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特集書評

The C/D Model as a Theory of the Phonetics-Phonology Interface[1)]

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音韻・音声のインターフェースとC/Dモデル

SUMMARY: The C/D model is a theory of the phonology-phonetics interface. This paper presents my personal understanding of the C/D model, based on my reading of Osamu Fujimura's work as well as my personal interaction with him. I also point out some key features of the C/D model as a theory of the phonology-phonetics interface.

Key words: phonetics, phonology, the interface, the C/D model, features, syllables

The following is my personal understanding of the C/D model, based on my reading of Osamu Fujimura's works (especially Fujimura 1999, 2000, 2002, 2003, 2007), as well as, perhaps more importantly, on my personal interaction with him.

To start, let us assume, as most grammatical theories do, that phonetics and phonology are two distinct modules of grammar. It is then necessary to think about how these two modules of grammar are related to one another. More concretely, discrete, abstract, and cognitive phonological symbols need to be "translated" into continuous, gradient, and physical phonetic gestures, the issue that is sometimes known as the "translation" problem[2)]. The C/D model is an explicit attempt to model this translation procedure. This characterization of the C/D model may sound trivial—well, any grammatical theory has to do it anyway, but as soon as we attempt to think about doing so explicitly, we come to appreciate the value of the C/D model. Let me try to walk us through the conceptual aspects of the C/D model as a theory of the phonetics-phonology interface.

The C/D model cares about both phonological representations and phonetic representations. To understand its value and how it came to life, it may be helpful to recall that Osamu, the creator of the C/D model, is a physicist who is interested in languages in general. He is one of those who introduced Chomsky's (1957) *Syntactic Structures* to Japan (Fujimura 1963), and has been sympathetic to generative linguistics (as far as I am aware of). Although he is a physicist/speech scientist, he has always been eager to hear about abstract phonological theories[3)]. He even goes so far as to say that "[t]he representation of utterances by the C/D model in a generative descriptive format is, conceptually, a logical continuation of generative phonology, as Chomsky and Halle (1968)" (Fujimura 2002, p. 21)—he clearly situates the C/D model within the tradition of generative phonology. The bottom line is that he cares about both the discrete mental representations of sounds (phonology) and the continuous physical aspects of sounds (phonetics).

Now to the extent that phonetics and phonology are different parts of grammar, then we need a theory of their interface. When we think about it, not very many theories are as explicit as the C/D model. Chomsky and Halle's (1968) *The Sound Patterns of English* (SPE) treated phonetics as some sort of "a universal speaking machine"; as long as phonology spits out right output, phonetics somehow translates them into appropriate phonetic gestures (see Keating 1985, 1988, Kingston and Diehl 1994 for this "phonetics-as-an-automatic-speaking-machine" view)[4)]. Most generative theories of phonology have somehow assumed that there is a miraculous "translation machine" out there that takes phonological outputs and spits out the right phonetic outcome. However, few phonologists have given serious considerations about what "this translation machine" really looks like. They just trust that there is one. On the other hand, phoneticians often think that there is no phonology anyway; some phoneticians are so anti-generative that they do not consider phonology to exist at all, or, to put it more mildly, they do not think that it is useful to model our speech behaviors in a way that modern phonologists think. We wouldn't have to worry about the phonetics-phonology interface, if there were no phonology at all (Maybe the second view involves a bit of exaggeration, but see Ohala 1990 and Port and Leary 2005, for example).

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There are, of course, exceptional attempts to explicitly model the phonetics-phonology interface, of which the C/D model is an example. Another example is Keating's (1990) window model of coarticulation. Yet another example would be the theory of f0 implementations by Pierrehumbert and Beckman (1988). Boersma's (1998) Functional Phonology considers in detail the relationship between phonetics and phonology. I do not attempt to compare these theories with the C/D model. Suffice it to say that the C/D model shares its goal with these theories.

Just to digress a bit, there are also recent proposals which posit that phonetic details are incorporated in phonological representations, a theory mainly pursued by Donca Steriade (1993, 1997 *et seq.*) and her former students at UCLA[5]. These proposals, however, are in my opinion still intended to account for phonological patterns, and are not explicit about how actual phonetics works; how phonetics works is given, and that is used to account for cross-linguistic phonological patterns. One could also go so far as to say that phonetics and phonology are isomorphemic, thereby obliterating the "translation problem." This is a position taken by Articulatory Phonology proposed and developed by Browman and Goldstein (1986, 1992, 1989 *et seq.*), in which phonological representations are already phonetic gestures with temporal information. Flemming (2001) also proposed a model in which phonetic and phonological wellformedness is evaluated simultaneously by the same constraint-based mechanism. I know that Osamu does not agree with these proposals. I do not know exactly why Osamu disagrees with these proposals (though see Fujimura 2002, section 1.4), but I myself concur with him for reasons that I do not mention here[6]. Let us assume, *a la* Osamu and most other people, that phonetics and phonology are distinct modules of grammar.

To summarize, then, the C/D model is an explicit model of how phonological representations and phonetic representations are related to one another. The model takes the classic "feed-forward" view, in which phonology precedes phonetics[7]. Therefore, phonological representations need to be translated to phonetic representations, but not vice versa (although it is of course possible to "reconstruct" phonological representations given output phonetic data).

Now let us recall that when we speak, we use several different articulatory organs, including jaw, lips, tongue, and larynx (and several muscles inside the larynx, including the cricothyroid muscle which we use to control f0). Phonological representations need to be thus converted to phonetic commands; moreover, these phonetic commands need to be "distributed" across different articulators. The C/D model has hence assumed its name ("C"onverted and "D"istributed); it converts phonological representations to phonetic commands, and commands for one phonological representation are distributed across different articulators.

It is important to note that the C/D model is not just a theory of the interface, but it is also a theory of the phonological representations and phonetic representations as well. The C/D model, unlike most other theories of grammar, asserts that the basic building blocks of phonology are syllables, rather than segments. I believe that Osamu's belief about this thesis (partly, at least) comes from the asymmetry between vowels and consonants, which has been known from the classic work of Öhman (1967). To simplify a bit, the C/D model posits that two vowels are adjacent to each other, unless there is a phrase boundary, both phonologically as well as phonetically, even in VCV sequences. Consonants are implemented as abrupt or ballistic events, ignited by Impulse Response Functions (IRFs), superimposed upon these vowel sequences[8]. To boil down the essence, vocalic elements generate slow gestural movements, which constitute baselines for utterances, and consonantal gestures generate abrupt movements, which are only locally superimposed on the vocalic baseline.

Phonetic studies have shown that indeed vowels are coarticulated with each other even across an intervening consonant; but consonants do not necessarily show a high degree of coarticulation across an intervening vowel (Öhman 1967). Arguably, this asymmetry should hold at the phonological level as well. It is a classic observation that while vowels can assimilate with each other across a consonant (i.e. vowel harmony), there are no languages in which consonants assimilate in place of articulation across an intervening vowel (Clements and Hume 1995, Gafos 1996, Kawahara 2007, NíChiosáin and Padgett 1997, 2001, Shaw 1991)—the observation that goes back to Clements (1985), who cites a personal communication with Morris Halle. The C/D model captures these phonetic and phonological generalizations.

Another important reason for taking the syllable-based position is because cues for "segments" are often distributed over syllables. An illustrative case is the voicing contrast in coda positions in English; the phonological voicing contrast between *hid* and *hit*, for example, manifests itself more in the preceding vowel (its duration, f0 and F1) than during the consonantal interval itself (Kingston and Diehl 1994, Lisker 1986). I believe that Osamu thinks that there are no strong reasons, beyond the matter of orthographic convention, not to postulate that this voicing contrast is that of entire syllables, rather than being localized to the coda consonant (well, phonetically speaking, it is not localized). Another example would be coda nasal; both in English (Cohn 1993) and Japanese (Vance 2008), nasality in coda consonants are realized throughout on the nucleus, continuing on till the end of the syllable. Yet again, phonetically speaking, it makes sense to say that nasalization is a property of a syllable, rather than being localized to the coda consonant[9].

Although the C/D model uses syllables as its basic units, it does not mean that the C/D model does not use sub-syllabic feature specifications. Syllables are units which are used to convert phonological representations into phonetic gestures, but it is not the case, I believe, that the C/D model commits itself to saying that all phonological generalizations can be stated in terms of syllables. Indeed, the C/D model involves distinctive features to distinguish between different syllables. To reiterate, syllables are units that are used when the phonology-phonetics translation occurs, but they are not indivisible atoms. Perhaps, syllables are molecules and distinctive features are atoms—pardon the analogy.

Another important aspect of the C/D model is that it asserts that phonetics is both controlled (i.e. non-automatic) and language-specific (see Fujimura 2002, in particular). This thesis is shared by many phonetic theories after the SPE (see Beddor et al. 2002, Bradlow 1995, Keating 1985, 1988, Kingston and Diehl 1994, Pierrehumbert et al. 2000, Port et al. 1980 among many others—see Ladd 2014 for a recent discussion). I believe that there are few practicing phoneticians and phonologists who would disagree with these theses (though cf. Chomsky 1995 cited in note 4).

The biggest appeal of the C/D model, as I understand it, is its explicitness. Let us recall the situation where phonologists just trust that there is "a miraculous machine" that would translate their phonological representations into phonetic gestures, and where phoneticians do not believe in phonological representations at all. The C/D model gives full credit to both levels of representations, which I believe is the most constructive way to pursue our research, and seriously thinks about how the two representations are modulated. To be bold, maybe the C/D model is the miraculous machine that phonologists have in mind.

There are a few key features of the C/D model that I believe are worth mentioning:

(1) Phonological representations
  a. The building blocks of phonology are syllables, which are used as units when phonological representations are mapped onto phonetic representations.
  b. Syllables have internal structures; p-fix, onset, nucleus, coda, and s-fix.
  c. No precedence relationships need to be specified among segments within the same syllable, at least in English and Japanese, because the precedence relationships are predictable[10].
  d. Phonological distinctions are represented with distinctive features.
  e. Features are specified only to the extent to distinguish different syllables (i.e. they are not fully specified, or underspecified: See Steriade 1995).
  f. Features are privative or unary (features are not binary; there are no [-F] features: See Steriade 1995 again)[11].
  g. Syllables are grouped into larger units of metrical structure.
  h. Each syllable is assigned different levels of prominence, *a la* the metrical phonology (Liberman and Prince 1977); e.g. feet and phonological phrases.
  i. Metrical structures define a domain of "declination", which we can take to be "articulatory weakening": It starts strong, and then gets weaker.
  j. Every language, even Japanese, has stress (this thesis is most clearly articulated in Fujimura 2001, 2003).

(2) Phonetic implementations
  a. Phonetics is not "a universal speaking machine." Phonetics is controlled and language-specific.
  b. Syllable structures manifest themselves in mandible lowering (jaw movement) as well as in tongue gesture movement.
  c. Oral gestures (jaw movement and tongue movement) and cricothyroid movement (control of f0) are for the most part independent of one another.
  d. Declination affects both oral gesture movement and cricothyroid movement.
  e. Numerical metrical strengths—which can for example be represented as the numbers of metrical grids (Liberman and Prince 1977, Prince 1983)—directly correlate with

strengths in articulatory patterns.

f. The articulatory distance between onset and nucleus is equidistant to the articulatory distance between nucleus and coda (i.e. the syllable triangle is symmetric)[12).

g. The "speed" of the consonantal articulation (i.e. the angles of syllable triangles) is determined algorithmically, irrespective of the place of articulation[13)].

h. Consonantal gestures are implemented differently in different syllabic positions (e.g. onset vs. coda)[14)].

i. The magnitude of consonantal gestures correlates with the magnitude of the syllable. Consonantal gestures are represented as time-shifted copies of syllable triangles (Fujimura 2000).

j. Allophonic variations (for consonants) are implemented as differences in IRF functions—how consonantal features are mapped onto phonetic gestures—rather than language-specific phonological rules.

k. Pause durations which reflect the strength and placement of phrasal boundaries are automatically derived from the calculation of the core syllable triangles.

(3) Other features

a. It can accommodate paralinguistic information, such as emotion.

b. It can also accommodate the effects of information structure, such as contrastive focus.

c. Contrastive focus increases the strength of both vocalic and consonantal gesture, although the manifestation of the latter may be less tangible from the surface.

d. Because of its computational explicitness, the model can predict phrasal boundaries from articulatory movement data alone.

With all this in mind, it would be interesting to test empirically how the predictions of the C/D model turn out. It may turn out that the C/D model is totally wrong, but nevertheless, it is better to be explicit and wrong than vague and not-so-wrong. If we don't like it, then we are obliged to propose an alternative theory which is as explicit as the C/D model.

Notes

1) This paper is written slightly informally, but deliberately so, in the hope that this strategy makes the C/D model more accessible to wider audience. I thank Donna Erickson and Osamu Fujimura on comments on this essay. Also, I would not have been able to write up this essay without consulting the bibliography of Osamu Fujimura, compiled by Kikuo Maekawa, whose effort I would like to gratefully acknowledge here. My research on the C/D model, especially for this paper, is supported by Keio Gijuku Academic Development Fund.

2) For example, Brownman and Goldstein (1986: 219) state that "[t]he gap between the linguistic and physical structure of speech has always been difficult for phonological theory to bridge."

3) The first piece of evidence, based on my personal observation, comes from his regular attendance to Tokyo Circle of Phonologists (TCP), in which, as far as I know, most talks presented concern phonological theories. Second, during TCP as well as in other occasions, Osamu has always been willing to listen to my ideas about phonological theories, even when my thoughts are not directly about phonetics, e.g. rendaku or accent. Finally, in many parts of Fujimura (2007), Osamu refers to work by Ito and Mester, which is highly technical work on phonological theory. In particular, I remember discussing Ito and Mester (1986) with Osamu one time, and he was praising that work as one of few which plausibly established the autosegmental nature of the feature [voice].

4) It seems that the Minimalist Program still continues to hold this view: "a condition on phonetic representation is that each symbol be interpreted terms of articulatory and perceptual mechanisms in a **language-invariant manner**: a representation that lacks this property is simply not considered a phonetic representation" (emphasis added) (Chomsky 1995, p. 151). In this view, phonetic representations are translated into articulatory gestures in a universal manner.

5) See Crosswhite (1999), Flemming (1995), Jun (1995), Kaun (1995), Kirchner (1997), Silverman (1995), Zhang (2000), and others. Of course, similar attempts have been made outside of UCLA, especially recently at MIT.

6) It simply takes too much space to fully defend this view. See, for example, Anderson (1981), Cohn (1993, 1998), Dinnsen (1980), Hayes (1999), Gordon (2002), Keating (1996), Ladefoged (1980), Leben (1999), Morén and Zsiga (2006), Pierrehumbert (1990), Pycha (2009), Zsiga (1997), among many others.

7) Although this thesis may sound trivially true, it is not universally accepted. See Anderson (1975) and McCarthy (2011), in which phonetic implementation rules precede phonological rules.

8) What kind of mathematical distribution is best suited for modeling consonantal behavior is currently investigated by Michinao Matsui (see Matsui 2014 and other works of his that are in progress). Matsui (2014) has tried

using γ-distribution to model the behavior of consonantal voicing. This is one interesting remaining question for the C/D model.

9) Fujimura (2007) refers to another piece of anecdotal evidence. In endnote 119 (p. 207), he cites personal communication with Alvin Liberman, who found that when monosyllabic words like *bag* were split into three portions—presumably, its onset, nucleus, and coda—any of its portion was sufficient to signal that the original stimulus was one closed syllable, consisting of three segments. No experimental evidence is cited, however.

10) A remaining question, I believe, is whether this principle holds in all languages, especially in languages with complex consonant clusters like Russian. Russian has a (near) minimal pair like [rtu] 'mouth (accusative)' vs. [truba] 'pipe' (thanks to Yosuke Igarashi for this example). For that matter, English does have a minimal pair like [æsk] and [æks], although [s] in the latter case may belong to the s-fix rather than to coda. See also Endnote 123 (p. 108) of Fujimura (2007) for some relevant discussion.

11) My impression, however, is that Osamu is not very committed to the unitary feature theory; he seems happy to deploy more standard binary features. Unary features, however, may more directly reflect the intuition that distinctive features represent active articulatory commands.

12) Though see the work by Erickson and Kim (this volume).

13) This assumption probably involves simplification, as different articulators differ from each other in terms of their speed of the movement (Maddieson 1997).

14) English [l], for example, is articulated with coronal gesture in onset, but with both coronal and dorsal gesture in coda (Sproat and Fujimura 1993). English [t], likewise, is accompanied by a glottal gesture only in coda position.

References

Anderson, S. (1975) "On the interaction of phonological rules of various types." *Journal of Linguistics* 11(1), 39–62.

Anderson, S. (1981) "Why phonology isn't "natural"." *Linguistic Inquiry* 12(4), 493–539.

Beddor, P. S., J. D. Harnsberger and S. Lindemann (2002) "Language-specific patterns of vowel-to-vowel coarticulation: Acoustic structures and their perceptual correlates." *Journal of Phonetics* 30(4), 591–627.

Boersma, P. (1998) *Functional phonology: Formalizing the interaction between articulatory and perceptual drives*. The Hague: Holland Academic Graphics.

Bradlow, A. R. (1995) "A comparative acoustic study of English and Spanish vowels." *Journal of the Acoustical Society of America* 97(3), 1916–1924.

Browman, C. and L. Goldstein (1986) "Towards an articulatory phonology." *Phonology Yearbook* 3, 219–252.

Browman, C. and L. Goldstein (1989) "Articulatory gestures as phonological units." *Phonology* 6(2), 201–251.

Browman, C. and L. Goldstein (1992) "Articulatory phonology: An overview." *Phonetica* 49(3–4), 155–180.

Chomsky, N. (1957) *Syntactic structures*. The Hague: Mouton.

Chomsky, N. and M. Halle (1968) *The sound pattern of English*. New York: Harper and Row.

Chomsky, N. (1995) *The minimalist program*. Cambridge, MA: MIT Press.

Clements, N. (1985) "The geometry of phonological features." *Phonology Yearbook* 2, 225–252.

Clements, N. and E. Hume (1995) "The internal organization of speech sounds. " In John A. Goldsmith (ed.) *The handbook of phonological theory*, 245–306. Cambridge and Oxford: Blackwell.

Cohn, A. (1993) "Nasalisation in English: Phonology or phonetics." *Phonology* 10(1), 43–81.

Cohn, A. (1998) "The phonetics-phonology interface revisited: Where's phonetics?" *Texas Linguistic Forum* 41, 25–40.

Crosswhite, K. (1999) *Vowel reduction in Optimality Theory*. Doctoral dissertation, University of California, Los Angeles.

Dinnsen, D. (1980) "Phonological rules and phonetic explanation." *Journal of Linguistics* 16(2), 171–191.

Flemming, E. (1995) *Auditory representations in phonology*. Doctoral dissertation, University of California, Los Angeles.

Flemming, E. (2001) "Scalar and categorical phenomena in a unified model of phonetics and phonology." *Phonology* 18(1), 7–44.

Fujimura, O. (1963) "Chomsky-no Syntactic Structures-ni tsuite [On Chomsky's Syntactic Structures]." *Gengo Kenkyu [Journal of the Linguistic Society of Japan]* 44, 14–24.

Fujimura, O. (1999) "Hatsuwa-no Kijutsuriron [Descriptive Theory of utterances: C/D model]." *Journal of Acoustical Society of Japan* 55(11), 762–768.

Fujimura, O. (2000) "The C/D model and prosodic control of articulatory behavior." *Phonetica* 57(2–4), 128–138.

Fujimura, O. (2001) "Metrical vs. tonal organization of speech." In Bohumil Palek and Osamu Fujimura (eds.) *Proceedings of LP 2000*, 163–175. Prague: Charles University Press.

Fujimura, O. (2002) "Temporal organization of speech utterance: A C/D model perspective." *Cadernos de Estudos Linguisticos, Instituto de Estudos da Linguagen, Campinas* 43, 9–36.

Fujimura, O. (2003) "Stress and tone revisited: Skeletal vs. melodic and lexical vs. phrasal." In Shigeki Kaji (ed.) *Cross-linguistic studies of tonal phenomena: Historical development, phonetics of tone, and descriptive studies*, 221–236. Tokyo: Tokyo University of Foreign Studies.

Fujimura, O. (2007) *Onseigaku genron* [*Principles of phonetics*]. Tokyo: Iwanami.

Gafos, A. (1996) *The articulatory basis of locality in phonol-*

ogy. Doctoral dissertation, Johns Hopkins University.

Gordon, M. (2002) “A phonetically driven account of syllable weight.” *Language* 78(1), 51–80.

Hayes, B. (1999) “Phonetically-driven phonology: The role of Optimality Theory and inductive grounding.” In Michael Darnell, Edith Moravscik, Michael Noonan, Frederick Newmeyer and Kathleen Wheatly (eds.) *Functionalism and formalism in linguistics, vol. 1: General papers*, 243–285. Amsterdam: John Benjamins.

Ito, J. and A. Mester (1986) “The phonology of voicing in Japanese: Theoretical consequences for morphological accessibility.” *Linguistic Inquiry* 17, 49–73.

Jun, J. (1995) *Perceptual and articulatory factors in place assimilation: An Optimality Theoretic approach*. Doctoral dissertation, University of California, Los Angeles.

Kaun, A. (1995) *The typology of rounding harmony: An Optimality Theoretic account*. Doctoral dissertation, University of California, Los Angeles.

Kawahara, S. (2007) “Copying and spreading in phonological theory: Evidence from echo epenthesis.” In Leah Bateman, Michael O’Keefe, Ehren Reilly and Adam Werle (eds.) *University of Massachusetts Occasional Papers in Linguistics 32: Papers in Optimality Theory III*, 111–143. Amherst: GLSA.

Keating, P. A. (1985) “Universal phonetics and the organization of grammars.” In V. Fromkin (ed.) *Phonetic linguistic essays in honor of Peter Ladefoged*, 115–132. Orlando: Academic Press.

Keating, P. A. (1988) “The phonology-phonetics interface.” In F. J. Newmeyer (ed.) *Linguistics: The Cambridge survey, vol. 1*, 281–302. Cambridge: Cambridge University Press.

Keating, P. A. (1990) “The window model of coarticulation: Articulatory evidence.” In John Kingston and Mary Beckman (eds.) *Papers in laboratory phonology I: Between the grammar and physics of speech*, 451–470. Cambridge: Cambridge University Press.

Keating, P. A. (1996) “The phonology-phonetics interface.” *Studia Grammatica* 41, 262–278.

Kingston, J. and R. Diehl (1994) “Phonetic knowledge.” *Language* 70(3), 419–454.

Kirchner, R. (1997) “Contrastiveness and faithfulness.” *Phonology* 14(1), 83–111.

Ladd, D. Robert (2014) *Simultaneous structure in phonology*. Oxford: Oxford University Press.

Ladefoged, P. (1980) “What are linguistic sounds made of?” *Language* 56(3), 485–502.

Leben, W. (1999) “Weak vowels and vowel sequences in Kwa: Sounds that phonology can’t handle.” In Osamu Fujimura, Brian Joseph and Bohumil Palek (eds.) *Proceedings of Linguistics and Phonetics 98*, 717–732. Prague: Charles University Press.

Liberman, M. and A. Prince (1977) “On stress and linguistic rhythm.” *Linguistic Inquiry* 8, 249–336.

Lisker, L. (1986) “‘Voicing’ in English: A catalog of acoustic features signaling /b/ versus /p/ in trochees.” *Language and Speech* 29(Pt 1), 3–11.

Maddieson, I. (1997) “Phonetic universals.” In W. Hardcastle and J. Laver (eds.) *The handbook of phonetics sciences*, 619–639. Oxford: Blackwell.

Matsui, M. (2014) “Vowel devoicing, VOT distribution and geminate insertion of sibilants.” *Theoretical and Applied Linguistics at Kobe Shoin* 17, 67–106.

McCarthy, J. J. (2011) “Perceptually grounded faithfulness in Harmonic Serialism.” *Linguistic Inquiry* 42(1), 171–183.

Morén, B. and E. Zsiga (2006) “The lexical and post-lexical phonology of Thai tones.” *Natural Language and Linguistic Theory* 24(1), 113–178.

NíChiosáin M. and J. Padgett (1997) “Markedness, segmental realization and locality in spreading.” *Tech. rep., University of California, Santa Cruz, Report*, LRC-97-01.

NíChiosáin M. and J. Padgett (2001) “Markedness, segment realization, and locality in spreading.” In Linda Lombardi (ed.) *Segmental phonology in Optimality Theory: constraints and representations*, 118–156. Cambridge: Cambridge University Press.

Ohala, J. J. (1990) “There is no interface between phonology and phonetics: A personal view.” *Journal of Phonetics* 18, 153–171.

Öhman, S. E. G. (1967) “Numerical model of coarticulation.” *Journal of the Acoustical Society of America* 39(2), 310–320.

Pierrehumbert, J. B. and M. Beckman (1988) *Japanese tone structure*. Cambridge: MIT Press.

Pierrehumbert, J. B. (1990) “Phonological and phonetic representation.” *Journal of Phonetics* 18, 375–394.

Pierrehumbert, J., M. Beckman and R. Ladd (2000) “Conceptual foundations of phonology as a laboratory science.” In Noel Burton-Roberts, Phillip Carr and Gerard Docherty (eds.) *Phonological knowledge: Conceptual and empirical issues*, 273–303. Oxford: Oxford University Press.

Port, R., S. Al-Ani and S. Maeda (1980) “Temporal compensation and universal phonetics.” *Phonetica* 37(4), 235–252.

Port, R. and A. Leary (2005) “Against formal phonology.” *Language* 81(4), 927–964.

Prince, A. (1983) “Relating to the grid.” *Linguistic Inquiry* 14(1), 19–100.

Pycha, A. (2009) “Lengthened affricates as a test case for the phonetics-phonology interface.” *Journal of the International Phonetic Association* 39(1), 1–31.

Shaw, P. (1991) “Consonant harmony systems: The special status of coronal harmony.” In Carole Paradis and Jean-François Prunet (eds.) *The special status of coronals*, 125–157. New York: Academic Press.

Silverman, D. (1995) *Phasing and recoverability*. Doctoral dissertation, University of California, Los Angeles.

Sproat, R. and O. Fujimura (1993) “Allophonic variation in English /l/ and its implications for phonetic implementation.” *Journal of Phonetics* 21, 291–311.

Steriade, D. (1993) “Closure, release, and other nasal contours.” In Marie K. Huffman and Rena A. Krakow (eds.) *Nasals, nasalization, and the velum*, 401–470. San Di-

ego: Academic Press.
Steriade, D. (1995) “Underspecification and markedness.” In John Goldsmith (ed.) *Handbook of phonological theory*, 114–174. Cambridge, MA: Blackwell.
Steriade, D. (1997) *Phonetics in phonology: The case of laryngeal neutralization*. Ms. University of California, Los Angeles.
Vance, T. (2008) *The sounds of Japanese*. Cambridge: Cambridge University Press.
Zhang, J. (2000) *The effects of duration and sonority on contour tone distribution: Typological survey and formal analysis*. Doctoral dissertation, University of California, Los Angeles.
Zsiga, E. (1997) “Features, gestures, and Igbo vowels: An approach to the phonology-phonetics interface.” *Language* 73(2), 227–274.

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