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11 The phonology–phonetics interface*

Patricia A. Keating

11.0. **Introduction**

Both phonetics and phonology are concerned with the sounds of human language: phonetics with their physical properties, and phonology with their patterning. Because the two fields share this domain of inquiry, there are many areas in which they should interface. However, historically that interface has been somewhat limited, mainly devoted to distinctive feature theory (e.g. Jakobson & Halle 1968, 'Phonology in relation to phonetics'). Since Chomsky & Halle (1968), the scope of inquiry has broadened to include questions of grammatical organization (e.g. Fromkin 1975, 'The interface between phonetics and phonology'), and in addition, questions of naturalness and phonetic explanation (e.g. Ohala 1979, 'The contribution of acoustic phonetics to phonology'). As these titles show, attention has been paid to the relation between the two fields; despite this fact, each field has developed largely independently, as was recently discussed by Liberman (1983). However, there is a heartening tendency these days for more and more cooperation between phoneticians and phonologists, and I predict that in the future each field will influence the other in more substantive ways than has previously been the case. In this chapter I will selectively survey the current state of this interaction and point out some interesting issues, with special attention to those where the activity is likely to be high in the next few years.

11.1. **Feature theory**

In considering the relation between phonetics and phonology, we begin with feature theory, in particular developments since Chomsky & Halle (1968, hereafter *SPE*). *SPE* served to maintain the interest of phoneticians and

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phonologists in questions of the proper set and definitions of features, by proposing that a feature theory be responsible for describing the details of a wide range of phonetic categories, as opposed to the highly abstract set of features due to Jakobson. Some overviews of features in the *SPE* framework include Anderson (1974), Hyman (1975), Sommerstein (1977), and Kenstowicz & Kisseberth (1979).

11.1.1. What are features for?

Features are linguistically significant phonetic aspects of sounds: they express the crucial fact that speech sounds can be organized as phonetic classes. Many issues surrounding the proper choice and definition of features remain open. I will discuss some of these in terms of various criteria or goals for feature theory (taken in part from Kenstowicz & Kisseberth 1979 and Fromkin 1979).

Phonologists usually want binary-valued, classificatory features to do two things: to characterize segment contrasts so that lexical entries will be distinct, and to group segments together into classes for writing phonological rules. The first task by itself would be trivial if there were no constraints; it would always be possible to add some new feature to the inventory to distinguish two sounds. The second task makes the first more interesting. Considering that the main use for a feature theory is to appropriately characterize natural classes and express generalizations about what classes occur in rules, it is somewhat surprising that feature theory has yet to be based on a really systematic survey of phonological natural classes. After the fact, certain features have been modified because the classes they identified were not attested. For example, the feature [strident], carried over from Jakobson, Fant & Halle (1963) into *SPE*, and originally defined to apply to a variety of fricatives, was then found to define natural classes only for coronal consonants. Halle & Stevens (1979) therefore redefined [strident] so that it is now equivalent to traditional features like grooved or sibilant; [strident] now picks out only coronal fricatives, and therefore identifies the natural class needed for such rules as the English plural epenthesis rule. However, it would be extremely valuable if a large-scale survey of groups of segments in rules were done to establish, independently of any particular feature system, what generalizations need to be expressed by such a system. While this would be an enormous undertaking, the success of Maddieson's (1984) survey of phoneme inventories may well encourage someone to begin.

Decisions about features in their distinctive function are often decided in conjunction with another goal for feature systems, namely, that they be phonetically grounded. Presumably, what makes natural classes natural is

their phonetic basis, i.e. their unitary nature in some articulatory or perceptual domain. Again, this requirement places interesting constraints on the choice of features. However, it is sometimes assumed that phonetics is the ultimate source of evidence about the proper set of phonetic features. In a sense, this is correct, if one intends the set of features to represent, for example, independent dimensions of articulatory control, or salient auditory properties. Nonetheless, I think it impossible to begin one's search for features with phonetic data. Phonetic studies provide an overwhelming number of feature candidates that can only be useful in the light of additional, phonological, evidence. As has traditionally been noted (see also Anderson 1974: ch. 1, 1981), precisely what is interesting about features is that only a subset of the abundant available phonetic dimensions is chosen for use in formal phonological computation. Consider some examples of feature candidates based on blind examination of some phonetic data.

Example A: On spectrograms, we can observe changes in formant frequencies – for example, fall or lowering (over short time intervals) in second formants. We might hypothesize that such lowering is a crucial phonetic property. Data on Swedish VCV utterances in Öhman (1966) reveals that the second formant falls in a large number of cases both into and out of vowels: between high front vowels and labial consonants, between high or mid front vowels and alveolar consonants, between high or mid front vowels and back velars, between high back vowels and back velars, between velars and following vowels after front vowels, and many other cases. A phonetic theory should account for the long list of contexts in which a falling second formant is observed, but should a phonological feature theory look to posit a common feature? This example is presented as a patently absurd case, to show that some phonetic properties are irrelevant to decisions about features.

Example B: In X-rays, we can observe the position of the tongue root and the general area of the lower pharynx. The following sounds: (a) low vowels in any language, (b) [constricted pharynx] vowels in languages with vowel harmony sets, (c) English 'bunched /r/,' and (d) pharyngeal (but not pharyngealized) consonants, all involve articulations in the lower pharynx (Delattre 1971; Ghazeli 1977; Lindau 1979). Does this information by itself motivate a shared feature? *A priori*, this seems unlikely, though we cannot rule it out without further investigation. The point is that such further study will not be phonetic; it will be to determine if the observed articulation is phonologically relevant.

The reverse kind of case is also found. Phonetic study will provide a range of candidates when we know a feature is needed to provide a distinction. For example, contrasts between dental and alveolar stops and nasals are found (Ladefoged 1971). A traditional account of these contrasts might be based on the location of the constriction (the 'place of articulation'), with a feature such as [±dental], but another option is to consider the positioning of the active articulator: Chomsky & Halle's feature [distributed] distinguishes laminal from apical articulations. Still other options are to consider the shape or position of the tongue as a whole (possibly, more back vs. less back), as Stevens, Keyser & Kawasaki (1986) suggest, or to look for acoustic distinctions (Lahiri, Gewirth & Blumstein 1984). Again, it is most likely that not all of these identifiable phonetic dimensions are phonologically relevant. Phonological evidence in favor of identifying the feature as [distributed] comes from Lardil (Hale 1973), in which a class of laminal dentals plus palatoalveolars ([+distributed]) can be opposed to a class of apical alveolars plus retroflexes ([−distributed]) in a final-consonant deletion rule.

There is another reason why phonetic data are not sufficient to determine a set of features: phonetic evidence is technology-driven and -bound. I suggest that changes in technology to date have had a great impact on proposals for feature inventories, especially in changing preferences for articulatory vs. acoustic feature definitions. Thus, the availability of the spectrograph and other methods of acoustic analysis made possible the general acoustic-based theory of features presented in Jakobson, Fant & Halle (1963), a major shift away from traditional articulatory descriptions. The change back to articulatory features in *SPE* followed a decade of work at Haskins Laboratories arguing that acoustic variation as revealed in spectrograms was much greater than the variation in the underlying articulations, and use of improved techniques for studying physiology, such as electromyography. Then in the 70s new computer-based acoustic displays became widely available, which, taken together with developments in neuroscience suggesting the possibility of neural detectors for phonetic features, led to further acoustically based proposals such as invariance theory (Stevens & Blumstein 1981). By now, a shift back to articulation is underway, as phoneticians begin to use speech gestures as the basis for phonetic description. Of course I do not mean to imply that technology is the only factor shaping feature theory; but it does shape our impression of the available phonetic dimensions. Phonetics is on the verge of widespread availability of technology that will greatly increase the amount of articulatory information available: both X-ray data from the microbeam system (Fujimura, Kiritani & Ishida 1973; Nadler, Abbs & Thompson 1985) and alternative technologies to X-ray (Perkell & Cohen 1985, also ongoing work at Stockholm University) will provide still more candidates for features and feature definitions. In the future it will continue to be important to bear in mind the distinction between the sum total of phonetic dimensions and the ways in which language exploits some of these for its own uses.

11.1.2. Issues and directions in feature theory

The criterion that features have a phonetic basis can be taken to mean that each feature should represent some intrinsic phonetic property of segments. More specifically, in the *SPE* framework features are intended to represent the set of independently controllable articulations available for speech, with each feature representing control of some articulatory dimension. This position is spelled out clearly in Halle (1983). Recent developments in phonological theory have resulted in some profound continuing changes in feature theory that bear more or less directly on these notions.

Views on what is the inherent phonetic content of segments have been affected by the addition of hierarchical and other multi-level structure to phonological theory. Several features proposed in or since *SPE* have been replaced in effect by structure, such that they are now treated as relational properties or timing effects. Thus the feature [stress], always problematic because it was not binary, is no longer a feature assigned to individual segments, but now is expressed in metrical theory (Hayes 1981) as strong–weak relations between syllables. Similarly, the feature [syllabic] was always recognized as a variable across languages, rather than an intrinsic property of segments; Kiparsky (1979), however, has argued that syllabicity is encoded in hierarchical tree structure built over segments, and is thus a relation between segments within a syllable. Of course, for both of these features, the exact nature of the posited structure differs across particular proposals, but the general effect of such theoretical developments with respect to these features seems agreed upon. Furthermore, some phonologists propose replacing the binary feature [sonorant] with the notion of a sonority hierarchy or continuum, so that this feature also will encode a relative property (Hankamer & Aissen 1974). This continuous feature would then be referred to by syllable structure constraints (Kiparsky 1979; Steriade 1982). The effect of thus recasting some features as structural relations is that the remaining features can be expected to refer to more specific articulatory properties intrinsic to segments.

Another way in which features are being replaced by structure concerns features encoding timing relations. Certain features were problematic because they existed only to represent temporal effects within segments. Thus [delayed release] represented the sequence of phonetic events within affricates, and later features such as [prenasalized] and [preaspirated] represented other sequences of manners mainly within stops. After *SPE*, various phonologists proposed complex segment representations to allow sequences of feature values within a single segment (e.g. Campbell 1974; Anderson 1976; Williamson 1977). In CV theory (McCarthy 1979, 1981; Halle & Vergnaud 1980; Steriade 1982) such complex segments are represented as a sequence of two feature matrices both linked to a single segment position, eliminating the need for such features of timing relations. Similarly, long or geminate segments were earlier represented as a single segment bearing a feature [+long]; in CV theory they may be represented as a single feature matrix linked simultaneously to two segment positions. Thus the total number of features is reduced under CV theory, and we can expect that future developments in the theory will effect further changes in the inventory or the definitions of features.

In the *SPE* theory, the inventory of features represents all linguistically controllable aspects of articulation. Further, every feature in the inventory is claimed to be available for distinguishing phonemes in underlying representation. However, earlier discussions of the phonology–phonetics interface by Fromkin (1975, 1979) suggested that some systematic phonetic distinctions are never used contrastively. This would mean either that in addition to the features there are other dimensions that function linguistically, or that there are two types of features. Fromkin based such suggestions on cross-language comparisons of phonetic detail being made by Ladefoged and colleagues (e.g. Ladefoged 1983a). The changes in feature inventories due to CV phonology provide new evidence that not all features are used contrastively. Consider the feature [length] as discussed by Stevens *et al.* (1986). They discuss a theory of redundant features in which every feature is available for contrastive use but may in a given language be merely redundant. In their theory the redundant features accompany particular contrastive features to enhance or accentuate their inherent properties. The feature [length] may redundantly accompany and enhance the contrastive feature [voice] in an adjacent segment, as appears to be the case in English. However, we have just seen that under CV theory no contrastive feature [length] is needed. Thus if the added duration encoded by a phonetic feature [length] really has a phonological function, as Stevens *et al.* claim for their enhancing features, then there must be linguistic features that are not used contrastively.

This point takes us back to the earlier discussion of the abundance of phonetic dimensions relative to formal features. There are also independently controllable aspects of articulation which do not get used contrastively, as features or as structure, but which presumably should be included in a phonetic description. One such example is tension of the vocal tract walls. This dimension has measurable aerodynamic and acoustic effects on sounds, but by itself probably does not produce large enough effects to be the basis of linguistic contrasts (e.g. Keating 1984b). However, it appears to be systematically controlled in the production of some sounds, for example obstruents traditionally characterized as [fortis] in Korean. Dart (1984) made aerodynamic and acoustic measurements of such stop

contrasts in Korean, and then compared these measurements with the outputs of an aerodynamic model to see what articulations might be involved. She found that a combination of vocal cord setting, wall tension, and increased subglottal pressure was required to simulate the observed data for the fortis stops. We can hypothesize that this complex interaction of control dimensions is needed to effect an adequate difference between the classes of Korean stops; and further, that it is precisely this degree of complexity that makes this contrast relatively rare. At the same time, wall tension (and also subglottal pressure) by itself is not distinctive; it is in this case simply associated with the glottal feature. Thus we do not want to define a theory of linguistic features *per se* as enumerating independent articulatory capabilities; rather, a feature theory must be supplemented by an account of the various parameters that underlie it. Though not developed to date, such an account will be given by the low-level rules of phonetic implementation; we turn now to questions about this part of the grammar.

11.2. Phonetic rules and derivations

Since phonetic rules interpret the output of the phonology, their exact form and function obviously depends on the nature of that output. In the theory advanced in *SPE*, the output of the phonology was taken to be a complete feature matrix in which each feature had a numerical (rather than binary) value for each segment, so that the matrix was essentially equivalent to an allophonic transcription. The provision of such numerical values was done in the phonological, not the phonetic, component. Recall also that all controllable articulatory dimensions were available as features, so were listed in the matrix and received values as part of the phonology. The phonetic component consisted of mostly automatic, universal rules for implementing these feature matrices as continuous physical events.

Much of the interest in generative phonetics was occasioned by the *SPE* proposals centered on the idea of a universal phonetics (e.g. Fromkin 1979; Keating 1985a). Phoneticians were encouraged to look for cross-language phonetic generalizations and for effects of articulatory biomechanics that could serve as the universal phonetic rules. However, the more phoneticians looked, the more exceptions they found to possible phonetic generalizations. The view that somehow phonetic processes are more regular, automatic, and hence trivial, than other linguistic processes, seems unjustified. Rather, phonetic rules appear to be at least partly language-specific and of linguistic interest. However, they may well derive from a basic set of preferences (called 'default options' in Keating 1985a) in, for example, speech production, which languages may incorporate into their grammars. On this view, cross-language patterns, and the phonetic rules that generate them, reflect universal 'conveniences' of the various physical phonetic systems. However, a language need not include rules that reflect a particular default pattern; non-default options are often chosen instead. Furthermore, even if a default pattern is used, it need not manifest itself as a purely 'phonetic' rule; it may hold at a more abstract phonological level than the surface output. As an example, vowel duration before voiced vs. voiceless consonants appears to be a patterning available to languages; some use it and some do not, and those that do, do so either as an opaque phonological rule, or in the phonetics (Chen 1970; Dinnsen 1985; Keating 1985a). The fact that the same types of patterns can occur at different levels of representation suggests that phonetic implementation is not something divorced from the rest of the grammar, but something controlled as part of the grammar. More and more, the phonetics is being viewed as largely the same sort of creature as the phonology, that is, a formal system of rules.

Since *SPE*, ideas about phonetic rules have been affected by several crucial changes in views as to the output of the phonology. These changes include proposals on autosegmental representations and underspecification of features. Also of great importance has been work on intonation, particularly at Bell Labs (Pierrehumbert 1980; Liberman 1983; Liberman & Pierrehumbert 1984; see also Cutler & Ladd 1983). The major presentation of this work is Pierrehumbert (1980), in which English intonation is analyzed as an autosegmental linking of tone units to text according to metrical theory. The importance of this work for phonetics is that it provides explicit rules for implementing sequences of phonologically motivated discrete tone units as continuous intonation contours. These rules distinguish the process of converting tones to actual pitch levels, from the process of constructing a contour between such discrete pitch levels; this distinction is likely to be influential in future work on segmental phonetic rules.

Let us consider the nature of such proposals as relevant to a model of interaction between phonology and phonetics. It should be noted that, given these proposals, it is too early to decide the exact division of labor between phonological and phonetic rules; in fact, it is no longer clear what is at stake in positing such a division, or what arguments would be relevant in deciding. Nonetheless, it is possible to suggest what tasks might be accomplished by one component or the other during a derivation.

Both in classical phonetic theory (Pike 1943) and in generative phonology (Anderson 1974, 1976) it has been proposed that each articulator's activities can be represented simultaneously but independently. This idea has been elaborated within the framework of autosegmental phonology (Goldsmith 1979), where tones and segments are represented on separate tiers but linked by association lines, which denote simultaneity of utterance. In the extension of autosegmental phonology to CV phonology, the segments themselves were decomposed into separate tiers, including a separate 'timing tier,' or 'skeleton,' consisting only of the elements C and V, and a featural specification, or 'melody'. However, the segmental melodies themselves may be further decomposed into component features. Some recent work in CV phonology (for example, Clements 1985) has addressed Goldsmith's original suggestion that such autosegmental representation could be used phonetically. The tiers of the phonological representation can be related to the control of individual articulators; by spreading and realignment of autosegmentalized features, segmental representations can be converted into coordinated 'orchestral scores' at the phonetic level. The CV tier remains as the core of the representation, controlling gross aspects of timing and serving as the skeleton to which all the articulatory tiers are (at least indirectly) linked.

At some point in this process the representation must come to include all the potentially independent articulatory parameters, not just those used as features. These parameters are controlled by features that are used contrastively. Following the orchestral score analogy, additional parameters may act more like double basses, doubling the cello part, than like separate parts in the score. Examples we have seen above include wall tension controlled by a glottal feature in Korean, length controlled by voicing in English, and activity of all lower pharyngeal articulators controlled by the features [low, back] for pharyngeal consonants in Arabic. It remains to be seen how many features can control a parameter, and how many parameters can be associated with a feature, in a given language.

Phonological rules operating on autosegmental representations may add association lines between tiers, in doing so sometimes also delinking existing associations. The added lines spread features associated with one segment to other segments, providing a mechanism for expressing assimilation processes. Such spreading is also one mechanism for filling in unspecified feature values for segments: with spreading, such an underspecified segment receives a value from the context. (For discussion of underspecification, see Kiparsky 1982; Archangeli 1984). This filling in of unspecified feature values is one of the tasks of a derivation. The other major way of accomplishing that task is by various sorts of table look-up, including default, rules. In Stevens *et al.* (1986), the focus is on look-up rules, in particular, rules which refer to the specified feature values of a segment to determine the unspecified values of that same segment. In Keating (1985b), the focus is on rules that spread values from context and equally on segments that receive no fill-in value at all. However it is that particular segments receive their redundant feature values, we want to know, first, when the phonology is sensitive to such values, and second, whether, once supplied, they have the same status as underlyingly specified values. On the first point, Stevens *et al.*

(1986) give a case from Lardil in which a redundant value for [back] supplied to certain consonants by one of their look-up rules, is then referred to by a phonological rule for consonant alternations. On the second point, Keating (1985b) suggests that a redundant value for [high] supplied to [s] may behave exactly like underlying [high] values in later phonetic rules. However, these questions obviously require more study.

After decomposition and redundant feature value fill-in, features are provided with quantitative values (Pierrehumbert 1980). At certain key points in an utterance (those endowed with feature values) articulatory targets that may be sensitive to the context are supplied. Thus a feature value for phonetic voicing will distribute control specifications to the vocal cords, to the pharynx (to vary size), and to wall tension (etc.) as a function of the other features of the segment in question, and of the context in which it is found. How are decisions made about balancing conflicting demands both within segments, and across segments within a span? The available evidence suggests that not all feature specifications provide equally important targets. At the point where evaluation is done, certain articulatory requirements are given a special status as organizing points or 'phonetic anchors' for a sequence of articulations. Phonetic anchors are the feature (or parameter) values which are evaluated first, regardless of context, with other features evaluated in terms of any nearby anchors. The anchor points resist coarticulation with their context, while requiring coarticulation on the part of neighboring segments. One example of a phonetic anchor, from Vaissière (1983), concerns the feature [nasal]. Here, syllable-initial consonants may serve as anchors, controlling velum height for neighboring segments. Another example, from Keating (1983), is the segment [s], which serves as an anchor for jaw height.

The final step of a derivation must be interpolation between specifications (Pierrehumbert 1980). What shapes the interpolating functions may have, and whether these can vary across languages is not yet known. What is known is that some segments appear to have no specifications of their own, even after all the fill-in rules have applied. It is clear from both acoustic data (Keating 1985b) and articulatory data (Vaissière 1983) that some segments instead simply lie along the 'path' from a value specified in a previous segment to a value specified in a later segment.

Note that in this proposal phonological feature values are never numerical. The rules of quantitative evaluation (target assignment) are phonetic rather than phonological – the numerical values assigned to features as interpretations of the binary values are to be construed as fairly concrete entities. Pierrehumbert (1980) suggested that rules of evaluation have much in common with rules of interpolation between values, in that both must refer to quantitative scales, and so should be found in the same component.

Furthermore, the thrust of Pierrehumbert's analysis of English intonation was that such phonetic rules are linguistic, not physical, in nature, and so should be considered part of the grammar, like the phonology. The extent to which her treatment of intonation, with no discrete level of representation corresponding to a phonetic transcription, will carry over to treatments of segmental phonetics, is unclear, but should be a very interesting focus of research in the near future.

11.3. Phonetic naturalness and explanation

The final topic to be addressed concerns the explanatory value of phonetics for phonology – that is, the role of phonetics in providing substance-based theories. Much of the interest of phoneticians and phonologists in each others' disciplines relates to questions of phonetic naturalness. Phoneticians look to phonology for phenomena to be explained, and phonologists look to phonetics for explanations in general and for support for particular analyses. Feature theory, which has already been discussed, can be viewed as a special instance of this theme. The phonetic correlates of features can be thought of as explanations for why certain sounds should naturally group together. In this section other instances of such explanation are considered: definitions of units, and motivations for rules. Phonologists often look to phonetics for evidence that a particular unit of analysis posited by a theory has some physical basis; they may also look for evidence that a proposed rule is plausible or natural.

11.3.1. Phonetic basis of phonological units

Segments

Although all of traditional phonetics (e.g. Ladefoged 1982) has been based on the notion of segment, some phoneticians are ready to abandon the segment as a phonetic entity, leaving the segment to phonologists without any phonetic justification. Ladefoged (1983b) and Lindblom (1983b) can be read in this way. Browman & Goldstein (1986) go still further to say that segments are not used even in lexical representations; rather, articulatory gestures are taken as the only basis of representation. Neither of these positions, as they stand, is likely to lead to an integrated theory of phonetics and phonology. A different tack is taken by Fowler and colleagues (e.g. Fowler *et al.* 1980): there are phonetic segments, but they are hard to see because they include a temporal dimension. This temporal dimension is present even in lexical representations, that is, phonetic segments can be used as phonological segments. Thus Ladefoged says that both phonological segments and phonetic representations exist but there is no relation between them; Browman & Goldstein say that phonological segments do not exist; Fowler says that phonological segments are just like phonetic segments. Finally, many phoneticians have posited intermediate rules of some sort to relate phonological and phonetic segments via some form of derivation: much of the traditional coarticulation literature, the older Haskins theories, Perkell (1980), Keating (1984a). Obviously the field is in some disarray on this point.

The most likely outcome, in my opinion, would be abandoning the claim that segments are directly attested in the phonetic signal as anything resembling discrete units. Rather, the component features of segments can be identified in the signal, misaligned with each other in time. This does not mean that there are no phonetic segments, but only that discrete segments are abstract, operating as a sort of control over or organizer of articulation. This view has already been outlined above, in the discussion of rules of phonetic implementation.

Syllables

SPE assumed that syllables play no role in the grammar, making syllables only a surface phonetic phenomenon. However, this view somewhat overestimates the extent to which syllables have received any coherent phonetic definition. The phonetic literature is quite inconclusive as to either what a syllable is, or how to define properties, such as sonority, that might be exploited to define syllables, although phonologists have been happy to assume that such questions are nearly settled. Thus, for example, Kahn (1976), in his discussion of syllables in generative phonology, repeats the idea that syllables are phonetically understood, and rather misleadingly concludes that there is as much evidence for phonetic syllables as for phonetic segments.

Kahn relies mainly on some hopeful general remarks by Ladefoged (1971), and on the hypothesis that each syllable is defined by a single respiratory muscular gesture. Ladefoged himself refuted this hypothesis, which was due to Stetson (1951), in his earlier work (summarized in Ladefoged 1967). Stetson had claimed that syllables can be defined by 'chest pulses,' but Ladefoged showed that respiratory muscular activity occurs for stressed syllables, and before voiceless fricatives, that is, in contexts requiring high airflow. Thus there is no special relation between syllables and respiration.

However, Ladefoged does believe that syllables act as units of organization for articulation. Kozhevnikov & Chistovich (1965) are often cited as phonetic evidence for such a claim. They proposed the syllable as an articulatory domain on the basis of coarticulation of lip rounding in Russian. However, their proposal should not be taken as support for a phonological unit. The syllables they found bear no relation to phonological syllables; they are defined as any number of consonants plus a following vowel. Also, Kozhevnikov & Chistovich looked only at lip rounding, whereas studies of other articulations have tentatively suggested other articulatory units. Furthermore, as Maddieson (1985: 217) points out, coarticulatory studies referring to syllables generally do not directly compare minimal differences in syllabification. In a related vein, the papers in Bell & Hooper (1978) on the role of syllables in phonetics attribute little phonetic role to an entire phonological syllable. However, the contribution of Fujimura & Lovins (1978) does rely on syllable components as an articulatory domain. A more recent and very promising study implicating syllable position as an articulatory organizer is Vaissière (1983), in which velum height is shown in some cases to depend on a consonant's syllable position.

Another result in this area concerns the role of the syllable in phonetic timing. Maddieson (1985) examined whether syllable membership, or the syllabification of a string of segments, can be determined from vowel durations, which are affected by a common phonetic rule shortening vowels in closed syllables. On the basis of a cross-language study, he argues that the application of such a rule indicates tautosyllabic membership of consonants after a vowel. The generality of closed syllable vowel shortening means that in at least some cases syllable membership can be read directly off the acoustic representations. Such results should be of interest to phonologists, and lead to further cooperation between experimentalists and theoreticians. In general, currently the phonological evidence for syllables is much more convincing than the phonetic evidence, but we can expect progress to be made in the phonetic directions charted by Vaissière and Maddieson.

The sonority hierarchy

In the discussion of features within new phonological theories, the sonority hierarchy was mentioned as a basis of (phonological) syllable structure representation. The basic notion is that stop consonants and open vowels are at opposite ends of a continuous dimension, with other segment classes ordered in between. Classes at the more sonorous end are used as syllabic nuclei, while syllable margins are supposed to be less sonorous than nuclei. However, the point along the hierarchy at which nuclei are distinguished from margins is not fixed in advance; this is determined by individual languages (or other proposals such as Steriade 1982). Thus, languages may differ in how they use the hierarchy to determine syllable structure. Hankamer & Aissen (1974) note that there is no phonetic definition for the hierarchy available, but they do want it to have one: phonetically different segments across languages should be ordered differently along the hierarchy. So far no one has provided a phonetic definition that would work across languages; and if they did, there are still intralanguage discrepancies. Thus Ladefoged (1975/1982) rejects the hypothesis that syllables can be defined phonetically by peaks in sonority (defined as relative loudness), because of the many counterexamples encountered in actual syllables.

A view that seems worth pursuing is that no single physical dimension entirely determines the sonority hierarchy or syllabicity. Rather, various properties of syllables can be distinguished, and together may provide a definition of syllables while still allowing the ambiguities and discrepancies observed across languages. Such an approach is discussed by Price (1980), Keating (1983), Ohala & Kawasaki (1985), and indirectly by Lindblom (1983a). Syllables can be seen as single cycles along various dimensions such as jaw movement, glottal gestures, first formant frequency, and acoustic energy, that is, physical dimensions largely relating to slow-moving articulators and their acoustic effects. While these dimensions are largely correlated and define similar 'sonority' hierarchies, there are at the same time subtle differences giving individual segments more than one position in an overall ordering of segments. Thus English alveolar obstruents have high jaw positions and so might favor positions in syllable margins when syllables are defined by a jaw movement cycle; but in a syllable defined by an intensity cycle a fricative like [s] will be more 'sonorous'. The large degree of overlap between hierarchies defined along these various dimensions gives the impression of a single sonority hierarchy, but really there is only a coincidental overall 'sonority look' to segment organization in syllables.

Feet

A foot consists of a stressed syllable, and optionally one or more stressless syllables; the exact nature of a foot depends on the particular phonological proposal. Generally in phonetics the topic of feet arises in connection with investigations of isochrony, meaning equal timing of some unit, usually the syllable or the stress foot (Lehiste 1977; Dauer 1983). Thus there have been many phonetic studies of syllable vs. stress timing across languages. However, most such studies do not draw in any way on recent theoretical proposals in the area of metrical phonology, and do not aim to offer any phonetic basis for the varied, and often abstract, feet posited by metrical phonologists. An exception is Nakatani, O'Connor & Aston (1981), who looked at stress timing using several kinds of feet, including feet headed by syllables with secondary stress. They found that foot duration depended on

foot size (type); furthermore, syllables with secondary stress were shorter than syllables with main stress, making any temporal definition of inter-stress intervals unlikely. However, studies of isochrony in both the acoustic and the perceptual domains continue, and may perhaps be related to concerns of phonological theory.

Of course the phenomenon of stress itself has been much studied (though a summary of that literature is beyond the scope of this chapter), and therefore the actual stressed syllables may be identified phonetically. But the question of whether the phonological unit plays any other role in determining phonetic form is more difficult. Öhman (1966) is often cited as showing that tongue body coarticulation goes from stressed vowel to stressed vowel – which might look like a foot basis for coarticulation. But in fact he only looked at VCV sequences in which both vowels were stressed, so his work shows only that coarticulation may extend at least that far; it does not define the foot as a coarticulatory unit.

Thus again we see that phonetics has yet to provide a physical basis for a useful theoretical construct. As more phonetics labs become equipped for a variety of experimental techniques, and as phoneticians try to formulate precise rules of quantitative implementation, we can expect more attention to the role of suprasegmental domains like syllables and syllable constituents in determining phonetic patterns. Phonetic evidence may then become clear enough to provide physical corroboration for theoretical constructs. But if past experience is any guide, we should not expect the phonetic evidence to be superficially direct.

11.3.2. Phonetic bases of inventory structure

Even though acoustic support for discrete segments has not been forthcoming, segments are still used as the basis of descriptions of languages' inventories of sounds. Furthermore, segmental phonemic descriptions allow comparisons across languages of segment occurrence; from such comparisons, many generalizations about distributions within inventories are found. Most recently, Maddieson (1984) has provided a statistical study of phoneme inventories that supersedes earlier accounts of cross-language generalizations and patterns. Some results are perhaps unsurprising. For example, languages are most likely to have two manner series of stop consonants, and those two series are most likely to be plain voiceless and plain voiced. Also, most languages have at least one nasal, and that nasal is usually dental or alveolar. However, the value of the statistical analysis lies equally in determining which cases are not themselves additional patterns but instead the result of the interactions of more basic patterns. Thus no special explanation is required for the lack of voiced velar stops in some languages; this gap can be attributed to a general lack of velars, plus a general preference for voiceless over voiced stops.

The fact that unrelated languages show recurring patterns of sounds suggests that there is some general or universal basis that is physiological or cognitive, or both, in nature. Thus the explanation of such generalizations may fall within the domains of both phonetics and phonology. Phonology may focus on structural principles such as maximal exploitation of a given feature contrast, or symmetry of inventories; phonetics will consider principles such as perceptual distinctiveness and articulatory ease. Phonetic explanations may be particularly likely for common gaps and asymmetries in inventories, which overall structural principles will not address.

Some of the best-known work in phonetics has been addressed to the issue of explaining segment inventory generalizations. Ohala (1983a and earlier work) considers certain individual generalizations from the point of view of articulation and perception. He briefly discusses, for example, sounds that never occur, the ratio of obstruents to sonorants within a language, and obstruent voicing patterns, including voicing of geminates and of different places of articulation. Especially noteworthy is his reliance on articulatory modeling as a technique for developing hypotheses.

Others have aimed at more general theories accounting for overall properties of segment inventories. Stevens's (1972) 'quantal theory' held that segment inventories are formed from a finite set of discrete phonetic categories; these categories in turn are based on discontinuities in the relation between articulation and acoustics, and between acoustics and perception. Similar categories are to be expected across languages because there is only a certain set of categories made available by physiology. However, quantal theory does not necessarily explain why particular subsets of categories occur more frequently than others. Another well-known theory is that of Liljencrants & Lindblom (1972; also Lindblom 1978), generally called 'dispersion theory'. Unlike quantal theory, dispersion theory focusses on the overall distribution of segments in an inventory without positing pre-existing phonetic categories. Thus unrounded front vowels, and rounded back vowels, are preferred because such vowels maximize the dispersion of vowels in the phonetic vowel space. The theory allows specific formulations of how a criterion of perceptual distance between sounds can be used to provide a distribution in a phonetic space. For further discussion and comparison of these two theories, see Disner (1983); she shows that neither theory by itself is adequate to account for all the facts she presents.

A more recent theory (Stevens *et al.* 1986), which can be called 'enhancement theory,' is presented in that paper from the viewpoint of

phonology, as a theory of fill-in rules for redundant feature values. However, the theory can also be considered from the viewpoint of phonetics, as a theory of segment inventory construction based on phonetic features. Enhancement theory holds that segments are chosen so that the value of one feature acoustically enhances or emphasizes the value of another feature; that is, particular combinations of feature values are preferred. This theory describes the example of back vowels being rounded as the enhancement of an acoustic correlate of backness, namely a low second formant, by an acoustic correlate of rounding, namely lowering of formant values. These correlates are complementary rather than contradictory, hence the enhancement relation. The theory attempts to extend this description to other cases besides vowel rounding. The notion of acoustic enhancement incorporates the idea of perceptual distinctiveness, while its formulation in terms of distinctive features retains the categorial basis of quantal theory. However, it remains to be seen just how generally the rules of enhancement can be formulated.

Although there is no phonetic theory of inventories that is currently widely accepted, it can be expected that in the future more work will be devoted to this question. More and better models of various aspects of both perception and articulation are being developed, and these models should lend themselves to formulating and testing explanations for inventory patterns.

11.3.3. Phonetic basis of rules

In *SPE* it was observed (pp. 400–2) that its formal theory provides no explanation for why some phonological rules are more plausible or natural than others. Since then phonetic naturalness has, for at least some phonologists, been a criterion for evaluating proposed rules (for example, Schane 1972; Hooper 1976; Stampe 1979). Many phonologists seem to take it for granted that metrics for phonetic naturalness have been or could easily be provided. Given this focus, it is perhaps surprising that relatively little attention has been given by phoneticians to phonetic motivations for particular phonological rules, or, more generally, to elaborating a general framework for evaluating rule naturalness. Ohala and his students have stood out for their interest in physiological explanations for phonological rules, both synchronic and diachronic. Ohala (1983a) is a recent statement of his views and results from articulatory modeling, with special attention to the effects of oral pressure variation on consonant voicing, affrication, and aspiration. He shows that certain synchronic and diachronic rules have plausible articulatory motivations. Another valuable piece of work in this direction is Beddor (1982), which provides a unified phonetic account of various synchronic and diachronic effects of nasalization on vowel quality, again using articulatory modeling techniques.

Westbury & Keating (1986) use such articulatory modeling to explore the limits of phonetic explanation by examining systematically a related set of phonetic patterns involving stop consonant voicing. Some of the patterns are indeed generated by the articulatory model, but others are counter-examples. This work shows how articulatory modeling can help identify cases where other, non-articulatory, bases for rule naturalness must be posited.

Phonetic explanations for phonological rules have been criticized by Dinnsen (1980) on the grounds that articulatory constraints never motivate a particular phonological rule. At best they define a 'problem' for articulation, and one or more possible solutions to the problem. For example, a problem sequence of two obstruents that disagree in voicing can be solved by a devoicing rule, by a voicing rule, by a directional assimilation rule, by a vowel epenthesis rule, or by a consonant deletion rule. Individual languages may deal with the situation differently, in ways that reflect the phonetic situation but do not spring directly from it. Thus the phonology cannot simply be reduced to such phonetic considerations. Similarly, Anderson (1981) and Keating (1985a) stress that even phonetically natural phonological rules may be more or less arbitrary in their instantiation in a given language; they may be ordered opaquely with other rules, and so have surface exceptions, or they may apply to a domain different from the phonetically most natural one. For example, final devoicing of obstruents can be motivated physically by aerodynamic considerations, but only for utterance-final position; languages that employ devoicing rules in word- or syllable-final positions are no longer responding only to physical considerations.

Such insistence on a distinction between physiology and phonology does not of course vitiate attempts to document the range of phonetic variation available for re-encoding as higher-level phonological rules. Study of low-level variation may be especially interesting in the area of diachronic phonology, as Ohala (e.g. 1983a, b, 1984) has shown. He proceeds from the point that the phonetic source of sound change is cross-language allophonic variation. Ohala (1983b) and Goldstein (1983) consider why changes proceed in one direction rather than another. Perhaps the best-known example of this kind of research is that on tonogenesis due to consonant voicing, discussed by Hombert, Ohala & Ewan (1979). In this case, an originally allophonic variation in vowel fundamental frequency becomes phonemic when the triggering consonant voicing distinction is lost, and in this sense we can say that the consonant voicing is the cause of the tonal development.

Thus at a certain point in time an originally phonetic pattern of variation ceases to be phonetically controlled.

The mechanism behind such sound changes is of great interest in terms of how grammars work. One sound induces a phonetic effect on another sound, and then disappears; but the allophonic effect on the second sound is preserved even without the surface trigger. The new surface pattern is now a synchronic counterexample to the cross-language phonetic pattern. Thus after the tonogenesis process it will not be the case that vowel fundamental frequency will depend on consonant voicing. To me, the interesting point about this process is that grammars allow suppression of phonetic patterning in this way, apparently without regrets for the abandoned surface generalization.

Phonological systems across languages have many things in common, from their basic constituent units to particular rules, that seem to both phonologists and phoneticians to warrant at least indirect grounding in phonetic substance. However, as we have seen, progress to date has not been equal to expectations, though some interesting approaches have been suggested.

11.4. Conclusion

The apparent complexity of the relation between phonological and phonetic descriptions of speech underscores the need for cooperative research strategies in both fields. Fortunately, prospects for progress are greatly enhanced by recent proposals within phonological theory and by new approaches to phonetic research. Both phonologists and phoneticians are interested in pursuing phonetic aspects of phonological derivations, treating phonetics as an integral part of the grammar that can provide evidence about formal representations and rules. Such cooperative research will benefit linguistic theory in general, and the study of linguistic sound systems in particular. It seems to me a very exciting time to be working in the area of generative phonetics.

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12 Syntactic change*

David Lightfoot

12.0. Introduction

People don't speak the way they used to. A middle-aged person who has kept letters or tape-recordings from 20 years ago can often see and hear that there are changes in the kinds of expressions used and sometimes in aspects of pronunciation. The most striking changes in an individual's speech involve the use of idiomatic phrases, which may change substantially in one's lifetime. More generally, the speech of Margaret Thatcher is different from that of William Shakespeare, more different from that of Geoffrey Chaucer, and even more different from what one finds in *Beowulf*. Linguistic change affects individuals and languages quite generally, and its generality formed the basis of the beginning of modern linguistics. The nineteenth-century linguists aimed to formulate principles which governed the way in which sound systems and morphology changed, but they recognized also that syntax changed in the course of time, although they had no very clear ideas about how change operated in this area.

This article will ask what kinds of things one can and cannot hope to explain about how and why syntactic systems change in an individual and in a language, and what kinds of things we can learn from such work for other purposes. These two questions are closely related because one will learn something from language change only if one understands it in some way, and conversely one will achieve explanations only if one relates language change to something else. Let us first describe as theory-neutrally as possible some fundamental aspects of how language changes, in the hope of clarifying certain points which are more controversial than they should be.

Some sort of linguistic system develops in children exposed to a range of linguistic expressions. At least some basic aspects of the system are 'fixed' by about the age of puberty and after that age simple exposure to an equivalent range of expressions in another linguistic setting does not lead to the development of such a system in the same way. Certain aspects of the

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