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Perceptual Distance of Contrast: Vowel Height and Nasality

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1 Introduction

The goal of this paper is to examine the relationship between vowel height and nasalization, a relationship that argues rather directly for the importance to phonological patterning of the perceptual distinctiveness of contrast. It thus adds to the list of cases making this point (see Flemming 1995, and also Ní Chiosáin and Padgett 1997 for others), and strengthens the case for an output-oriented conception of contrast: in order for the perceptual distinctiveness of a contrast to be evaluated at the surface, contrast itself must be discernable by constraints at the surface.

Some recent strands of research in phonology combine to suggest a whole that is arguably more *Saussurian* than anything in the history of generative phonology. Consider Saussure's views on alternation and contrast in phonology.[1] Saussure took alternation to be "...a correspondence existing between two definite sounds or groups of sounds and shifting regularly between two series of coexisting forms." (Saussure 1959, p.158). He took as one example the *s* ~ *r* alternation called Latin Rhotacization illustrated in (1). The sounds in correspondence are *s* and *r*, while the "coexisting forms" are pairs of related words like *gerō* and *gestus*.

(1) Alternation as a surface relation: Latin Rhotacization

gerō	↔	gestus	
oneris	↔	onus	
maeor	↔	maestus	etc.

According to Anderson (1985, pp.52-3), "[Saussure] took the rules involved to be ones which directly related one surface form (in a given language) to another, without assigning priority

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[1] On the following see Saussure's *Cours de linguistique générale*, and for interpretation Wells (1957) and Anderson (1985). The usual caveats when one attributes views to Saussure apply here.

to either (or setting up an indirectly attested third form from which both are derived)." In other words, Saussure did not envision anything like an underlying representation (UR) of generative phonology in order to relate such forms, but related them directly at the surface. While it is probably very easy to overstate similarities between views of Saussure and much more richly developed contemporary work, it is hard to miss the similarity between this view and current work pursuing output-output correspondence or paradigm uniformity in Optimality Theory: Benua (1995), Buckley (1995), Burzio (1994, 1996), Flemming (1995), Itô and Mester (to appear), Kager (1996), Kenstowicz (1996), McCarthy (1995), cf. Orgun (1994, 1996), Kenstowicz (1995), Raffelsiefen (1993).

Saussure also understood *contrast* to be a surface relation among forms, something he called an *associative opposition*. Speaking of the imaginary contrast shown below, he wrote "In the imaginary grouping *anma*, for instance, the sound *m* stands...in associative opposition to all other sounds that may come to mind." (Saussure 1959, p.131). If we are to revel here in statements so evocative and yet cryptic, it seems fitting to add the most famous quote of all, "...dans la langue il n'y a que des différences...sans termes positifs" (cited from Wells 1957); or, in the same vein, "Language is a system of interdependent terms in which the value of each term results solely from the simultaneous presence of the others..." (Saussure 1959, 114).

(2)	Contrast as a surface relation	*a n m a*	To be *m* is to
		↕	
		a n v a	not be *v* and to
		↕	
		a n d a	not be *d*...(in this position)

This is of course the famous Saussurian structuralist view, the core idea for our purposes being that a form can be understood fully only in the context of the larger system of forms of which it is a part. Let us call this the *systemic view of contrast*. Returning to the issue of surface vs. underlying levels, we note that Anderson (1985, pp.47-9) considers the most plausible understanding of Saussure here something he calls the *fully specified surface variant* theory. What this means is that the grammar determines directly whether two forms are in contrast, without recourse to any underlying representation.

Martinet (1964) (and in other works) develops a bit more concretely a view of Saussurian structuralism and its implications for sound systems. For example, he suggests that given a three-way height contrast such as that shown in (3)a, where /e̝/ indicates a particularly closed mid vowel, "...the norm of the phoneme /e/ would soon be shifted to a point equidistant between /i/ and /a/", as in (3)b (pp.191-2, cf. p.22).

(3) Perceptual distinctiveness of contrast

a.	|....../i/......./e̝/................................./a/....|	Unstable
b.	|....../i/..................../e/..................../a/....|	Stable

A key idea for Martinet is that the perceptual distinctiveness of contrasts should be maximized; this is the sense in which the wellformedness of /e/ (and the other vowels) cannot be determined in isolation, but requires the systemic view. Within the bounds imposed by perceptual distinctiveness, Martinet argues also that sound systems are shaped by constraints on articulatory economy. These views are motivated by facts involving (positional) inventories, chain shifts, and variation/allophony, among others.

The preceding observations are not only a matter of historical interest. The central ideas mentioned in relation to contrast—that evaluating forms requires a systemic view of contrast, that issues of perceptual distinctiveness and articulatory complexity are important to phonology, and that phonological generalizations even about contrast might be expressible at the surface—have much to recommend them, as current work is making clear. Flemming (1995) in particular argues all three points, and develops an implementation of them called Dispersion Theory (DT). DT recasts and extends ideas of Lindblom's (1986, 1990) Adaptive Theory of Dispersion, couching them in Optimality Theory (Prince and Smolensky 1993). (Cf. Steriade 1995, Boersma 1997 for related ideas.) As Flemming points out, URs are motivated by a) alternation and b) contrast. Should it turn out that both (a) and (b) are better handled at the surface, then it isn't clear we need URs.

2 Dispersion Theory

At the heart of DT are three desires, often in conflict: a) maximize the number of contrasts; b) maximize the perceptual distinctiveness of contrasts; and c) minimize articulatory effort. We focus here on (a) and (b). (See Flemming 1995 for underpinnings, arguments, and further elaboration.) There is first of all a family of constraints that dictate the number of contrasts a language will have along some (auditory) dimension F of possible contrast, e.g., vowel color, vowel height, voice onset time, nasality, and so on:

(4) Number of contrasts

Maintain 2-way Contrast_F >> Maintain 3-way Contrast_F >> ... >> Maintain *n*-way Contrast_F

These constraints rate inventories in the way illustrated below, focusing on the dimension of vowel height. Importantly, candidates are not individual forms or segments, but rather sets of forms or segments taken to be in contrast ('•' denotes a contrast).[2] The constraints simply count the number of contrasts along the relevant dimension. The demand for a 2-way contrast is met by all hypothetical inventories but those in (5)f-h, which have no contrast at all. Similarly (5)c-h lack a 3-way contrast, and (5)b-h a 4-way contrast.

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[2] For our purposes here candidates are sets of segments—inventories—but ultimately DT must evaluate sets of possible words, taking into account the fact of positional contrast and neutralization, and so on.

(5) How Contrast constraints rate inventories

	2-way Contrast	3-way Contrast	4-way Contrast
a. i • ɪ • ɛ • æ			
b. i • e • æ			*
c. ɪ • ɛ		*	*
d. i • æ		*	*
e. i • ɪ		*	*
f. i	*	*	*
g. e	*	*	*
h. æ	*	*	*

This constraint ranking is taken to be universal in DT. The effect of this is that any candidate violating *n*-way Contrast violates (*n*+1)-way Contrast, for any *n* (along a particular dimension F), as the tableau makes clear. The best candidate, all else being equal, is that which maximizes the *number* of contrasts; the *quality* of the contrast is irrelevant to this family of constraints. The general effect, therefore, is that "more contrasts (hence less perceptual distance—see below) is always better".

A second family of constraints rates the quality of a contrast in terms of perceptual distance or distinctiveness. One way to understand distance along some dimension is by means of fractions of the entire range: a requirement that segments be separated by 1/3 of the range is less demanding than one requiring they be separated by 1/2 of the range, and so on. This is the meaning of the fractions in the constraints (F is again any auditory dimension of contrast):

(6) Perceptual distinctiveness of contrast

$\text{Space}_F \geq 1/n$ >> $\text{Space}_F \geq 1/n\text{-}1$ >> ... >> $\text{Space}_F \geq 1/2$ >> $\text{Space}_F \geq 1$

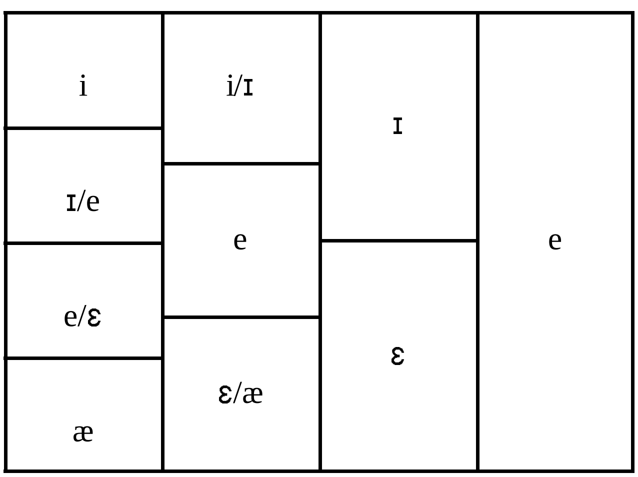
In particular, these Space constraints are understood as follows, focusing still on vowel height. (The acoustic correlate of vowel height is the height of the first vowel formant (F1), now indicated.)

(7) $\text{SPACE}_{F1} \geq 1/\text{N}$: any two segments contrasting in F1 differ by at least *1/n*th of the full F1 range

For the purposes of understanding this constraint family, suppose a 4-way contrast in vowel height is the maximum possible for any language. (The precise number is not the issue here. This has always been a controversial area in feature theory, one difficulty being to tease apart height distinctions and ATR or tense distinctions. See Ladefoged and Maddieson 1996 on the existence of 4-way height contrasts, and for a tentative case of a 5-way contrast.) If so, then 4-WAY CONTRAST is the most demanding Contrast constraint that can be obeyed for vowel height. (There might be more demanding constraints, but they can have no effect by hypothesis.) Now, we might reasonably ask why there is such an upper limit on the number of contrasts in height (a question rarely raised in feature theory). DT's answer is that it follows from perceptual distinctiveness demands. In particular, more contrasts would mean too crowded a perceptual space. We can now say that this is because SPACE$_{F1} \geq 1/4$ is inviolable (see below); a 5-way contrast would require a vowel spacing that violates this constraint. Therefore let us assume that this constraint is in GEN. The reasoning seen here and above will be the same for any contrast dimension, except that the upper limit on the number of contrasts will vary. Generally things will be simpler, since most contrast dimensions allow only a two- or three-way contrast.

One way to implement these ideas is illustrated in (8). (Here and throughout the paper only front vowels are shown, though the discussion is meant to cover vowel height generally.) Every SPACE constraint presupposes a division of the height space into *n* equal parcels. Suppose we locate a vowel in the center of each such parcel. This means that at most 4 vowels fit into a 4-way subdivision, and so on.[3]

(8) Martinet's intuition



[3] We could instead place vowels at extremes whenever there is contrast, essentially wherever there is a horizontal line in the diagram. This would mean that **5** vowels fit into a 4-way subdivision, and so on. Nothing important is meant to hinge on this choice.

The above transcriptions were arrived at with the assistance of figures 8.5 and 9.1 of Ladefoged (1993), which show "...the average of a number of authorities' values..." for F1 in American English. It might be helpful to see the numbers in order to grasp the basic idea, and they are shown below. However, it should be emphasized, first, that the numbers themselves are not important, since (as always) speakers' values differ greatly, and it is the relative spacing that matters. The numbers were simply useful in determining this spacing and the resultant transcriptions. Second, the transcriptions themselves are only rough guesses based on those figures, and the implementation of Space constraints here is in many ways speculative. The point is not to make claims about precise realizations, but to make clear the idea that the vowel height dimension is a continuous range that can be divided up into arbitrarily many distances (within universal bounds of perceptual distinctiveness); this idea is central to DT. As is well known, phonetic transcription is somewhat antithetical to such a view, since it imposes discrete categories onto this continuum: a vowel is either *i* or *ɪ*, but not something in between. These categories are of course useful for most purposes, but they turn out to cause odd predictions in DT if we hold on to them too tightly.[4]

(9)
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 |...i...|...ɪ...|...e...|...ɛ...|...æ...|      Minimal
250 |       |       |       |       |  750      Distance ≈ 100 Hz
   300     400     500     600     700          (Assume impossible)

 |....i....|...ɪ/e...|...e/ɛ...|....æ....|      Minimal
250 |         |         |         |    750      Distance ≈ 125 Hz
   312.5     437.5     562.5     687.5          Space≥1/4

 |....i/ɪ.....|......e......|.....ɛ/æ....|      Minimal
250  |             |             |     750      Distance ≈ 167 Hz
    333           500           667             Space≥1/3

 |.........ɪ.........|.........ɛ.........|      Minimal
250         |                   |        750    Distance ≈ 250 Hz
           375                 625              Space≥1/2

 |..................e..................|        Minimal
250                 |                 750       Distance ≈ 500 Hz
                   500                          Space≥1
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[4] Most likely for the sake of familiarity, Flemming (1995) retains categorical [æ ɛ e ɪ i]. Within DT, such a system has the odd property of predicting 2-, 3-, and 5-way contrasts, but not (in any direct way) a 4-way contrast. The reason is this: a 4-way contrast would draw on 4 of the vowels [æ ɛ e ɪ i], and would be possible only if Space constraints allowed vowels to be as close as these vowels are. But if Space constraints allow this, they also allow the 5-way contrast [æ ɛ e ɪ i], since these vowels are equally spaced. Given the effect of the Contrast constraints ('maximize the number of contrasts', see above), the latter inventory will therefore always be favored (all else equal) over any 4-way inventory. Avoiding such results is possible once we abandon the categories and attempt to state effects on the continuum.

To see how the Space constraints rate inventories, consider (10) below. Recall that Space≥1/4 is assumed to be in GEN; hence candidates containing, e.g., i • ɪ are not possible. (Recall also that pure height distinctions are at question, with [ATR] and tenseness out of the picture.) In tableaux containing Space constraints an attempt is made to show the relative positions and spacing of the vowels in each candidate inventory. Thus candidates (10)a-c do equally poorly by the Space constraints, since the vowels they have (regardless of number) are equally close. The same holds for (10)d-e. It can be seen from the tableau that any candidate that violates Space≥1/*n* violates Space≥1/(*n*-1). As with the Contrast constraints, this ranking is universal. This means that the second-best candidate (all else equal) is always the most distant pair, here *ɪ • ɛ*. The best candidate, according to Space constraints, is always no contrast as in (10)g-h, since such inventories vacuously satisfy Space constraints perfectly. (It is up to other constraints, such as those on articulatory complexity, to favor one of these candidates.) The effect in this case is "more distance (hence fewer contrasts) is always better".

(10) How Space constraints rate inventories

|....F1 space.....|	Space≥1/3	Space≥1/2	Space≥1
a. i •ɪ/e • e/ɛ • æ	*	*	*
b. i •ɪ/e • e/ɛ	*	*	*
c. e/ɛ • æ	*	*	*
d. i/ɪ • e • ɛ/æ		*	*
e. i/ɪ • e		*	*
f. ɪ • ɛ			*
g. i			
h. e			

It should be obvious that the Contrast and Space constraints are in competition. Suppose that all Contrast constraints outrank all Space constraints, as shown below. The result is the maximal possible inventory. Given the reverse, All Space >> All Contrast, we get no contrast, as the reader can verify.

(11) All Contrast >> All Space: maximal contrast

	2-way	3-way	4-way	space≥ 1/3	space≥ 1/2	space≥1
a. ☞ i•ɪ/e • e/ɛ • æ				*	*	*
b. i/ɪ • e • ɛ/æ			*!		*	*
c. ɪ • ɛ		*!	*			*
d. e	*!	*	*			

Suppose we wish to derive a 2-way contrast. For this to happen, the constraint 2-WAY CONTRAST must outrank SPACE≥1, since the latter constraint demands the use of the entire vowel space. This is shown below. (The non-crucial rankings are indicated with a dotted line, by the usual convention.) . For similar reasons, a 3-way contrast requires the ranking 3-way >> Space≥1/2, as the reader can verify. Most generally, for an *n*-way contrast, we require N-WAY CONTRAST >> SPACE≥1/N-1.

(12) 2-way >> Space≥1: 2-way contrast

	space≥ 1/3	space≥ 1/2	2-way	space≥1	3-way	4-way
a. i•ɪ/e • e/ɛ • æ	*!	*		*		
b. i/ɪ • e • ɛ/æ		*!		*		*
c. ☞ ɪ • ɛ				*	*	*
d. e			*!		*	*

The above discussion in most respects simply follows Flemming (1995). The upshot is that these two families of constraints together predict a smooth range of possibilities from no contrast to a 4-way contrast in height, and similar reasoning extends to all dimensions of contrast.[5] The intuitions are simple, and the systemic view of contrast in DT brings real explanatory advantages to phonology over other approaches to markedness (see Flemming 1995, and also Ní Chiosáin and Padgett 1997). The ideas above might nevertheless appear to be an imposition on phonological theory, but it must be made clear that Contrast and Space

[5] No language lacks a height contrast altogether, an issue we do not address here. Many languages neutralize height contrasts completely in certain positions, however.

constraints (together with constraints on articulatory complexity) are intended as a full account of facts of markedness, segment realization, contrast and neutralization. For instance, since the number and kinds of contrasts are regulated by these constraints, they are intended to replace input-output faithfulness in Optimality Theory.

The following table illustrates this point by comparing the explanatory response of DT and Distinctive Feature Theory (where the latter term is meant also to subsume current uses of faithfulness) to basic facts of contrast, cross-linguistic (first two rows) and language-particular (last two rows). In DT, features still exist in the sense of properties referred to in determining contrast, natural class patterning, etc. But contrast is directly regulated by output constraints, as shown above. An interesting result of this is that there is no reason to minimize by stipulation the number of phonetic features, or segment types, in phonology: constraints rein in any potential overgeneration of contrast. (See especially Flemming 1995, to appear on this point; see also Kirchner 1995, and Ní Chiosáin and Padgett 1997.) DT extends the insight of Prince and Smolensky (1993) that contrast is derived from the constraint hierarchy, essentially an output property. As noted earlier, it captures this insight more directly, however, since contrast is not mediated by inputs, and inputs are not obviously necessary to the theory (see Flemming 1995).

(13) Dispersion theory compared to distinctive feature theory

Observation	Response - dist.feature theory	Response - DT
Languages show at most a 2-way contrast in vowel nasality	Posit *one* feature, [nasal]	Put $Space_{Nasal} \geq 1/2$ in GEN
Languages show at most a 4-way contrast in vowel color	Posit *two* (or more) features, e.g., [back], [round]	Put $Space_{Color} \geq 1/4$ in GEN
English has only one color contrast, i.e. *i* vs. *u*	Allow only one feature in UR, or *ɯ, *y >> Faith	Only 2-way Contrast is satisfied
Turkish has a 4-way color contrast, *i, y, ɯ, u*	Allow all relevant features in UR, or Faith >> *V	Only 4-way Contrast is satisfied

3 Vowel height, nasality, and perceptual distinctiveness

The vowel system of Early Proto-Slavic (PSl) is shown below. (See Černykh 1962, Shevelov 1965, Carlton 1991; according to these, the transcription may overstate the lowness of the non-high pair.) Each vowel occurred long or short; long vowels contrasted in pitch accent also.

(14) Early Proto-Slavic vowels

i	u
æ	ɑ

By Late PSl, two nasal vowels had been added to this system, due to the loss of syllable-final nasal consonants with retention of nasality on the preceding vowel, i.e., tautosyllabic CVN → Cṽ (N= *n* or *m*). These nasalized vowels retained their frontness; however, height was neutralized: iN, æN → ę, and uN, ɑN → ǫ. The symbols ę, ǫ are traditional Slavic notation for these nasalized vowels. The actual height realizations varied by dialect, as shown below. Our focus here will be on the neutralization itself, leaving open the question what principles (if any) govern the choice of height across dialects.

(15) Nasalized vowel realizations for ancestors of...

ǫ:	ũ:	East Slavs, Czechs, Slovaks, Upper/Lower Lusatians, Serbs, Croatians
	ɑ̃/ʌ̃:	Bulgarians, Macedonians, Poles
	õ:	Slovenians
ę:	ẽ:	South Slavic, many others
	æ̃:	East Slavs, Czechs, Slovaks

Most dialects lost nasal vowels by the 11th century. Traces of them are found today in Polish/Kushabian, Macedonian and Slovenian. The only direct evidence for these vowels in Common Slavic comes from Old Church Slavonic documents, where the nasal vowels were distinctly spelled. Some examples are given in (16), with cognates from related languages showing the original nasal. Some Old Church Slavonic alternations between VN and nasalized V are shown in (17), with the relevant segments bolded. (The symbols ъ and ь stand for back and front vowels, respectively, that are short/lax and high.)

(16) Old Church Slavonic forms

Exx:	OCS		Latin		
	kǫpinɑ	'shrub'	cɑmpus	'field'	< ɑ̆N
	skǫdъ	'indigent'	skɑndulɑ	'shingle'	
	ǫgъlъ	'corner'	ɑngulus	'corner'	< ɑ̄N
	(ob)ǫxɑti	'smell'	ɑnimus	'soul'	
	tętivɑ	'bowstring'	tempus	'time'	< æN
	tręsti	'shɑke'	tremō	'tremble'	
			Old Norse		
	gǫbɑ	'sponge'	kumpr	'lump'	< uN
	dɑdęti	'give'			< IE -N̥t-

(17) Alternations in Old Church Slavonic (syll boundaries shown):

Inf.	Pres.	
(j)**ę**.ti	**i.m**ǫ	'take'
kl**ę**.ti	klь**.n**ǫ	'curse'
(na)č**ę**.ti	-čь**.n**ǫ	'begin'

Vowel neutralizations such as these under nasalization are very common cross-linguistically. It is well known that nasalized vowel inventories are generally a subset (proper or not) of their oral counterparts in a given language. More specifically, however, what gets neutralized under nasalization is almost always vowel *height*. The reason, according to Wright (1986) and Beddor (1993), is the following. (See Maeda 1993 and Johnson 1997 for a more detailed and complicated picture.) Nasalization introduces a so-called nasal formant (FN), whose frequency is fixed (independent of the vowel being uttered) and relatively low (roughly 400 Hz or lower for a male speaker). FN is typically near enough to F1, the primary correlate of vowel height, to be perceptually integrated with F1. That is, a speaker perceives something like a weighted average of FN and F1. This means that the effective range of perceived F1, and therefore perceived height, is reduced when vowels are nasalized. It follows from this that the perceptual distance in height between two oral vowels is reduced whenever those same vowels are nasalized. This would be true, note, no matter what the value of FN or those of F1, assuming perceptual integration. As it happens, the typical value of FN (see above) is such as to be higher than F1 for high vowels and lower than F1 for low vowels; therefore, high vowels are perceptually lowered, while low vowels are perceptually raised. This reduction of the nasalized vowel space is illustrated below. Here we assume the F1 values for a two-height system given earlier, as well as FN at 400 Hz, and equal weighting for averaging F1 and FN; this leads to the shift shown. Given these assumptions, we can draw the important conclusion that an *n*-way contrast for nasal vowels *necessarily violates* SPACE≥1/N as defined for *oral* vowels, all else equal. Let us call this result *nasal contraction*. Our two-vowel oral system, for example, obeys SPACE≥1/2 so long as the vowels are 250 Hz apart; but the nasalized counterparts shown violate this constraint. The numerical assumptions here abstract away from any complexities resulting from, e.g., differential weighting, and more complex effects of nasalization on the vowel spectrum. For the purposes of the upcoming discussion, let us simply assume nasal contraction as stated above.

(18) Violates Space≥1/2 Nasalized vowels sound closer together

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              ___________
             |           |
 |.........ɪɪ̃.........|ɛ̃.........ɛ........|
250          |                    |          750    Distance ≈ 250 Hz
            375                  625                Space≥1/2
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Given the two-height oral system of PSL, the ranking of Space and Contrast constraints must crucially include 2-WAY >> SPACE≥1 (see (12) above).

(19) Oral vowels in PSl: 2-way >> Space≥1

	space≥ 1/3	space≥ 1/2	2-way	space≥1	3-way	4-way
a. i •ɪ/e • e/ɛ • æ	*!	*		*		
b. i/ɪ • e • ɛ/æ		*!		*		*
c. ☞ ɪ • ɛ				*	*	*
d. e			*!		*	*

According to the assumption of nasal contraction, each nasalized candidate inventory incurs one *higher* Space violation than its oral counterpart. Fixing the ranking SPACE≥1/2 >> 2-WAY left indeterminate in the last tableau, we derive height neutralization under nasalization with one ranking for PSl.

(20) Nasal vowels in PSl: Space≥1/2 >> 2-way

	space≥ 1/3	space≥ 1/2	2-way	space≥1	3-way	4-way
a. ĩ •ɪ̃/ẽ • ẽ/ɛ̃ • æ̃	*!	*		*		
b. ĩ/ɪ̃ • ẽ • ɛ̃/æ̃	*!	*		*		*
c. ɪ̃ • ɛ̃		*!		*	*	*
d. ☞ ẽ			*	*	*	*

It is useful to compare at this point a similar phenomenon in American English. Southern American dialects neutralize the distinction between lax mid and high ɪ/ɛ before tautosyllabic nasals. Next to General American lax *pin* • *pen* • *pan*, or *him* • *hem* • *ham* (ɪ/ɛ/æ respectively), we find only *pin/pin* • *pan*, or *him/him* • *ham*. Vowels before tautosyllabic nasals are nasalized in American English, and this is an instance of the same effect seen in PSl. If we focus on only the lax English vowels, then oral vowels in both General and Southern American evince a 3-way contrast. According to our general results earlier, this requires the ranking 3-WAY >> SPACE≥1/2. In order to derive neutralization to a 2-way system under nasalization, we need only fix the ranking SPACE≥1/3 >> 3-WAY as well. (Compare this total ranking to PSl SPACE≥1/2 >> 2-WAY >> SPACE≥1 just above.) The oral and nasal inventories are derived together in (21).

(21) Southern American: Space≥1/3 >> 3-way >> Space≥1/2

	2-way	space≥ 1/3	3-way	space≥ 1/2	4-way	space≥1
a. ĩ • ɛ̃ • æ̃		*!		*	*	*
b. ☞ ĩ • æ̃			*	*	*	*
c. ɛ̃	*!		*		*	*
d. ☞ ɪ • ɛ • æ				*	*	*
e. ɪ • æ			*!		*	*
f. ɛ	*!		*		*	

The reader can see from (20) that if the ranking SPACE≥1/2 >> 2-WAY were reversed in PSl, then there would be no neutralization of height under nasalization. Similarly here, a way to understand General American, where no neutralization occurs, is to reverse the ranking SPACE≥1/3 >> 3-WAY seen above, as shown in (22). Again the nasal and oral inventories are derived together.

(22) General American: 3-way >> Space≥1/3 >> Space≥1/2

	2-way	3-way	space≥ 1/3	space≥ 1/2	4-way	space≥1
a. ☞ ĩ • ɛ̃ • æ̃			*	*	*	*
b. ĩ • æ̃		*!		*	*	*
c. ɛ̃	*!	*			*	*
d. ☞ ɪ • ɛ • æ				*	*	*
e. ɪ • æ		*!			*	*
f. ɛ	*!	*			*	

Nasalization inevitably reduces the perceptual distinctiveness of a contrast, all else being equal. Given this, we can entertain three possible outcomes of the situation in a language. First, reduction of perceptual distance might lead directly to neutralization, as in PSl and Southern American. Second, contrast might be salvaged if the language will tolerate the reduced perceptual distance. This is the analysis of General American implicit in tableau (22), where Contrast constraints more effectively outrank Space considerations than in Southern American. To understand the third scenario, we have to recall DT's constraints on articulatory complexity, largely ignored in this paper. It is possible to salvage contrast *and* retain the same perceptual distance across oral and nasal contexts, if the language will tolerate increased articulatory complexity for the nasal vowels. This is because the inherent loss of distance under nasalization can be offset by overarticulating the nasal vowels in comparison to their oral counterparts.

More generally, DT predicts the three scenarios regarding potential neutralization shown below. Though we have not considered constraints on articulatory complexity here, they play an important role in the larger picture, as can be seen here. Both PSl and Southern American are instances of (23)c. The analysis above implies that General American is a case of (23)a. However, whether it is this, or a case of (23)b—or possibly even both, if Space and Articulation constraints are in variable ranking—are open questions.

(23)	a) Contrast, Articulation >> Space:	Contrast at the expense of perceptual distance
	b) Contrast, Space >> Articulation:	Contrast at the expense of articulatory complexity
	c) Space, Articulation >> Contrast:	Neutralization

4 Conclusion

Though traditional feature theory has understood the markedness of nasal vowels with respect to oral vowels in terms of increased featural complexity, the fact that height (in particular) is neutralized under nasalization has remained mysterious. The phonetic basis for the effect seems reasonably clear; DT capitalizes on this explanation, providing a direct link between height and nasalization effects by crucial reference to perceptual distinctiveness of contrast in the output. It is hard to see how this connection could be genuinely made without reference to perceptual distinctiveness of F1 contrasts. DT's success in this small area provides more support for the idea generally that perceptual distinctiveness of contrast must be evaluated in the output. Since this requires that contrast itself be discerned in the output, it lends support to the larger claim that contrast must be regulated in the output. (The question of how to formalize this notion of output contrast remains in some respects an open matter.) Whether inputs can therefore be eliminated (a conclusion based on Occam's razor) is a question for the future, but obviously one worth asking.

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