# Incomplete neutralization via paradigm uniformity and weighted constraints

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## 1.    Introduction

Incomplete neutralization occurs when two underlying segments become *phonologically* neutralized, but do not surface as *phonetically* identical. This phenomenon presents a challenge for traditional modular feed-forward grammatical architectures (Chomsky & Halle 1968, Bermúdez-Otero 2007) in which only the phonological output—not the phonological input—can influence phonetic realization. If two sounds are phonologically neutralized, they must be realized identically on the surface.

Despite not being predicted by the traditional model, incomplete neutralization has been found in many languages, mostly in processes of final devoicing—a voicing contrast is neutralized phonologically, but phonetic distinctions remain between underlyingly voiceless segments and devoiced segments (see, e.g. Port & O'Dell 1985 on German). Other cases of incomplete neutralization include morphological tone merger in Cantonese (Yu 2007b), flapping in American English (Herd et al. 2010, Braver 2013, 2014), and monomoraic noun lengthening in Japanese (Braver 2013, Braver & Kawahara 2014a,b).

We argue that incomplete neutralization is best viewed as a tension between two independently motivated grammatical forces: adherence to a segment's canonical realization vs. faithfulness to a base (Benua 1997, Steriade 2000). This tension is modeled in a phonetic grammar with weighted constraints (Legendre et al. 1990, Zsiga 2000, Flemming 2001).

### 1.1    Previous accounts

Perhaps the earliest theoretical account of incomplete neutralization is due to Anderson (1975), who argued that some phonetic rules can precede phonological ones. More recently, van Oostendorp (2008) has argued that phonologically neutralized segments may still have structural differences which influence phonetic realization.

A third type of analysis—and the one we build upon—relies on paradigm uniformity among morphologically related forms (e.g., Steriade 2000, Yu 2007a for subphonemic dif-

ferences, and Benua 1997 generally). Steriade (2000), for example, describes an (optional) schwa deletion processes in French which renders forms such as *bas retrouvé* [baʁətʁuve] 'stocking found again' → *bas r'trouvé* [baʁtʁuve]. This latter form with schwa deletion is not, however, identical to *bar trouvé* [baʁtʁuve] 'bar found'—the boldface [ʁ] in the schwa-deleted *bas r'trouvé'* differs from the one in 'bar found'—it is more like the [ʁ] in the canonical pronunciation of the (schwa-ful) *bas retrouvé* (Steriade 2000, p. 327). Steriade (2000) argues that forms with schwa deletion (e.g. *bas r'trouvé'*) are faithful (to some degree) to their non-schwa-deleted counterparts (e.g., *bas retrouvé*). We further develop this paradigm uniformity approach in Section 4 by means of an output-output faithfulness constraint.

## 1.2    Generalizations

There are two major generalizations that must be captured by any theory of incomplete neutralization: *directionality* and *magnitude*. Incomplete neutralization takes a phonological contrast and reduces the size of the phonetic differences. Any remaining phonetic correlates of the underlying contrast should match the direction of those correlates found in non-neutralizing contexts. This is the *Directionality Generalization*.

For example, in the case of final devoicing, the underlying contrast is [± voice]. One of the many correlates of this contrast is preceding vowel duration: cross-linguistically vowels preceding voiced stops are longer than vowels preceding voiceless stops (Chen 1970). The Directionality Generalization predicts that if incompletely neutralized forms maintain a distinction in preceding vowel duration, vowels preceding devoiced (i.e., formerly voiced) segments should be longer than vowels preceding underlyingly voiceless segments. This is precisely what we see in every language with incomplete neutralization of final devoicing (e.g., Port & O'Dell 1985, Slowiaczek & Dinnsen 1985, Charles-Luce 1997, Dmitrieva 2005). The opposite situation is unattested: we never observe a case of incomplete neutralization in which vowels preceding devoiced segments have a shorter duration than vowels preceding underlyingly voiceless segments.

The second generalization, the *Magnitude Continuum*, is a typological observation. Among languages with incomplete neutralization that maintains a small surface vowel duration distinction, the precise magnitude of this distinction varies. For example, while incomplete neutralization in German final devoicing yields vowel duration differences on the order of 10–15 ms (Port & O'Dell 1985), the vowel duration differences seen in American English flapping are closer to 5–10 ms (Herd et al. 2010, Braver 2013, 2014). Further, Japanese monomoraic lengthening shows vowel duration differences of 25–30 ms (Braver & Kawahara 2014a,b). Any theory of incomplete neutralization should be able to capture this difference in magnitude.

## 2.    The pieces

Our model relies on two independently motivated theoretical mechanisms: paradigm uniformity (Benua 1997, Steriade 2000) and weighted phonetic constraints (Legendre et al. 1990, Zsiga 2000, Flemming 2001). We briefly outline these two components here.

## 2.1    Paradigm uniformity

Paradigm uniformity, as discussed in Section 1.1, requires morphologically-related forms to be faithful to one another either phonologically (Benua 1997) and/or phonetically (Steriade 2000). We formalize the phonetic pressure to remain faithful to a base in the constraint OO-ID-DUR, defined below in (7).

## 2.2    Weighted phonetic constraints

Weighted constraint grammars (Legendre et al. 1990, Pater 2009) assign weights to constraints, rather than strictly ranking them as in classic Optimality Theory (Prince & Smolensky 1993). A candidate's total cost is the sum of its weighted violations across all constraints. The winning candidate is the one with the lowest cost.

We follow Zsiga (2000) and Flemming (2001) in positing a phonetic grammar with weighted constraints. The main consequence of this model is that a candidate's violations are tabulated gradiently—e.g., a constraint may penalize a candidate for each millisecond that the candidate strays from some target.

## 3.    Japanese monomoraic noun lengthening

To illustrate the model described below we use the example of Japanese monomoraic noun lengthening (Mori 2002, Braver & Kawahara 2014a,b), which we describe in this section.

Japanese requires that all Prosodic Words (PrWd) have at least two moras (Itô 1990, Poser 1990). When a PrWd would have only one mora, lengthening occurs to fill out the minimal template. One context in which this can occur is with monomoraic nouns. Nouns normally occur in a PrWd with a case particle, in which case the monomoraic noun plus a monomoraic case particle meet the two-mora minimum, as in (1a). In casual speech, however, nouns can occur without case particles, as in (1b). In this case, if the only content in the PrWd is a monomoraic noun, lengthening must occur.[1] Underlyingly bimoraic nouns can surface with no case particle and do not require lengthening, as in (1c).

(1)    a.    [ ki    mo        ]*PrWd*    nakushita yo
              tree PARTICLE              lost        PARTICLE
              '(I) lost a tree too'

       b.    [ ki    ø         ]*PrWd*    nakushita yo
              tree ø                     lost        PARTICLE
              '(I) lost a tree'

       c.    [ kii   ø         ]*PrWd*    nakushita yo
              key ø                      lost        PARTICLE
              '(I) lost a key'

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[1]For evidence that this lengthening process is phonological, rather than purely phonetic, see Braver & Kawahara (2014a).

In spite of the identical surface mora counts in (1b) and (1c) (due to lengthening in (1b)), lengthened monomoraic nouns are not identical in duration to underlyingly long nouns. Braver & Kawahara (2014a) found that lengthened nouns were on average 32.47 ms shorter than underlyingly long nouns, as summarized in the table in (2).

(2)   *Mean, standard deviation, and rounded values for vowel duration of nouns (in ms).*
      12 speakers, 15 sets of 3 nouns (=45 total items), 7 repetitions.

| Condition | Mean (ms.) | SD | Rounded |
|---|---|---|---|
| Unlengthened short (with particle) | 54.99 | 21.89 | 50 |
| Lengthened short (without particle) | 124.98 | 34.91 | 125 |
| Underlyingly long | 157.45 | 39.21 | 150 |

For ease of explication, we will use rounded values for the target duration of short, lengthened, and underlyingly long nouns, as shown in the rightmost column of the table in (2). For a parallel analysis using unrounded values, see Braver (2013), Appendix D.

## 4.    A model of incomplete neutralization

Let us assume that all segments which bear one mora in Japanese have a target duration of *TargetDur(μ).*[2] Further, all segments which bear two moras have a target duration of *TargetDur(μμ)*. The rounded durations shown in the table in (2) provide values for these two variables—unlengthened short vowels average approximately 50 ms, while underlyingly long vowels are approximately 150 ms. We therefore assume the target durations in (3):

(3)   a.   *TargetDur(μ)* = 50 ms          b.   *TargetDur(μμ)* = 150 ms

Candidate forms are pressured to conform to these language-specific duration targets by a family of constraints, DUR(X)=TARGETDUR(X) (see Flemming's 2001 C-DURATION and σ-DURATION constraints). We define one member of this constraint family in (4), and an equivalent one mora version, DUR(μ)=TARGETDUR(μ) (not shown here for space reasons) both of which penalize a candidate for durations which diverge from their target:

(4)   DUR(μμ)=TARGETDUR(μμ)
      For a mora-bearing unit $\beta$ which bears two moras in the output, where the canonical output duration of $\beta$ = *TargetDur(μμ)*, and the actual duration of $\beta$ = *Dur(β)*, let the candidate's cost be $cost = (TargetDur(\mu\mu) - Dur(\beta))^2$.

These constraints are illustrated in the tableaux in (5) and (6), showing the cost of various candidates for inputs which consist of short nouns in the non-lengthening context (5), and both short and long nouns in lengthening context ((6), i.e., nouns not followed by

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[2]This assumption is a simplification—monomoraic units may vary in duration based on a number of factors including vowel quality (House 1961), pitch (Hoequist 1983), and other contextual variations (e.g., Klatt 1973). We take *TargetDur(μ)* to be a cover term which abstracts away from these contextual differences, though a more specific target could be specified in this analysis as required.

case particles). Candidates consist of vowel durations $Dur(\beta)$, which, along with the values for *TargetDur(μ)* and *TargetDur(μμ)* laid out in (3), are used in computing the cost incurred by a given candidate for each constraint. The candidate with the lowest cost is the winner.

(5)

| /short + particle/ | | | DUR(μ)=TARGETDUR(μ) |
|---|---|---|---|
| | a. | $Dur(\beta)$ = 40 ms | 100 $(50-40)^2$ |
| | b. ☞ | $Dur(\beta)$ = 50 ms | 0 $(50-50)^2$ |
| | c. | $Dur(\beta)$ = 70 ms | 400 $(50-70)^2$ |

As can be seen in the tableau in (6), short nouns without a particle—which have two moras on the surface—incur the lowest cost for DUR(μμ)=TARGETDUR(μμ) as they increase their duration towards *TargetDur(μμ)*.

(6)

| /short + ø/ (lengthening; 2 moras) | | | DUR(μμ)=TARGETDUR(μμ) |
|---|---|---|---|
| | a. | $Dur(\beta)$ = 130 ms | 400 $(150-130)^2$ |
| | b. ☞ | $Dur(\beta)$ = 150 ms | 0 $(150-150)^2$ |
| | c. | $Dur(\beta)$ = 170 ms | 400 $(150-170)^2$ |
| /long + ø/ (no lengthening; 2 moras) | d. | $Dur(\beta)$ = 130 ms | 400 $(150-130)^2$ |
| | e. ☞ | $Dur(\beta)$ = 150 ms | 0 $(150-150)^2$ |
| | f. | $Dur(\beta)$ = 170 ms | 400 $(150-170)^2$ |

This pressure, though, is not the only factor to impact the duration of these lengthened nouns. The output-output correspondence constraint OO-ID-DUR (defined in (7)) penalizes candidates for vowel durations which differ from a morphologically-related base. Due to space restrictions, we do not discuss how this base is selected, though we refer the reader to Braver (2013) for further discussion. We assume here that the base to which a short noun must be faithful is a short noun in the non-lengthening context, and that therefore the duration of this base is *TargetDur(μ)* = 50 ms.

(7)    OO-ID-DUR
       For a mora-bearing unit $\beta$ whose actual duration is $Dur(\beta)$ and whose base duration is $Dur(\text{base})$, let the candidate's cost be $cost = (Dur(\beta) - Dur(\text{base}))^2$.

OO-ID-DUR is exemplified in the tableau in (8). The input is a short noun in the lengthening context; the base is a short noun in the non-lengthening context whose duration is 50 ms. Therefore, for this input OO-ID-DUR prefers candidates whose duration is as close to 50 ms as possible.

(8)

| /short + ø/ (lengthening; 2 moras) | | | OO-ID-DUR |
|---|---|---|---|
| | a. | $Dur(\beta)$ = 25 ms | 625 $(25-50)^2$ |
| | b. ☞ | $Dur(\beta)$ = 50 ms | 0 $(50-50)^2$ |
| | c. | $Dur(\beta)$ = 75 ms | 625 $(75-50)^2$ |

We now consider the interaction of these constraints. For space reasons we consider here only /short + ø/ (lengthening) inputs (which show incomplete neutralization), and not /short + particle/ or /long/ candidates (which do not). This means DUR($\mu$)=TARGETDUR($\mu$) is perfectly satisfied (and is hence not shown) in the tableaux that follow. DUR($\mu\mu$)=TARGETDUR($\mu\mu$) and OO-ID-DUR place competing pressures on /short + ø/ candidates: DUR($\mu\mu$)=TARGETDUR($\mu\mu$) rewards bimoraic candidates whose duration approaches 150 ms (i.e., *TargetDur*($\mu\mu$), as shown in (6)), while OO-ID-DUR prefers /short + ø/ candidates whose duration approaches 50 ms (i.e., *Dur(Base)*, as shown in (8)).

To determine the winning candidate, the tension between DUR($\mu\mu$)=TARGETDUR($\mu\mu$) and OO-ID-DUR must be resolved. This is accomplished by computing a total cost for each candidate by summing the cost of each candidate on each constraint. In order to balance the relative importance of these two constraints, we assign a weight $w$ to each constraint—a candidate's cost on a given constraint is multiplied by this weight before summing the cost of all constraints. Therefore, the total cost incurred by a given candidate on these two constraints is computed as in (9a) (and equivalently in (9b)), where $w_1$ is the weight assigned to OO-ID-DUR and $w_2$ is the weight given to DUR($\mu\mu$)=TARGETDUR($\mu\mu$):

(9)  a.  *Total cost* $= w_1(cost(\text{OO-ID-DUR})) + w_2(cost(\text{DUR}(\mu\mu)=\text{TARGETDUR}(\mu\mu)))$
     b.        $= w_1(Dur(\beta) - Dur(Base))^2 + w_2(TargetDur(\mu\mu) - Dur(\beta))^2$

As an example, consider the calculations in (10). Here $w_1 = 1$ and $w_2 = 3$; we assume a candidate with duration $\beta = 125$ ms, *Dur(Base)* = 50 ms, and *TargetDur($\mu\mu$)* = 150 ms.

(10)   *Total Cost* $= w_1(Dur(\beta) - Dur(Base))^2 + w_2(TargetDur(\mu\mu) - Dur(\beta))^2$
              $= 1(125 - 50)^2 \qquad\quad + 3(150 - 125)^2$
              $= 7500$

Given the weights $w_1$=1 and $w_2$=3, and the durations *TargetDur*($\mu\mu$)=150 ms and *Dur*(*Base*)=50 ms, this model accurately predicts that the actual duration of a /short + ø/ (lengthening) noun should be 125 ms, as shown in the table in (11). The candidate with the lowest cost is *Dur*($\beta$)=125 ms—as candidates move away from this value, their cost increases. Because $w_2 > w_1$, candidates closer to *TargetDur($\mu\mu$)* than to *Dur(Base)* have the lowest cost.

(11)   *Costs for given /short + ø/ vowel durations, where $w_1$=1, $w_2$=3,* Dur(Base)=*50ms, and* TargetDur($\mu\mu$)=*150ms*

| Dur($\beta$) (ms) | cost(OO-ID-DUR) $w_1(Dur(\alpha) - Dur(Base))^2$ | cost(DUR($\mu\mu$)=TARGETDUR($\mu\mu$)) $w_2(TargetDur(\mu\mu) - Dur(\alpha))^2$ | Total Cost |
|---|---|---|---|
| 100.00 | $1(100 - 50)^2$ | $3(150 - 100)^2$ | $10,000.00$ |
| 125.00 | $1(125 - 50)^2$ | $3(150 - 125)^2$ | $7,500.00$ |
| 150.00 | $1(150 - 50)^2$ | $3(150 - 150)^2$ | $10,000.00$ |

The relative strength of the two constraints can be modified by changing the constraints' weights. The table in (12) shows the result of doing just that: the first two columns show the weights for $w_1$ and $w_2$; the third column shows the duration *Dur(β)* of the candidate which wins at this weighting. The patterns in this table follow expectations: as the value of $w_1$ increases relative to $w_2$, winning durations are closer to 50 ms (*Dur(Base)*); as the value of $w_2$ increases relative to $w_1$, winning durations are closer to 150 ms (*TargetDur(μμ)*).

(12)  *Predicted duration of /short + ø/ (lengthening) nouns for sample weightings of* OO-ID-DUR *($w_1$) and* DUR(μμ)=TARGETDUR(μμ) *($w_2$), where* Dur(Base)=*50 ms and* TargetDur(μμ)=*150 ms.*

| $w_1$ | $w_2$ | Duration of winner (ms) |
|---|---|---|
| 1 | 2 | 116.17 |
| 1 | 3 | 125.00 |
| 1 | 4 | 130.00 |

## 5.    Discussion

### 5.1    Weighted vs. ranked constraints

The benefit of weighted constraints in this model is their ability to make compromises. If a compromise can be reached between OO-ID-DUR, which prefers /short + ø/ candidates to remain near 50 ms, and DUR(μμ)=TARGETDUR(μμ) which prefers these candidates to remain near 150 ms, the model will generate an output with a duration somewhere between 50–150 ms. This 'compromise' can be seen in Figure (13): the *x*- and *y*-axes represent the weights of the constraints, and the *z*-axis represents the predicted duration of the lengthened /short + ø/ vowels. *Dur(Base)* was set to 50 ms and *TargetDur(μμ)* to 150 ms, as above.

(13)  *Predicted /short + ø/ vowel durations, given weights for* OO-ID-DUR *($w_1$) and* DUR(μμ)=TARGETDUR(μμ) *($w_2$).* Dur(Base)=50 ms *and* TargetDur(μμ)=150 ms.
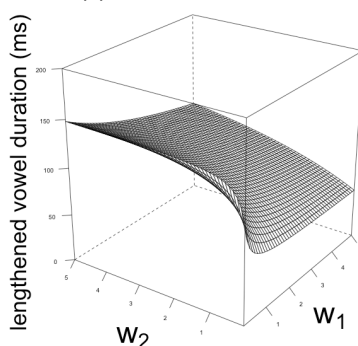


This sort of compromise is not possible in a system with strictly ranked constraints. If OO-ID-DUR were ranked above DUR(μμ)=TARGETDUR(μμ), then /short + ø/ nouns would fail to lengthen, due to overzealous faithfulness to a short base. Similarly, if

DUR(μμ)=TARGETDUR(μμ) were ranked above OO-ID-DUR, /short + ø/ nouns would, in an attempt to reach the canonical length of bimoraic units, lengthen too much.

## 5.2 The directionality generalization and magnitude continuum

In Section 1.2 we laid out two generalizations required of any model of incomplete neutralization: directionality and magnitude. The Directionality Generalization reflects the fact that surface distinctions in cases of incomplete neutralization mirror their counterparts in non-neutralizing contexts, but to a smaller degree. The Magnitude Continuum captures the fact that surface distinctions in incomplete neutralization vary in size from language to language and case to case. The model presented above captures both of these generalizations.

First, the model respects the Directionality Generalization. In non-neutralizing contexts, the Japanese vowel length distinction is represented by a duration difference in which long vowels are longer than short vowels. We should therefore expect that in incompletely neutralizing contexts, /short + ø/ (lengthening) nouns should be longer than non-neutralizing short nouns, but shorter than underlying long nouns. This is the result—when short nouns average 50 ms and long nouns average 150 ms, lengthened nouns average 125 ms. The model makes a similar prediction: as can be seen in Figure (13), regardless of the relative weights $w_1$ and $w_2$, the predicted duration for lengthened short vowels ranges between 50 and 150 ms, the two categorical extremes. In other words, lengthened short vowels can never become longer than underlyingly long vowels under this model.

Second, the model accurately captures the magnitude continuum. As can again be seen in Figure (13), varying the weights $w_1$ and $w_2$ allows the model to predict duration distinctions along a broad continuum, representing the diversity of incomplete neutralization cross-linguistically. We conclude that the current proposal accurately models the nature of incomplete neutralization. See Braver (2013) for comparison with other models.

## 5.3 Another case of incomplete neutralization

This model generalizes to other cases of incomplete neutralization. As an additional case study, we show the required constraint weightings to capture the incomplete neutralization of the voicing contrast in Russian final devoicing.

As shown by Matsui (2015), vowels preceding /t/ in the (non-neutralizing) VtV context are on average 115 ms, while vowels preceding /d/ in the (non-neutralizing) VdV context are on average 126 ms. In word-final position (V‿#V), which induces neutralization of the voicing contrast, pre-/t/ vowels are on average 106 ms and pre-/d/ vowels are on average 111 ms. The constraint OO-ID-DUR works in the same way as above: cost is accrued as the duration of the target vowel differs from its canonical realization in non-neutralizing position. This constraint conflicts with the generalization that the first vowel in a VCV sequence is longer than the first vowel in a VC#V sequence: when preceding a final consonant (in neutralizing position), vowels tend to be shorter than in other positions. This generalization is reflected in the constraint SHORTEN(V/‿C#), which compels shortening by setting a target duration for vowels in this context. Given the data above, we assume that SHORTEN(V/‿C#) prefers vowels which precede /t/ in neutralizing position (VT#V) to be

88% as long as their counterparts in non-neutralizing position ($111/126 = .88$) and vowels which precede /d/ in neutralizing position (VD#V) to be 92% as long as their counterparts in non-neutralizing position ($106/115 = .92$). Constraint weights of $w_{OO-ID-Dur} = 1$ and $w_{Shorten(V/\_C\#)} = 30$ yield the desired result: pre-/t/ vowels in neutralizing position are predicted to be 106 ms and pre-/d/ vowels in the same position are predicted to be 111 ms.

## 5.4  Conclusion

Two independently motivated theoretical mechanisms—paradigm uniformity and weighted phonetic constraints—can be used to model cases of incomplete neutralization. The Directionality Generalization and Magnitude Continuum are accurately represented; as shown in Figure (13) for the Japanese case, the predicted duration for lengthened vowels can range between—but never outside of—the duration of short vowels on the one hand and the duration of long vowels on the other.

## References

Anderson, Stephen R. 1975. On the interaction of phonological rules of various types. *Journal of Linguistics* 11:39–62.

Benua, Laura. 1997. Transderivational identity: Phonological relations between words. Doctoral dissertation, University of Massachusetts, Amherst.

Bermúdez-Otero, Ricardo. 2007. Diachronic phonology. In *The cambridge handbook of phonology*, ed. Paul de Lacy, 497–517. Cambridge: Cambridge University Press.

Braver, Aaron. 2013. Degrees of incompleteness in neutralization: Paradigm uniformity in a phonetics with weighted constraints. Doctoral dissertation, Rutgers, The State University of New Jersey, New Brunswick, NJ.

Braver, Aaron. 2014. Imperceptible incomplete neutralization: Production, identification, and discrimination of /d/ and /t/ flaps in American English. *Lingua* 152:24–44.

Braver, Aaron, & Shigeto Kawahara. 2014a. Incomplete neutralization in Japanese monomoraic lengthening. Annual Meeting on Phonology (AMP) 2014.

Braver, Aaron, & Shigeto Kawahara. 2014b. Incomplete vowel lengthening in Japanese: A first study. In *Proceedings of the 31st Meeting of the West Coast Conference on Formal Linguistics*, ed. Robert E. Santana-LaBarge. Somerville, MA: Cascadilla Press.

Charles-Luce, Jan. 1997. Cognitive factors involved in preserving a phonemic contrast. *Language and Speech* 40:229–248.

Chen, Matthew. 1970. Vowel length variation as a function of the voicing of the consonant environment. *Phonetica* 22.

Chomsky, Noam, & Morris Halle. 1968. *The sound pattern of English*. New York: Harper and Row.

Dmitrieva, Olga. 2005. Incomplete neutralization in Russian final devoicing: Acoustic evidence from native speakers and second language learners. Master's thesis, University of Kansas, Lawrence, Kansas.

Flemming, Edward. 2001. Scalar and categorical phenomena in a unified model of phonet-

ics and phonology. *Phonology* 18:7–44.

Herd, Wendy, Allard Jongman, & Joan Sereno. 2010. An acoustic and perceptual analysis of /t/ and /d/ flaps in American English. *Journal of Phonetics* 38:504–516.

Hoequist, Charles E. 1983. Durational correlates of linguistic rhythm categories. *Phonetica* 40:19–31.

House, Arthur S. 1961. On vowel duration in English. *Journal of the Acoustical Society of America* 33:1174–1178.

Itô, Junko. 1990. Prosodic minimality in Japanese. In *Proceedings of chicago linguistic society 26: Parasession on the syllable in phonetics and phonology*, ed. Michael Ziolkowski, Manual Noske, & Karen Deaton, 213–239. Chicago: Chicago Linguistic Society.

Klatt, Dennis H. 1973. Interaction between two factors that influence vowel duration. *Journal of the Acoustical Society of America* 54:1102–1104.

Legendre, Géraldine, Yoshiro Miyata, & Paul Smolensky. 1990. Harmonic grammar—a formal multi-level connectionist theory of linguistic well-formedness: An application. In *Proceedings of the twelfth annual conference of the cognitive science society*, 884–891. Mahwah, NJ: Lawrence Erlbaum Associates.

Matsui, Mayuki. 2015. Voicing contrast and contrast reduction in Russian: Acoustics and perception. Doctoral dissertation, Hiroshima University.

Mori, Yoko. 2002. Lengthening of Japanese monomoraic nouns. *Journal of Phonetics* 30:689–708.

van Oostendorp, Marc. 2008. Incomplete devoicing in formal phonology. *Lingua* 118:1362–1374.

Pater, Joe. 2009. Weighted constraints in generative linguistics. *Cognitive Science* 1–37.

Port, Robert, & Michael O'Dell. 1985. Neutralization and syllable-final voicing in German. *Journal of Phonetics* 13:455–471.

Poser, William. 1990. Evidence for foot structure in Japanese. *Language* 66:78–105.

Prince, Alan, & Paul Smolensky. 1993. Optimality theory: Constraint interaction in generative grammar. URL ROA 537, ruCCS-TR-2.

Slowiaczek, Louisa M., & Daniel Dinnsen. 1985. On the neutralizing status of Polish word-final devoicing. *Journal of Phonetics* 13:325–341.

Steriade, Donca. 2000. Paradigm uniformity and the phonetics-phonology boundary. In *Papers in laboratory phonology v: Acquisition and the lexicon*, ed. Janet Pierrehumbert & Michael Broe, chapter 22, 313–334. Cambridge University Press.

Yu, Alan C. L. 2007a. Tonal phonetic analogy. In *Proceedings of the International Congress of Phonetic Sciences XVI*, ed. Jürgen Trouvain & William J. Barry, 1749–1752. Saarbrücken: Saarland University.

Yu, Alan C. L. 2007b. Understanding near mergers: The case of morphological tone in cantonese. *Phonology* 24:187–214.

Zsiga, Elizabeth. 2000. Phonetic alignment constraints: Consonant overlap and palatalization in English and Russian. *Journal of Phonetics* 28:69–102.

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