PHONETIC EXPLANATIONS FOR SOUND PATTERNS: IMPLICATIONS FOR GRAMMARS OF COMPETENCE.

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ABSTRACT

Phonological grammars try to represent speakers' knowledge so that the 'natural' behavior of speech sounds becomes self-evident. Phonetic models have the same goals but have no psychological pretensions. Phonetic models succeed in explaining the natural behavior of speech, whereas phonological representations largely fail. The 'phonetic naturalness' requirement in phonological grammars should be re-examined and probably abandoned.

INTRODUCTION

The quest to find a representation of speech sounds that makes their behavior self-evident goes back at least 3 centuries (Amman 1694; Jespersen 1889; Key 1855) but has been most intense in the past 3 decades. Two approaches to "natural" representation have been developed in parallel, one, the "mainstream" phonological one which employs discrete linguistic primitives and at the same time purports to represent the knowledge of the native speaker (Chomsky & Halle 1968 [*SPE*]; Clements 1985; Goldsmith 1979; McCarthy 1988) and another, phonetic models which are expressed with continuous physical primitives (Fant 1960; Fujimura 1962; Ohala 1976; Scully 1990; Stevens 1971; Westbury & Keating 1985) but which do not pretend to reflect psychological structure.

In this paper I review certain well-known cases of sound patterns which are better explained by phonetic rather than mainstream phonological representations and then discuss the relevance of this for phonological (mental) grammars.

CONSTRAINS ON VOICING

There is a well known aerodynamic constraint on voicing in obstruents. Some languages, like Korean and Mandarin have only voiceless stop phonemes; in languages like English that possess both voiced and voiceless stops, the voiceless [p], [t], [k] tend to occur more often in connected speech than the voiced [b], [d], [g]. This constraint derives from the following: voicing (vocal cord vibration) requires sufficient air flow through the glottis; during an obstruent air accumulates in the oral cavity such that oral air pressure rises; if the oral pressure nears or equals the subglottal pressure, air flow will fall below the threshold necessary to maintain vocal vibration and voicing will be extinguished. This constraint can be overcome (within limits) by expanding the oral cavity volume to absorb the accumulating air. Such expansion may be done passively, due to the natural compliance or "give" of the vocal tract walls to impinging pressure, or actively, by lowering the tongue and jaw, lowering the larynx, etc. But there are fewer options for vocal tract enlargement the further back the obstruent is articulated. Thus voiced velar stops are often missing in languages that use the voicing contrast in stops at other places of articulation; they may lose their voicing, their stop character or both. This is the reason why /g/ is missing (in native vocabulary) in, e.g., Dutch, Thai, Czech. See (Maddieson 1984; Ohala 1983, 1994) for additional phonetic and phonological data reflecting this.

Additional considerations and variations on this constraint account for (a) the greater bias against voicing in fricatives than stops and in geminate (long) stops than in singletons (Ohala 1983, 1994).

If back-articulated stops such as [g] and [ɢ] are threatened in voiced stop series, it seems that it is the front-articulated stop [p] that is threatened in the voiceless series. This is not due as such to aerodynamic but rather to acoustic factors: an abrupt amplitude transient is one of the cues for a stop; the stop burst of a [p] is less intense and thus less noticeable than those for other, further back, places of articulation because a labially-released stop lacks any down-stream resonator. [p] seems thus frequently to become a labial fricative (which happened in the history of Japanese). (Although the burst form the voiced [b] would be subject to the same factors, a rapid amplitude gradient on the voicing that follows it would still cue its stop character; with [p] and especially [p^h], this additional stop cue would be weak.)

Thus, for aerodynamic reasons, place of articulation can influence what happens at the glottis and for acoustic reasons what happens at the glottis can influence the viability of place distinctions supraglottally.

How have these constraints been represented using conventional phonological notations? Although the phonetic reasons for the voicing constraint are clearly stated (in prose) by Chomsky & Halle (1968) in *SPE* (p. 330-1), and they explicitly recognize that the formal representation of phonological rules fails to reflect the 'intrinsic content' of the features, their response is the marking convention (p. 406):

$$[u\ \text{voice}] \rightarrow [-\ \text{voice}]\ /\ \underset{[-\text{son}]}{\underline{\qquad}}$$

(read 'the unmarked value of voice is minus voice in combination with minus sonorant') which is to say that the voicing constraint on obstruents is just stipulated – it is not made self-evident; it is treated as a primitive. None of the newer formal notations in phonology have offered any improvement.

Feature geometry (Clements 1985; McCarthy 1988) proposed to capture dependency relations between features using a simple, transitive, asymmetric relation "dominates". 'Simple' in that it is the same relation everywhere it is used; 'transitive' in that if F_a dominates F_b and F_b dominates F_c, then F_a also dominates F_c; 'asymmetric' in that if F_a dominates F_b, then F_b cannot dominate F_a. The relation 'dominate' can be a one-to-many relation, such that a given feature may dominate more than one other features but a given feature may itself be immediately dominated by only one other feature. It follows as a corollary of this that features at intermediate or terminal nodes in the resulting feature hierarchy may not dominate each other. A simplified version of this hierarchy is given in Fig. 1.

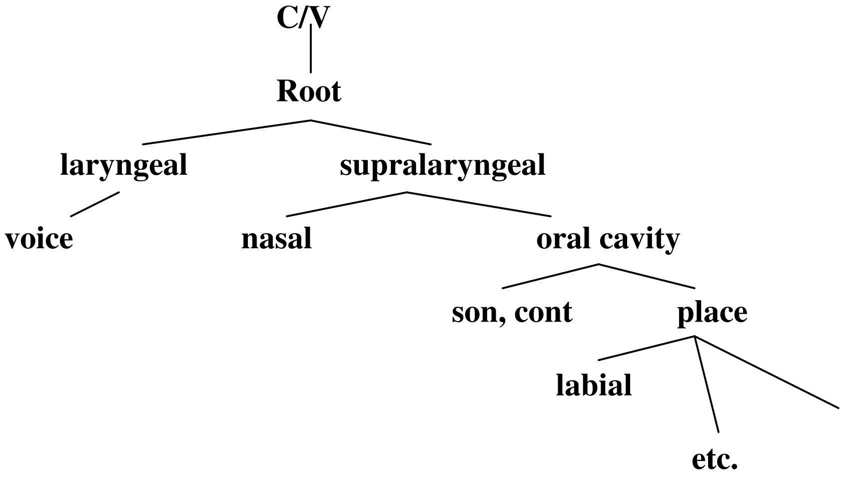

Fig. 1. Feature hierarchy proposed by Clement (1985).

Such an arrangement makes it impossible to capture (other than by stipulation) the aerodynamic constraints between obstruency and voicing, between voicing and place of articulation, or the acoustic constraints between glottal state and supraglottal place of articulation. For the most part Fig. 1 loosely embodies the configuration of the vocal tract by virtue of the particular dependency relations proposed, i.e., separating the laryngeal mechanism from the supralaryngeal system whish, in turn, is divided into nasal and oral cavities. The simple monolithic character of the relation 'dominates' prevents a separate encoding of dependency relations due to speech aerodynamics, acoustics, or perception. The asymmetric character of "dominates" prevents simultaneous dominance of place by laryngeal features and vice-versa and prevents dominance by features that are at terminal nodes or intermediate nodes of different branches of the feature hierarchy. In addition, there is nothing in the feature geometry mechanism to allow only ***one*** value of a feature, e.g., [-voice], to dominate or be dominated by another feature without the other value of the feature ([+voice]) also sharing in the relation.

Within Optimality Theory, constraints are stated much as in SPE, e.g.,

> OBS/VOI: 'If [-sonorant] then [-voice]; if [-sonorant] then not [+voice]' (Elzinga 1999).

The difference is that such constraints are assumed to reflect elements of Universal Grammar, that is, they are part of the human genome. Unresolved (to everyone's satisfaction) is the question of why phonological constraints that arise from the way the physical world is structured need to be redundantly represented in human's genes (Menn 2002).

Thus, as with the formalism used in *SPE*, the modern phonological representations can state (stipulate) things known to be true about the behavior of speech sounds but they are inherently incapable of showing the "natural" of self-evident character of these relations. Phonetic models, however, which are also formal, succeed in deriving this behavior from primitives which are for the most part extra-linguistic, e.g., entities and relations from the physical universe (Ohala 1976; Scully 1990; Westbury & Keating 1985).

OBSTRUENTS FROM NON-OBSTRUENTS.

There are morphophonemic alternations in Welsh and Kwakiutl (and other American languages in the vicinity of British Columbia and Washington state) where the voiced lateral approximant [l] alternates with the voiceless lateral fricative [ɬ] (Ball 1990; Boas 1947). Although perhaps not obvious, I think a related phonological phenomenon, an extremely common one, is the affrication of stops before high close glides or vowels; see examples in Table 1 (Guthrie 1967-1970). Both are cases of what I call emergent obstruents [21].

Table 1. Stops become affricated before high, close vowels but not before lower vowels.

Proto-Bantu	**Mvumbo**	**Translation**
*-buma	bvumo	*fruit*
*-dib-	dʒiwo	*shut*
*-tiitʊ	t͡ʃir	*animal*
*-kiŋgo	t͡ʃiuŋ	*neck, nape*
*-kuba	p͡fuwo	*chicken*
BUT		
*-bod	buo	*rot* (v)
*-dɪ	di	*eat*

Does the obstruent character of the [ɬ] or the affricated release of the stops have to be introduced explicitly by a special rule? Not at all; I claim they are directly derivable from pre-existing elements. To see why, it is necessary to briefly review some of the aerodynamic factors giving rise to turbulence (Ohala 1994; 1997a; Scully 1990; Stevens 1971).

Turbulence increases when the velocity, v, (so-called ‘particle velocity’) of the air increases. Particle velocity, in turn, varies as a function of volume velocity, U (how much air is moving past a given point per unit time), divided by the physical characteristics of the channel it moves through, simplified as d (= diameter), in (1).

(1) $\boldsymbol{v = U / d}$

Volume velocity, in turn, is determined by the area of the aperture, A, through which the air moves, and the pressure difference across that aperture (given as $P_{Oral} - P_{Atmospheric}$), as in (2) ($c$ is a constant and a varies between 1 and 0.5 depending on the nature of the flow).

(2) $\boldsymbol{U = A\,(P_{Oral} - P_{Atmos})^{a}\ c}$

From these equations we see that turbulence can be increased by decreasing the cross-dimensional area of the channel. This is the usual view of how fricatives differ from approximants. But I don't think this is what is involved in the cases cited. Rather, another way to create turbulence is by increasing U, the volume velocity and this, in turn, can be effected by increasing P_{Oral}. In the case of the [ɬ], the P_{Oral} is increased by virtue of its voicelessness: this reduces the resistance at the glottis to the expiratory air flow. The upstream pressure is then essentially the higher pulmonic pressure. Thus the fricative character of the [ɬ] need not result from its having a narrower channel than the approximant [l] but simply from being [-voice]. In the case of the affrication developing on stops before high close vowels or glides, the higher P_{Oral} occurs for different reasons: a stop generates a high upstream pressure; when the stop is released before a high close vowel or glide, some of the air must escape through the narrow channel present. It can take a few tens of milliseconds for the P_{oral} to reach P_{Atmos} and during this time the air will be forced through the constriction at a higher rate. Hence the initial portions of the vowel or glide can be fricated, especially after a voiceless stop but also after a voiced stop.

To my knowledge there has been no attempt to use current phonological representations to capture the phonetic naturalness of such cases where [-son] elements emerge from [+son] segments simply by appearing simultaneously with [-voice] or sequentially after [-cont, -son]. But, again, the current models such as feature geometry would be inherently incapable of handling these cases because, first, they ignore the aerodynamic aspects of speech and, second, because of the prohibition on dependency relations between separate branches of the feature hierarchy (e.g., [voice] may not dominate [manner]).

EMERGENT STOPS

Occasionally one finds a stop consonant emerging between a nasal consonant and an oral consonant: *Thom**p**son* (< *Thom* + *son*); *Alham**b**ra* (< Arabic *al hamra,* "the red (edifice)"); *hum**b**le* (related to *humility*, < Latin *hŭmĭlis* "of the earth"); *em**p**ty* < Old English *amtig*; Sanskrit *viṣɳu* "Vishmu"> *viṣ**ʈ**ɳu* > Bengali *biṣʈu.*

To understand how these stops arise, it is necessary to view speech production (in part) as a process controlling the flow of expiratory air using certain anatomical structures as valves. A nasal consonant is made by channeling air through the nasal cavity: there must be a valvular closure in the mouth and a valvular opening into the nasal cavity (by a lowering of the soft palate). The nasal consonant [m], for example, has the lips closed while the passage between the oral and nasal cavities is open (represented schematically in Fig. 2a). An oral consonant like [s] on the other hand, requires a closure of the nasal valve (by an elevation of the soft palate); see Fig. 2c. If the oral consonant's soft palate closure is made prematurely during the latter portion of the nasal, i.e. undergoes anticipatory assimilation, then with both the oral and nasal valves closed (and there are no other outlet channels for the expiratory airflow) a complete stoppage of the air flow is produced; see Fig. 2b.

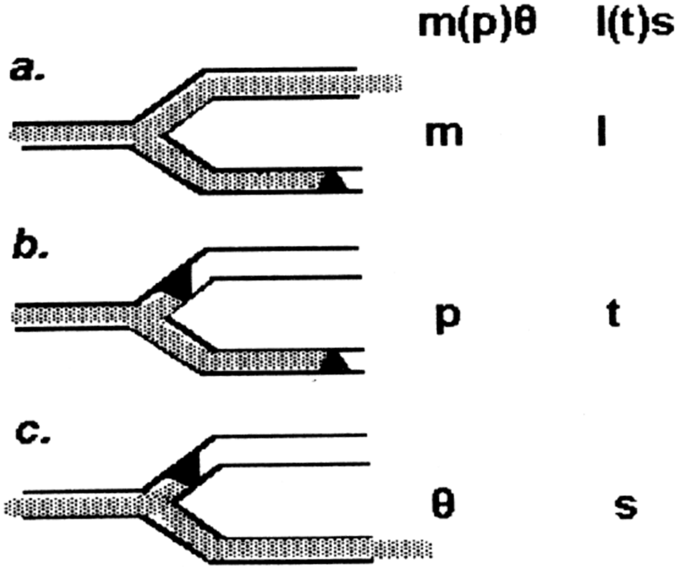

Fig 2. Schematic representation of the vocal tract and the valves which regulate the flow of air; expiratory air symbolized by gray; valves by black triangles.

Fig. 2 also serves to show the basis for changes of the sort [ls] > [lts] except that in this case the upper branch represents the lateral air passage – which is open for the lateral [l] and closed for the fricative [s] – and the lower branch represents the midline passage – which is closed for [l] and open for [s]. In the transition between these two sounds, both air passages may be briefly closed, thus forming a stop. (See Ohala 1995, 1997b) for more details, further data and references, and discussion of how the same principles can account for some cases of emergent ejectives and clicks.)

Using autosegmental notation, Wetzels (1985) and Clements (1987) correctly characterize /mθ/ > [mpθ] as arising from the spreading of [-nasal] from the [θ] into the [m] (although they incorrectly assume that such spreading could not occur from left-toright as in Sanskrit *viʂɳu*, cited above). But in case of [ls] > [lts] or [sl] > [stl], they resort to a rule that simply inserts a consonant; it seems they are unable to generate a [-continuant] from the spreading of features from two [+continuants]. But as detailed above, and illustrated in Fig. 2, the overlap of gestures from two continuants *can* create a non-continuant or obstruent! The problem with the phonological representations here lies in taking [±continuant] or [±sonorant] as *primitives*, whereas they are in fact *derived* from the states of the valves which control air-flow.

THE STORY OF [w]

The labial velars [w], [k͡p], [g͡b] and [ŋ͡m] are doubly-articulated consonants, having two simultaneous primary constrictions, labial and velar. In spite of their two constrictions in certain cases these sounds pattern with simple labials, such as [p], [b] and [m], and in other cases with simple velars [k], [g] and [ŋ]. But their behavior as labial or velar depends on the nature of the particular contextual effect involved.

When generating noise, labial velars are labial.

When generating noise (frication or stop bursts) labial velars tend to behave as labials, Some examples: Brit. English [lɛftɛnənt] for *lieutenant*; in Tenango Otomi the /h/ before /w/ is realized as the voiceless labial fricative [ɸ]. The probable reason for this is that since noise is inherently a relatively high frequency sound, even if noise were generated equally at both the velar and labial places, the noise at the velar constriction would be attenuated by the low-pass filtering effect of the downstream resonator. (See (Fant 1960; Stevens 1971).

Nasals assimilating to [w] are velar.

A nasal assimilating to the labio-velar [w], insofar as it shows any assimilatory change and shows only one place of articulation, becomes the velar nasal [ŋ], not the labial nasal [m]. Tswana /-roma/ “send” + /wa/ (pass. sfx.) = / -roŋwa/; Melanesian dialects show the variant pronunciation /mwala/ ~ /ŋwala/ for the name of *Mala Island*.

Some principles adduced by Fujimura (1962) help to explain this pattern. (See also Ohala & Ohala 1993).) Fig. 3 gives a schematic representation of the air spaces that determine the resonances of nasal consonants. As shown in the figure, all nasal consonants have the pharyngeal-nasal air space in common (marked by a dashed line). What differentiates one nasal from another is the length of the air cavity (marked by a dotted line), a cul-de-sac, which branches off of this pharyngeal-nasal air space. Measured from the point where the two air cavities diverge, this branch is quite long in the case of the labial nasal [m] but is quite short in the case of the velar nasal [ŋ]. In the case of the labio-velar nasal there are two constrictions, one labial and one velar, but only the rearmost constriction defines the extent of the branch (measured from the point where it diverges form the pharyngeal-nasal cavity); the forwardmost (labial) constriction will be largely irrelevant in determining the characteristic resonances. Thus labio-velar nasals will tend to sound like simple velar nasals.

These labial velar sound patterns could not fall out from current phonological representations since they fail to incorporate aerodynamic and acoustic relations and do not allow for dependency relations between [nasal], [manner], and [place] features.

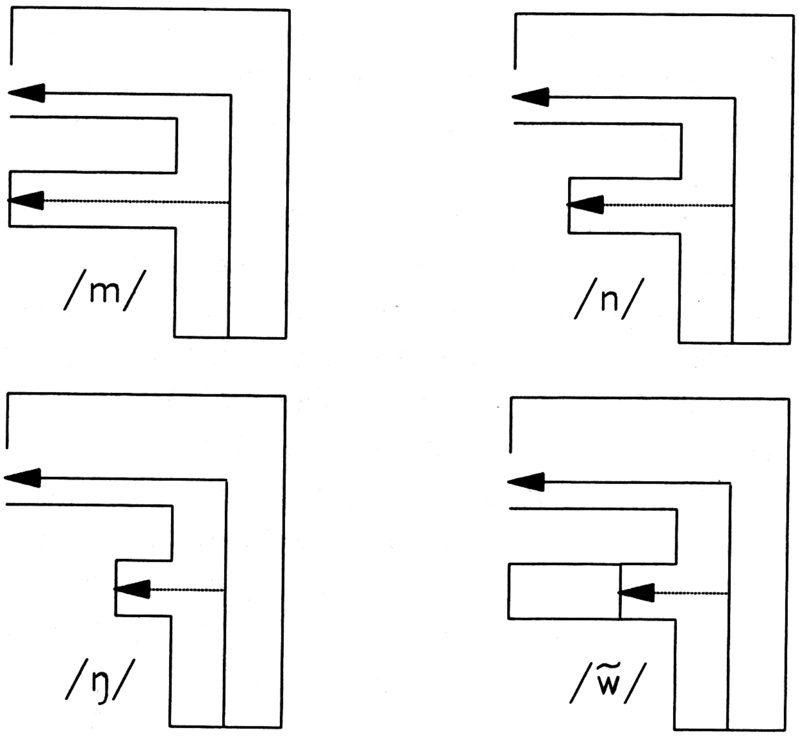

Fig. 3. Schematic representation of the air spaces creating the distinctive resonances for nasal consonants. The pharyngeal-nasal resonating air spaces are identical in all nasals; it is the oral air spaces, measured from the pharynx to the point of constriction in the oral cavity, that contribute resonances that differ between nasals.

CONCLUSION: EXPLANATIONS FOR SOUND PATTERNS IN LANGUAGE

Mainstream phonological representations purport to simultaneously (a) reflect speakers' knowledge of the sound patterns in their language and (b) represent this knowledge in a way that makes the 'naturalness' of the sound patterns self-evident. I have tried to demonstrate in this paper that the second goal is not achieved. Could this goal be met by some appropriate modification of the representations used, e.g., by some new feature geometry having separate dependency relations for speech articulations, aerodynamics, acoustics, etc., including the inter-domain dependencies (aerodynamics and acoustics together determine why the noise generated by labial velars is predominantly labial)? I submit that if such a revised representation were constructed, one that would then be capable of embodying the 'intrinsic content' of the elements of speech, it would be identical to the phonetic models referred to above. But this solution would be unacceptable because such models use continuous physical parameters and physical relations between them such as Boyle-Mariotte's Law – and with justification no one believes that a speaker's competence includes knowledge of physics.

I see no way out of this impasse except to abandon the requirement that phonological grammars reflect the phonetic naturalness of the sound patterns in language. Can we justify this step and, if so, what are its consequences?

A full justification would require more space than I am allotted here but a few comments are possible. In searching for the origin of the requirement that the rules in the speaker's mental grammar reflect phonetic naturalness, it seems that it came about in two steps. Chomsky (1957), *Syntactic structures* , (and earlier in Chomsky 1956) proposed that simplicity be a criterion for evaluation competing grammars. By explicit projection the criterion used by the linguist to find a theory (grammar) of the language should also be the criterion the language learner uses to evaluate grammatical specifications of his language. Features, alpha variables, abstract underlying forms, ordered rules, the transformational cycle, etc. were subsequently shown to lead to simplifications of grammar. At this, the ‘quantitative’ phase, simple length was used to evaluate grammars and their parts. In *SPE*, chap. 9, the authors declared that a simple quantitative evaluation of rules was not sufficient and that further simplifications could be achieved if a qualitative differentiation could be made between common, widely-attested sound patterns and those less common – a way that would reflect the ‘intrinsic content’ of features. Thus the burden was shifted to the representation of speech sounds. The marking conventions, autosegmental notation, feature geometry, etc. were designed to incorporate more of the inherent structure – presumably their phonetic structure – which is responsible for the ‘natural’ behavior of speech. But as far as I have been able to tell, the proposals to make grammars quantitatively and qualitatively optimal were made without any serious consideration of psychological evidence or implications. The whole notion of ‘simplicity’ is quite elusive and what sorts of optimization speakers impose on their mental representation of the phonological component of their language is largely unknown. The amount of psychological evidence on speakers’ awareness of what is phonetically natural is in inverse relation to the impact that the issue of ‘naturalness’ has had on mainstream phonological theory. Moreover, there is some evidence that non-phonetic factors, e.g., morphology, semantics, play a much more important role in speakers’ conception and manipulation of sound patterns (Ohala & Ohala 1987).

The existence of phonetically natural processes in the sound patterns of languages needs no special or extravagant explanation. Universal, physical phonetic factors lead to a speech signal which obscures the speaker’s intended pronunciation; listeners may misinterpret ambiguous phonetic elements in the signal and arrive at a pronunciation norm that differs from the speaker’s. This is how sound change works (Ohala 1993a, b) and how natural sound patterns arise. Such changes will reflect phonetic constraints without speaker or listener having to "know" about them. Similarly, when we eat, walk, see, hear, etc. our behavior is subject to a myriad of universal physical constraints without the necessity of our knowing them either consciously or unconsciously. Even a rock obeys the laws of physics without having to know them.

There is, in sum, more than ample justification to abandon the 'phonetic naturalness' requirement for the representation of speakers' competence.

What would the consequences of this move be for current phonological practice? Historical grammars or any account of phonological universals would, as now, still have to meet the requirement of representing speech sound in a way that would accurately predict their behavior. For this purpose existing phonetic models suffice, as illustrated in the body of this paper. Of course, there is now and always will be a need to elaborate and revise existing models and to introduce new ones as we seek to explain more sound patterns in language. Adequate representations of native speakers' competence could – ironically – be much simpler, possibly formulated with no more than unanalyzed phonemes (Myers 1994). There may be no need for features, underspecification, autosegmental notation, feature geometry or similar speculative devices. However, whatever is attributed to the speaker's mental grammar should be subject to the same standards of empirical verification as are elements in phonetic models. Such evidence would probably come from psycholinguistic experiments.

No matter what sort of account or model is given of speech sounds and their behavior it would be beneficial if they were preceded by an explicit statement regarding what part of the universe the model represented, whether the speaker's vocal tract, the speaker's mind, or the speaker's DNA. That would determine the part of the universe where empirical verification of the model would be sought (Ohala 1986; Ohala & Jaeger 1986).

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