

## A Noisy Harmonic Grammar analysis of gradient OCP effects in English syllables\*

Yeong-Lim Oh

Sung-Hoon Hong\*\*

(Hankuk University of Foreign Studies)

**Oh, Yeong-Lim and Sung-Hoon Hong. 2013. A Noisy Harmonic Grammar analysis of gradient OCP effects in English syllables.** *Studies in Phonetics, Phonology and Morphology* 19.3. 433-455. This study investigates the effects of the Obligatory Contour Principle (OCP) on consonant co-occurrence in English syllables, considering places of articulation of consonants. Previous studies have failed to present a model that can capture the gradient effects of the OCP. This study suggests that a Noisy Harmonic Grammar is an effective model to describe the gradience in consonant co-occurrence restrictions, focusing especially on inconsistency in coronal pairs. According to each O/E (observed frequency divided by expected frequency) values for consonant pairs, the effects of OCP-Place are obvious for labial-labial and dorsal-dorsal syllables, whereas coronal co-occurrences do not appear to be under any restrictions. To address this idiosyncrasy, this study introduces the effects of OCP-Manner and OCP-Voice on coronal pairs. According to the data from this study, coronal obstruent pairs and sonorant pairs are underrepresented and the restriction on coronal obstruent pairs becomes more obvious when coronal obstruent pairs are subdivided into voiced and voiceless pairs. (Hankuk University of Foreign Studies)

Keywords: OCP, Obligatory Contour Principle, consonant co-occurrence, Noisy Harmonic Grammar, English phonotactics, gradient

### 1. Introduction

It is well-known that there is a tendency to avoid co-occurrences of similar consonants within a certain domain in various languages. McCarthy (1988: 88) defined this tendency as the Obligatory Contour Principle (henceforth, OCP; McCarthy 1986), which prohibits “adjacent identical elements.”

However, it is important to note that no previous studies claim that the OCP is applicable in all conditions. Instead, it has been suggested that the OCP is optional, applying only in particular domains to a degree determined on a language-specific basis. If the OCP holds obligatorily, sequences of the same consonants within a syllable in English like *Bob*, *cake* and *dead* should be prohibited because onsets and codas in those syllables are identical. Still, we can find many cases of OCP violation in English and other languages. Therefore we can say that the OCP is not an absolute phonological principle.

The purpose of this paper is to investigate the effects of OCP-Place on

---

\* This work was supported by the Hankuk University of Foreign Studies Research Fund of 2013. We express our appreciation to Tae-Yeoub Jang, YooKang Kim, William Hart and three anonymous reviewers for their helpful contributions.

\*\* Corresponding author

syllables in English. Many previous studies have found that in many languages there is a tendency to avoid sequences of consonants that are identical in terms of place of articulation (Pierrehumbert 1993, Berkley 1994a, b, Frisch et al. 2004, Coetzee and Pater 2005, Kawahara et al. 2006, Anttila 2008, Dmitrieva and Anttila 2008, Coetzee 2010, Taylor 2011). This paper will show that CVC and *s*-cluster syllables (sCVC and sCCVC) are affected by the OCP so that identical OCP constraints are applicable to the description of the restrictions on consonant co-occurrences as long as the distance between two consonants within a syllable is the same.

The gradient of underrepresentation and overrepresentation of syllables will be measured by the Observed/Expected value (O/E; Pierrehumbert 1993, Hong 2010). To model the gradient effects of OCP-Place, this study adopts a theoretical framework similar to Optimality Theory (OT; Prince and Smolensky 1993/2004) called “Noisy Harmonic Grammar” (Noisy HG; Boersma and Pater 2008, Coetzee and Kawahara 2010), an extended version of Harmonic Grammar (Smolensky and Legendre 2006, Pater 2008, 2009). The current study implements Noisy HG because it has been recognized as the best tool in terms of its associated learning algorithm (Coetzee and Kawahara 2010).

This paper is organized as follows. In section 2, we will present the methodology of the study and the O/E values for CVC, sCVC and sCCVC syllables in the British English (BE) lexicon. In section 3, different frameworks of OT models and Noisy HG will be compared. The effects of OCP-Place on homorganic consonant pairs and OCP-Manner/Voice on coronal pairs will be formalized by using OCP-related constraints with the framework of Noisy HG. In section 4, concluding remarks will be presented.

## 2. Gradient OCP-Place effects

### 2.1 Data and methodology

The data of this study contains all CVC, sCVC and sCCVC syllables from the CELEX<sup>1</sup> lexical database of English (Baayen et al. 1995). Each syllable is considered an individual token (3,420 CVC, 448 sCVC and 165 sCCVC syllable types; total 5,540,991 CVC, 215,811 sCVC and 70,776 sCCVC tokens). For example, the two syllables of the word *guilty* [gɪl.tɪ] are counted individually as [gɪl] and [tɪ] and each token is given the frequency of the whole word. Although the CELEX database includes all possible pronunciations of all entries and each pronunciation is classified

<sup>1</sup> CELEX transcribes syllable boundaries using hyphens (SAM-PA character set) and square brackets (CELEX character set). For example, the syllables in the word *constitute* are transcribed as ‘kQn-stɪ-tju:t’ (SAM-PA) and ‘[kQn][stɪ][tju:t]’ (CELEX). Since the differences between SAM-PA and CELEX is only a matter of transcription method, this study syllabifies each word based on the CELEX character set to maintain consistency.

as a primary or secondary pronunciation, the data used in this study only contains the primary pronunciation of each entry because the goal is to describe general tendencies of English, not the entire pronunciation pattern. Second, the CELEX lemma lexicon consists of derivational and compositional variations of words. Since Berkley (1994b) has already proved that OCP effects exist across suffix boundaries, the morphological information of syllables is disregarded in the current analysis.

All onsets and codas from the collected tokens are categorized into coronals, labials and dorsals. Possible vowel and consonant sets from CELEX are listed in (1). Only syllables with short and long vowels and diphthongs are considered and the vowels that are classified as nasalized in CELEX are excluded from the data set.

(1) Consonants<sup>2</sup>

|          |  |
|----------|--|
| Coronals | [t, d, θ, ð, s, z, ʃ, ʒ, tʃ, dʒ, l, n] |
| Labials  | [p, b, f, v, m]                        |
| Dorsals  | [k, g, ŋ, w <sup>3</sup> ]             |

Vowels

|              |                                  |
|--------------|----------------------------------|
| Short vowels | [i, e, æ, ʌ, ɑ, ʊ, ə]            |
| Long vowels  | [i:, a:, ɔ:, u:, ɜ:]             |
| Diphthongs   | [eɪ, aɪ, ɔɪ, əʊ, aʊ, ɪə, eə, ʊə] |

The gradient effects of OCP-Place on co-occurrence restrictions on onset-coda pairs can be calculated using Observed/Expected (O/E) values, which are obtained by the following formula in (2).

- (2)  $O/E = \text{Observed frequency} / \text{Expected frequency}$   
 Observed frequency = frequency of onset-coda pairs  
 Expected frequency = (the probability of onset occurrence)  $\times$   
 (the probability of coda occurrence)  $\times$  (the total number of syllables)

The observed frequency is equal to the number of co-occurrences of corresponding consonant pairs. Multiplying the probabilities of onset and coda occurrences and again multiplying them by the total number of syllables yields the expected frequency of the pairs. If an O/E value for a certain co-occurrence is greater than 1, it means that the relevant pairs are overrepresented. On the other hand, if an O/E value is smaller than 1, it means that the relevant pairs are underrepresented. The underrepresentation of homorganic consonant pairs will be represented by the O/E value

<sup>2</sup> We exclude coronal /r/ from the data because the CELEX database only includes non-rhotic British English accents.

<sup>3</sup> Although the exact features involved with place of articulation differ according to different theoretical proposals, the analyses of this study are based on the framework presented in McCarthy (1988), which classifies /w/ as dorsal.

under each consonant pair.

## 2.2 Gradient OCP effects in English syllables

In this section, we present the O/E values for each combination of consonants and show whether they are overrepresented or underrepresented. First, we will observe the O/E values for CVC syllables and then those of *s*-cluster syllables. The reason why this study presents the results from each type of syllables individually, even though co-occurrence restrictions on consonant pairs show very similar patterns in both CVC syllables and *s*-clusters, is because these two kinds of syllables show slightly different OCP effects in terms of manner of articulation. Also the effects of OCP-Manner and OCP-Voice will be suggested as a breakthrough for the handling of the comparative well-attestation of problem in coronal pairs.

### 2.2.1 CVC syllables

Table 1 shows the distribution of homorganic onset-coda pairs in CVC syllables<sup>4</sup>. All homorganic onset-coda pairs show a lower observed frequency than expected frequency so that their O/E values are below 1. Since all homorganic consonant co-occurrence pairs are underrepresented, the data can serve as evidence of OCP-Place effects, especially those with dorsal and labial co-occurrences.<sup>5</sup>

---

<sup>4</sup> This study conducts analyses with both identical and homorganic CVC, sCVC, and sCCVC syllables because the exclusion of identical consonant does not show sufficient enough difference in O/E values to conclude that identical and homorganic co-occurrences undergo different OCP effects.

<sup>5</sup> The homorganic pairs are represented in the shaded cells. The numbers in bold type indicate that the corresponding pairs are underrepresented.

Table 1. Distribution of onset-coda pairs in English C<sub>1</sub>VC<sub>2</sub> syllables

| C <sub>1</sub> | C <sub>2</sub> |                                   |   |                                     |                             |
|----------------|----------------|-----------------------------------|---|-------------------------------------|-----------------------------|
|                |                | dorsal                            | labial  | coronal                             |                             |
|                | dorsal         | 67084<br>175716.36<br><b>0.38</b> | 166187<br>211551.56<br><b>0.79</b> <sup>6</sup> | 1090638<br>936641.08<br>1.16        | observed<br>expected<br>O/E |
|                | labial         | 162278<br>149768.02<br>1.08       | 75828<br>180311.36<br><b>0.42</b>               | 890299<br>798325.62<br>1.12         | observed<br>expected<br>O/E |
|                | coronal        | 423097<br>326974.62<br>1.29       | 543505<br>393657.08<br>1.38                     | 1496940<br>1742910.3<br><b>0.86</b> | observed<br>expected<br>O/E |

It seems that OCP-Place effects are somehow weaker on coronals even though the O/E value for coronal co-occurrences is lower than 1. Relatively weaker restrictions on coronal-coronal pairs have been observed in many previous studies (Pierrehumbert 1993, Berkley 1994a, b, Coetzee and Pater 2005, Anttila 2008, Dmitrieva et al. 2008, Willson and Obdeyn 2009). These studies suggest that manner of articulation features should be considered to address weaker OCP-Place effects on coronal co-occurrences.<sup>7</sup>

As suggested in the previous studies, coronal co-occurrences can be better understood when homorganic consonants were subdivided into obstruents and sonorants, a situation which will be referred to henceforth as ‘OCP-Manner’ effects. McCarthy (1988) argues that OCP-Place effects become stronger when coronals are separated into sonorants and obstruents. Berkley (1994a, b) observed greater OCP effects on coronal co-occurrences in English monosyllables when coronals are subdivided into obstruents and sonorants. Pierrehumbert (1993) also suggests that there is no co-occurrence restriction on coronal sonorant-obstruent pairs in Arabic. She

<sup>6</sup> Dorsal-labial (dorsal as onset and labial as coda) pairs show underrepresentation (O/E=0.79). When /w/ is classified as labial, labial-dorsal (labial as onset and dorsal as coda) pairs are also underrepresented (O/E=0.87, see Appendix 1). It might be possible to account for these inconsistencies in non-homorganic consonant pairs by reference to a feature classification problem. Under the feature system that predates SPE, dorsal and labial are classified together for place of articulation under the feature [grave]. Some languages, such as Korean, put dorsal and labial together as a peripheral place of articulation in contrast to coronal. However, this issue will not be discussed in this study and will be left for further research.

<sup>7</sup> Dmitrieva et al. (2008) have suggested that the stress pattern of syllable can affect the gradience of the OCP effect. They present evidence that OCP effects are relatively weaker in stressed labial and dorsal syllables than in unstressed ones, yet shows the opposite pattern in coronal syllables. In the current study, however, all types of consonant co-occurrences are underrepresented regardless of their stress types except coronal pairs in the data presented. Therefore, the stress type of each syllable will be excluded from further analyses.

notes “the larger place classes are the ones that are clearly divided into manner subclasses, while the smaller place classes provide much less evidence for an effect of manner. Thus, similarity must be a function of the size of the inventory at each place of articulation (Frisch et al. 2004: 197).” Alderete (1997) explains the odd behavior of coronals by associating them with their relative unmarkedness. He argues that unmarked structures are inactive in phonological phenomena such as dissimilation, which directly target marked structures. Since coronals are relatively unmarked sounds (Prince and Smolensky 1993/2004), as compared to labials and dorsals, markedness can explain why coronal pairs show relatively weaker OCP effects.

To investigate why coronals exhibit weaker OCP effects, we also subdivided coronal consonants into two categories: obstruents and sonorants. The distribution in coronal co-occurrences is presented in terms of manner of articulation. The lower O/E value for coronal sonorant pairs suggests that co-occurrence of coronal pairs with the feature of [+sonorant] is restricted.

**Table 2. Distribution of coronal-coronal pairs in English  $C_1VC_2$  syllables: subdivided into obstruents and sonorants**

| $C_1$ | $C_2$     |                                   |                                  |                             |
|-------|-----------|-----------------------------------|----------------------------------|-----------------------------|
|       |           | obstruent                         | sonorant                         |                             |
|       | obstruent | 737406<br>792426.5<br><b>0.93</b> | 353241<br>298220.5<br>1.18       | observed<br>expected<br>O/E |
|       | sonorant  | 350219<br>295198.5<br>1.19        | 56074<br>111094.5<br><b>0.50</b> | observed<br>expected<br>O/E |

However, the O/E value for obstruent pairs is relatively higher than that of sonorant pairs. Therefore other possible factors that may affect the co-occurrence of coronal obstruents will be explored. This study has subdivided coronal obstruents in terms of manner of articulation (stop, fricative and affricate), place of articulation (dental, alveolar and palatal) and the feature value for [ $\pm$ continuant] (see Appendix 2). The O/E values for coronal obstruent co-occurrences subdivided by each factor proved that none of homorganic and non-homorganic pairs showed significant difference in their O/E values. Therefore the features of place/manner of articulation and continuancy as a factor affecting the OCP effects for coronal obstruents are ruled out.

In Coetzee and Pater (2005:12), co-occurrences of voiced stops and nasals in Muna are underrepresented. They suggest that the feature [ $\pm$ voice] plays a role in co-occurrence restrictions on coronals. Frisch et al. (2004) also suggests evidence for the effect of voicing on coronal obstruent

pairs in Arabic. Therefore the next step is to subdivide coronal obstruents into voiced and voiceless obstruents.

**Table 3. O/E values for coronal obstruents in English C<sub>1</sub>VC<sub>2</sub> syllables:  
subdivided by[±voice]**

|          | [+voice]    | [-voice]    |
|----------|-------------|-------------|
| [+voice] | <b>0.64</b> | 1.14        |
| [-voice] | 1.57        | <b>0.78</b> |

Table 3 shows that voiced coronal obstruents tend to avoid co-occurrence with other voiced coronal obstruents and as do their voiceless counterparts. Thus, we can conclude that the OCP-Place effects get stronger when coronal obstruents are subdivided into voiced and voiceless obstruents. We call this ‘OCP-Voice’. The O/E value for voiced coronals seems to be lower compared to voiceless coronal pairs in the table above. According to Alderete (1997), voiceless coronals are under the relatively weaker effects of the OCP because unmarked sounds tend to be less active in phonological processes. Since voiceless sounds are considered unmarked, there is no way but for the co-occurrences of voiceless sounds to be less restricted than the co-occurrences of voiced ones.

To sum up the restrictions on consonant co-occurrences in CVC syllables, dorsal and labial co-occurrences are underrepresented under the effects of the OCP. Coronal pairs, however, show relatively weaker restriction. Subdividing coronals into obstruent-sonorants resolves this inconsistency for coronal sonorants and the effects of OCP-Voice handle the gradient effects of the OCP in coronal obstruent pairs. Generally, coronal pairs seem to show the relatively weaker OCP effects than labials and dorsals, whichever categories they are subdivided into. The relative weakness of the OCP effects on coronals can be explained, as mentioned before, from the perspective of markedness relations as proposed by Alderete (1997). Since coronals are less marked than labials and dorsals, coronals are relatively inactive in the phonological processes of the OCP. We will show that similar restriction patterns occur in *s*-cluster syllables in the next section.

### 2.2.2 sCVC and sCCVC syllables

The results from *s*-cluster syllables are quite similar to those from CVC syllables. In sCVC syllables, the first consonant to the right of /s/ was labeled as onset and the last consonant as coda. In sCCVC syllables, the consonant immediately preceding the vowel was labeled as onset and the consonant following the vowel as coda. According to Berkley (1994a, b), OCP effects are consistent when the distance between two segments is the same. Pierrehumbert (1993) also states that increased distance between

OCP-target consonants weakens OCP effects. Therefore this analysis only considers onset-coda pairs separated by the same distance, i.e. consonants directly adjacent to the vowel, to rule out the distance effects on the OCP. Table 4 shows O/E values for consonant pairs in English *s*-cluster syllables.

Table 4. Distribution of onset-coda pairs in English *s*(C)<sub>1</sub>VC<sub>2</sub> syllables

| C <sub>1</sub> | C <sub>2</sub> |                                |                                |                                   |                             |
|----------------|----------------|--------------------------------|--------------------------------|-----------------------------------|-----------------------------|
|                |                | dorsal                         | labial                         | coronal                           |                             |
|                | dorsal         | 1574<br>5603.09<br><b>0.28</b> | 8711<br>6463.96<br>1.35        | 25281<br>23498.95<br>1.08         | observed<br>expected<br>O/E |
|                | labial         | 14071<br>11139.85<br>1.26      | 104<br>12851.41<br><b>0.01</b> | 56536<br>46719.75<br>1.21         | observed<br>expected<br>O/E |
|                | coronal        | 28711<br>27613.07<br>1.04      | 42356<br>31855.6<br>1.33       | 104209<br>115807.30<br><b>0.9</b> | observed<br>expected<br>O/E |

Labial and dorsal pairs are underrepresented just as in CVC syllables. On the other hand, coronal pairs are underrepresented to a relatively insignificant extent, even though their O/E values is lower than 1. This is consistent with the argument in Taylor (2011) that words like *sbib*, *spap* and *skig* containing labial or dorsal pairs are underrepresented in the English lexicon. Taylor excluded coronal pairs because he believes that the relatively weak restriction on coronals is ‘tangential’ to the issues presented in his paper. Now, coronals in *s*CVC and *s*CCVC syllables will be subdivided into coronal obstruents and sonorants as they were for CVC syllables above, as shown in Table 5.

Table 5. Distribution of coronal-coronal pairs in English *s*(C)<sub>1</sub>VC<sub>2</sub> syllables: subdivided into obstruents and sonorants

| C <sub>1</sub> | C <sub>2</sub> |                                  |                                 |                             |
|----------------|----------------|----------------------------------|---------------------------------|-----------------------------|
|                |                | obstruent                        | sonorant                        |                             |
|                | obstruent      | 28538<br>36630.37<br><b>0.78</b> | 33846<br>25753.63<br>1.31       | observed<br>expected<br>O/E |
|                | sonorant       | 32651<br>24558.63<br>1.33        | 9174<br>17266.37<br><b>0.53</b> | observed<br>expected<br>O/E |

Both obstruent and sonorant co-occurrences are underrepresented. However, as in CVC syllables, coronal obstruents are more likely to co-occur than coronal sonorants, even though the O/E value for these pairs is lower than 1. This might be due to the fact that the only possible onset



consonant in coronal obstruent cluster is /t/ (i.e., /t/ in /st/). Since the only possible coronal obstruent as  $C_1$  in  $s$ -cluster syllables is /t/, a relatively higher O/E value for coronal obstruents is inevitable. From another perspective, this can be explained by applying the markedness hypothesis from Alderete (1997), which holds that more unmarked sounds, coronal obstruents in this case, are relatively less active in phonological process than marked sounds. On the matter of voicing, voiced coronal obstruents in coda position seem to co-occur freely with voiceless obstruents, as shown in Table 6. In contrast, voiceless obstruents are less likely to co-occur with voiceless obstruents.

**Table 6. Distribution of subdivided coronals in English  $s(C)C_1VC_2$  syllables**

| $C_1$ | $C_2$                  |                           |                                  |                                 |                             |
|-------|------------------------|---------------------------|----------------------------------|---------------------------------|-----------------------------|
|       |                        | voiced<br>cor. obs.       | voiceless<br>cor. obs.           | cor. son.                       |                             |
|       | voiceless<br>cor. obs. | 8936<br>8424.11<br>1.06   | 19602<br>28206.27<br><b>0.69</b> | 33846<br>25753.63<br>1.31       | observed<br>expected<br>O/E |
|       | cor. son.              | 32651<br>24558.63<br>1.33 |                                  | 9174<br>17266.37<br><b>0.53</b> | observed<br>expected<br>O/E |

This can be another explanation for why coronal obstruent pairs are more likely to co-occur freely than coronal sonorant pairs since there is less restriction on voiced-voiceless coronal obstruent. This observation is also consistent with our earlier finding that the effects of the OCP become stronger where coronal obstruents are subdivided into voiced and voiceless coronal obstruents.

Table 7 shows the comprehensive results synthesizing O/E analyses on consonant co-occurrence restrictions, including all three types of syllables.

**Table 7. Distribution of onset-coda pairs in English C<sub>1</sub>VC<sub>2</sub>, sC<sub>1</sub>VC<sub>2</sub> and sCC<sub>1</sub>VC<sub>2</sub>  
syllables: subdivided coronals**

| C <sub>1</sub> | C <sub>2</sub>      |                                   |                             |                                   |                                   |                                   |
|----------------|---------------------|-----------------------------------|-----------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
|                |                     | voiced<br>cor. obs.               | voiceless<br>cor. obs.      | cor. son.                         | labial                            | dorsal                            |
|                | voiced<br>cor. obs. | 79272<br>114478.03<br><b>0.69</b> | 373622<br>324097.76<br>1.15 | 387087<br>325738.75<br>1.19       | 585861<br>424803.06<br>1.38       | 451808<br>353785.5<br>1.28        |
|                |                     | voiceless<br>cor. obs.            | 131289<br>101463.64<br>1.29 |                                   |                                   |                                   |
|                | cor. son.           | 382870<br>321521.75<br>1.19       |                             | 65248<br>126596.25<br><b>0.52</b> |                                   |                                   |
|                | labial              | 946835<br>845314.41<br>1.12       |                             |                                   | 75932<br>193036.49<br><b>0.39</b> | 176349<br>160765.11<br>1.10       |
|                | dorsal              | 1115919<br>958359.16<br>1.16      |                             |                                   | 174898<br>218851.45<br><b>0.8</b> | 68658<br>182264.39<br><b>0.38</b> |

So far, the effects of OCP in CVC and *s*-cluster syllables have been examined by comparing their O/E values. In summary, there are co-occurrence restrictions on homorganic consonant pairs in CVC and *s*-cluster syllables. The effects of OCP-Place are relatively stronger on labial and dorsal pairs than on coronal pairs since labials and dorsals are more marked than coronals. When coronal consonants are subdivided into obstruents and sonorants, the effects of OCP-Manner, which prohibits coronal pairs from co-occurring when they are either obstruent pairs or sonorant pairs, become apparent. The OCP-Voice can account for the underrepresentation of coronal obstruents<sup>8</sup>. In section 3, we will see how OCP-related constraints reflect these tendencies and how the Noisy HG model deals with the co-occurrence restrictions on homorganic consonants.

<sup>8</sup> An anonymous reviewer pointed out that additional analyses are needed to verify the independent effects of OCP-Manner and OCP-Voice in co-occurrence restrictions. Therefore, this study investigated O/E values among obstruent/sonorant pairs and voiced/voiceless pairs regardless of their place of articulation. According to the results, homorganic obstruent/sonorant pairs are underrepresented and homorganic voiced/voiceless obstruent pairs also showed underrepresentation. The O/E values for each pair are presented in Appendix 3.

### 3. Modeling gradient OCP-Place effects

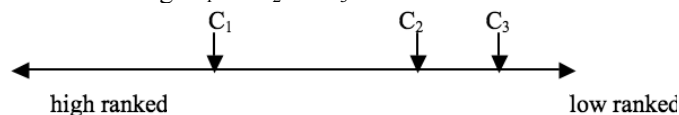
#### 3.1 Noisy Harmonic Grammar

For many years, various models have been suggested to account for non-categorical phonological phenomena. For example, Labov's (1969) variable rule model provides an account of variation within the framework of classic rule-based phonology. As many studies point out, however, the former phonological rule framework cannot capture gradience in phonological rule application. Prince and Smolensky (1993/2004) proposes Optimality Theory (henceforth, Standard OT) as a model easing "the explanatory burden" of rewriting a phonological rule to cover the gradient phonological phenomena and phonological variations. However, these ordinal constraint rankings used in Standard OT do not successfully capture all phonological variants.

Boersma and Hayes (2001) introduces an extended version of OT using the Gradual Learning Algorithm (GLA), called Stochastic OT. Stochastic OT implements two concepts: a continuous ranking scale and stochastic candidate evaluation. On continuous scales, constraints are located linearly and the scale of strictness on the line can illustrate their rankings. A model of continuous scales of constraints are shown in (3).

- (3) *Categorical ranking along a continuous scale* (Boersma and Hayes 2001: 3)

Invariable ranking:  $C_1 \gg C_2 \gg C_3$



The relative closeness between constraint  $C_2$  and  $C_3$  suggests that it is more likely that the ranges of their ranking values overlap. This overlap may cause a change in the ranking order of the constraints when the constraint ranking is applied to the evaluation of a candidate set.

In Stochastic OT, the constraint ranking order can vary as the ranking values of constraints are fluctuated by adding or subtracting a value called 'noise'. Before the numerical values of constraints are parsed into a ranking, each one undergoes 'noisy evaluation,' which evaluates the weight of each constraint using a noise value that is on the scale of a normal distribution with a mean of zero.

However, Pater (2008) has presented evidence indicating that sometimes the learning algorithm associated with Stochastic OT fails to learn some logically probable grammars. Boersma and Pater (2008) introduce a noisy version of a theory of generative grammar called Harmonic Grammar and associate it with a learning algorithm. In HG, constraint violations are

marked with negative numbers instead of asterisks as in Standard OT. HG selects the best candidate based on its harmonic representation, which can be measured by its harmony value. The harmony values (H-scores) for each candidate is calculated by multiplying the weight of each violated constraints by the negative number of violations and then summing these values for every constraint violated by the candidate. This is shown in (4).

(4) A candidate's Harmony in HG (Coetzee and Kawahara 2010: 6)

$$H(cand) = \sum_{i=1}^n w_i C_i(cand)$$

Where  $w_i$  is the weight of constraint  $C_i$  and  $C_i(cand)$  is the number of violations of candidate *cand* in terms of  $C_i$  expressed as a negative integer.

The HG model chooses the candidate with the highest H-score as optimal, which is the one closest to zero since the number of violations is given in a negative number. This is because a higher H-score means that the candidate either violated constraints with relatively lower weights or violated the same constraints with a fewer number of violations than the other candidates. This is one way that HG differs from stochastic OT. The harmony values in HG allow a candidate to be optimal even if it violates the highest weighted constraint while also prohibiting a candidate with a critical number of multiple violations of constraints with lower weights from being the most harmonic output. Therefore it is possible for a candidate violating the highest weighted constraint yet satisfying other lower weighted constraints to be selected as the most harmonic output, as long as its final H-score is closer to zero than those of the competing candidates.

However, this HG model cannot deal with phonological variations since its constraint ranking is fixed. The new version of HG, Noisy HG, adopts the concept of 'noise' from Stochastic OT. As explained above, Stochastic OT postulates that the value of each constraint may vary within a range of standard deviation because it is perturbed by noise. By applying this concept to HG, with noise perturbing constraint weights, we can use Noisy HG to model the gradient effects of the OCP. The modified version of the formula from HG is given in (5).

- (5) A candidate's Harmony in Noisy HG (Coetzee and Kawahara 2010: 8)

$$H(cand) = \sum_{i=1}^n (w_i + nz_i) C_i(cand)$$

Where  $w_i$  is the weight of constraint  $C_i$ ,  $nz_i$  the noise associated with constraint  $C_i$  at this evaluation occasion and  $C_i(cand)$  is the number of violations of candidate  $cand$  in terms of  $C_i$  expressed as a negative integer.

Tableaux in (6) shows that Noisy HG can deal with variations by adopting fluctuating constraint weights. By adding a positive or negative noise value to each constraint weight, the relative prominence of constraints fluctuates so that it makes various outputs possible.

- (6) A Noisy HG model predicting two possible outputs

| /input/           | $w$                     | $nz$ | $w$                     | $nz$ | H    |
|-------------------|-------------------------|------|-------------------------|------|------|
|                   | 1.0                     | 0.1  | 0.8                     | -0.1 |      |
|                   | Cons <sub>1</sub> (1.1) |      | Cons <sub>2</sub> (0.7) |      |      |
| Cand <sub>1</sub> | -1                      |      |                         |      | -1.1 |
| Cand <sub>2</sub> |                         |      | -1                      |      | -0.7 |
| Cand <sub>3</sub> | -2                      |      |                         |      | -2.2 |

| /input/           | $w$                     | $nz$ | $w$                     | $nz$ | H    |
|-------------------|-------------------------|------|-------------------------|------|------|
|                   | 1.0                     | -0.1 | 0.8                     | 0.2  |      |
|                   | Cons <sub>1</sub> (0.9) |      | Cons <sub>2</sub> (1.0) |      |      |
| Cand <sub>1</sub> | -1                      |      |                         |      | -0.9 |
| Cand <sub>2</sub> |                         |      | -1                      |      | -1.0 |
| Cand <sub>3</sub> | -2                      |      |                         |      | -1.8 |

So far, we have compared different constraint-based models and discussed which model is the most appropriate for dealing with gradient and variant phonological effects. We suggest that Noisy HG is an effective model to describe the OCP effects in English consonant co-occurrences. In what follows, we will see how Noisy HG can explain the gradient in co-occurrence restrictions on consonant pairs.

### 3.2 A Noisy Harmonic Grammar analysis

In this section, we will provide Noisy HG analyses of gradient OCP effects using OCP-related constraints. In particular, we will show how the results can be modeled using Praat (Boersma and Weenink 2007). The first step of conducting a Noisy HG analysis using Praat is to set an 'input' and then generate a possible candidate set. To attest the OCP-Place effects on

consonant pairs, this model adopts  $/(\text{s})\text{C}_i\text{VC}_i/^\rho$ , a syllable that has two identical consonants, as an input. We limited the possible input form to a syllable that contains an identical consonant pair to observe how and to what extent inputs violating the OCP can be realized. The possible candidates are the homorganic candidates, subdivided into  $/(\text{s})\text{tVt}/$ ,  $/(\text{s})\text{pVp}/$  and  $/(\text{s})\text{kVk}/$  in order to explore the gradient effects of the OCP among all possible combinations and the non-homorganic candidate  $/(\text{s})\text{C}_i\text{VC}_j/$ . In addition, more candidates are needed to attest OCP-Manner and OCP-Voice effects. Therefore this model also adopts candidates including all possible combinations of voiced and voiceless coronal obstruents and coronal sonorants, as shown in (7).

(7) A candidate set for  $/(\text{s})\text{C}_i\text{VC}_i/$  input

|   |  |
|---|--|
| $/(\text{s})\text{kVk}/$                      | Dorsal pairs                                   |
| $/(\text{s})\text{pVp}/$                      | Labial pairs                                   |
| $/(\text{s})\text{tVt}/$                      | Voiceless coronal obstruents                   |
| $/(\text{s})\text{tVd/dVt}/$                  | Voiced and voiceless coronal obstruent pairs   |
| $/\text{dVd}/$                                | Voiced coronal obstruents                      |
| $/(\text{s})\text{tVn}/(\text{s})\text{nVt}/$ | Voiceless coronal obstruent and sonorant pairs |
| $/\text{dVn}/(\text{s})\text{nVd}/$           | Voiced coronal obstruent and sonorant pairs    |
| $/(\text{s})\text{nVn}/$                      | Coronal sonorants                              |
| $/(\text{s})\text{C}_i\text{VC}_j/$           | Non-homorganic consonant pairs                 |

The constraints for evaluating the candidates are presented in (8).

(8) Set of constraints

|                      |   |
|----------------------|---|
| <b>OCP-DOR</b>       | Adjacent dorsals are prohibited.                      |
| <b>OCP-LAB</b>       | Adjacent labials are prohibited.                      |
| <b>OCP-COR</b>       | Adjacent coronals are prohibited.                     |
| <b>OCP-COR[+SON]</b> | Adjacent coronal sonorants are prohibited.            |
| <b>OCP-COR[+VOI]</b> | Adjacent voiced coronal obstruents are prohibited.    |
| <b>OCP-COR[-VOI]</b> | Adjacent voiceless coronal obstruents are prohibited. |
| <b>IDENT(F)</b>      | Output must preserve feature identity with input.     |

<sup>9</sup> Previous studies (Berkley 1994a, b, Coetzee 2008) also implemented input form as  $/\text{sC}_i\text{VC}_i/$ . If we consider input sCVC, where there is no limit to possible consonant pairs, the constraint **IDENT(F)** would play no role in candidate evaluation process. Without **IDENT(F)**, the hierarchy of constraints in Noisy HG still maintains their relative values and successfully describes the phenomenon but the constraint weights significantly drop from the approximate range of 70-120 to 1-3. This problem might be solved in a Maximum Entropy model, which we leave for further study.

The subdivided OCP-constraints are **OCP-DOR**, **OCP-LAB** and **OCP-COR**. These markedness constraints prohibit the co-occurrence of consonants agreeing in place of articulation. If the weights of OCP constraints are high enough, homorganic candidates will be excluded from the most harmonic output set. The **OCP-COR** constraint had to be subdivided into more specific constraints due to the subtle effects of the OCP on coronal pairs. The constraint **OCP-COR[+SON]** bans the co-occurrence of coronal sonorants. There is no constraint that prohibits the occurrence of coronal obstruents because the restriction on coronal obstruent pairs is not significant enough. The markedness constraints **OCP-COR[+VOI]** and **OCP-COR[-VOI]** prohibit coronal obstruents from straddling the vowel within a syllable when they are both either voiced or voiceless. The faithfulness constraint **IDENT(F)** regulates the output to maintain the elements in the input. If an output feature of a segment differs from its corresponding value in the input, one violation marked will be assigned. Two or more changes in the features of segments result in a candidate being given multiple violation marks for **IDENT(F)**.

To model the data using the Noisy HG module in Praat, we need two kinds of text files: 'Grammar files' and 'Distribution files.' The former includes information on a constraint set, default constraint weights, input form, a candidate set and the number of violations from each candidate for each constraint.

(9) The 'Grammar.txt' for attesting OCP effects

```

OCP Grammar_OCP_total -- Edited
File type = "ooTextFile"
Object class = "OTGrammar 2"

<LinearOT>
0 ! leak
7 constraints
  constraint [1]: "OCP-DOR" 100 100 1 !
  constraint [2]: "OCP-LAB" 100 100 1 !
  constraint [3]: "OCP-COR" 100 100 1 !
  constraint [4]: "OCP-COR[+VOI]" 100 100 1 !
  constraint [5]: "OCP-COR[-VOI]" 100 100 1 !
  constraint [6]: "OCP-COR[+SON]" 100 100 1 !
  constraint [7]: "Ident(F)" 50 50 1 !

0 fixed rankings

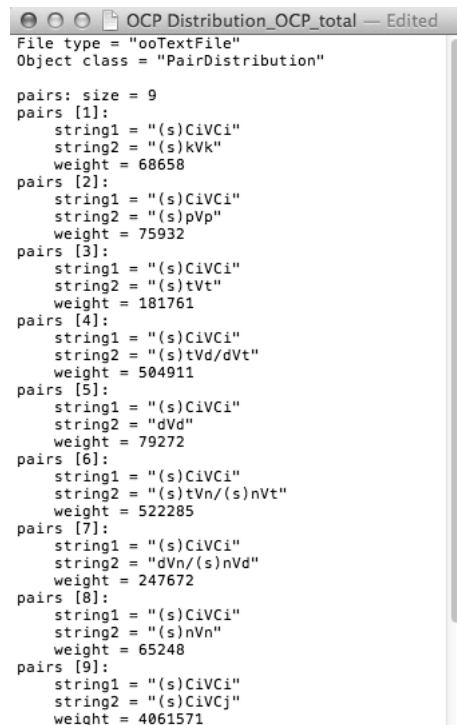
1 tableaux
input [1]: "(s)CiVCi" 9
  candidate [1]: "(s)kVk" 1 0 0 0 0 0 0
  candidate [2]: "(s)pVp" 0 1 0 0 0 0 0
  candidate [3]: "(s)tVt" 0 0 1 0 1 0 0
  candidate [4]: "(s)tVd/dVt" 0 0 1 0 0 0 1
  candidate [5]: "dVd" 0 0 1 1 0 0 0
  candidate [6]: "(s)tVn/(s)nVt" 0 0 1 0 0 0 1
  candidate [7]: "dVn/(s)nVd" 0 0 1 0 0 0 1
  candidate [8]: "(s)nVn" 0 0 1 0 0 1 0
  candidate [9]: "(s)CiVCj" 0 0 0 0 0 0 1

```

There are a total of seven constraints and each constraint is given a default weight of 100 except the faithfulness constraint **IDENT(F)**, which is given the initial weight of 50 (Coetzee and Pater 2008: 219). The input form is represented as  $/(s)C_iVC_i/$ , a syllable with identical consonants in onset and coda position. Candidates 1, 2 and 3 are less similar homorganic candidates that violate OCP-Place constraints and candidates from 4 to 8 are more similar homorganic candidates that violate either OCP-Manner or OCP-Voice related constraints or both. The numbers on the right of each candidate represent the number of violations for each corresponding constraint in order. The first number is for the first constraint **OCP-DOR**, the second number for the second constraint **OCP-LAB** and so forth. Additionally, violations are marked with numbers according to their frequency, i.e. 0 for no violations, 1 for a single violation and 2 for two violations. The 8<sup>th</sup> candidate  $/(s)nVn/$  violates the constraint **OCP-COR** and **OCP-COR[+SON]**, so its total violations are indicated with a mark of 1 in the third and sixth positions.

The distribution file containing the observed frequency of each candidate is shown in (10).

(10) The ‘Distribution.txt’ for attesting OCP effects



```

File type = "ooTextFile"
Object class = "PairDistribution"

pairs: size = 9
pairs [1]:
  string1 = "(s)CiVCi"
  string2 = "(s)kVk"
  weight = 68658
pairs [2]:
  string1 = "(s)CiVCi"
  string2 = "(s)pVp"
  weight = 75932
pairs [3]:
  string1 = "(s)CiVCi"
  string2 = "(s)tVt"
  weight = 181761
pairs [4]:
  string1 = "(s)CiVCi"
  string2 = "(s)tVd/dVt"
  weight = 504911
pairs [5]:
  string1 = "(s)CiVCi"
  string2 = "dVd"
  weight = 79272
pairs [6]:
  string1 = "(s)CiVCi"
  string2 = "(s)tVn/(s)nVt"
  weight = 522285
pairs [7]:
  string1 = "(s)CiVCi"
  string2 = "dVn/(s)nVd"
  weight = 247672
pairs [8]:
  string1 = "(s)CiVCi"
  string2 = "(s)nVn"
  weight = 65248
pairs [9]:
  string1 = "(s)CiVCi"
  string2 = "(s)CiVCj"
  weight = 4061571

```



There are a total of nine candidates in this analysis and each candidate is presented as an input-output pair in the text file. The input is placed on the string 1 of each pair and candidates are on the string 2. The weight of each pair in the file indicates the observed frequency of the pair.

The learned constraint weights in (11) are computed from Praat by feeding the grammar and distribution files in (9) and (10).

(11) Mean values for all constraints related to the OCP

|                      |  |              |
|----------------------|--|--------------|
| <b>OCP-DOR</b>       | Adjacent dorsals are prohibited                  | <b>93.24</b> |
| <b>OCP-LAB</b>       | Adjacent labials are prohibited                  | <b>93.18</b> |
| <b>OCP-COR</b>       | Adjacent coronals are prohibited                 | <b>0.88</b>  |
| <b>IDENT(F)</b>      | Output must preserve feature identity with input | <b>87.22</b> |
| <b>OCP-COR[+SON]</b> | No Adjacent coronal sonorants                    | <b>92.6</b>  |
| <b>OCP-COR[+VOI]</b> | No Adjacent voiced coronal obstruents            | <b>92.33</b> |
| <b>OCP-COR[-VOI]</b> | No Adjacent voiceless coronal obstruents         | <b>91.43</b> |

The constraint weights are the mean values acquired by running the learning process 10 times. The constraint weights of **OCP-LAB** and **OCP-DOR** are the highest of all constraints in the set. Therefore we can conclude that the effects of the OCP are the strongest in labial and dorsal consonant sequences and relatively weaker in other consonant co-occurrences. This result also accords with the earlier observation that labial and dorsal pairs have a lower O/E value (0.39 and 0.38, respectively) than other consonant pairs (i.e., the O/E value for coronal sonorant pairs is 0.52). The constraint weight of **OCP-COR** is far lower than that of any other OCP-related constraint, which means that the restriction on co-occurrence of coronal pairs is weaker than those on homorganic consonant pairs with non-coronal places of articulation. For the constraints regarding OCP-Manner and OCP-Voice, the constraint weight of **OCP-COR[+SON]** is the highest. This implies that coronal sonorants are less likely to co-occur freely than coronal obstruent pairs. Also, the overall weights of constraints related to OCP-Manner and OCP-Voice are lower than those for **OCP-DOR** and **OCP-LAB**. The tableau in (12) shows how these weighted constraints evaluate the given candidates and yields non-homorganic candidate as an optimal output.

(12) Input  $/(\text{s})\text{C}_i\text{VC}_j/ \rightarrow$  less similar harmonic consonant pair outputs

|   | OCP-DOR<br>(93.24) | OCP-LAB<br>(93.18) | OCP-COR<br>[+SON]<br>(92.6) | OCP-COR<br>[+VOI]<br>(92.33) | OCP-COR<br>[-VOI]<br>(91.43) | IDENT<br>(F)<br>(87.22) | OCP-COR<br>(0.87) | H      |
|---|--------------------|--------------------|-----------------------------|------------------------------|------------------------------|-------------------------|-------------------|--------|
| (s)kVk                                    | -1                 |                    |                             |                              |                              |                         |                   | -93.24 |
| (s)pVp                                    |                    | -1                 |                             |                              |                              |                         |                   | -93.18 |
| (s)tVt                                    |                    |                    |                             |                              | -1                           |                         | -1                | -92.3  |
| (s)tVd<br>/dVt                            |                    |                    |                             |                              |                              | -1                      | -1                | -88.09 |
| dVd                                       |                    |                    |                             | -1                           |                              |                         | -1                | -93.2  |
| (s)tVn<br>/(s)nVt                         |                    |                    |                             |                              |                              | -1                      | -1                | -88.09 |
| (s)dVn<br>/(s)nVd                         |                    |                    |                             |                              |                              | -1                      | -1                | -88.09 |
| (s)nVn                                    |                    |                    | -1                          |                              |                              |                         | -1                | -93.47 |
| <del>(s)C<sub>i</sub>VC<sub>j</sub></del> |                    |                    |                             |                              |                              | -1                      |                   | -87.22 |

The Noisy HG model nicely predicts the output distribution of almost all consonant pairs, with the exception of less similar harmonic consonant pairs such as  $/(\text{s})\text{tVd}/$  and  $/(\text{s})\text{nVd}/$ , as shown in Table 8.

**Table 8. Output distributions for consonant co-occurrences with subdivided coronals from Praat**

| Candidates                        | Obsvd. Freq. | Actual output distribution (A) | Learned output distribution (B) | $ (A)-(B) $ |
|-----------------------------------|--------------|--------------------------------|---------------------------------|-------------|
| (s)kVk                            | 68658        | 1.18                           | 1.25                            | 0.07        |
| (s)pVp                            | 75932        | 1.31                           | 1.21                            | 0.10        |
| (s)tVt                            | 181761       | 3.13                           | 3.20                            | 0.07        |
| (s)tVd<br>/dVt                    | 504911       | 8.69                           | 7.30                            | 1.39        |
| dVd                               | 79272        | 1.37                           | 1.28                            | 0.09        |
| (s)tVn<br>/nVt                    | 522285       | 8.99                           | 7.26                            | 1.73        |
| dVn<br>/(s)nVd                    | 247672       | 4.26                           | 7.17                            | 2.91        |
| (s)nVn                            | 65248        | 1.12                           | 1.04                            | 0.08        |
| (s)C <sub>i</sub> VC <sub>j</sub> | 4061571      | 69.94                          | 70.29                           | 0.35        |
| Total # of syllables              | 5807310      | 100%                           | 100%                            | Total (%)   |

For more similar homorganic candidates, the average difference between the actual output distribution and the output distribution learned by Noisy HG is less than 0.1%. The total distribution of less similar homorganic obstruents is 21.95% for the actual distribution and 21.73% for the learned distribution, with a difference of only 0.22% between the values. Therefore we can conclude that Noisy HG is an effective model for analyzing the gradient effects of the OCP in CVC and *s*-cluster syllables in English.

#### 4. Conclusion

This study conducted a research on the gradient effects of the OCP on CVC, sCVC and sCCVC syllables in BE, especially the effects of OCP-Place constraints on consonant co-occurrence and the effects of OCP-Manner and OCP-Voice constraints on coronal pairs. There are co-occurrence restrictions on consonant pairs when they have the same place of articulation. The tendency of avoiding homorganic consonant sequences within a certain domain, namely syllables in which a single vowel separates the two consonants, is stronger on labial and dorsal pairs than on coronal pairs. The weaker effects of the OCP on coronals could be explained by the size of the coronal inventory (Frisch et al. 2004) or on the unmarkedness of coronal sounds (Alderete 1997). For coronals, OCP-Manner prohibits two homorganic consonants agreeing in [ $\pm$ sonorant] from co-occurring. According to our analysis, coronal obstruent-obstruent and sonorant-sonorant pairs are underrepresented. Again, the restriction on coronal obstruent pairs becomes more obvious when coronal obstruents are subdivided into voiced and voiceless coronal obstruents. This is explained by using constraints related to OCP-Voice.

This paper adopts a framework of statistical analysis known as Noisy HG to generalize the gradient effects of the OCP. OCP-related markedness constraints have higher weights than the faithfulness constraint which conflicts with them and thus have the most “say” in determining the most harmonic candidate. The constraint hierarchy fluctuated by noise value allows both homorganic and non-homorganic candidates to emerge as the most harmonic outputs. The gradient constraint weight values reflect the gradient effects of the OCP. Noisy HG successfully produces the output distribution, thus proving itself an effective model for dealing with gradience in phonological processes.

**Appendix 1. O/E distribution when /w/ is classified as labial**

| C <sub>1</sub> | C <sub>2</sub> |                                  |                                   |                                      |                             |
|----------------|----------------|----------------------------------|-----------------------------------|--------------------------------------|-----------------------------|
|                |                | dorsal                           | labial                            | coronal                              |                             |
|                | dorsal         | 33027<br>97134.62<br><b>0.34</b> | 154928<br>115305.19<br>1.34       | 540818<br>516333.19<br>1.05          | observed<br>expected<br>O/E |
|                | labial         | 208647<br>239282.83<br>0.87      | 90694<br>284044.49<br><b>0.32</b> | 1495929<br>1271942.69<br>1.18        | observed<br>expected<br>O/E |
|                | coronal        | 423097<br>328353.56<br>1.29      | 543505<br>389777.32<br>1.39       | 1496940<br>1745411.12<br><b>0.86</b> | observed<br>expected<br>O/E |

**Appendix 2. O/E values of coronal obstruent pairs in CVC syllables**

## a. Coronal obstruents subdivided by MOA

|           | stop        | fricative   | affricate   |
|-----------|-------------|-------------|-------------|
| stop      | <b>0.72</b> | 1.33        | 1.51        |
| fricative | 1.10        | <b>0.92</b> | <b>0.61</b> |
| affricate | <b>0.25</b> | 1.27        | 5.75        |

## b. Coronal obstruents subdivided by POA

|          | dental      | alveolar    | palatal     |
|----------|-------------|-------------|-------------|
| dental   | <b>0.00</b> | 1.11        | <b>0.00</b> |
| alveolar | 2.69        | <b>0.87</b> | 2.07        |
| palatal  | <b>0.06</b> | <b>0.93</b> | 1.96        |

## c. Coronal obstruents subdivided by [±continuant]

|         | [+cont]     | [-cont]     |
|---------|-------------|-------------|
| [+cont] | <b>0.92</b> | 1.05        |
| [-cont] | 1.32        | <b>0.82</b> |

**Appendix 3. O/E values of all consonant pairs**

## a. Consonant pairs subdivided into obstruents and sonorants

|           | obstruent   | sonorant    |
|-----------|-------------|-------------|
| obstruent | <b>0.96</b> | 1.07        |
| sonorant  | 1.08        | <b>0.88</b> |

## b. Consonant pairs subdivided by [±voice]

|          | [+voice]    | [-voice]    | sonorant    |
|----------|-------------|-------------|-------------|
| [+voice] | <b>0.95</b> | 1.30        | <b>0.70</b> |
| [-voice] | <b>0.89</b> | <b>0.73</b> | 1.34        |
| sonorant | 1.15        | 1.05        | <b>0.88</b> |

## c. Obstruent pairs subdivided by [±voice]

|          | [+voice]    | [-voice]    |
|----------|-------------|-------------|
| [+voice] | <b>0.84</b> | 1.06        |
| [-voice] | 0.12        | <b>0.92</b> |

**REFERENCES**

- ALDERETE, JOHN. 1997. Dissimilation as local conjunction. In Kiyomi Kusumoto (ed.), *Proceedings of the North East Linguistics Society* 27, 17-32.
- ANTTILA, ARTTO. 2008. Gradient phonotactics and the complexity hypothesis. *Natural Lang Linguist Theory* 26, 695-729.
- BAAYEN, HARALD, RICHARD PIEPENBROCK and LEON GULIKERS. 1995. The CELEX lexical database (CD-ROM). Linguistic Data Consortium, University of Pennsylvania.
- BERKLEY, DEBORAH. 1994a. Variability in Obligatory Contour Principle effects. *Proceedings of CLS* 30, 1-12.
- \_\_\_\_\_. 1994b. The OCP and gradient data. *Studies in the Linguistic Sciences* 24, 59-72.
- BOERSMA, PAUL and BRUCE HAYES. 2001. Empirical tests of the Gradual Learning Algorithm. *Linguistic Inquiry* 32, 45-86.
- BOERSMA, PAUL and JOE PATER. 2008. Convergence properties of a gradual learner in Harmonic Grammar. Ms. Meertens Institute and University of Massachusetts Amherst. ROA-970.

- BOERSMA, PAUL and DAVID WEENINK. 2007. *Praat: Doing phonetics by computer*. (Version 5.3.47). [Computer program]. Retrieved April 23, 2013, from <http://www.praat.org/>
- COETZEE, ANDRIES. 2008. Grammaticality and ungrammaticality in phonology. *Language* 84, 218-257.
- \_\_\_\_\_. 2010. Gradient well-formedness in Harmonic Grammar: Phonological performance as a window on phonological competence. *Journal of the Phonetic Society of Japan* 14, 13-23. [A pre-publication version]
- COETZEE, ANDRIES and SHIGETO KAWAHARA. 2010. Frequency and other biases in phonological variation. Ms. Michigan University and Rutgers University. [Submitted for publication in *Natural Language and Linguistic Theory*]
- COETZEE, ANDRIES and JOE PATER. 2005. Lexically specific constraints: gradience, learnability, and perception. *Proceedings of the 3rd Seoul International Conference on Phonology*, 85-119.
- \_\_\_\_\_. 2008. Weighted constraints and gradient restrictions on place co-occurrence in Muna and Arabic. *Natural Language Linguistic Theory* 26, 289-337.
- DMITRIEVA, OLGA and ARTO ANTILA. 2008. The gradient phonotactics of English CVC syllables. Poster to be presented at *LabPhon* 11. Wellington, New Zealand. June 30-July 2, 2008.
- DMITRIEVA, OLGA, MATTHEW ADAMS, JASON GRAFMILLER, SCOTT GRIMM, YUAN ZHAO and ARTO ANTILA. 2008. Gradient OCP and harmonic alignment in English phonotactics. Poster to be presented at *The 82nd Annual Meeting of the Linguistic Society of America*. Chicago, United States of America. January 3, 2008.
- FRISCH, STEFAN, JANET PIERREHUMBERT and MICHAEL BROE. 2004. Similarity avoidance and the OCP. *Natural Language and Linguistic Theory* 22, 179-228.
- HONG, SUNG-HOON. 2010. Gradient vowel cooccurrence restrictions in monomorphemic native Korean roots. *Studies in Phonetics, Phonology and Morphology* 16, 279-295.
- KAWAHARA, SHIGETO, HAJIME ONO and KIYOSHI SUDO. 2006. Consonant co-occurrence restrictions in Yamato Japanese. *Japanese/Korean Linguistics* 14, 27-38.
- LABOV, WILLIAM. 1969. Contraction, deletion, and inherent variability of the English copula. *Language* 45, 715-762.
- MCCARTHY, JOHN. 1986. OCP Effects: Gemination and antigemination. *Linguistic Inquiry* 17, 207-263.
- \_\_\_\_\_. 1988. Feature geometry and dependency: A review. *Phonetica* 43, 84-108.
- PATER, JOE. 2008. Gradual learning and convergence. *Linguistic Inquiry* 39, 334-345.

- \_\_\_\_\_. 2009. Weighted Constraints in generative linguistics. *Cognitive Science* 33, 999-1035.
- PIERREHUMBERT, JANET. 1993. Dissimilarity in the Arabic verbal roots. *Proceedings of the North East Linguistics Society* 23, 367-381.
- PRINCE, ALAN and PAUL SMOLENSKY. 1993. *Optimality Theory: Constraint Interaction in Generative Grammar*. MA Thesis. Rutgers University Center for Cognitive Science. [Published as Prince and Smolensky 2004]
- \_\_\_\_\_. 2004. *Optimality Theory: Constraint interaction in generative grammar*. Malden, MA and Oxford, UK: Blackwell. [Published version of Prince and Smolensky 1993]
- SMOLENSKY, PAUL and GÉRALDINE LEGENDRE. 2006. *The Harmonic Mind: From Neural Computation to Optimality-Theoretic Grammar. Volume 1: Cognitive Architecture. Volume 2: Linguistic and Philosophical Implication*. Cambridge, MA: MIT Press.
- TAYLOR, BENJAMIN. 2011. Why not “Spop”? OCP and prominent position effects on the English lexicon. *Proceedings of the GMU Working Papers in Linguistics* 8.
- WILSON, COLIN and MARIEKE OBDEYN. 2009. Simplifying subsidiary theory: Statistical evidence from Arabic, Muna, Shona and Wargamay. Ms. Johns Hopkins University.

Yeong-Lim Oh  
Department of English Linguistics  
Hankuk University of Foreign Studies  
107 Imun-ro, Dongdaemun-gu, Seoul  
Korea 130-791  
e-mail: oh.ylim@gmail.com

Sung-Hoon Hong  
Department of English Linguistics  
Hankuk University of Foreign Studies  
107 Imun-ro, Dongdaemun-gu, Seoul  
Korea 130-791  
e-mail: hongshoon@hufs.ac.kr

received : October 30, 2013  
revised : December 6, 2013  
accepted : December 10, 2013