(vii) { a → ɔ/w __ (was, swan, quarrel; Middle English).
{ ø → œ/ __ r ([ø:va] vs [œ:ra]; Swedish).

(viii) { x → { ç / +front V __ ; x / elsewhere } ([lɪçt] vs [axt]; German).
/h/ realizations of Japanese cf. (v) above.

(ix) { n → m / b __ ([ha:bm] (haben); German).
/n/ realizations of Swedish cf. (iii) above.

(x) { r → r̥ / [-voic, -son] __ (try, cry, pry; English).
{ ʒ → ʒ̊ / __ [-voic] [nɛʒ̊fɔ̃dy]
{ k → k̬ / __ [+voic] [sak̬dɔʀ] French

The above examples of pro- and regressive assimilations suggest that assimilation be hypothetically described as a reduction of articulatory distance in articulatory space. Do they imply a syntagmatic pronounceability condition, favoring a reduction of the physiological equivalent of a power constraint, mechanical work (force x distance)/time (a LESS EFFORT principle)? Can at least some phonological facts be interpreted as cases of contrast-preserving articulatory simplifications? What is their behavioral origin?

3. Speech - a Physiological Pianissimo.

3.1 The question also arises whether spoken language underexploits the degrees of freedom that in principle the anatomy and physiology of speech production make available. Seen against the full range of capabilities, speech gestures, like many other skilled movements, appear to be physiologically "streamlined" both as regards muscle recruitment and force levels (cf. jaw closure as a speech gesture and in mastication, speech breathing vs respiration in general, articulatory gestures vs swallowing etc.). Extreme displacements of articulatory organs do not occur (PIKE 1943, 150) although such configurations are available and yield acoustically equivalent results (evidence from non-speech: body-arm, eye-head coordination; and from speech: lip/tongue-mandible and tongue blade-tongue body coordination (LINDBLOM et al 1974)). Do we in these circumstances see the operation of an economy of effort principle? A principle that we should invoke to explain how and why speech and non-speech sounds differ

and to account for certain phonological regularities as well as the instances of hypo-articulation (reductions, ellipses, co-articulations etc.) in spontaneous speech. "Todays's allophonic variation leads to tomorrow's sound change..." OHALA (1979).

3.2 Pronounceability and Syllable Structure.

FIG. 1 shows average measurements of jaw positions for Swedish apical consonants in the environment [a'Cɑ:]. The production of these consonants permits a variable influence of the open jaw positions of the vowels. Thus the dimension of jaw opening reveals one aspect of their "willingness" to coarticulate. It is of considerable interest to see that this measure correlates well with their universally favored position in initial and final phonotactic structures (ELERT 1970). If the present observations are generalized, they imply that the phonetic structure of clusters can be explained at least in part with reference to ease of co-articulation (ELERT 1970, BRODDA 1972).

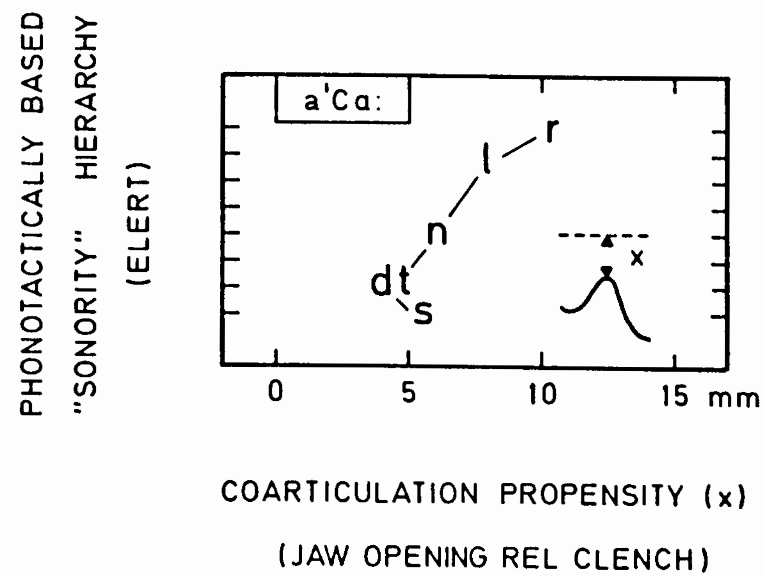

FIG. 1

4. The Distinctiveness "Conspiracy".

4.1 Language structure exhibits redundancy at all levels.

4.2 Speech generation is an output-oriented process: The reference input to the speech control system is specified in terms of a desired output. The dimensions of the target specifications are sensory, primarily auditory. Evidence supporting the primacy of auditory targeting comes from work on compensatory articulation, speech development and the psychological reality of phonological structure (LINDBLOM et al to appear, LINELL 1974).

4.3 Speech understanding is an active (top-down or conceptually driven) process. (Cf. the demonstrations of context-sensitive processing, resistance to signal degradation, phonemic restoration, verbal transformation etc.)

4.4 The speech system may possess specialized mechanisms that contribute towards enhancing the distinctiveness of stimulus cues. Examples of such hypothetical mechanisms are "feature detectors" in speech perception. Specialization of speech production has been suggested in the case of the phylogenetic development of the human supralaryngeal vocal tract whose shape LIEBERMAN (1973) interprets as a primarily speech-related adaptation increasing the acoustic space available for speech sounds.

4.5 Phonetic targets are selected so as to retain acoustic stability in the face of articulatory imprecision (STEVENS 1972).

The properties listed in 4.1 through 4.3, do they have a common origin in a basic principle of language design viz., the DISTINCTIVENESS CONDITION: different meanings sound different? The preservation of meaning across encoding and decoding seems to be favored by redundancy, output-oriented and active processing (rather than by lack of redundancy, exclusively input-oriented encoding and purely passive decoding strategies). Thus the question arises whether these at first seemingly unrelated attributes form an evolutionary "conspiracy". Do they constitute three different ways of coping with a physical signal which is inevitably going to be noisy, variable and ambiguous? 4.4 and 4.5 could offer related advantages. What is the behavioral origin of the distinctiveness condition?

5. Speech Development.

5.1 Imperfect learning: Can perceptual similarity and articulatory reinterpretation serve as a source of phonological innovation (cf. JONASSON (1971))? Many sound substitutions in children's speech appear compatible with this interpretation: θ→f, ɫ→w cf. 2.1. The child is a cognitive and phonetic bottle-neck through which language must pass. Does the process of acquisition leave its imprints on language structure?

5.2 Selection of the fittest: A speech community may use in free variation several realizations of a given form. The set of fricatives may contain /f, s, ʃ, ç/ and /h/ with the /ʃ/ produced as [ɧ] and [ʂ] (cf. Swedish). The distinctiveness principle favors [ɧ] which contrasts better with [ç] than [ʂ]. The lower confusion risk of the pair [ɧ] / [ç] promotes its reception and learning by the child. There is in this case thus a behavioral rather than teleological motivation for the distinctiveness condition. If sound patterns show evidence of perceptual differentiation, is communicative "selection of the fittest" among several competing forms one of the evolutionary mechanisms? Selection occasionally occurs from a rich variety of hypo- as well as hyper-articulated forms (STAMPE 1972). Is hyperarticulation another behavioral source of distinctiveness?

6. Non-Phonetic Origins of Sound Patterns: Social Biasing.

Selection of speech forms is influenced not only by production and perception factors. Phonological contrasts vary as a function of social variables (prestige, age, class, sex, style etc.). Does the interaction of the sometimes conflicting requirements of social and phonetic factors account for the fact that there is no evidence (GREENBERG 1959) that language change leads to more efficient linguistic systems? Is local rather than global phonetic evaluation of systems (KIPARSKY 1975) another reason why languages do not seem to be converging toward a single optimum equilibrium?

The emergence of a phonological system can be simulated on the basis of current models of production and perception. FIG. 2 shows some computational results obtained by an application of

$$\sum_{i=2}^{n} \sum_{j=1}^{i-1} T_{ij}(t) \cdot L_{ij}(t) \cdot S_{ij}(t) < \text{CONSTANT} \qquad (1)$$

where n is the size of a universal inventory of segments, T_{ij} represents a (time-varying) talker-dependent measure of evaluation for a given contrast (pronounceability condition), L_{ij}

refers to a listener-dependent evaluation (distinctiveness condition), and S_{ij} reflects the balance between social and phonetic factors. FIG. 2 illustrates the

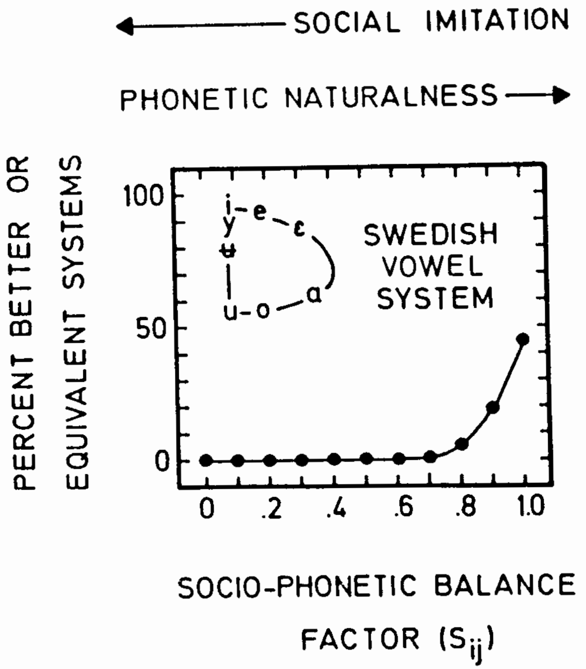

FIG. 2

interaction between the criteria of distinctiveness and social imitation in deriving the Swedish vowel system from a larger set of universal vowel types (represented in terms of canonical auditory patterns). The socio-phonetic balance varies from zero ("social imitation" dominates) to unity (natural phonetic factors, T and L, dominate). It is applied to the contrasts of Swedish with the values shown. For non-Swedish contrasts S=1. Apparently there are many systems (out of a total of 92378) that meet our present criterion of distinctiveness equally well or better. If we had reason to believe that the role of natural phonetic factors in the genesis of the Swedish vowels was correctly and exhaustively reflected in our calculations we would conclude that social factors are quite important in their development. We don't. A great deal of work on phonetic naturalness remains to be done before any safe conclusions can be drawn.

However, we believe that the approach will be useful in studying phonological contrasts particularly in child language and cross-linguistically.

7. A "Darwinian" Theory of Phonological Universals.

Suppose that we answer all the questions of the preceding discussion in the affirmative. We accept as our null hypotheses the assumptions that learnability, pronounceability and perceptibility conditions can account for differences between speech and non-speech sounds, that discreteness reflects the operation of memory, learning and decoding mechanisms, that sound changes are influenced by social variables and shaped by demands for perceptual efficiency and convenience of production, and that the origin of such demands is prosaically behavioral rather than mysteriously teleological. Such acceptance boils down to the idea that phonological structure arises both phylogenetically and ontogenetically by "natural selection" of sound patterns from sources of phonetic variation. Language structure emerges in response to the biological and social conditions of language use. Natural selection is based on the communicative (perceptual as well as social) value of contrasts and "phonetic variation" is defined with respect to possible segment, possible sequence and their possible variation. According to this "Darwinian" theory, phonological universals will be explained with reference to how speech is acquired, produced and understood, or rather in terms of our models of these processes.

This conclusion may seem uncontroversial. However, a truly quantitative and explanatory theory along these lines is not likely to appear until we learn to recognize its full intellectual, educational and administrative implications for how linguistics should be done. Language is the way it is partly because of our brains, ears, mouths as well as our minds. In this sense linguistics is a natural science. Phonetics can contribute by formulating its behavioral *explanans* principles.

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