Knowledge of Variation

Janet B. Pierrehumbert

Papers from 30th Regional Meeting of the Chicago Linguistic Society. Volume 2
The Parasession of Variation in Linguistic Theory (1994). Chicago Linguistic Society, Chicago, pp 232-256.

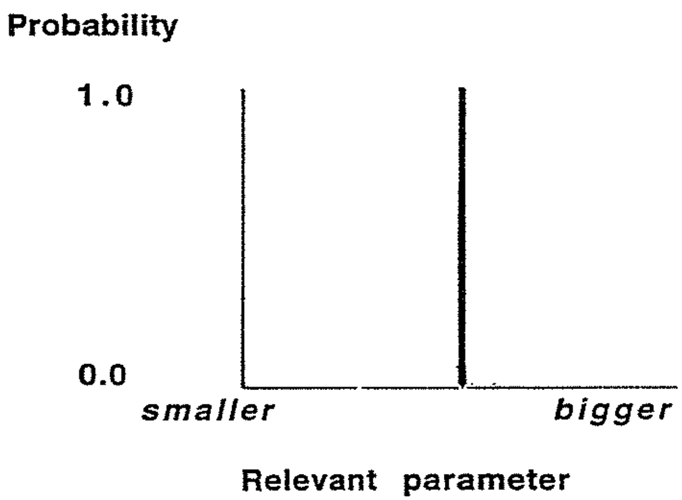
KNOWLEDGE OF VARIATION*

Janet Pierrehumbert
Northwestern University

0. Introduction

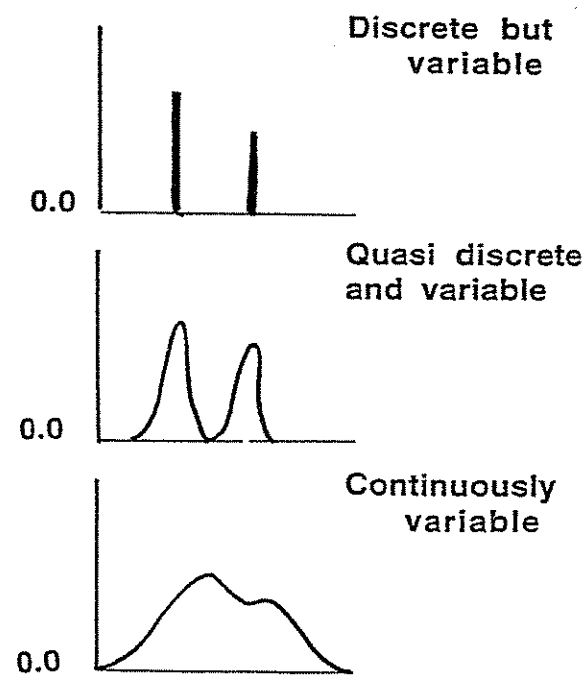
This papers deals with the cognitive representation of language variation, in particular phonological or phonetic variation. To address this issue, consider first what variation is. Variation may be defined by contrast to non-variation, which is illustrated in Figure 1. This figure displays a probability distribution for the values of some relevant parameter of some thing. The distribution takes the form of a delta function: for some specific value of the parameter, the probability is 1.0 and for all other values the probability is 0.0. In short, for the thing under consideration, the parameter always exhibits the same value, no matter what.

Figure 1: Nonvariation



The term "variation" covers all other situations. Some simple examples of variation are shown in Figure 2. In the first panel (characterizable as "discrete variation") the parameter takes on only two values, but does indeed vary between these two values. In the second panel, an example of quasi-discrete variation, the parameter takes on an infinite number of different values but these may for practical purposes be grouped into a small number of nonoverlapping clusters. In the third panel, the variation is continuous though some values of the parameter are more likely than others.

Figure 2: Variation



By way of a more concrete example of variation and nonvariation, consider the Sears tower. The tare weight (or weight empty) of the Sears tower is for all practical purposes invariant. The gross weight varies with the time and date. The latitude of the front door, neglecting continental drift, is invariant. The latitude of the top also varies because the wind causes swaying, which is psychologically salient to the occupants of the upper stories. The height varies due to thermal expansion and contraction; because temperatures in Chicago range over some 80 degrees Centigrade, this height variation was a matter of serious concern to the building's designers. In summary, the Sears tower is variable in some relevant respects.

To my knowledge, no linguist has ever proposed that language is less variable than the Sears Tower. Quite to the contrary, variation is observed amongst languages, amongst dialects, amongst idiolects, and within the speech of individuals. Furthermore, language exhibits variability at all levels of representation, from phonetics to phonology and syntax, right through to pragmatics. Thus the issue is how variation fits into our scientific understanding of language. Is the variation peripheral or central to Language with a capital "L"? Is it represented in the mind and if so how? How does variation fit into our understanding of language and of cognition in general? The position of this paper is that variation penetrates further into the core of the theory than generally supposed, and that variation should be exploited rather than disregarded in investigating language.

1. Mental Representation Of Variation

Linguistic theory deals with implicit knowledge, or the cognitive representation of language. To what extent can people form mental representations of statistical variation? The evidence is that people are quite successful in internalizing patterns of statistical variation for entities (though less successful for relations). For example, in a classic experiment of Grant, Hake, and Hornseth (1951), subjects were presented with a light which blinked at random, but with various probabilities. They had to guess whether the light would next be on or off, and after sufficient experience, their guesses closely approximated the underlying probability of the light being on.

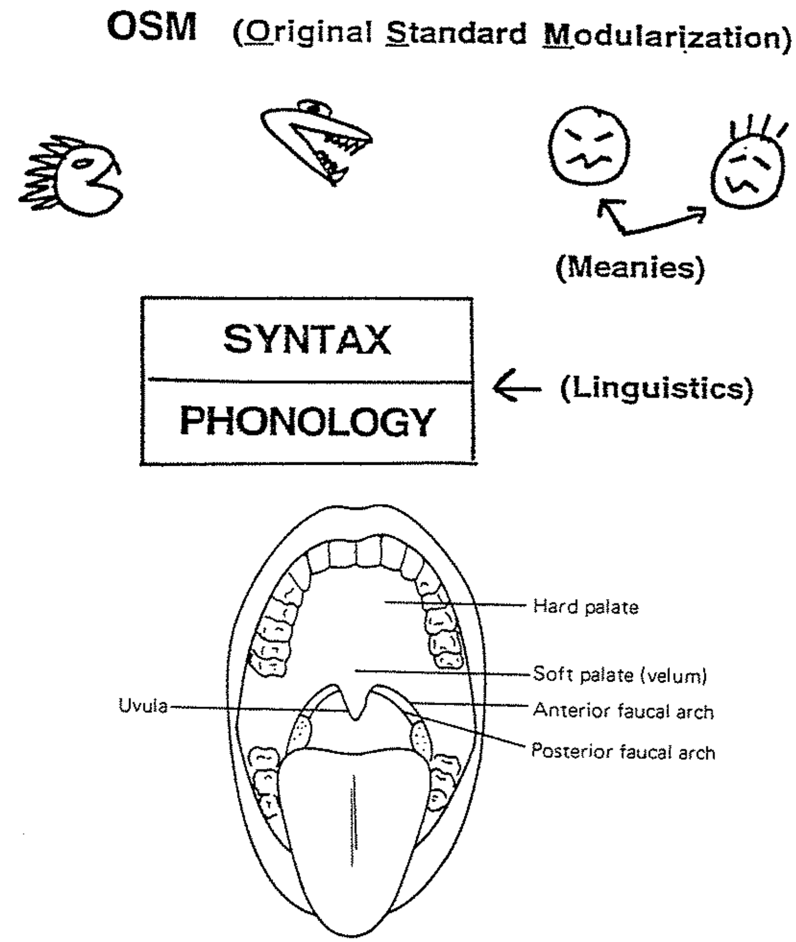
For speech, internalized frequencies are known to have two pervasive sets of effects. One set is related to word frequencies. Higher frequency words are recognized more reliably in noise (Howes, 1957), recognized faster (Taft & Hambly, 1986) and produced faster in picture naming (Oldfield & Wingfield, 1964). They are less subject to phonological errors (Stemberger & MacWhinney 1986) and they tend to replace lower-frequency words in substitution of semantic associates (Levelt 1989). See Cutler (in press) for discussion of both the results just cited and others.

The other set of well-established frequency effects is related to frequencies within the immediate context rather than long-term frequencies. This is the group of phenomena described as sequential, range, or adaptation effects on phoneme boundaries (see Repp and Liberman, 1987). In all of these cases, the character and frequency of particular phonetic outcomes in the general context of a speech segment are found to affect phonetic category boundaries. These experimental findings can be related to studies of language change in progress (see Labov, 1986). Such studies show, first, that phonological changes typically originate as subphonemic changes in pronunciation, and second, that the behavior of speakers is incrementally modified through their conversational interactions with people they identify with or admire. In order to model this pattern of change, it is obviously necessary to impute to speakers detailed allophonic representations and implicit knowledge of their frequencies.

2. OSM AND MESM

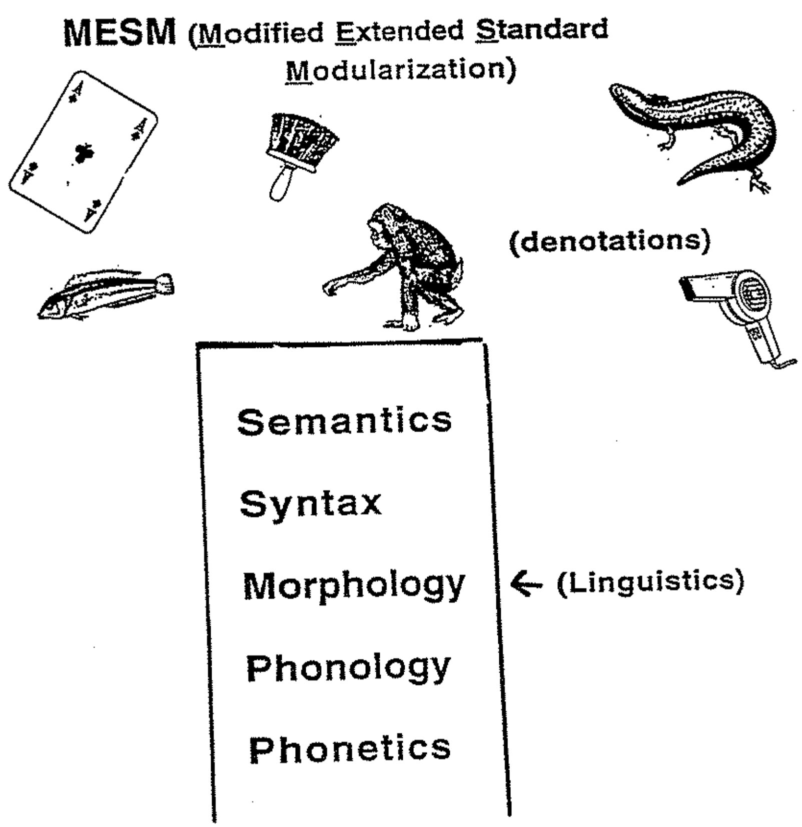
The issue of where variation belongs in our theory of language may be elucidated by considering theoretical developments over the last few decades. One of the hallmarks of generative linguistics has been its commitment to modularity, and the discussion here will concentrate on what modules have been held to exist and what properties been attributed to them. As a starting point, consider OSM (or the Original Standard Modularization), as illustrated in Figure 3. According to OSM, linguistic theory had two modules, namely phonology and syntax. Both of these modules were purely structural and the relationship of the entities posited in these modules to external reality was held to be outside of the purview of linguistics. Specifically, the exclusion applied both to the area of meaning (a terra incognita inhabited by meanies) and to phonetics (which as indicated in the figure was viewed as the province of physical and biological scientists.)

Figure 3:



The response to OSM, developed in the late seventies and in the eighties, was MESM (or Modified Extended Standard Modularization). MESM, illustrated in Figure 4, is the position with which I am chiefly associated; see position papers Pierrehumbert (1990) and Pierrehumbert (1991). People who know me will realize from the sudden and belated capitalization that I am about to attack it.[1]

Figure 4:



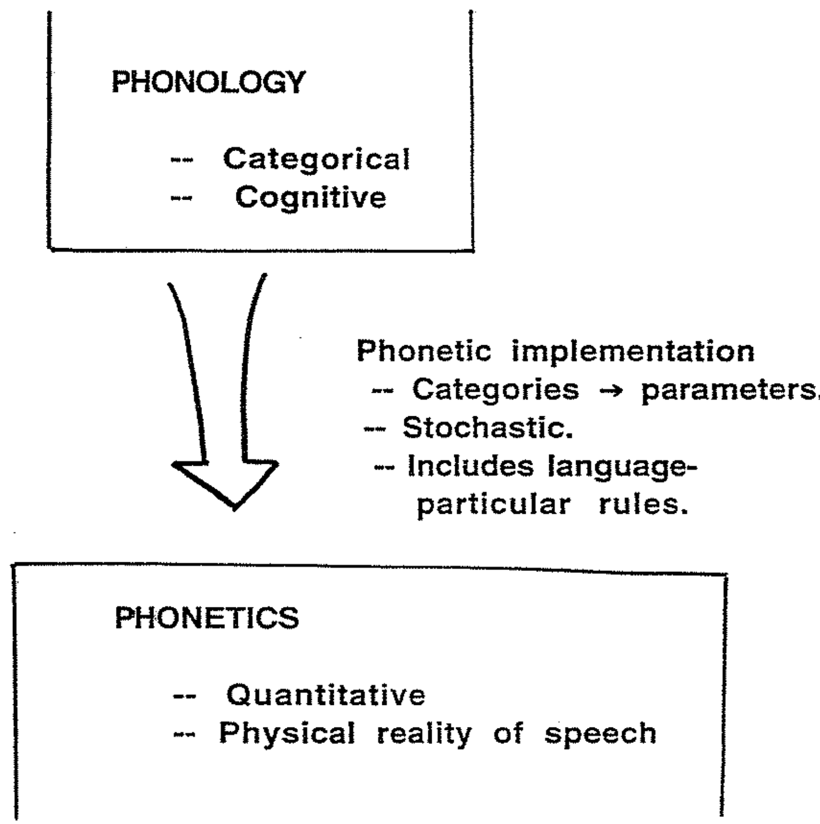
According to MESM the modules of linguistic theory include not only phonology and syntax, but also morphology, semantics and phonetics. Despite notable penetration of pragmatics into semantics in recent years, there still seems to be agreement that some matters of world knowledge fall outside of linguistics. This is suggested in the figure by assorted pictures of actual denotations of words. Linguistic phonetics, in contrast, now includes not merely mental representations of quantitative details of speech, but even their physical reality. Any physical measurement of speech acoustics or articulation can be used in a paper on linguistic phonetics, provided only that it is shown to provide evidence about a significant linguistic issue. Indeed many people (including me) will give you trouble if you write a paper which purports to be about linguistic phonetics and which does not present the relevant objective measurements.

There have been two chief reasons for this wholesale inclusion of phonetics within linguistics. One has been pursuit of the Jakobsonian viewpoint, as expressed in Jakobson, Fant and Halle (1952). According to this viewpoint, distinctive

features are not arbitrary classifiers but are rather founded in dimensions of articulatory and acoustic contrast; their phonological behavior reflects their phonetic nature. Subsequent work within phonology strongly bears out this view. The other reason has been the discovery that even the most inescapably quantitative details of language sound structure are subject to language particular conventions, and hence must be learned and represented in the mind. That is, the cognitive representation of language is not confined to categorical structure and rules, but rather includes arbitrarily fine details of allophony. It would hardly be an exaggeration to say that every allophonic process that has been investigated in rigorous detail has been found to exhibit variation across languages.

Figure 5, a magnification of the bottom of Figure 4, shows the specific method by which such results are accommodated in MESM.

Figure 5: Sound Structure in MESM

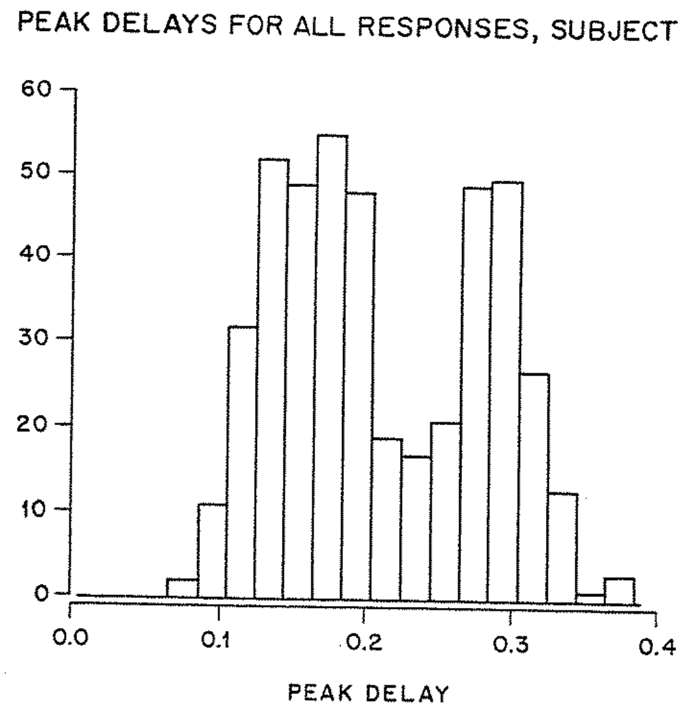


As in OSM, phonology is taken to cover implicit knowledge of categorical aspects of sound structure. Phonetics proper is responsible for the quantitative description of the physical reality of speech. Phonology is related to phonetics by a powerful and language particular set of phonetic implementation rules. These rules relate completely prosodized phonological representations to quantitative parameters. Or to be more precise, since the rules are stochastic, they relate phonological representations to probability distributions of quantitative parameters. Since the rules are language particular, they, along with all of phonology, are held to comprise part of the speaker's implicit knowledge.

Simple examples of the MESMic approach are provided by Keating (1983) and Pierrehumbert and Steele (1989). Keating (1983) investigated the voice onset time (VOT) for voiced and voiceless stops in different languages. For English, the VOT of word-initial /b/s in stressed syllables exhibited some variation around a modal value of +10 msec. /p/s in the same position exhibited broader variation around a mode of +50 msec. In medial falling stress position, /p/s clustered about +20 msec (considerably overlapping the value for initial /b/s); the distribution for /b/s was bimodal, with one mode at -60 msec and another mode +20 msec. Polish and German were found to exhibit different distributions in comparable positions. Thus, the objective manifestation of the feature [voice] is a statistically variable function of the prosodic position (here, of the stress and word boundary location). Moreover, this function is language dependent.

Pierrehumbert and Steele (1989) investigated the claim of Pierrehumbert (1980) that English has two categorically different pitch accents, L*+H and L+H*. Both are claimed to have the same shape (a distinctively low fundamental frequency value followed by a peak); they are claimed to differ in how the peak is aligned with the stressed syllable of the accented word. In the experiment, 15 different versions of the sentence "Only a millionaire" were created with natural spectral properties and synthetic f0 contours. The synthetic f0 contours all had a rise-fall-rise shape, but differed along a continuum in the alignment of the f0 peak with the first syllable of "millionaire". Subjects heard the stimuli many times in randomized order, and had to imitate them. If the distinction in peak alignment were gradient, the subjects should be successful, on the average, in imitating the variation in the stimuli. If the distinction is categorical, the imitations are expected to exhibit two preferred peak placements. Figure 6 provides a histogram of the timing of the peak relative to the /m/ release for one subject.

Figure 6:



This figure does not look like the first panel of Figure 2; there were some productions at all values of peak delay. However, the distribution is strongly bimodal. This outcome is fairly typical of experimental data on production or perception of categories. Hence, the interpretation is that the stimuli were perceived in terms of two categories (L*+H and L+H*) and that each of these categories was produced using a preferred peak timing with a certain amount of random variation.

It should be emphasized that the analyses just sketched are not embedded in any particular capitalized theory of phonology, such as (in alphabetical order) Cognitive Phonology, Declarative Phonology, Government Phonology, Harmonic Phonology, Lexical Phonology, Optimality Theory. (See, respectively, Lakoff 1993, Scobbie 1993, Kaye et al. 1990, Goldsmith 1993, Kiparsky 1985, McCarthy and Prince, in press) Instead, it embodies assumptions which are shared by all of these theories. That is, all of these theories posit a categorical core, and work under all approaches increasingly relies on powerful phonetic implementation rules to explain regularities which do not lend themselves to categorical approximation. Examples of work exhibiting such a reliance include: Hayes (1984), Kiparsky (1985), Lombardi (1990), Coleman (1992) and much though not all work in Variationist Theory. Therefore, MESM is not a competitor to CP, DP, GP, HP, LP, OT, or VT, but rather represents a common theoretical foundation for all of them.

3. FEATURES OF MESM

At this point, we are ready to identify some of the less obvious but still critical features of the MESMic approach. First, MESM adopts from OSM the idealization of the ideal speaker-hearer. Though it does not deny the existence of variability within the speech community, it presumes that the mental representations of individual speakers are structured as if they were operating in a uniform speech community. Second, MESM treats stochastic variation as peripheral. It provides for stochastic variation at the phonetic and pragmatic edges of the grammar; it also provides for stochastic variation between entire grammars. But it still has an OSMic core which is not stochastic. Third, phonetic implementation rules are treated in MESM as rewrite rules. They have a structural description and apply when their structural description is met, differing from the rewrite rules of Chomksy and Halle (1968) only in having variable quantitative outputs rather than categorical outputs. Note that with the widespread acceptance of constraint-based theories of phonology, this makes phonetic implementation almost the last bastion of rewrite rules.[2] These features provide more explanatory power than is sometimes realized, but I will suggest that they are all untenable when examined closely.

3.1 *A MESMic success*

To understand what these features provide, consider the phenomenon of near mergers, as discussed in Labov et. al. 1991. The phenomenon may be summarized as follows: Phonemes which are well distinguished in some dialects are marginally distinguished in others. For example, the vowels in the words "ferry" and "furry" are at best marginally distinguished in Philadelphia English, though very distinct in other dialects. Such marginal distinctions breed a strange but now well-replicated experimental result. Some speakers cannot hear distinctions which are objectively present in their own speech, as established by statistics on acoustic measures. The basic paradigm for establishing this point is to record many tokens of a candidate distinction (such as the words "ferry" and "furry"). The vowel formants are measured and a discriminant analysis is used to establish that a distinction is objectively present. Then the tokens are randomized and the original speaker is asked to identify them; the identification data are compared to the results of the acoustic analysis.

Labov, et al. suggest that this outcome in itself undermines the very concept of a category. But this suggestion is not well-founded; the central observations are quite amenable to MESMerization. Assume that the two categories are completely distinct in the phonological representation, as in the top panel of Figure 2. A stochastic production process leads to some spread in the productions, perhaps even partial overlap (see the 2nd panel in Figure 2). But now perception is also stochastic; the result of composing production and perception is doubly stochastic, and hence the discrimination in perception is predicted to be less reliable than the objective difference in productions (see the bottom panel in Figure 2). Hence, MESM deals successfully with the findings that productions are more distinct than percepts; and also with the finding that perceptual confusions are found specifically when the categories are objectively close (that is, when within category variation is great compared to the distance between the categories.)

3.2 *MESM and the ideal speaker-hearer*

However, MESM fails to relate the cited experimental results to a further contributing factor noted in Labov et al. (1991), namely the existence of diversity in the speech community. The point may be strengthened by considering another study of a near merger, reported in Schulman (1983). The background to this study is the fact that speakers of Lyksele dialect of Swedish have (in production) a set of four vowels (i, e, ä, a) where Stockholm speakers have only three. In Stockholm dialect, /e/ and /ä/ have merged historically. A not surprising consequence is that Stockholm speakers are unable to recognize the distinction between /e/ and /ä/ in speech from Lyksele. Furthermore, Lyksele speakers are rather poor at recognizing the distinction between /e/ and /ä/ in their own speech.

Schulman's study used subjects who were bilingual in Lyksele Swedish and English. A continuum of vowels from /i/ to /a/ was constructed and spliced into an /s__t/ frame. This frame was selected because it yields four actual words in English ("sit", "set", "sat", "sot"), and similarly in Swedish. The identical stimuli were used twice, once with the instructions in English and once with the instructions in Swedish. The result was that Lyksele speakers proved to be better at distinguishing /e/ from /ä/ in English than in Swedish. This was true despite the fact that the distinction existed in their own speech and despite the fact that they were less fluent in English than in Swedish.

Now, the system of categories is at the core of the phonology. Specifically, if phonology is formalized (using formal language theory), the phonological grammar will specify a set of terminal elements (or categories) and principles or rules by which the categories are combined. Therefore, if the abstraction of the ideal speaker-hearer in a uniform speech community is anywhere appropriate, it should be here. Schulman's result indicates, however, that the category system which is active in perception indirectly reflects diversity in the speech community. Listeners use the information that they deem to be statistically reliable for the community in which they are operating. The Lyskele Swedes have found the /e/-/ä/ distinction to be unreliable in Swedish, and so they disregard it. The fact that they use this distinction in processing English (in which it is more reliable) shows that the issue is not a perceptual deficit, but rather differential focus of attention or use of information. One might observe from this result that nature has designed speech perception to be robust under socio-linguistic variation.

Counterparts to this result are also known for production. As background, consider first the classic bite block experiments of Lindblom, et al. (1979). These experiments showed that when the distance between the teeth is fixed by inserting bite blocks, speakers can still immediately achieve acoustic targets for vowels. They exploit the degrees of freedom of the tongue to make up for the lack of freedom of the jaw which is imposed by the bite block. This is an example of articulatory compensation. Evidence of tongue-jaw compensation in normal speech production is provided in Maeda (1991). Within the speech community, this compensation makes it possible for speakers who differ greatly in the amount of jaw movement they employ to produce mutually intelligible vowels. (The diversity of jaw strategies across speakers is documented in Edwards 1985 and deJong 1990.) A further point is that tongue-jaw compensation is not the only type of compensation available. As discussed in Mrayati et al. (1988) the acoustics of the vocal tract has a very consequential anti-symmetry. Expansion somewhere in the front half of the vocal tract has the same result as constriction at some place in the back half, and vice versa. This anti-symmetry provides general support for equivalencies between articulatory gestures carried out in different parts of the vocal tract. For example, it is specifically exploited in articulation of the English rhotic /r/. The low third formant characteristic of /r/ is achievable by lip rounding, raising the tongue blade, or a constriction in the pharyngeal region; different speakers do in fact use different methods of producing /r/. Thus, current understanding of the mapping between articulation and acoustics also provides evidence that robustness under inter-speaker variation is a foundational property of the category system.

3.3 *MESM and peripheral variation*

Let us now turn to the issue of whether statistical variation is peripheral, in the sense described above. That is, is statistical variation in the OSMic core reasonably characterized as variation between one entire grammar and another one?

The answer, I will argue, is "no". There are by now a number of well-documented cases of stochastic principles in core areas of phonology. One such case is the process of /t/ deletion which yields /mIs/ as a pronunciation of "mist". Work by Guy demonstrates that this rule is both stochastic and lexical; I will not review this work since it is presented by Guy himself elsewhere in this volume. A second case is the finding of Pierrehumbert (in press, a) that the structural description of medial clusters in English can be vastly simplified by assuming that combinations of improbable codas and improbable onsets are simply too improbable to be expected in a lexicon of realistic size. The low probability of the combinations follows from the fact that the joint probability of two independent events is the product of their independent probabilities, hence smaller than each taken separately. As Pierrehumbert shows, this factor alone reduces the number of candidates for triconsonantal medial clusters from some 8000 down to about 200.

The third case, which I will now take up at greater length, is that of OCP-Place. OCP-Place, or the Obligatory Contour Principle for place of articulation, is concerned with the fact that combinations of homorganic consonants are disfavored in many languages. This fact has been documented in Arabic, English, Russian, as well as other languages; see Greenberg (1950), McCarthy (1986, 1988, in press), Padgett (1992), Pierrehumbert (1993, in press, a) and Yip (1988). Though the effect has been known since Greenberg's tabulation, its theoretical significance was brought to current attention by McCarthy's notable (1986) paper. This paper dealt with a subclass of cases of OCP-Place -- namely cases of total identity between consonants. It established that the OCP effect on consonants is not merely a morpheme structure condition (or a generalization over lexical entries for morphemes), but is also active within the phonology proper. In particular, it can block processes which would otherwise be expected to apply and it can cause multiple instances of the same consonant type to be treated phonologically as single tokens.

In view of the fact that OCP-Place is active in the phonology, most theoretical analyses treat it categorically. Specifically, McCarthy (1986) proposed a marking condition prohibiting adjacent identical elements. Identity of consonants separated by a vowel is prohibited when the consonants are rendered adjacent by projection of the vowels onto a separate tier. Tier segregation is proposed to handle cases in which a morpheme boundary blocks OCP effects, e.g. when identical consonants are permitted, despite adjacency, because of the presence of a morpheme boundary. This approach is extended in McCarthy (in press), Yip (1988) and Padgett (1992) to also cover cases in which combinations of homorganic but not identical consonants are prohibited. The requisite marking condition inspects the place tiers (e.g. the feature tiers [labial], [dorsal], etc) instead of phoneme tiers; privative place features are used to permit the marking condition to operate even across intervening consonants with other places. For example, in [1], the combination of two labial consonants in an otherwise possible Arabic verb root is ruled out; the two consonants, though nonadjacent, appear in adjacent position on the [labial] tier. This follows from the assumption that /q/ does not appear on the [labial] tier at all.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[1]   *    b        q        m
           |        |        |
           |    [dorsal]     |
        [labial]          [labial]
```

However, OCP-Place is not an absolute effect, providing on the contrary a classic example of a soft principle. McCarthy (in press) elegantly documents this fact with its display of adjacent consonant combinations in Arabic, with each cell shaded according to the statistical significance with which the combination in question is underrepresented. Underrepresentation is found down the diagonal of the chart (representing combinations of homorganic or completely identical consonants). However, most underrepresented combinations are nonetheless to some extent attested.

In Pierrehumbert (1993) the categorical treatment of OCP-Place is abandoned in favor of a gradient model. The strength of the OCP is quantified by taking the ratio of O (the number of roots observed with a particular combination of consonant types) to E, (the number expected if consonants combined at random). Two major determinants of O/E are distance and overall similarity. For all places of articulation the effect is weakened by distance; this is shown in [2], which gives O/E for adjacent versus nonadjacent consonant pairs by place of articulation.

[2]

Class	O/E adjacent	O/E nonadjacent
Labial	0.00	0.29
Coronal Son.	0.06	0.67
Coronal Obstruents	0.29	0.67
Dorsals	0.04	0.34
Guttural Approx.	0.06	0.36

The effect of similarity for consonants at the same place comes out most strongly in the fact that the effect is stronger for totally identical consonants than for homorganic but not identical consonants. Pierrehumbert (1993) also shows that for nonidentical consonants, it is in general stronger for consonants which have many properties in common. [3] illustrates the point with a tabulation of O/E for consonants in nonadjacent position (eg. first and third in the triconsonantal root) contrasting total identity to nonidentical homorganic combinations.

[3]	Class	O/E, identical	O/E nonidentical
	Labial	0.05	0.41
	Cor. Sonorants	0.08	0.95
	Cor. Obstruents	0.46	0.70
	Dorsal	0.24	0.35
	Guttural Approx.	0.05	0.69

Note that [3] shows that the constraint against total identity crosses intervening material better than the constraint against mere same place of articulation. This result is inconsistent with the categorical treatment illustrated in [1], which permits effects on nonadjacent consonants only via a constraint on a single place tier. In short, according to [1], total and partial identity should exhibit the same behavior in nonadjacent position. In fact, the total OCP is much stronger. This result supports an analysis in which the strength of the OCP is a cumulative effect of similarity and proximity.

Gradual weakening of OCP-Place with distance is further documented in two subsequent works. Buckley (1993) analyzed roots of two, three and four consonants in Tigrinya. Berkley (1994a) presents an analysis of monomorphemic words of English. She carried out a multiple regression analysis which displays the cumulative interaction between place of articulation and distance. Both of these studies, like Pierrehumbert (1993), concern distance within a morpheme which can be at least crudely quantified by counting phonemes. As discussed in McCarthy (1986), the OCP is also less active when there is a morpheme boundary between two consonants. The morpheme boundary may be viewed as contributing psychological if not temporal distance. Still, a number of cases of operation of OCP-Place across a morpheme boundary are known. Jesperson (1939) reports that the -en infinitive suffix was historically preserved just in cases in which its loss would have yielded a past tense form involving two coronal obstruents in close proximity. In short, we say "The sky brightened", not "The sky brighted". Berkley (1994b) provides a statistical demonstration that affixation of -ity is avoided on stems ending in /t/; the result is Latinate forms ending in -ness. Her inventory of other affixes extends the observation of Anschen et. al. (1986) that forms such as "fishish" are avoided. An OCP effect affecting selection of morphemes in Latin is statistically documented in Liberman (1994).

To summarize: OCP-Place is stronger for highly similar than for dissimilar consonants at the same place of articulation. It is stronger for consonants which are close together than for consonants which are separated by other phonemes. It is stronger for consonants which are tauto-morphemic than for those which are not. The first two effects are demonstrably gradient and interact cumulatively.

Consider under what circumstances OCP-Place is known to be phonologically active. As far as is known, OCP-Place is totally productive for identical tautomorphemic consonants which are absolutely adjacent (true geminates); although these bridge two prosodic positions, it forces these to act as single segmental tokens, produced with a single gesture (see McCarthy, 1986 Hayes, 1986; Lahiri and Hankamer, 1988). As noted by Schein and Steriade (1986), adjacent homorganic consonants tend to exhibit the same behavior. McCarthy (1986) provides evidence for productivity of the OCP in Semitic languages for totally identical consonants which are separated by a vowel on the surface but adjacent in the underlying representation for the morpheme they belong to. For example, a rule assigning secondary articulations in Chaha assigns the secondary articulation to the last two consonants in a word just in case they are

identical. He also describes a language game which permutes the consonants of the root; this game treats identical consonants as one single consonant. Pierrehumbert (in press, a) reports similar but somewhat weaker evidence of OCP productivity for non adjacent identical consonants in English, which does not have a noncatenative morphology. Experimental data are presented showing that nonsense disyllabic words tend to be interpreted as compounds when the first and third consonants of a medial cluster are identical. Evidence for OCP effects operating across a morpheme boundary is more sporadic, but is concentrated on situations in which the consonants are in close proximity. Overall, then, we observe a strong relationship between the statistical reliability of the OCP and the degree to which it is phonologically active.

The legs of this analysis are quantitative description of the data. Categorizing the data at the outset of the analysis makes it impossible to relate the total OCP to the OCP for nonidentical consonants. It cannot capture the interaction of similarity and proximity, nor the gradient of productivity. Furthermore, it is clear that OCP-Place does not lend itself to treatment in terms of grammar-to-grammar variation. First, it is ludicrous to posit entirely different grammars for different prosodic distances or places of articulation; the point of a phonological grammar is to bring together all the speaker's implicit knowledge of the language. More generally, grammar-to-grammar variation is most successful in handling cases such as the first panel of Figure 2, in which two discrete outcomes occur probabilistically. When the situation approximates continuous variation, as in the bottom panel, the approach is rendered infeasible by the need to posit an entire continuum of grammars. Lastly, it fails to support the description of cumulative effects.

3.4 MESM and phonetic implementation rules

The third issue to be addressed was whether phonetic interpretation is adequately characterized in terms of rewrite rules which apply when their structural descriptions are met to convert qualitative phonological representations into quantitative representations. Let me first remind the readers what a structural description is and what it means for it to be met, as developed in Chomsky & Halle (1968).

A structural description is a fragment of a formal representation—here a fragment of a phonological representation. It looks just like a phonological representation of an individual word or phrase, except that many details are omitted. As a result, it is true of a whole class of forms, not merely of an individual form. The rule applies to an individual form if the structural description subsumes the form—that is, if everything in the structural description actually is true of the form. Consider, by way of example, a typical rule of intervocalic velar lenition, [4].

[4] -sonorant —> [+continuant] / V ___ V
dorsal

This rule applies to intervocalic /g/ because /g/ is [-sonorant, dorsal, voiced], hence all features in the structural description are true of /g/, though not all features of /g/ are present in the structural description. Because the structural description contains too few features to uniquely identify the phoneme /g/, the rule also applies to other phonemes besides /g/, in particular /k/ and (vacuously) the velar fricatives.

MESM extended this approach by keeping structural descriptions while changing the output. For example, the rule which assigns VOT to /b/ word initially in a stressed syllable looks something like:

[5]
F
|
σ_s
/
w[b —> +20 msec VOT

A comprehensive set of rules like this gives a speech synthesizer; see Granstrom and Carlson (1986). Note, however, that rule [5] only specified the modal VOT value for /b/ -- a perfectly sufficient adequate degree of detail for speech synthesis. To specify the specify the entire pattern of VOT for /b/ in this position, it is necessary to assume that the output is a probability distribution over a quantitative parameter, not merely a value of that parameter. In short, the output of the rule is amended to

[6] —> P(V)

where P is a probability function ranging over voice onset times V.

At this point, I would like to present the inadequacy of this approach for a set of my own experimental data. The data are taken from a larger study of glottalization, which is also reported in Pierrehumbert (in press, b) and Pierrehumbert and Frisch (forthcoming). Here, I will discuss just the data on glottalization of voiceless stops in coda position.

The minimal pair "nitrate/night-rate" is of course familiar. In "nitrate" the medial /t/ is affricated whereas in "night-rate", /t/ in the identical segmental context is glottalized and may even be reduced to a glottal stop. The other voiceless stops (/p/ and /k/) are also subject to glottalization though less subject to complete loss of oral articulation. In "nitrate/night-rate", the critical factor conditioning glottalization appears to be the syllable structure; in "nitrate" the /t/ is in a complex onset with /r/ whereas in "night-rate" it is in coda position. Another conditioning factor, as reported in Selkirk (1982), appears to be whether the /t/ is released into a vowel or not. However, the interplay between these factors is unclear. Furthermore, most data on glottalization of voiceless stops are only impressionistic and are therefore open to question.

In the study, acoustic data on /t/ and /p/ allophony were gathered for two speakers. /t/ and /p/ were placed in varying segmental contexts by constructing compounds in which the first word ended in either of the stops. The specific compounds examined are displayed in [7] ("N" is used to represent the class of nasal stops:

[7]

Context	/p/	/t/
/__#V	shop owner	boat-engine
/N_#V	lamp oil	mint issue
/_#r	pep rally	hat rack
/N_#r	rumproast	sprint races
/_#N	Grapenuts	nutmeg
/N_#N	swamp maple	printmaker
/_#f	Trapp family	catfish
/N_#f	campfires	ventfeed
/_#st	chopsticks	footstool
/N_#st	campstove	Flintstones
/_#Stop	soupbone	nightgown
/N_#Stop	humpback	paintbrush

The compounds were produced in contexts in which they appeared as nonfinal elements in a list. [8] and [9] provide examples; the target areas are marked with an underscore.

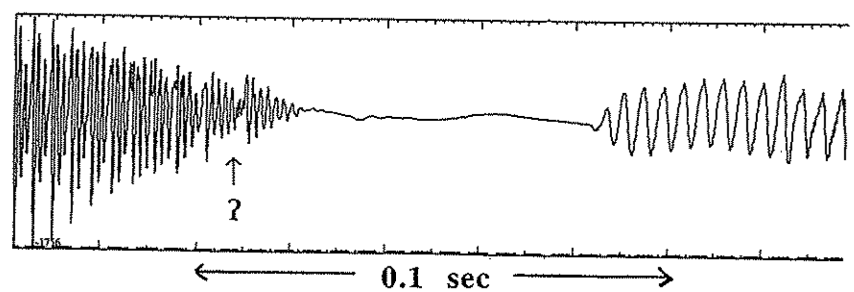
[8] Please stock up at the Chinese grocery. Get a soup_bone, some wontons, more chop_sticks, some hoisin sauce ...

[9] He's had a lot of different jobs. He's been a print_maker, a paralegal, a shop_owner, a hairdresser ...

This type of context, an open-ended list, was selected because it supports the H* H L% intonation pattern, in which the entire region from the stressed syllable onwards is produced on a sustained f0 towards the middle of the speaker's total range; see Ladd (1980). Keeping f0 in the middle of the range eliminated the glottalization which is often found when the intonation takes speakers into the bottom of their ranges, which in this experiment would have been a confounding factor in the acoustic analysis. There were two female speakers, both selected for their generally modal voice quality. Speech was recorded in a sound isolation booth directly onto disk using a Shure SM81 condensor microphone and an Ariel Proport; waveforms and spectrograms were examined for signs of glottalization using Entropics xwaves+ software package.

Because of the controlled intonational design, glottalization was rather readily discerned in the speech signal. The primary objective correlate of glottalization, as discussed in Pierrehumbert and Talkin (1992), is long, irregular pitch periods; a typical example is shown in Figure 7.

Figure 7: Waveform around /t/ in "wattmeter"



Glottalization also decreases the formant bandwidths because the vocal fold adduction reduces losses to the subglottal system. It is also expected to boost the upper frequencies in the spectrum because it causes the closure of the vocal folds to be sharper than normal.

A careful examination of the speech tokens showed that the two subjects had no glottalization whatsoever in many contexts in which glottalization is frequently transcribed. It is of course possible that these two subjects had less glottalization than is usual in American English. However, the possibility of transcription errors must also be entertained. In particular, it was often the case that the coda consonant was so reduced or so overlapped with the next consonant that the first syllable of the compound was in effect a lax open syllable. It seems likely that English-speaking transcribers confuse lack of a consonant with existence of a glottal stop; this confusion may be caused by the lack of formant transitions for glottal stops and by the frequent appearance of glottal stops in the onset of underlyingly vowel-initial words. This finding underscores again the importance of examining objective data.

In contexts were glottalization did occur, it displayed the hallmarks of a variable process. That is, it occurred some of the time rather than all of the time. When it did occur, it occurred to different degrees even in repetitions of the same word. However, in the following discussion, I will present only data on the frequency with which glottalization occurred at all, disregarding the extent to which it occurred. The data are presented in this way for expository clarity, since the thread of the quantitative argument is preserved even under this simplification.

The results showed the same pattern for the two subjects, although one (ST) glottalized overall slightly less than the other. Therefore, they are conflated in the following table, which shows the percentage of tokens exhibiting any evidence of glottalization for each type. Each cell represents a summary over 12 speech tokens (6 per speaker, combined over presence or absence of a nasal to the left of the target.)

[10]

Context	/p/s	/t/s
/_#V	0	0[3]
/_#r	0	50%
/_#m	50%	67%
/_#st	0	0
/_#f	0	0
/_#Stop	0	8%

In short, /p/ was glottalized only before a nasal. /t/ was glottalized both before the nasal and before /r/; there was one marginal case of glottalization of /t/ before a stop. Lack of glottalization of /t/ before fricatives is probably related to co-articulation. Fricatives require a spread glottis to enhance airflow, and this requirement would tend to interfere with vocal fold adduction in the immediately preceding position.

The general force of these results is strengthened by the results of a second experiment, which used the same speakers and the same intonation pattern, but which included two additional sonorant consonants, /w/ and /l/. The primary goal of this experiment, as discussed in Pierrehumbert (in press, b), was to examine how much phrasal stress affected the degree of glottalization, comparing glottalization of voiceless stops in coda position to the glottalization found in a V-V hiatus at a word boundary. Here, I will discuss only the data on the voiceless stops. The relevant subset of the words examined is:

[11] T-WORDS

/__#m	art museum, oatmeal, wattmeter, scoutmaster, grant money, fontmanager
/__#w	Atwood, artwork, footwear, knotweed, bentwood, frontwards
/__#l	outlook, eightleaf, dateloaf, bootleggers, tentlily, mintleaves

[12] P-WORDS

/__#m	tapemeasure, mapmaker
/__#w	stopwatch, stepladder
/__#l	siplids, lapwings

Each word appeared twice in the materials for each of the two subjects, once in nuclear position and once in post-nuclear position. Therefore, each row in [13a] corresponds to 24 speech tokens and each row in [13b] corresponds to 8 speech tokens.

	Type		% with glottalization
[13a]	all /t/s		92%
		t/__ m	96%
		t/__ w	96%
		t/__ l	83%
[13b]	all /p/s		21%
		p/__m	50%
		p/__w	12%
		p/__ l	0%

Putting together the results of these two studies, the main pattern is as follows. In the dialect studied, /t/ was subject to glottalization before sonorant consonants (/m/, /w/, /l/, /r/). /p/ was subject to glottalization only before the nasal /m/. Glottalization of /p/ before /m/ was less reliable than glottalization of /t/ before /m/. (It also appeared to be less extensive.)

All of the consonants studied were in coda position, because the word boundary in the compound induced a syllable boundary. Recall, however, that /t/ is also glottalized in words such as "button", "Danton", and even "countenance" when the medial schwa is elided, leaving a syllabic nasal. In these words, the /t/ is arguably in onset position in a syllable whose nucleus is a syllabic nasal. (This follows from imposition of the universal core CV template for syllables; see Ito 1988). According to some researchers, it is ambisyllabic. However, the idea that it might be resyllabified into the coda of the preceding stressed syllable is implausible for "Danton" (whose first syllable is already bimoraic) and for "countenance" (whose first syllable is oversaturated). Thus, the analysis must accommodate the observation that onset or ambisyllabic /t/ is glottalized before syllabic /n/, but that in the same position before syllabic /r/ and /l/, /t/ is not glottalized in American English (c.f "butter", "bottle").

Consider now the question of how the glottalization rule would be formalized under MESM. As a starting point, take the glottalization of /t/ before nasals. The MESMic approach would be something like [14] (/t/ probabilistically acquires glottal constriction of some degree when in coda position preceding a nasal.)

$$[14]\quad \begin{bmatrix} \text{-sonorant} \\ \text{coronal} \\ \text{-cont} \\ \text{-voice} \end{bmatrix} \longrightarrow [\text{X constricted glottis}]\ /\ \_\_\_\_\ ]_\sigma\ \ {}_\sigma[\ [\text{+nasal}]$$

where X is a continuous stochastic variable.

To extend the rule to describe glottalization of /p/ (and presumptively, /k/) before nasals, rule [14] must be modified by dropping the place specification:

$$[15]\quad \begin{bmatrix} \text{-sonorant} \\ \text{-cont} \\ \text{-voice} \end{bmatrix} \longrightarrow [\text{X constricted glottis}]\ /\ \_\_\_\_\ ]_\sigma\ \ {}_\sigma[\ [\text{+nasal}]$$

This modification already leads to a difficulty; the mean (X) should be different for /p/ and /t/ but [15] says they are the same. In short, MESM provides no method for collapsing the rules into a more general rule with simultaneously collapsing the probability distributions, since rules are the points of attachment for probability distributions.

The problem is even more acute when we attempt to extend the rule further to also cover all cases of glottalization of voiceless stops before other sonorants. In order to generalize from [14] to include /t/ in onset or ambisyllabic position, it is necessary to drop the syllable brackets. To describe glottalization in the context of non-nasal sonorants, the feature [nasal] is replaced with its superordinate category [+sonorant +consonantal]. The result is [16] (voiceless stops are glottalized before sonorant consonants.)

$$[16]\quad \begin{bmatrix} \text{-sonorant} \\ \text{-cont} \\ \text{-voice} \end{bmatrix} \longrightarrow [\text{X constricted glottis}]\ /\ \_\_\_\_\ [\text{+son +cons}]$$

However, [16] grossly overgenerates. It glottalizes onset or ambisyllabic /t/ before /w/, /r/, and /l/ as well as before nasals. It glottalizes /p/ and /k/ before all sonorant consonants, just like /t/. Another way of looking at this situation is to observe that when the cases are collapsed into a single general rule, mean (X) ranges for the various subcases from almost 1.00 (e.g /t/ is almost always glottalized before nasals) to 0. (e.g. /p/ is never glottalized before /r/). In addition,

the cases exhibiting intermediate probability of glottalization (namely t /__ #r and p/ __#m) cannot be described as a natural class. This follows from the fact that the properties they have in common also cover p/__#r (exhibiting no glottalization) and t /__ #m (exhibiting highly reliable glottalization.) In short, in order to assign the correct probabilities to the various cases, it is necessary to split the rule out into a family of highly specific rules, each decorated with its own probability distribution. This would be a prima facie case of a missed generalization. Therefore, MESM does not deal successfully with this case.

A far more promising alternative is the possibility that glottalization is controlled by a prototype, and that phonological configurations tend to trigger glottalization in relation to their similarity to the prototype.[4] In short, glottalization extends readily to phonological combinations differing in a single particular, less readily to combinations differing in more particulars, and not at all to configurations which exhibit numerous and substantial differences.

As the prototype, I would suggest specifically coda /t/ before /n/. This choice is made as the prototype both on empirical and on principled grounds. Empirically, this configuration is at the center of the observed cases of glottalization, and configurations close to it are very reliably glottalized. In principle, coda /t/ before /n/ is a particularly strong candidate for glottalization. The argument is as follows.

Glottalization is arguably an expression of the feature [-voice]. Voicing, or regular oscillation of the vocal folds, can be suppressed either by vocal fold abduction or adduction. In syllable onset before vowels, especially stressed vowels, the English strategy is abduction, yielding the familiar aspirated allophone found in these contexts. However, as discussed in Ohala (1983) and Ohala and Ohala (1993), aspiration introduces a side-branch into the vocal tract whose spectral consequences should be highly confusable with the consequences of involving the nasal side branch; an experimental study by Ohala and Amador reported in these papers demonstrates that breathy and nasalized vowels actually are confused in perception. Applying this result to the present issue suggests that aspiration would not be an effective way of cueing [-voice] in nasalized contexts, since the consequences are extremely similar to spectral features which would be independently present. Adduction, or glottalization, provides a much more effective expression of [-voice] because the resulting irregularity in the excitation would be perceptible in any sonorant region.

The chief functional drawback to adduction is that it tends to result in glottal pulses which are so far apart that the formant transitions expressing place of articulation are obscured. In fact, in the present data set, it was often extremely difficult to determine if the speakers had executed a coronal closure or not. In the case of /t/ before /n/, however, the place feature is shared by both consonants and hence expressed by the second one. Therefore, there is no real loss of information if the place information for the first consonant is obscured. The fact that glottalization of /t/ before /m/ is also very reliable may provide another illustration of the well-known status of [coronal] as a default.

4. CONCLUSION

I've argued that MESM fails in three major regards. First, by adopting the abstraction of the ideal speaker-hearer in a uniform speech community, it fails to address ways in which linguistic structure is founded in robustness under variation.

Second, it pushes statistical variation to the periphery of the model in a fashion which proves to be untenable. Third, its reliance on rewrite rules to express principles of phonetic implementation leads to systematic loss of generality. Thus, I would argue that statistical variation is intrinsic to the nature of language and therefore should be intrinsic to our scientific theory of language.

5. POSTSCRIPT: CLS DISCUSSION

I would like to summarize some of the discussion following presentation of this paper.

A questioner in the audience raised the issue of the relationship between results like Schulman's, which suggest a strong role for socio-linguistic conventions, and work suggesting a universal physical basis for category systems, such as Kuhl (1988) and Stevens and Blumstein (1978).

It appears that some dimensions of variation are more amenable than others to variable categorization. The differences quite likely relate to the differences in the extent of nonlinearity found in the physical situation and in the production and perception systems; different researchers in this area emphasize different types of nonlinearity as foundational to categorization. For example, the physical consequences of vocal fold abduction are very nonlinear, and there are strong parallels for patterning of voice onset time across languages. Even so, some differences are found as discussed above. The vowel space also exhibits nonlinearities (see Stevens, 1989) but perhaps not to the same degree; in any case, there is seems to be more latitude for different societies to agree on different organizations of the vowel space. Even the categories which draw on the most nonlinear aspects of speech acoustics exhibit more variability in running speech than when produced in isolation; a preponderance of studies using phonemes or syllables in isolation may have resulted in overestimation of the phonetic stability of these categories. Insightful reviews of this issue are found in Repp (1984) and Repp and Liberman (1988).

Another questioner asked me to comment on the competence-performance distinction.

I'd like to answer this question both narrowly and rather broadly.

The narrow answer is based on the fact that all linguistic data represents some kind of linguistic performance. In particular, contrary to the hopes of many researchers, judgments of well-formedness do not provide a direct tap into linguistic competence. Providing a well-formedness judgment is a complicated meta-linguistic task. It is known by now that the results can systematically deviate from patterns of actual usage. Furthermore, an interview with an informant by a researcher is in effect a small experiment with a single subject. It is subject to all the hazards of experimentation including random variation, time order effects, fatigue, and untoward consequences of leading instructions.

I've presented various kinds of data. The work presented does not fall into what Soames (1984), for example, claims to be the purview of linguistics proper, namely accounting for patterns of well-formedness judgments. But Soames' position is accurately attacked in Chomsky (1986), who points out that no established science restricts its methods in advance in such a fashion. He also points out that Soames' proposal would exclude the work of some of the most distinguished figures in the history of linguistics, such as Sapir and Jakobson. I am in complete agreement with Chomsky on this matter.

Let me now take up the issue of whether the competence-performance distinction provides any leverage on the proper treatment of linguistic variation. The term "linguistic competence" refers to the underlying principles which make it possible for humans to use language in a completely general fashion, fluently producing and understanding novel as well as familiar utterances. As another example of "competence", one can consider Thor's meteorological competence. By productive exercise of basic principles of physics, Thor has generated some four billion years of earthly weather. Not even one second of the weather has been absolutely identical to any other second, and every second of the weather represents a bona fide instance of weather and not a performance error. Meteorologists are scientists who try to understand Thor's competence, just as linguists are scientists who try to understand human linguistic competence. It's already clear that scientific understanding of Thor's competence must take the form of a set of differential equations, not a formal syntax. In short, the distinction between competence and performance is completely separate from the issue of what type of mathematics to apply in constructing a scientific model. This last issue is, as Chomsky would say, an empirical question. The evidence at this point is that even core areas of linguistic competence are only quasi-categorical. That is, while they may be more categorical than the weather, they are not so categorical that the mathematics of formal language theory is entirely sufficient.

NOTES

* This work was supported by NSF Grant No. BNS-9022 484.

1 A classic example of capital punishment.

2 However, an important difference between phonetic implementation rules and derivational rules of phonology is that phonetic implementation rules are not usually thought to be amenable to extrinsic ordering.

3 I had released aspirated /t/ plus glottalized onset to V. Falling stress disfavors glottalization (cf. Pierrehumbert and Talkin 1992, Pierrehumbert in press).

4 Kemmer (in this volume) also presents an argument for prototypes.

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Structural dimensions of first language loss*

Maria Polinsky
University of Southern California

Introduction. This paper examines cross-linguistic syntactic changes accompanying first language loss. Throughout the paper, the following terms are used. The term *attrition* is used below as the umbrella name denoting incomplete language competence which may be due to first language loss, incomplete acquisition, and probably some other factors. A language that undergoes attrition is called *reduced* and is opposed to a *full* language, i.e., a language characterized by full conventionalized knowledge. Speakers of a reduced language are known as *semi-speakers.*[1] Next, a distinction is made between, on the one hand, *first* and *second* language, which differ by the temporal order of acquisition, and, on the other hand, between *primary* and *secondary* language which differ by the prevalence of usage, as the language spoken predominantly vs. the language spoken under restricted circumstances.

The social circumstances of language attrition are extremely varied, and, therefore, it is important to determine whether attrition is characterized by recurrent structural features. If a language is spoken by only a small community where the majority of speakers are are bilingual or multilingual, there is a risk that attrition of the socially inferior language or languages is already present. Thus, it would be crucial, in determining diagnostic structural features of attrition to compare the non-endangered full language and its reduced version. This has been the point of departure for this paper which compares full and reduced versions of several languages that have a large number of competent speakers.

Based on data collected from semi-speakers of Armenian, Kabardian, Polish, Russian, and Tamil, this paper addresses two major problems: first, is it possible to establish syntactic diagnostics of first language loss?; and second, is there a correlation between the degree of language loss in syntax and in lexicon?

Section 1 describes the subjects and the procedures of this study. Section 2 summarizes the major results concerning the syntax of reduced languages. Section 3 demonstrates the correlation between lexical and syntactic attrition.

1. Subjects and procedure.

1.1. General description of semi-speakers. All the languages in this study exist in their full versions. Full Tamil, a Dravidian language, is spoken in Tamilnadu, in the south-east of India. Full Kabardian, also known as Circassian, belongs to the Abkhaz-Adyghe family and is spoken primarily in the rural areas of the inland north-west Caucasus (rural Kabarda).[2] Armenian exists in two distinct variants, Western and Eastern; in this paper, speakers and semi-speakers of Eastern Armenian were interviewed. As for Polish and Russian, the regions where the full versions are spoken are well-known.

Whereas the status of Russian and Polish as fill languages is apparent (they