Inuktitut dialects, Keley-i, Korean, Lithuanian, Malay, Malayalam, Nchufie, Thai, Toba Batak, Yakut, and Yoruba. However, the assimilatory patterns that emerge are the same as those discussed in a much larger data set employed in Jun (1995). I will classify the attested patterns according to the same four categories used in the preceding section.

### 3.1 Target manner

The following table shows a summary of surveyed patterns of place assimilation with respect to the manner of the target:<sup>1</sup>

#### (8) Patterns for target manner

<i>Language list</i>	<i>nasal</i>	<i>stop</i>	<i>continuant</i>
Catalan <sup>2</sup> , English, German, Korean, Malay, Thai, Yakut	yes	yes	no
Brussels Flemish, Diola Fogny, Hindi, Keley-I, Lithuanian, Malayalam, Nchufie, Toba Batak, Yoruba	yes	no	no

(yes = ‘targeted’, no = ‘untargeted’ and ‘undetermined/unknown’)

In the above table, “yes” indicates that a consonant produced with the corresponding manner of articulation can be targeted in place assimilation, and “no” indicates that the consonant cannot be targeted. In some cases it is impossible to determine whether the relevant consonant can be targeted or not; for instance, this is true of fricatives in Korean, since only

codas can be targeted in Korean place assimilation but fricatives never appear in coda position. There are also cases whose patterns are not known to me. These cases are included in the “no” category.

From the above list, two observations can be made. First, continuants (i.e. fricatives, liquids and glides) virtually never undergo place assimilation. (There are cases, e.g. Japanese, in which continuants can undergo place assimilation as part of a process of total assimilation; such cases are excluded from consideration here.)

Second, among the noncontinuants, nasals are more likely to undergo place assimilation than stops, and there is an implicational relation: if in some language stops can be targeted for assimilation, so can nasals. Thus, languages such as Malayalam allow only nasals to be targeted, and languages like English target both oral stops and nasals, but there are no languages in which only oral stops can be targeted.

### 3.2 Target place

The following table sorts the surveyed data according to the place of articulation of the target:

## (9) Patterns for target place

<i>Language list</i>	<i>coronal</i>	<i>labial</i>	<i>velar</i>
Diola Fogy, Malay, Nchufie, Yoruba, Thai	yes	yes	yes
Korean	yes	yes	no
Hindi, Malayalam	yes	yes	
Catalan, English, German, Toba Batak, Yakut	yes	no	no
Brussels Flemish, Keley-I, Lithuanian	yes	no	

(“yes” = ‘targeted’, “no” = ‘untargeted’, blank = ‘undetermined or unknown’)

“Yes” indicates that a consonant produced at the corresponding place of articulation can be targeted in place assimilation; “no” indicates that it cannot. Unlike in (8), undetermined (and unknown) cases are unmarked. This table shows that consonants produced at different places of articulation tend to be targeted in place assimilation to a different degree. First, coronals are a target in all surveyed languages. The prevalence of coronals among place assimilation targets has been noted earlier by Bailey (1970), Kiparsky (1985), Cho (1990), Paradis & Prunet (1991), and others. In Brussels Flemish, Catalan, English, German, Keley-I, Lithuanian, Toba Batak and Yakut, only coronals are targeted in place assimilation. There are also languages such as Diola-Fogy, Hindi, Korean and Malayalam, in which not only coronals but also noncoronals can be targeted. However, I am not aware of any languages where only noncoronals are targets. Thus, it seems that in any language, if noncoronals can

be targets of place assimilation, so can coronals.

Among the languages surveyed, Korean is the only language which shows a clear asymmetry among noncoronals, i.e. between labials and velars: Korean place assimilation targets both coronals and labials, but not velars. However, additional data in Dorais's (1986) survey of Inuktitut dialects (not included in my own database) involve a number of cases in which coronals and labials, but not velars, assimilate.<sup>3</sup> The Korean and Inuktitut data together suggest that labials are more likely to undergo place assimilation than velars. We propose, then, the implicational statements in (10):

(10) Target Place

- a. If velars are targets of place assimilation, so are labials.
- b. If labials are targets of place assimilation, so are coronals.

### 3.3 Position of the target consonant

It is well known that in intervocalic position, regressive assimilation is much more common than progressive assimilation. Beckman (1998: 22) suggests that this is not just a tendency: where all else is equal between  $C_1$  and  $C_2$ , 'progressive assimilation in consonant clusters is virtually unattested'. The preference for  $C_1$  target is confirmed in my survey data: all the patterns involve  $C_1$ , not  $C_2$ , as a target. Webb's (1982) survey, in which two hundred languages were examined as part of the Stanford Archiving Project, yielded similar results.

However, there are two exceptions to the pattern of regressive assimilation, both of

which find independent explanations. First, in cases like Kambata (Hudson 1980: 105), Musey (Shryock 1993), and Dutch (Trommelen 1983), the initial consonant of a suffix assimilates to the final consonant of a stem. This appears to reflect the widely-noted tendency that stems resist alternation in comparison to affixes (see e.g. Casali 1996, Silverman 1995). The second exception is that in word-final VC<sub>1</sub>C<sub>2</sub>, C<sub>2</sub> sometimes assimilates to C<sub>1</sub>, as in German /va:gən/ → [va:gŋ] ‘Wagen’ (Kohler 1990: 83). This “exception” is only an apparent one: since the word-final C<sub>2</sub> lacks most of the perceptual cues of C<sub>2</sub> in VC<sub>1</sub>C<sub>2</sub>V, none of the discussion above is relevant to such cases.

In sum, except for these special contexts, place assimilation appears to be always regressive.

### 3.4 Trigger place

Most surveyed patterns do not show any asymmetries with respect to the place of articulation of the trigger consonant. A relevant case, however, can be found in Korean place assimilation.

(11) Korean (from Jun 1996b)<sup>4</sup>

a. Noncoronals are triggers.

/ip+ko/ → [ikko] ‘wear and’

b. Coronals are not triggers.

/ip+tolok/ → [iptolok], \*[ittolok] ‘wear + causative marker’

In Korean, labials do not assimilate to following coronals (11b), but they do assimilate to

following velars (11a). A similar asymmetry is seen in Latin stop assimilation (Kühner & Holzweissig 1966): stops assimilate to following velars and labials (e.g. *su/b+k/urro* → *su[kk]urro* ‘I rush up to’) but they do not assimilate to following coronals (*scri/b+t/um* → *scri[pt]um*, not \**scri[tt]um* ‘write-neuter passive participle’). In the absence of counterexamples, I will assume the following descriptive statement: If coronals trigger place assimilation, so do noncoronals.

### 3.5 Summary

The typological survey of place assimilation presented above yields the following implicational statements.

#### (12) Implicational statements of place assimilation

##### a. Target manner

- (i) If continuants are targets of place assimilation, so are stops.
- (ii) If stops are targets of place assimilation, so are nasals.

##### b. Target place

- (i) If velars are targets of place assimilation, so are labials.
- (ii) If labials are targets of place assimilation, so are coronals.

##### c. Position of target

In  $C_1C_2$  cluster, if  $C_2$  is a target of place assimilation, so is  $C_1$  (exceptions:  $C_2$  in suffixes;  $C_2$  not prevocalic)

#### d. Trigger place

If coronals are triggers, so are noncoronals.

In the following section, I develop a formal analysis intended to capture these generalisations.

#### 4. Analysis

To begin, it will be useful to consider the phonetic events that occur in place assimilation.

Two articulatory gestures, encoding the place of articulation of the target and trigger segments, are involved. Occurrence of place assimilation means loss of the target gesture, with concomitant extension in time of the trigger gesture so as to occupy the slot formerly held by the target.<sup>5</sup>

It has been suggested by Browman & Goldstein (1990) that loss of gestures does not occur in assimilation, and that assimilation is simply the submergence of one articulatory gesture under another. My own data suggest otherwise. In Jun (1996b) I explored the patterns of gestural overlap and reduction in Korean and English labial-initial stop clusters, e.g. /ipku/, using intraoral pressure data. I found that mere gestural overlap does not yield perceptual place assimilation; overlapped /pk/ is in fact heard as [pk]. Assimilation is perceived only when there is gestural reduction (partial or complete) of the target consonant. Moreover, the observed gestural reduction occurs in exactly the contexts where traditional phonological analysis posits a process of assimilation; that is, for labials preceding velars, not coronals. Nolan's (1992) study of assimilation of coronals in English obtained similar results. Thus,

the articulatory process which corresponds at the phonetic level to phonological assimilation appears to be more complex than mere overlap. Rather, the correct mechanism appears to be gestural reduction of the target consonant, with concomitant temporal extension of the trigger consonant. The analysis below proceeds under this assumption.

Why do speakers reduce articulatory gesture of the target segment? A widely held view of phoneticians (e.g. Lindblom 1983, 1990) is that speech production is the result of reconciling two conflicting requirements: ease of articulation and ease of perception. Under this view, gestural reduction occurs in order to satisfy the requirement of ease of articulation. (We will see below, however, that perceptual requirements also play a role.)

Let us consider how assimilation can be treated formally within this general view. I assume the general theoretical framework of Optimality Theory (Prince & Smolensky 1993). My proposal is that the constraints predicting the patterns of place assimilation represent the grammatical reflexes of the requirements of articulation and perception (cf. Kohler 1990, Mohanan 1993).

A constraint motivated by ease of articulation, which I call WEAKENING, formulates the minimisation of articulatory effort, as stated in (13):<sup>6</sup>

(13) WEAKENING: Conserve articulatory effort.

Following Kirchner (1998, this volume), I assume that violations of WEAKENING are assessed based on the effort cost (i.e. ‘a mental estimate of the biomechanical energy’) required for the

articulation of each candidate. For present purposes a simplified computation of the effort cost may be assumed: an arbitrary positive value is assigned to all complete closure gestures, while a zero value is assigned in cases of elimination of gestures. (In section 5, a finer distinction between the effort costs will be made in the analysis of gradient assimilation.) A violation mark of WEAKENING is incurred whenever an articulatory gesture occurs in a candidate. WEAKENING thus has the effect of reducing or eliminating articulatory gestures, leading to place assimilation in consonant clusters.

WEAKENING conflicts with Faithfulness constraints, stated here as mandating the preservation of the perceptual cues to features (Flemming 1995):

(14) PRESERVE: Preserve perceptual cues for input features.


I follow Steriade (1997) in assuming that Faithfulness constraints are evaluated relative to a hypothesised phonetic interpretation of the input string; this is a mental representation that includes the articulatory realisation of the input features and the acoustic-auditory consequences of the articulations. Faithfulness to the input is assessed in terms of maximal preservation of these acoustic-auditory properties of the phonetically interpreted input. PRESERVE has the indirect effect of preserving gestures insofar as these gestures have acoustic/auditory consequences; thus gestural reduction or elimination is penalised, and therefore, so is place assimilation.

The tableaux in (15) illustrate how the occurrence and absence of place assimilation


follow from the interaction of the WEAK(ENING) and PRES(ERVE) constraints.

(15) Occurrence and absence of place assimilation

a.

/tk/	Articulation	Perception	WEAK	PRES(place)
(i)	coronal <input type="text"/> dorsal <input type="text"/>	[tk]	***!	
(ii) 	coronal dorsal <input type="text"/>	[kk]	*	*

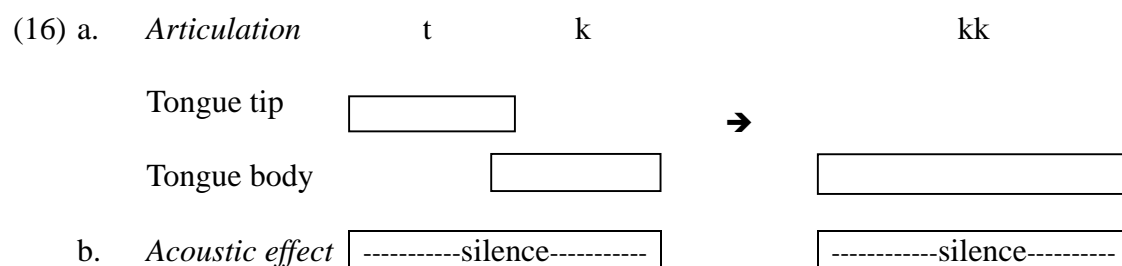
b.

/tk/	Articulation	Perception	PRES(place)	WEAK
(i) 	coronal <input type="text"/> dorsal <input type="text"/>	tk		**
(ii)	coronal dorsal <input type="text"/>	kk	*!	*

For each output candidate, articulatory gestures encoding the input place features are represented with boxes, and their corresponding perceptual consequences are represented with phonetic symbols. In candidate (15i), two gestures are made and thus two violation marks of WEAKENING are provided, whereas in candidate (15ii) only a single gesture is made, thus incurring a single violation of WEAKENING.<sup>7</sup> Consider next the evaluation of PRESERVE(place). Candidate (15i) is a hypothesised phonetic interpretation of the input in

which all the input features are phonetically realised. As such, it preserves all the perceptual information of the input places, and therefore incurs no violations of PRESERVE(place). In contrast, in candidate (15ii), the coronal gesture is not made, and thus its perceptual information is not preserved, so that PRESERVE(place) is violated.<sup>8</sup> When WEAKENING outranks the PRESERVE constraint for place features, place assimilation occurs (15a); otherwise, no assimilation results (15b).

In assimilation, deletion of the target gesture is accompanied by the lengthening of the trigger gesture, which is another aspect of the process that a phonological analysis must account for. I treat this process as a kind of Faithfulness effect: the goal is to maintain in the output the manner cues of the input target gesture. For example, when the target is a voiceless stop, the period of silence obtained by lengthening the trigger gesture will have the effect of preserving the manner cues of the target gesture.



In (16a), the boxes represent stop closure gestures which result acoustically in silence, as represented in (16b). By comparing the left and right sides of the arrow, we observe that the tongue tip closure gesture is completely reduced and that the tongue body closure gesture

lengthens. The stop closure is acoustically silent; thus, there would not be any loss of the stop manner cue, i.e. silence.

In terms of the formal analysis, place assimilation—as opposed to deletion—occurs under the following ranking: { PRESERVE constraints for manner cues } >> WEAKENING >> { PRESERVE constraints for place cues }. This can be seen in tableau (17). (In the remainder of this paper, candidates in tableaux will include only phonetic symbols indicating the perceptual consequences of the articulatory gestures involved.)

(17) Occurrence of place assimilation, not deletion

	Input = /tk/	PRES(manner)	WEAK	PRES(place)
a.	☞ kk (assimilation)		*	*
b.	tk (no change)		**!	
c.	k (deletion)	*!	*	*

Let us consider how this analysis can be used to explain the typological results given above. The crucial principle will be a universal ranking for PRESERVE constraints, which is a formal implementation of the hypothesis in (18) (cf. Kohler 1990, 1991, 1992; Steriade 1993; and Byrd 1994):

(18) Production Hypothesis

Speakers make more effort to preserve the articulation of speech sounds with relatively more powerful acoustic cues.

According to this hypothesis, speakers exert less effort on articulations which present inherent acoustic weaknesses. They exert more effort on articulations with acoustically

salient consequences, since the effort will pay off in enhancing the perceptibility of the segment.

The Production Hypothesis provides a general basis for ranking PRESERVE constraints: constraints preserving perceptually more salient segments must be ranked above those preserving perceptually less salient segments. I propose the following formalisation of this idea:

(19) PRES(X(Y)): Preserve perceptual cues for X (place or manner of articulation) of Y (a segmental class).

Universal ranking: PRES(M(N)) >> PRES(M(R)),

where N's perceptual cues for M are stronger than R's cues for M.

Assuming (19), the following sets of position- or segment-specific PRESERVE constraints and their internal rankings can be directly projected from the perceptibility scales proposed in section 2.

(20) Position/segment-specific PRESERVE constraints and universal rankings

a. Target manner: PRES(pl( $\frac{\quad}{[+cont]}$  C)) >> PRES(pl( $\frac{\quad}{[stop]}$  C)) >> PRES(pl( $\frac{\quad}{[nasal]}$  C))

b. Target place: PRES(pl(dorsal<sup>1</sup>)) >> PRES(pl(labial<sup>1</sup>)) >> PRES(pl(coronal<sup>1</sup>))

c. Target position: PRES(pl(\_\_V)) >> PRES(pl(\_\_C))

d. Trigger place: PRES(pl(\_\_coronal)) >> PRES(pl(\_\_noncoronal))

I will now show how the interaction of these ranked Faithfulness constraints and WEAKENING

explains typological patterns of place assimilation discussed in section 3.

#### 4.1 Target manner

The ranking in (20a) indicates that place cues of continuant consonants must be preserved in preference to stop place cues, which are, in turn, preserved in preference to nasal place cues.

This ranking mirrors the implicational statements about manner of articulation of the target consonant, shown in (12a). More specifically, the ranked constraints in (20a) may produce different assimilation patterns depending on their ranking relative to **WEAKENING**:

##### (21) Possible language-specific rankings

a. **WEAKENING** >> PRES(pl( $\frac{\quad}{[+cont]}$  C)) >> PRES(pl( $\frac{\quad}{[stop]}$  C)) >> PRES(pl( $\frac{\quad}{[nasal]}$  C))

→ Continuants, stops and nasals are all targets.

b. PRES(pl( $\frac{\quad}{[+cont]}$  C)) >> **WEAKENING** >> PRES(pl( $\frac{\quad}{[stop]}$  C)) >> PRES(pl( $\frac{\quad}{[nasal]}$  C))

→ Stops and nasals are targets but continuants are not.

c. PRES(pl( $\frac{\quad}{[+cont]}$  C)) >> PRES(pl( $\frac{\quad}{[stop]}$  C)) >> **WEAKENING** >> PRES(pl( $\frac{\quad}{[nasal]}$  C))

→ Only nasals are targets.

All attested patterns, discussed in section 3.1, can be derived from the rankings above. For example, (21b) explains patterns in which stops and nasals can be targeted but continuants cannot, as in English, German, Malay and Yakut. Ranking (21c) derives patterns in which only nasals can be targeted, as in Brussels Flemish, Hindi, Keley-I, Malayalam and Toba Batak. Moreover, there are no possible rankings for unattested patterns. For instance, patterns in which stops, but not nasals, can be targeted, do not exist. Such a pattern would require that **WEAKENING** should outrank **PRESERVE** for stops but at the same time be outranked by the

PRESERVE for nasals. This is impossible according to (20a). To demonstrate how attested patterns can be analysed by the proposed mechanism, let us consider cases in which only nasals are targeted by assimilation. The following tableaux illustrate an analysis of Malayalam data (taken from Mohanan 1993).

(22) a. Nasals are targets: /awan+karaññu/ → [awaŋkaraññu] ‘he cried’

Input = /awan+karaññu/	PRES(pl( $\frac{\text{---}}{\text{[stop]}}$ C))	WEAK	PRES(pl( $\frac{\text{---}}{\text{[nasal]}}$ C))
(i) awankaraññu		**!	
(ii) awaŋkaraññu		*	*

b. Stops are not targets: /uṭkarṣam/ → \* [ukkarṣam] ‘progress’

Input = /uṭkarṣam/	PRES(pl( $\frac{\text{---}}{\text{[stop]}}$ C))	WEAK	PRES(pl( $\frac{\text{---}}{\text{[nasal]}}$ C))
(i) uṭkarṣam		**	
(ii) ukkarṣam	*!	*	


(In the above and the remainder of this paper, only a crucial consonant cluster is considered in assessing violations of constraints)

In (22a), the fully-faithful candidate incurs double violations of WEAKENING, since both coronal and dorsal gestures are made. In contrast, candidate (22a.ii), with place assimilation, incurs a single violation of WEAKENING, since the coronal gesture is reduced and so only a single gesture, i.e. dorsal, is made. This candidate also violates the PRESERVE constraint for place of articulation of a nasal; i.e. it does not preserve the place cues of the coronal nasal, due to the reduction of the coronal gesture. But since the PRESERVE constraint is lower ranked than WEAKENING, candidate (22a.ii) is the optimal output. Consequently, it is shown that if  $C_1$

is a nasal, place assimilation occurs. In (22b), a candidate displaying place assimilation violates a higher-ranked PRESERVE constraint for place of articulation of an oral stop. In contrast, the faithful candidate violates only the lower-ranked WEAKENING, and thus is optimal. Thus, if  $C_1$  is a stop, no assimilation occurs. In conclusion, asymmetric typological patterns of place assimilation with respect to the manner of the target can be analysed by the interaction of WEAKENING and internally-ranked PRESERVE constraints, as proposed above.

There is an alternative account for some of the typological patterns of place assimilation analysed in this section. One might argue that the reason why fricatives, liquids and glides are rarely targeted in place assimilation is because the continuants are often limited to the small number of places of articulation, not because their place cues are prominent. For instance, if [s] is the only acceptable fricative in a certain language, /sk/ would not become /xk/ even if /tk/ become [kk]. This can be analysed by ranking a structure preservation constraint  $*_x$  and Faithfulness constraints for manner, PRES(mnr), over WEAKENING:

(23) No fricative target: /sk/ → [sk] (with no general occurrence of [x])

Input = /sk/	$*_x$	PRES(mnr)	WEAK	PRES(place)
a.  sk			**	
b. xk	*!		*	*
c. kk		*!	*	*

Here, the assimilating candidate  $*[xk]$  is ruled out by undominated  $*_x$ . However, an analysis that relies on structure preservation constraints to block assimilation of continuants cannot provide a general account for the asymmetries under consideration. There are languages in which continuants with a variety of places of articulation can occur in general but fricative

assimilation is still blocked. For instance, in German, the fricative /s/ cannot yield [x] through assimilation to velars (e.g. au[sg]eben, \*au[xg]eben ‘to spend’), even though [x] would be legal in this position. It seems that only the perception-based approach proposed in the present study can provide a general account for manner asymmetries in place assimilation.

#### 4.2 Target place

The ranking in (20b), PRES(pl(dorsal<sup>1</sup>)) >> PRES(pl(labial<sup>1</sup>)) >> PRES(pl(coronal<sup>1</sup>)), captures the implicational statements about place of articulation of the target consonant in (12b), namely, that if velars are targets of place assimilation, so are labials, and that if labials are targets of place assimilation, so are coronals.. The following shows the interactions of WEAKENING and PRESERVE constraints that are consistent with (20b):

#### (24) Possible language-specific rankings

a. **WEAKENING** >> PRES(pl(dor<sup>1</sup>)) >> PRES(pl(lab<sup>1</sup>)) >> PRES(pl(cor<sup>1</sup>))

→ Coronals and noncoronals are all targets.

b. PRES(pl(dor<sup>1</sup>)) >> **WEAKENING** >> PRES(pl(lab<sup>1</sup>)) >> PRES(pl(cor<sup>1</sup>))

→ Labials and coronals are targets but velars are not.

c. PRES(pl(dor<sup>1</sup>)) >> PRES(pl(lab<sup>1</sup>)) >> **WEAKENING** >> PRES(pl(cor<sup>1</sup>))

→ Only coronals are targets.

All patterns predicted from the interaction of the relevant constraints are identical with the typological patterns of place assimilation discussed in section 3.2.

Consider, for instance, the cases in which only coronals are the target. The following tableaux are for the English pattern, where (for example) /t/ assimilates to /k/ but /p/ does not.

(25) a. Coronals are targets: /let kəl/ → [lek kəl] ‘late call’

Input = /let kəl/	PRES(pl(lab <sup>ʰ</sup> ))	WEAK	PRES(pl(cor <sup>ʰ</sup> ))
(i) let kəl		**!	
(ii) ↗ lek kəl		*	*

b. Noncoronals are not targets: /lip kwikli/ -x-> [lik kwikli] ‘leap quickly’

Input = /lip kwikli/	PRES(pl(lab <sup>ʰ</sup> ))	WEAK	PRES(pl(cor <sup>ʰ</sup> ))
(i) ↗ lip kwikli		**	
(ii) lik kwikli	*!	*	

Here, WEAKENING is ranked between PRES(pl(lab<sup>ʰ</sup>)) and PRES(pl(cor<sup>ʰ</sup>)). Thus a coronal gesture must be reduced to obey WEAKENING, sacrificing lower-ranked PRES(pl(cor<sup>ʰ</sup>)) (25a).

In contrast, a labial gesture must be maintained to obey the dominant PRES(pl(lab<sup>ʰ</sup>)), sacrificing WEAKENING (25b). Similar rankings, not given here, derive the other possible patterns in analogous ways. There are no possible rankings for unattested patterns: for example, only labials as the target. In order for labials but not coronals to be the target of place assimilation, WEAKENING must outrank PRES(pl(lab<sup>ʰ</sup>)) and at the same time be outranked by PRES(pl(cor<sup>ʰ</sup>)). This is impossible according to the proposed universal ranking in (20b).

#### 4.3 Target position

Here the crucial ranking is the one given in (20c): PRES(pl(\_\_V)) >> PRES(pl(\_\_C)).

Placing WEAKENING in the relevant locations for this ranking, we obtain the following:

(26) *Possible language-specific rankings*

a.  $\text{PRES(pl(\\_V))} \gg \text{WEAKENING} \gg \text{PRES(pl(\\_C))}$

→ Only  $C_1$  is the target.

b.  $\text{WEAKENING} \gg \text{PRES(pl(\\_V))} \gg \text{PRES(pl(\\_C))}$

→ Both  $C_1$  and  $C_2$  are the target.

The following tableau illustrates regressive assimilation in Yakut.

(27) Yakut: /at+ka/ → [akka], \*[atta] ‘to a horse’ (Krueger 1962)

Input = /at+ka /	PRES(pl(\\_V))	WEAK	PRES(pl(\\_C))
a. atka (no change)		**!	
b. ↻ akka (regressive)		*	*
c. atta (progressive)	*!	*	

Cases of progressive assimilation in suffixes were discussed in section 3.3. To account for these, I adopt the view (e.g. McCarthy & Prince 1995) that Faithfulness constraints for stem material are always ranked above Faithfulness constraints for affixes.

The ranking in (26b) produces cases in which both progressive and regressive assimilations occur: for instance, in a hypothetical language where only coronals can be targeted, both /atka/ and /akta/ would become [akka]. I have not yet discovered any cases of this sort.<sup>9</sup>

An important aspect of the analysis is that contexts are defined in terms of neighbouring segments, rather than in terms of prosodic positions such as coda. As a number of authors

have argued (Padgett 1995; Steriade 1999, 2000, 2001; Côté 2000), syllable or prosodic positions are not appropriate for characterising typical target positions of place assimilation or indeed of other segmental phenomena. To give an example from place assimilation, nasals which are preconsonantal but in the onset characteristically do assimilate, as in Luganda (e.g. [lu.ga.nda]). The same is true for syllabic nasals, as in Kpelle (e.g. [ɱbolu]; forms from Padgett 1995); these presumably occupy the nucleus, not the coda.

#### 4.4 Trigger Place

The ranking in (20d),  $\text{PRES}(\text{pl}(\_\text{coronal})) \gg \text{PRES}(\text{pl}(\_\text{noncoronal}))$ , indicates that place cues of a consonant must be preserved before coronals in preference to before noncoronals.

The possible rankings of WEAKENING within this hierarchy derive the observed typology:

#### (28) Possible language-specific rankings

a.  $\text{PRES}(\text{pl}(\_\text{cor})) \gg \text{WEAKENING} \gg \text{PRES}(\text{pl}(\_\text{noncor}))$


→ Only noncoronals are the trigger.

b.  $\text{WEAKENING} \gg \text{PRES}(\text{pl}(\_\text{cor})) \gg \text{PRES}(\text{pl}(\_\text{noncor}))$

→ Both coronals and noncoronals are the trigger.

Ranking (28a) is attested in Latin and Korean; here is a Korean example:

#### (29) a. Noncoronals are triggers.

Input = /ip+ko/	$\text{PRES}(\text{pl}(\_\text{cor}))$	WEAK	$\text{PRES}(\text{pl}(\_\text{noncor}))$
(i) ipko		**!	
(ii)  ikko		*	*

b. Coronals are not triggers.

Input = /ip+tolok/	PRES(pl(__cor))	WEAK	PRES(pl(__noncor))
(i) $\rightarrow$ iptolok		**	
(ii) ittolok	*!	*	

Because the ranking  $\text{PRES(pl(__noncor))} \gg \text{PRES(pl(__cor))}$  is disallowed, there is no ranking that permits assimilation to coronals only.

### 5. Gradient assimilation

Patterns of place assimilation fall into two major types, categorical and gradient. In categorical assimilation, loss of a target gesture is always complete. An example is found in the English prefix *in-*, in such morphophonemic alternations as  $i[n]+ept$  vs.  $i[m]+possible$ ). Categorical alternation is characteristically insensitive to speech rate and style.

In gradient assimilation, a residual gesture corresponding to  $C_1$  appears on the surface. Such remnants of the target gesture have been observed in German (Kohler 1976), English (Barry 1985; Browman & Goldstein 1990; Nolan 1992; and Byrd 1994), and Korean (Jun 1996b). Gradient assimilation is characteristically sensitive to rate and style.

A complete analysis of assimilation must provide a way of treating the gradient/nongradient distinction. In the account proposed here, all gestural reduction comes from the high ranking of WEAKENING, which requires the conservation of articulatory effort. An output which displays no target gesture at all will best satisfy this constraint. To analyse gradient assimilation, we need to establish what prevents the reduction from going all the

way to zero.

I claim that partial reduction is the result of an attempt to preserve small remnants of the perceptual cues for the original segment. Specifically, I propose that the PRESERVE(place) is a constraint family which can be decomposed into constraints distinguished by the amount of place-of-articulation information, i.e., PRESERVE<sub>n</sub>(place) = ‘Preserve at least  $n$  percent of the perceptual cues for place of articulation’, where  $1 \leq n \leq 100$ . PRESERVE<sub>100</sub>(place) requires maximum preservation of the perceptual cues for place; thus, when this constraint is undominated, a complete closure gesture is produced. In contrast, PRESERVE<sub>1</sub>(place) ... PRESERVE<sub>99</sub>(place) require preservation of lesser degrees of perceptual cues; thus the dominance of any of these constraints guarantees the production of some kind of partially reduced closure. To implement the idea that at least some of the perceptual information may need to be preserved when the maximum preservation is not possible, the following internal ranking is proposed: PRESERVE<sub>1</sub>(place) >> ... PRESERVE<sub>50</sub>(place) ... >> PRESERVE<sub>100</sub>(place) (cf. Hayes 1995, Boersma 1998).

WEAKENING likewise can be decomposed into continuous constraints distinguished by the amount of effort cost, i.e., WEAKENING<sub>m</sub> = ‘Do not produce an articulatory gesture whose effort cost is at least  $m$ ’ (cf. Kirchner 1998, this volume). Following Kirchner’s assumption that ‘the impetus to lenite more effortful gestures is stronger than the impetus to lenite easier gestures,’ the universal ranking of the decomposed constraints must be the following:

$\text{WEAKENING}_{1x} \gg \dots \text{WEAKENING}_{0.5x} \dots \gg \text{WEAKENING}_{0.1x}$  where  $1x$  is the effort cost required for the production of a complete closure gesture (cf. Boersma 1998).

To show how various reduction patterns of the target segment follow from the interaction of the proposed decomposed constraints, consider ten ranked constraints selected from each of the PRESERVE and WEAKENING families:  $\{\text{PRES}_{10}(\text{place}), \text{PRES}_{20}(\text{place}) \dots \text{PRES}_{100}(\text{place})\}$  and  $\{\text{WEAK}_{1x}, \text{WEAK}_{0.9x} \dots \text{WEAK}_{0.1x}\}$ . I assume that the PRESERVE and WEAKENING constraints conflict in such a way that  $\text{WEAK}_{1x} \leftrightarrow \text{PRES}_{100}(\text{place})$ ,  $\text{WEAK}_{0.9x} \leftrightarrow \text{PRES}_{90}(\text{place}) \dots \text{WEAK}_{0.1x} \leftrightarrow \text{PRES}_{10}(\text{place})$  (where  $\leftrightarrow$  indicates ‘conflict with’). For instance,  $\text{WEAK}_{1x}$  prohibits the occurrence of a complete closure gesture, which would provide 100 percent of perceptual cues for place; whereas  $\text{PRES}_{100}(\text{place})$  requires the maximum preservation of perceptual cues, which can be achieved only by making a complete closure. Then there is no way to satisfy the two constraints at the same time.

I assume further that as the speech becomes faster and more informal, the ranking of the WEAKENING constraints relative to the PRESERVE constraints increases; whereas as the speech become slower and more formal, the ranking of PRESERVE constraints increases.

The following table shows how the interaction of these constraints produce different reduction forms of the target segment in place assimilation depending on the speech style and speed.

## (30) Ranking variation and reduction patterns

speech speed/style	← slow & formal				informal & fast →	
Constraint Ranking	P <sub>10</sub>	P <sub>10</sub>	P <sub>10</sub>	...	W <sub>1x</sub>	W <sub>1x</sub>
	P <sub>20</sub>	P <sub>20</sub>	P <sub>20</sub>		W <sub>0.9x</sub>	W <sub>0.9x</sub>
	...	...	...		W <sub>0.8x</sub>	W <sub>0.8x</sub>
	P <sub>70</sub>	P <sub>70</sub>	P <sub>70</sub>		W <sub>0.7x</sub>	W <sub>0.7x</sub>
	P <sub>80</sub>	P <sub>80</sub>	W <sub>1x</sub>		...	...
	P <sub>90</sub>	<b>P<sub>90</sub></b>	<b>P<sub>80</sub></b>		<b>W<sub>0.2x</sub></b>	<b>W<sub>0.2x</sub></b>
	<b>P<sub>100</sub></b>	<b>W<sub>1x</sub></b>	<b>W<sub>0.9x</sub></b>		<b>P<sub>10</sub></b>	<b>W<sub>0.1x</sub></b>
	<b>W<sub>1x</sub></b>	<b>P<sub>100</sub></b>	<b>P<sub>90</sub></b>		<b>W<sub>0.1x</sub></b>	<b>P<sub>10</sub></b>
	W <sub>0.9x</sub>	<b>W<sub>0.9x</sub></b>	<b>W<sub>0.8x</sub></b>		<b>P<sub>20</sub></b>	P <sub>20</sub>
	W <sub>0.8x</sub>	W <sub>0.8x</sub>	P <sub>100</sub>		...	...
	W <sub>0.7x</sub>	W <sub>0.7x</sub>	W <sub>0.7x</sub>		P <sub>70</sub>	P <sub>70</sub>
	...	...	...		P <sub>80</sub>	P <sub>80</sub>
	W <sub>0.2x</sub>	W <sub>0.2x</sub>	W <sub>0.2x</sub>		P <sub>90</sub>	P <sub>90</sub>
	W <sub>0.1x</sub>	W <sub>0.1x</sub>	W <sub>0.1x</sub>		P <sub>100</sub>	P <sub>100</sub>
reduction degree	0	10	20	...	90	100

(P<sub>n</sub> = PRESERVE<sub>n</sub>(place), W<sub>m</sub> = WEAKENING<sub>m</sub>; crucial parts are shaded)

In the above table, each column represents the ranking of WEAKENING and PRESERVE constraints for a given speech style/speed: the higher in the column, the higher the ranking. In the first column, which describes the most formal/slowest speech, all PRESERVE constraints outrank all WEAKENING constraints, preventing even a small amount of reduction. In the second column, for slightly more informal/faster speech, W<sub>1x</sub> outranks P<sub>100</sub>, thus preventing the occurrence of a full closure gesture. However, since P<sub>90</sub> still outranks its conflicting partner W<sub>0.9x</sub>, the reduction must not be so drastic that more than 10 percent of perceptual cues would be lost. As a result, an optimal output form will show at most 10 percent reduction of the target gesture. As the speech rate/style becomes faster and more informal, the ranking of the WEAKENING constraints relative to PRESERVE constraints becomes higher, thus

increasing the degree of reduction in the output. In the last column, for the most informal/fastest speech, all WEAKENING constraints outrank all PRESERVE constraints, thus producing zero closure. Consequently, in addition to forms with full and completely-reduced closures, the proposed mechanism may produce various semi-reduced forms, which can be observed in gradient assimilation.

In summary, the proposed analysis incorporates gradient assimilation by expanding the PRESERVE and WEAKENING constraint families to cover multiple, quantitative values. Categorical assimilation results when the families are completely nonoverlapped in the ranking, with all WEAKENING constraints dominating all PRESERVE constraints.

## 6. Conclusion

The two most crucial aspects of the present study of place assimilation are as follows. First, the analysis can deal with both language-specific and universal patterns. This is made possible by the use of Optimality Theory: language-specific assimilation patterns result from language-specific constraint rankings, while the scope of cross-linguistic variability is limited by universal rankings. Second, I have appealed to phonetic research to give the analysis a non-arbitrary basis: the proposed constraints and their universal rankings are determined by principles and properties which are supported empirically by research in speech perception and production.

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## Notes

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<sup>1</sup> See Jun (1995) for the discussion of the typological data and their original sources.

<sup>2</sup> In Catalan, among continuants, only /l/ may assimilate in place to a following palatal or velar but it cannot to a following labial (Mascaró 1978). This limited case is not specified in (8) for simplicity's sake.

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<sup>3</sup> The assimilation of labials in the relevant dialects is a well-established diachronic fact; however, because of the lack of labial-final stems (Bobaljik 1996: 323), it is harder to show synchronically. Preconsonantal labials are phonologically illegal except before another labial, a gap that could easily be accounted for by assuming assimilation.

<sup>4</sup> Broad phonetic transcriptions are employed for these examples. For instance, actual phonetic forms are subject to the regular process of post-obstruent fortition, whereby lenis obstruents become fortis after an obstruent (Kim-Renaud 1986).

<sup>5</sup> See section 5 below for gradient assimilation, in which the loss can be partial.

<sup>6</sup> Kirchner (1998, this volume) and Boersma (1998) adopt the same type of constraint.

<sup>7</sup> In assessing violations of the WEAKENING, short and long gestures are not differentiated.

<sup>8</sup> For the analysis shown in (15), a perceptual definition of faithfulness provided in (14) does not seem to be necessary; a conventional articulatory definition will be sufficient. However, in section 5, the role of the perceptual faithfulness will be evident in the analysis of gradient place assimilation.

<sup>9</sup> If the gap is genuine, it cannot be explained by a universal ranking PRESERVE(pl(\_\_V)) >> WEAKENING, since this ranking would exclude all cases of progressive assimilation in suffixes (section 3.3).